EXPANDED ENVIRONMENTAL NOTIFICATION FORM

MEPA MGL c. 30 ss 61-62I

Ballard Street Salt Marsh Restoration

Eastern Avenue and Ballard Street
Saugus, MA

March 16, 2015

Prepared for: dcr **Department of Conservation and Recreation**

Prepared by: PARSONS BRINCKERHOFF **Parsons Brinckerhoff, Inc.**

Applied Coastal Research & Engineering, Inc.
Boelter & Associates

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Boston, MA 02116

Massachusetts DOT District #4
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ENVIRONMENTAL NOTIFICATION FORM

See following pages.

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Commonwealth of Massachusetts

Executive Office of Energy and Environmental Affairs
Massachusetts Environmental Policy Act (MEPA) Office

Environmental Notification Form

For Office Use Only
EEA#: ______________
MEPA Analyst: ______________

The information requested on this form must be completed in order to submit a document electronically for review under the Massachusetts Environmental Policy Act, 301 CMR 11.00.

Project Name: **Ballard Street Salt Marsh Restoration**		
Street Address: **Ballard Street and Eastern Avenue**		
Municipality: **Saugus**	Watershed: **North Coastal**	
Universal Transverse Mercator Coordinates:	Latitude: 42° 26' 51.8" Longitude: -70° 59' 5.0"	
Estimated commencement date: **Fall 2015**	Estimated completion date: **Spring 2017**	
Project Type: **Salt Marsh Restoration**	Status of project design: **75%** %complete	
Proponent: **Department of Conservation and Recreation**		
Street Address: **251 Causeway Street**		
Municipality: **Boston**	State: **MA**	Zip Code: **02114**
Name of Contact Person: **Rachel J. Burckardt**		
Firm/Agency: **Parsons Brinckerhoff**	Street Address: **75 Arlington Street, 9th Fl.**	
Municipality: **Boston**	State: **MA**	Zip Code: **02116**
Phone: **617-960-4861**	Fax: **617-482-8487**	E-mail: **burckardt@pbworld.com**

Does this project meet or exceed a mandatory EIR threshold (see 301 CMR 11.03)?
☒Yes ☐No

If this is an Expanded Environmental Notification Form (ENF) (see 301 CMR 11.05(7)) or a Notice of Project Change (NPC), are you requesting:

a Single EIR? (see 301 CMR 11.06(8))	☐Yes ☒No
a Special Review Procedure? (see 301CMR 11.09)	☐Yes ☒No
a Waiver of mandatory EIR? (see 301 CMR 11.11)	☒Yes ☐No
a Phase I Waiver? (see 301 CMR 11.11)	☐Yes ☒No

(Note: Greenhouse Gas Emissions analysis must be included in the Expanded ENF.)
See Section 1.6 of EENF Narrative

Which MEPA review threshold(s) does the project meet or exceed (see 301 CMR 11.03)?
Alteration of one or more acres of salt marsh 301 CMR 11.03(3)(1)(a)
Alteration of ten or more acres of other wetlands 301 CMR 11.03(3)(1)(b)
Location within ACEC 301 CMR 11.03(11)(b)
Direct alteration of 25 acres or more of land 301 CMR 11.03(1)(b)(1)

Which State Agency Permits will the project require?
DEP Chapter 91 License and Permit (possible)
DEP 401 Water Quality Certification
Mass Wetlands Protection Act Order of Conditions
MassDOT Temporary Highway Access Permit (existing permit # 4-2014-0128 for Winthrop Beach Nourishment Project will be extended)

Identify any financial assistance or land transfer from an Agency of the Commonwealth, including the Agency name and the amount of funding or land area in acres:

DCR funded under Capital Projects

Summary of Project Size & Environmental Impacts	Existing	Change	Total
LAND			
Total site acreage	54		
New acres of land altered		0	
Acres of impervious area	1.0	0	1.0
Square feet of new bordering vegetated wetlands alteration		0	
Square feet of new other wetland alteration		36.9	
Acres of new non-water dependent use of tidelands or waterways		0	
STRUCTURES			
Gross square footage	None	0	0
Number of housing units	None	0	0
Maximum height (feet)	N/A	N/A	N/A
TRANSPORTATION			
Vehicle trips per day	N/A	N/A	N/A
Parking spaces	N/A	N/A	N/A
WASTEWATER			
Water Use (Gallons per day)	N/A	N/A	N/A
Water withdrawal (GPD)	N/A	N/A	N/A
Wastewater generation/treatment (GPD)	N/A	N/A	N/A
Length of water mains (miles)	N/A	N/A	N/A
Length of sewer mains (miles)	N/A	N/A	N/A

Has this project been filed with MEPA before?
☐ Yes (EEA #) ☒ No

Has any project on this site been filed with MEPA before?
☒ Yes (EEA **#12889, 13993 , 10113**) ☐No

GENERAL PROJECT INFORMATION – all proponents must fill out this section

PROJECT DESCRIPTION:

This Project will restore quality habitat within areas of former and degraded salt marsh, and improve flood protection for residents in the adjacent neighborhood. Currently less than 1/3 of its original size, much of the salt marsh has converted to freshwater marsh dominated by non-native and invasive common reed (*Phragmites australis*), or trended to forested upland. Restoration of this nearly 37 acre portion is the highest priority project in Rumney Marsh for the MA Division of Fish and Game-- Department of Ecological Restoration

Tidal water formerly flowed in this area from three sources, the Saugus and Pines Rivers and Bear Creek. However, flows have been severely impeded by land fill and obstructed culverts, etc. causing poorly functioning salt marsh as well as exacerbated flooding in the adjacent area.

The Project will restore tidal flow with excavation of 15 acres of remnant marsh; removal of a broken tide gate on the Ballard St. culvert and obstructions at the Bristow St. culvert; two new culverts west of Bristow Street to provide tidal flow from the Pines River; construction of a dike with a 1-foot diameter culvert near Ballard Street to hydraulically separate the east and west marsh cells while maintaining a Saugus River connection; installation of one-way duckbill valves on the existing Eastern Avenue culverts, and excavation of new creeks within the new marsh to convey tidal flow. The Project will address flooding issues in the East Saugus neighborhood with installation of a one-way, 48-inch auxiliary culvert under Eastern Avenue to improve discharge of inland runoff.

Describe the on-site project alternatives (and alternative off-site locations, if applicable), considered by the proponent, including at least one feasible alternative that is allowed under current zoning, and the reasons(s) that they were not selected as the preferred alternative:
Alternative methods would require either more marsh excavation or more structures requiring oversight and maintenance difficult to ensure over time; See Section 3.0 of Narrative

Summarize the mitigation measures proposed to offset the impacts of the preferred alternative:
As the project qualifies as a limited project, the restoration of tidal connection to the Eastern Marsh and restoration of historically filled and degraded marsh and tidal creeks in the Western Marsh is sufficient mitigation considering the ancillary impacts from installing the projects elements described herein necessary to balance restoration of resources, fish access, improve flood protection, and protect health and human safety. See Section 6.0 in the Narrative for more information

If the project is proposed to be constructed in phases, please describe each phase:
N/A

AREAS OF CRITICAL ENVIRONMENTAL CONCERN:
Is the project within or adjacent to an Area of Critical Environmental Concern?
☒Yes (Specify **Rumney Marsh ACEC**)
☐No
if yes, does the ACEC have an approved Resource Management Plan? ___ Yes _x_ No;
If yes, describe how the project complies with this plan.

____

Will there be stormwater runoff or discharge to the designated ACEC? _x_ Yes ___ No;
If yes, describe and assess the potential impacts of such stormwater runoff/discharge to the designated ACEC.
Existing runoff from East Saugus drains to the Project Area. The Project results in no change in volume or rate of runoff to the ACEC.

RARE SPECIES:
Does the project site include Estimated and/or Priority Habitat of State-Listed Rare Species? (see http://www.mass.gov/dfwele/dfw/nhesp/regulatory_review/priority_habitat/priority_habitat_home.htm)
☐Yes (Specify________________________________) ☒No

HISTORICAL /ARCHAEOLOGICAL RESOURCES:
Does the project site include any structure, site or district listed in the State Register of Historic Place or the inventory of Historic and Archaeological Assets of the Commonwealth?
☒Yes (Specify___**MHC-19-ES-258**______________________________) ☐No
If yes, does the project involve any demolition or destruction of any listed or inventoried historic or archaeological resources? ☐Yes (Specify________________________________) ☒No

WATER RESOURCES:
Is there an Outstanding Resource Water (ORW) on or within a half-mile radius of the project site?
_x_Yes ___No;
if yes, identify the ORW and its location. **Rumney Marsh ACEC**
(NOTE: Outstanding Resource Waters include Class A public water supplies, their tributaries, and bordering wetlands; active and inactive reservoirs approved by MassDEP; certain *waters* within Areas of Critical Environmental Concern, and certified vernal pools. Outstanding resource waters are listed in the Surface Water Quality Standards, 314 CMR 4.00.)

Are there any impaired water bodies on or within a half-mile radius of the project site? ___Yes _X_No; if yes, identify the water body and pollutant(s) causing the impairment: ______________________.

Is the project within a medium or high stress basin, as established by the Massachusetts Water Resources Commission? ___Yes _X_No

STORMWATER MANAGEMENT:

Generally describe the project's stormwater impacts and measures that the project will take to comply with the standards found in MassDEP's Stormwater Management Regulations:
N/A – The Project is salt marsh restoration and Project neither increases nor decreases volume of stormwater runoff. It will have a positive benefit in conveying stormwater runoff from the adjacent residential neighborhood.

MASSACHUSETTS CONTINGENCY PLAN:
Has the project site been, or is it currently being, regulated under M.G.L.c.21E or the Massachusetts Contingency Plan? Yes ___ No _X_ ; if yes, please describe the current status of the site (including Release Tracking Number (RTN), cleanup phase, and Response Action Outcome classification):
_____**N/A**_____

Is there an Activity and Use Limitation (AUL) on any portion of the project site? Yes ___ No _X_;

if yes, describe which portion of the site and how the project will be consistent with the AUL: ___________________.

Are you aware of any Reportable Conditions at the property that have not yet been assigned an RTN? Yes ___ No _X_ ; if yes, please describe:_________________________________

SOLID AND HAZARDOUS WASTE:

If the project will generate solid waste during demolition or construction, describe alternatives considered for re-use, recycling, and disposal of, e.g., asphalt, brick, concrete, gypsum, metal, wood: ______**N/A**____

(NOTE: Asphalt pavement, brick, concrete and metal are banned from disposal at Massachusetts landfills and waste combustion facilities and wood is banned from disposal at Massachusetts landfills. See 310 CMR 19.017 for the complete list of banned materials.)

Will your project disturb asbestos containing materials? Yes ___ No _X_ ;
if yes, please consult state asbestos requirements at http://mass.gov/MassDEP/air/asbhom01.htm

Describe anti-idling and other measures to limit emissions from construction equipment: **Vehicles and equipment will be turned off when not in use for more than 5 minutes in accordance with Mass. Anti Idling Laws._**

DESIGNATED WILD AND SCENIC RIVER:

Is this project site located wholly or partially within a defined river corridor of a federally designated Wild and Scenic River or a state designated Scenic River? Yes ___ No _X_ ;
if yes, specify name of river and designation:

If yes, does the project have the potential to impact any of the "outstandingly remarkable" resources of a federally Wild and Scenic River or the stated purpose of a state designated Scenic River? Yes ___ No ___ ; if yes, specify name of river and designation: ___________;
if yes, will the project will result in any impacts to any of the designated "outstandingly remarkable" resources of the Wild and Scenic River or the stated purposes of a Scenic River.
Yes ___ No ___ ;
if yes,describe the potential impacts to one or more of the "outstandingly remarkable" resources or stated purposes and mitigation measures proposed.

ATTACHMENTS:

1.	List of all attachments to this document.	**See Table of Contents**
2.	U.S.G.S. map (good quality color copy, 8-½ x 11 inches or larger, at a scale of 1:24,000) indicating the project location and boundaries.	**See page USGS-1 and Fig. 1.02**
3..	Plan, at an appropriate scale, of existing conditions on the project site and its immediate environs, showing all known structures, roadways and parking lots, railroad rights-of-way, wetlands and water bodies, wooded areas, farmland, steep slopes, public open spaces, and major utilities.	**See Figs. 2.01, 2.02, 2.05, and 2.17**
4.	Plan, at an appropriate scale, depicting environmental constraints on or adjacent to the	**ACEC – Fig. 1.01;**

	project site such as Priority and/or Estimated Habitat of state-listed rare species, Areas of Critical Environmental Concern, Chapter 91 jurisdictional areas, Article 97 lands, wetland resource area delineations, water supply protection areas, and historic resources and/or districts.	**Ch. 91 areas – Fig. 7.01** **WRAs – Fig. 2.15**
5.	Plan, at an appropriate scale, of proposed conditions upon completion of project (if construction of the project is proposed to be phased, there should be a site plan showing conditions upon the completion of each phase).	**See Fig 4.01 and Attachment 4-1 at the end of Section 4.0 of the narrative**
6.	List of all agencies and persons to whom the proponent circulated the ENF, in accordance with 301 CMR 11.16(2).	**See ENF Distribution List page v**
7.	List of municipal and federal permits and reviews required by the project, as applicable.	**See Section 7.0**

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LAND SECTION – all proponents must fill out this section

I. Thresholds / Permits

A. Does the project meet or exceed any review thresholds related to **land** (see 301 CMR 11.03(1) ___ Yes _X_ No; if yes, specify each threshold:

II. Impacts and Permits

A. Describe, in acres, the current and proposed character of the project site, as follows:

	Existing	Change	Total
Footprint of buildings			
Internal roadways			
Parking and other paved areas	1.0	0	1.0
Other altered areas	21.2	-5.1	16.1
Undeveloped areas	31.8	+5.1	36.9
Total: Project Site Acreage	54	0	54

Has any part of the project site been in active agricultural use in the last five years?
___ Yes _X_ No; if yes, how many acres of land in agricultural use (with prime state or locally important agricultural soils) will be converted to nonagricultural use?

Is any part of the project site currently or proposed to be in active forestry use?
___ Yes _X_ No; if yes, please describe current and proposed forestry activities and indicate whether any part of the site is the subject of a forest management plan approved by the Department of Conservation and Recreation:

D. Does any part of the project involve conversion of land held for natural resources purposes in accordance with Article 97 of the Amendments to the Constitution of the Commonwealth to any purpose not in accordance with Article 97? ___ Yes _X_ No; if yes, describe:

E. Is any part of the project site currently subject to a conservation restriction, preservation restriction, agricultural preservation restriction or watershed preservation restriction? ___ Yes_X_ No; if yes, does the project involve the release or modification of such restriction? ___ Yes ___ No; if yes, describe:

F. Does the project require approval of a new urban redevelopment project or a fundamental change in an existing urban redevelopment project under M.G.L.c.121A? ___ Yes _X_ No; if yes, describe:

G. Does the project require approval of a new urban renewal plan or a major modification of an existing urban renewal plan under M.G.L.c.121B? Yes ___ No _X_; if yes, describe:

III. Consistency

Identify the current municipal comprehensive land use plan
Title: **Land Use Plan – Town of Saugus** Date **1990**

Describe the project's consistency with that plan with regard to:

1) economic development **N/A**
2) adequacy of infrastructure **No Impact**
3) open space impacts **consistent with goals to develop open space of conservation and recreation areas including the Saugus Marsh**
4) compatibility with adjacent land uses **preserves existing residential neighborhood**

Identify the current Regional Policy Plan of the applicable Regional Planning Agency (RPA)

RPA: __**MAPC – Metropolitan Area Planning Council**__

Title: **Metro Future** Date **May 2008**

Describe the project's consistency with that plan with regard to:

1) economic development **N/A**
2) adequacy of infrastructure **N/A**
3) open space impacts **consistent with goals of improving condition of wetlands for enhanced wildlife and recreational use**

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RARE SPECIES SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **rare species or habitat** (see 301 CMR 11.03(2))? ___ Yes _X_ No; if yes, specify, in quantitative terms:

(NOTE: If you are uncertain, it is recommended that you consult with the Natural Heritage and Endangered Species Program (NHESP) prior to submitting the ENF.)

B. Does the project require any state permits related to **rare species or habitat**? ___ Yes _X_ No

C. Does the project site fall within mapped rare species habitat (Priority or Estimated Habitat?) in the current Massachusetts Natural Heritage Atlas (attach relevant page)? ___ Yes _X_ No.

D. If you answered "No" to all questions A, B and C, proceed to the **Wetlands, Waterways, and Tidelands Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Rare Species section below.

II. Impacts and Permits

A. Does the project site fall within Priority or Estimated Habitat in the current Massachusetts Natural Heritage Atlas (attach relevant page)? ___ Yes ___ No. If yes,

1. Have you consulted with the Division of Fisheries and Wildlife Natural Heritage and Endangered Species Program (NHESP)? ___Yes ___No; if yes, have you received a determination as to whether the project will result in the "take" of a rare species? ___ Yes ___ No; if yes, attach the letter of determination to this submission.

2. Will the project "take" an endangered, threatened, and/or species of special concern in accordance with M.G.L. c.131A (see also 321 CMR 10.04)? ___ Yes ___ No; if yes, provide a summary of proposed measures to minimize and mitigate rare species impacts

3. Which rare species are known to occur within the Priority or Estimated Habitat?

4. Has the site been surveyed for rare species in accordance with the Massachusetts Endangered Species Act? ___ Yes ___ No

4. If your project is within Estimated Habitat, have you filed a Notice of Intent or received an Order of Conditions for this project? ___ Yes ___ No; if yes, did you send a copy of the Notice of Intent to the Natural Heritage and Endangered Species Program, in accordance with the Wetlands Protection Act regulations? ___ Yes ___ No

B. Will the project "take" an endangered, threatened, and/or species of special concern in accordance with M.G.L. c.131A (see also 321 CMR 10.04)? ___ Yes ___ No; if yes, provide a summary of proposed measures to minimize and mitigate impacts to significant habitat:

WETLANDS, WATERWAYS, AND TIDELANDS SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **wetlands, waterways, and tidelands** (see 301 CMR 11.03(3))? _X_ Yes ___ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits (or a local Order of Conditions) related to **wetlands, waterways, or tidelands**? _X_ Yes ___ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Water Supply Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Wetlands, Waterways, and Tidelands Section below.

II. Wetlands Impacts and Permits

Does the project require a new or amended Order of Conditions under the Wetlands Protection Act (M.G.L. c.131A)? _X_ Yes ___ No; if yes, has a Notice of Intent been filed? ___ Yes _X_ No; if yes, list the date and MassDEP file number: ______; if yes, has a local Order of Conditions been issued? ___ Yes ___ No; Was the Order of Conditions appealed? ___ Yes ___ No. Will the project require a Variance from the Wetlands regulations? ___ Yes ___ No.

B. Describe any proposed permanent or temporary impacts to wetland resource areas located on the project site: **Please refer to Section 5.1 of the attached Narrative**

C. Estimate the extent and type of impact that the project will have on wetland resources, and indicate whether the impacts are temporary or permanent:

Coastal Wetlands	Area (square feet) or Length (linear feet)	Temporary or Permanent Impact?
Land Under the Ocean	0	
Designated Port Areas	0	
Coastal Beaches	0	
Coastal Dunes	0	
Barrier Beaches	0	
Coastal Banks	0	
Rocky Intertidal Shores	0	
Salt Marshes	**31.8 acres**	**31.7 Temporary (Marsh Restoration)/0.1 Permanent (dike/culverts)**
Land Under Salt Ponds	0	
Land Containing Shellfish	0	
Fish Runs	0	
Land Subject to Coastal Storm Flowage	**721,306 SF** **2400 SF** **1600 SF**	**Temporary – Marsh Restoration** **Permanent – Fill for Dike** **Temporary – excavation for culvert**

Inland Wetlands		
Bank (lf)	0	
Bordering Vegetated Wetlands	0	
Isolated Vegetated Wetlands	0	
Land under Water	0	
Isolated Land Subject to Flooding	0	
Bordering Land Subject to Flooding	0	
Riverfront Area	**165,783 SF** **2400 SF**	**Temporary – Marsh Restoration** **Permanent – Fill for dike**

D. Is any part of the project:

1. proposed as a **limited project**? _X_ Yes ___ No; if yes, what is the area (in sf)?

31 acres ecological restoration under 310 CMR 10.24 (8)

2. the construction or alteration of a **dam**? ___ Yes _X_ No; if yes, describe:
3. fill or structure in a **velocity zone** or **regulatory floodway**? ___ Yes _X_ No
4. dredging or disposal of dredged material? ___ Yes _X_ No; if yes, describe the volume of dredged material and the proposed disposal site:
5. a discharge to an **Outstanding Resource Water (ORW)** or an **Area of Critical Environmental Concern (ACEC)**? _X_ Yes ___ No
6. subject to a wetlands restriction order? ___ Yes _X_ No; if yes, identify the area (in sf):
7. located in buffer zones? _X_ Yes ___ No; if yes, how much (in sf) ______

E. Will the project:

1. be subject to a local wetlands ordinance or bylaw? _X_ Yes ___ No
2. alter any federally-protected wetlands not regulated under state law? ___ Yes _X_ No; if yes, what is the area (sf)?

III. Waterways and Tidelands Impacts and Permits

A. Does the project site contain waterways or tidelands (including filled former tidelands) that are subject to the Waterways Act, M.G.L.c.91? _X_ Yes ___ No; if yes, is there a current Chapter 91 License or Permit affecting the project site? _X_ Yes ___ No; if yes, list the date and license or permit number and provide a copy of the historic map used to determine extent of filled tidelands: **See Figure 7.01 in attached narrative and license no. 10289.**

Does the project require a new or modified license or permit under M.G.L.c.91? ___ Yes _X_ No; if yes, how many acres of the project site subject to M.G.L.c.91 will be for non-water-dependent use? Current _0_ Change _0_ Total _0_

If yes, how many square feet of solid fill or pile-supported structures (in sf)?

C. For non-water-dependent use projects, indicate the following:

Area of filled tidelands on the site:__________________

Area of filled tidelands covered by buildings:__________

For portions of site on filled tidelands, list ground floor uses and area of each use:

____

Does the project include new non-water-dependent uses located over flowed tidelands? Yes ___ No ___

height of building on filled tidelands______________

Also show the following on a site plan: Mean High Water, Mean Low Water, Water-dependent Use Zone, location of uses within buildings on tidelands, and interior and exterior areas and facilities dedicated for public use, and historic high and historic low water marks.

D. Is the project located on landlocked tidelands? ___ Yes _X_ No; if yes, describe the project's impact on the public's right to access, use and enjoy jurisdictional tidelands and describe measures the project will implement to avoid, minimize or mitigate any adverse impact:

E. Is the project located in an area where low groundwater levels have been identified by a municipality or by a state or federal agency as a threat to building foundations? ___Yes _X_ No; if yes, describe the project's impact on groundwater levels and describe measures the project will implement to avoid, minimize or mitigate any adverse impact:

F. Is the project non-water-dependent **and** located on landlocked tidelands **or** waterways or tidelands subject to the Waterways Act **and** subject to a mandatory EIR? ___ Yes _X_

No;(NOTE: If yes, then the project will be subject to Public Benefit Review and Determination.)

G. Does the project include dredging? ___ Yes _X__ No; if yes, answer the following questions:
What type of dredging? Improvement ___ Maintenance ___ Both ____
What is the proposed dredge volume, in cubic yards (cys) _________
What is the proposed dredge footprint ____length (ft) ___width (ft)____depth (ft);
Will dredging impact the following resource areas?

Intertidal Yes__ No__; if yes, ___ sq ft
Outstanding Resource Waters Yes__ No__; if yes, ___ sq ft
Other resource area (i.e. shellfish beds, eel grass beds) Yes__ No__; if yes __ sq ft
If yes to any of the above, have you evaluated appropriate and practicable steps to: 1) avoidance; 2) if avoidance is not possible, minimization; 3) if either avoidance or minimize is not possible, mitigation?
If no to any of the above, what information or documentation was used to support this determination?
Provide a comprehensive analysis of practicable alternatives for improvement dredging in accordance with 314 CMR 9.07(1)(b). Physical and chemical data of the sediment shall be included in the comprehensive analysis.
Sediment Characterization
Existing gradation analysis results? __Yes ___No: if yes, provide results.
Existing chemical results for parameters listed in 314 CMR 9.07(2)(b)6? ___Yes ____No; if yes, provide results.
Do you have sufficient information to evaluate feasibility of the following management options for dredged sediment? If yes, check the appropriate option.

Beach Nourishment ___
Unconfined Ocean Disposal ___
Confined Disposal:
Confined Aquatic Disposal (CAD) ___
Confined Disposal Facility (CDF) ___
Landfill Reuse in accordance with COMM-97-001 ___
Shoreline Placement ___
Upland Material Reuse____
In-State landfill disposal____
Out-of-state landfill disposal ____
(NOTE: This information is required for a 401 Water Quality Certification.)

IV. Consistency:

A. Does the project have effects on the coastal resources or uses, and/or is the project located within the Coastal Zone? _X_ Yes ___ No; if yes, describe these effects and the projects consistency with the policies of the Office of Coastal Zone Management:

The Project is consistent with CZM's policies, especially in reducing coastal hazards (Coastal Hazards Policies #1 & #2), protection of habitat (Habitat Policies #1 & #2) and providing public access. CZM consistency review will be required as part of the Army Corps Section 404 review of this Project as well.

B. Is the project located within an area subject to a Municipal Harbor Plan? ___ Yes _X_ No; if yes, identify the Municipal Harbor Plan and describe the project's consistency with that plan:

WATER SUPPLY SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **water supply** (see 301 CMR 11.03(4))? ___ Yes _X_ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **water supply**? ___ Yes _X_ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Wastewater Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Water Supply Section below.

II. Impacts and Permits

A. Describe, in gallons per day (gpd), the volume and source of water use for existing and proposed activities at the project site:

	Existing	Change	Total
Municipal or regional water supply	______	______	______
Withdrawal from groundwater	______	______	______
Withdrawal from surface water	______	______	______
Interbasin transfer	______	______	______

B. If the source is a municipal or regional supply, has the municipality or region indicated that there is adequate capacity in the system to accommodate the project? ___ Yes ___ No

C. If the project involves a new or expanded withdrawal from a groundwater or surface water source, has a pumping test been conducted? ___ Yes ___ No; if yes, attach a map of the drilling sites and a summary of the alternatives considered and the results. ______________

D. What is the currently permitted withdrawal at the proposed water supply source (in gallons per day)? Will the project require an increase in that withdrawal? ___Yes ___No; if yes, then how much of an increase (gpd)? ___________________

E. Does the project site currently contain a water supply well, a drinking water treatment facility, water main, or other water supply facility, or will the project involve construction of a new facility? ___ Yes ___No. If yes, describe existing and proposed water supply facilities at the project site:

	Permitted Flow	Existing Avg Daily Flow	Project Flow	Total
Capacity of water supply well(s) (gpd)	______	______	______	______
Capacity of water treatment plant (gpd)	______	______	______	______

F. If the project involves a new interbasin transfer of water, which basins are involved, what is the direction of the transfer, and is the interbasin transfer existing or proposed?

G. Does the project involve:

1. new water service by the Massachusetts Water Resources Authority or other agency of the Commonwealth to a municipality or water district? ___ Yes ___ No
a Watershed Protection Act variance? ___ Yes ___ No; if yes, how many acres of alteration?
3. a non-bridged stream crossing 1,000 or less feet upstream of a public surface drinking water supply for purpose of forest harvesting activities? ___ Yes ___ No

III. Consistency

Describe the project's consistency with water conservation plans or other plans to enhance water resources, quality, facilities and services:

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WASTEWATER SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **wastewater** (see 301 CMR 11.03(5))? ___ Yes _X_ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **wastewater**? ___ Yes _X_ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Transportation -- Traffic Generation Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Wastewater Section below.

II. Impacts and Permits

A. Describe the volume (in gallons per day) and type of disposal of wastewater generation for existing and proposed activities at the project site (calculate according to 310 CMR 15.00 for septic systems or 314 CMR 7.00 for sewer systems):

	Existing	Change	Total
Discharge of sanitary wastewater	________	________	________
Discharge of industrial wastewater	________	________	________
TOTAL	________	________	________

	Existing	Change	Total
Discharge to groundwater	________	________	________
Discharge to outstanding resource water	________	________	________
Discharge to surface water	________	________	________
Discharge to municipal or regional wastewater facility	________	________	________
TOTAL	________	________	________

B. Is the existing collection system at or near its capacity? ___ Yes ___ No; if yes, then describe the measures to be undertaken to accommodate the project's wastewater flows:

C. Is the existing wastewater disposal facility at or near its permitted capacity? ___ Yes___ No; if yes, then describe the measures to be undertaken to accommodate the project's wastewater flows:

D. Does the project site currently contain a wastewater treatment facility, sewer main, or other wastewater disposal facility, or will the project involve construction of a new facility? ___ Yes ___ No; if yes, describe as follows:

	Permitted	Existing Avg Daily Flow	Project Flow	Total
Wastewater treatment plant capacity (in gallons per day)	_______	________	________	________

E. If the project requires an interbasin transfer of wastewater, which basins are involved, what is the direction of the transfer, and is the interbasin transfer existing or new?

(NOTE: Interbasin Transfer approval may be needed if the basin and community where wastewater will be discharged is different from the basin and community where the source of water supply is located.)

F. Does the project involve new sewer service by the Massachusetts Water Resources Authority (MWRA) or other Agency of the Commonwealth to a municipality or sewer district? ___ Yes ___ No

G. Is there an existing facility, or is a new facility proposed at the project site for the storage, treatment, processing, combustion or disposal of sewage sludge, sludge ash, grit, screenings, wastewater reuse (gray water) or other sewage residual materials? ___ Yes ___ No; if yes, what is the capacity (tons per day):

	Existing	Change	Total
Storage	___	___	___
Treatment	___	___	___
Processing	___	___	___
Combustion	___	___	___
Disposal	___	___	___

H. Describe the water conservation measures to be undertaken by the project, and other wastewater mitigation, such as infiltration and inflow removal.

III. Consistency
Describe measures that the proponent will take to comply with applicable state, regional, and local plans and policies related to wastewater management:

If the project requires a sewer extension permit, is that extension included in a comprehensive wastewater management plan? ___ Yes ___ No; if yes, indicate the EEA number for the plan and whether the project site is within a sewer service area recommended or approved in that plan:

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TRANSPORTATION SECTION (TRAFFIC GENERATION)

I. Thresholds / Permit

A. Will the project meet or exceed any review thresholds related to **traffic generation** (see 301 CMR 11.03(6))? ___ Yes _X_ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to state-controlled roadways? _X_ Yes ___ No; if yes, specify which permit: **Temporary Highway Access Permit – Rt. 107 – Existing Permit #4-2014-128 will be extended for duration of construction**

C. If you answered "No" to both questions A and B, proceed to the **Roadways and Other Transportation Facilities Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Traffic Generation Section below.

II. Traffic Impacts and Permits

A. Describe existing and proposed vehicular traffic generated by activities at the project site:

	Existing	Change	Total
Number of parking spaces	______	______	______
Number of vehicle trips per day	______	______	______
ITE Land Use Code(s):	______	______	______

B. What is the estimated average daily traffic on roadways serving the site?

Roadway	Existing	Change	Total
1. ______________	______	______	______
2. ______________	______	______	______
3. ______________	______	______	______

C. If applicable, describe proposed mitigation measures on state-controlled roadways that the project proponent will implement:

D. How will the project implement and/or promote the use of transit, pedestrian and bicycle facilities and services to provide access to and from the project site?

Is there a Transportation Management Association (TMA) that provides transportation demand management (TDM) services in the area of the project site? ____ Yes ____ No; if yes, describe if and how will the project will participate in the TMA:

Will the project use (or occur in the immediate vicinity of) water, rail, or air transportation facilities? ____ Yes ____ No; if yes, generally describe:

If the project will penetrate approach airspace of a nearby airport, has the proponent filed a Massachusetts Aeronautics Commission Airspace Review Form (780 CMR 111.7) and a Notice of Proposed Construction or Alteration with the Federal Aviation Administration (FAA) (CFR Title 14 Part 77.13, forms 7460-1 and 7460-2)?

III. Consistency

Describe measures that the proponent will take to comply with municipal, regional, state, and federal plans and policies related to traffic, transit, pedestrian and bicycle transportation facilities and services:

TRANSPORTATION SECTION (ROADWAYS AND OTHER TRANSPORTATION FACILITIES)

I. Thresholds

A. Will the project meet or exceed any review thresholds related to **roadways or other transportation facilities** (see 301 CMR 11.03(6))? ___ Yes _X__ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **roadways or other transportation facilities**? ___ Yes _X__ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Energy Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Roadways Section below.

II. Transportation Facility Impacts

A. Describe existing and proposed transportation facilities in the immediate vicinity of the project site:

B. Will the project involve any

1. Alteration of bank or terrain (in linear feet)? ________
2. Cutting of living public shade trees (number)? ________
3. Elimination of stone wall (in linear feet)? ________

III. Consistency -- Describe the project's consistency with other federal, state, regional, and local plans and policies related to traffic, transit, pedestrian and bicycle transportation facilities and services, including consistency with the applicable regional transportation plan and the Transportation Improvements Plan (TIP), the State Bicycle Plan, and the State Pedestrian Plan:

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ENERGY SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **energy** (see 301 CMR 11.03(7))?
___ Yes _**X**_ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **energy**? ___ Yes _ **X** __ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Air Quality Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Energy Section below.

II. Impacts and Permits

A. Describe existing and proposed energy generation and transmission facilities at the project site:

	Existing	Change	Total
Capacity of electric generating facility (megawatts)	______	______	______
Length of fuel line (in miles)	______	______	______
Length of transmission lines (in miles)	______	______	______
Capacity of transmission lines (in kilovolts)	______	______	______

B. If the project involves construction or expansion of an electric generating facility, what are:

1. the facility's current and proposed fuel source(s)?
2. the facility's current and proposed cooling source(s)?

C. If the project involves construction of an electrical transmission line, will it be located on a new, unused, or abandoned right of way? ___Yes ___No; if yes, please describe:

D. Describe the project's other impacts on energy facilities and services:

III. Consistency

Describe the project's consistency with state, municipal, regional, and federal plans and policies for enhancing energy facilities and services:

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AIR QUALITY SECTION

I. Thresholds
A. Will the project meet or exceed any review thresholds related to **air quality** (see 301 CMR 11.03(8))? ___ Yes _ **X** __ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **air quality**? ___ Yes _ **X** __ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Solid and Hazardous Waste Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Air Quality Section below.

II. Impacts and Permits
A. Does the project involve construction or modification of a major stationary source (see 310 CMR 7.00, Appendix A)? ___ Yes ___ No; if yes, describe existing and proposed emissions (in tons per day) of:

	Existing	Change	Total
Particulate matter	______	______	______
Carbon monoxide	______	______	______
Sulfur dioxide	______	______	______
Volatile organic compounds	______	______	______
Oxides of nitrogen	______	______	______
Lead	______	______	______
Any hazardous air pollutant	______	______	______
Carbon dioxide	______	______	______

B. Describe the project's other impacts on air resources and air quality, including noise impacts:

III. Consistency
A. Describe the project's consistency with the State Implementation Plan:

B. Describe measures that the proponent will take to comply with other federal, state, regional, and local plans and policies related to air resources and air quality:

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SOLID AND HAZARDOUS WASTE SECTION

I. Thresholds / Permits

A. Will the project meet or exceed any review thresholds related to **solid or hazardous waste** (see 301 CMR 11.03(9))? ___ Yes _ **X** __ No; if yes, specify, in quantitative terms:

B. Does the project require any state permits related to **solid and hazardous waste**? ___ Yes __ **X** _ No; if yes, specify which permit:

C. If you answered "No" to both questions A and B, proceed to the **Historical and Archaeological Resources Section**. If you answered "Yes" to either question A or question B, fill out the remainder of the Solid and Hazardous Waste Section below.

II. Impacts and Permits

A. Is there any current or proposed facility at the project site for the storage, treatment, processing, combustion or disposal of solid waste? ___ Yes ___ No; if yes, what is the volume (in tons per day) of the capacity:

	Existing	Change	Total
Storage	________	________	________
Treatment, processing	________	________	________
Combustion	________	________	________
Disposal	________	________	________

B. Is there any current or proposed facility at the project site for the storage, recycling, treatment or disposal of hazardous waste? ___ Yes ___ No; if yes, what is the volume (in tons or gallons per day) of the capacity:

	Existing	Change	Total
Storage	________	________	________
Recycling	________	________	________
Treatment	________	________	________
Disposal	________	________	________

C. If the project will generate solid waste (for example, during demolition or construction), describe alternatives considered for re-use, recycling, and disposal:

D. If the project involves demolition, do any buildings to be demolished contain asbestos? ___ Yes ___ No

E. Describe the project's other solid and hazardous waste impacts (including indirect impacts):

III. Consistency

Describe measures that the proponent will take to comply with the State Solid Waste Master Plan:

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HISTORICAL AND ARCHAEOLOGICAL RESOURCES SECTION

I. Thresholds / Impacts

A. Have you consulted with the Massachusetts Historical Commission? ___ Yes _ **X** _ No; if yes, attach correspondence. For project sites involving lands under water, have you consulted with the Massachusetts Board of Underwater Archaeological Resources? ____Yes __ **X** _ No; if yes, attach correspondence

B. Is any part of the project site a historic structure, or a structure within a historic district, in either case listed in the State Register of Historic Places or the Inventory of Historic and Archaeological Assets of the Commonwealth? ___ Yes _ **X** __ No; if yes, does the project involve the demolition of all or any exterior part of such historic structure? ___ Yes ___ No; if yes, please describe:

C. Is any part of the project site an archaeological site listed in the State Register of Historic Places or the Inventory of Historic and Archaeological Assets of the Commonwealth? ___ Yes _**X**__ No; if yes, does the project involve the destruction of all or any part of such archaeological site? ___ Yes _**X**__ No; if yes, please describe:

D. If you answered "No" to all parts of both questions A, B and C, proceed to the **Attachments and Certifications** Sections. If you answered "Yes" to any part of either question A or question B, fill out the remainder of the Historical and Archaeological Resources Section below.

II. Impacts

Describe and assess the project's impacts, direct and indirect, on listed or inventoried historical and archaeological resources:

III. Consistency

Describe measures that the proponent will take to comply with federal, state, regional, and local plans and policies related to preserving historical and archaeological resources:

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CERTIFICATIONS:

1. The Public Notice of Environmental Review has been/will be published in the following newspapers in accordance with 301 CMR 11.15(1):

(Name) **Saugus Advertiser** (Date) **March 26, 2015**

2. This form has been circulated to Agencies and Persons in accordance with 301 CMR 11.16(2).

Signatures:

3/16/15 Date — Signature of Responsible Officer or Proponent	3/16/15 Date — Signature of person preparing ENF (if different from above)
Kevin Whalen, Deputy Commissioner for Operations Name (print or type)	**Rachel J. Burckardt, PE, Project Manager** Name (print or type)
Dept. of Conservation & Recreation Firm/Agency	**Parsons Brinckerhoff, Inc.** Firm/Agency
251 Causeway Street, Suite 700 Street	**75 Arlington Street, 9th Floor** Street
Boston, MA 02114 Municipality/State/Zip	**Boston, MA 02116** Municipality/State/Zip
(617)-626-1250 Phone	**(617) 427-7330** Phone

USGS Map


Ballard Street Salt Marsh Restoration
0 1/4 1/2 mile
Last modified: 2/13/15
dcr
PARSONS BRINCKERHOFF
Project Area
REVERE

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1.0 Project Overview

1.1 Introduction

This document is an Expanded Environmental Notification Form (EENF) and Request for a Waiver of the requirements for preparation of an Environmental Impact Report for the Ballard Street Salt Marsh Restoration Project (the Project) in the Town of Saugus, Massachusetts. The location of the Project is shown on the USGS topographic quadrangle identified as Fig. 1.02. This EENF is submitted on behalf of the Massachusetts Department of Conservation and Recreation (DCR) to the Massachusetts Executive Office of Energy and Environmental Affairs (EEA) under the Massachusetts Environmental Policy Act (MEPA), in accordance with 301 Code of Massachusetts Regulations (CMR) 11.00 and with General Laws Chapter 30, Sections 61 through 62H. In accordance with 301 CMR 11.05(4), this EENF includes a concise and accurate description of the Project and its alternatives, identification of review thresholds and agency actions, and an assessment of potential environmental impacts and mitigation measures.

The Project is categorically included for preparation of an Environmental Impact Report (EIR) as noted in Section 1.4. DCR believes this Project meets all of the requirements for a Waiver of the EIR as described in 301 CMR 11.11(1) and (3) and discussed in Section 8.0.

1.2 Description of Project Area

The Ballard Street salt marshes are located within the 2,363-acre Rumney Marsh system in the North Coastal Watershed of Massachusetts, as shown in Fig. 1.03. The upland watershed includes most of the coastal drainage areas north of Boston. Rumney Marsh and the 422-acre Belle Isle Marsh to the south comprise the 2,785-acre Rumney Marsh Area of Critical Environmental Concern (ACEC) and drain an area of approximately 65 square miles. See Fig. 1.01.

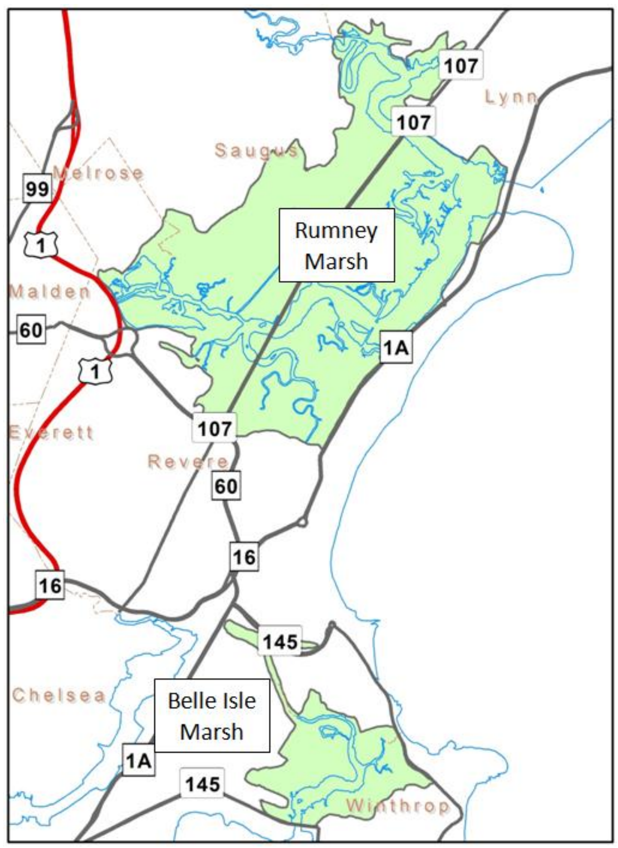

Fig. 1.01 Rumney Marshes ACEC includes Belle Isle Marsh to the south

The 54-acre Project Area is located within East Saugus and is generally bordered by Eastern Avenue on the west, Ballard Street on the north, Salem Turnpike (Route 107) on the east and the abandoned Bristow Street right-of-way on the south. See Figures 1.02, 1.03 and 1.04. Lands within the Project Area are owned by either DCR or by the Town of Saugus (the Town), with some parcels also subject to a care and control agreement between DCR and the Town.

The Project Area contains two areas of historically filled and/or degraded salt marshes, hereafter referred to as the Eastern and Western Marshes, which are bifurcated by a large linear embankment of sand and gravel fill placed in the late 1960s for the layout of I-95 (see Fig. 1.04). At that time, I-95 was planned to run from the circle at Route 60 in Revere, passing through the Rumney Marsh in a gentle arc, and then crossing the Saugus River into Lynn.

In the intervening years, little by little, agencies of the Commonwealth have been removing portions of the embankment for beneficial use, including roadway subbase and beach nourishment at Revere and Winthrop. The most recent extraction is part of the DCR's Winthrop Beach Nourishment Project (Contract No. P11-2686-C4A, EEA #10113), which is ongoing.

The remains of the embankment can be seen in Fig. 1.04.

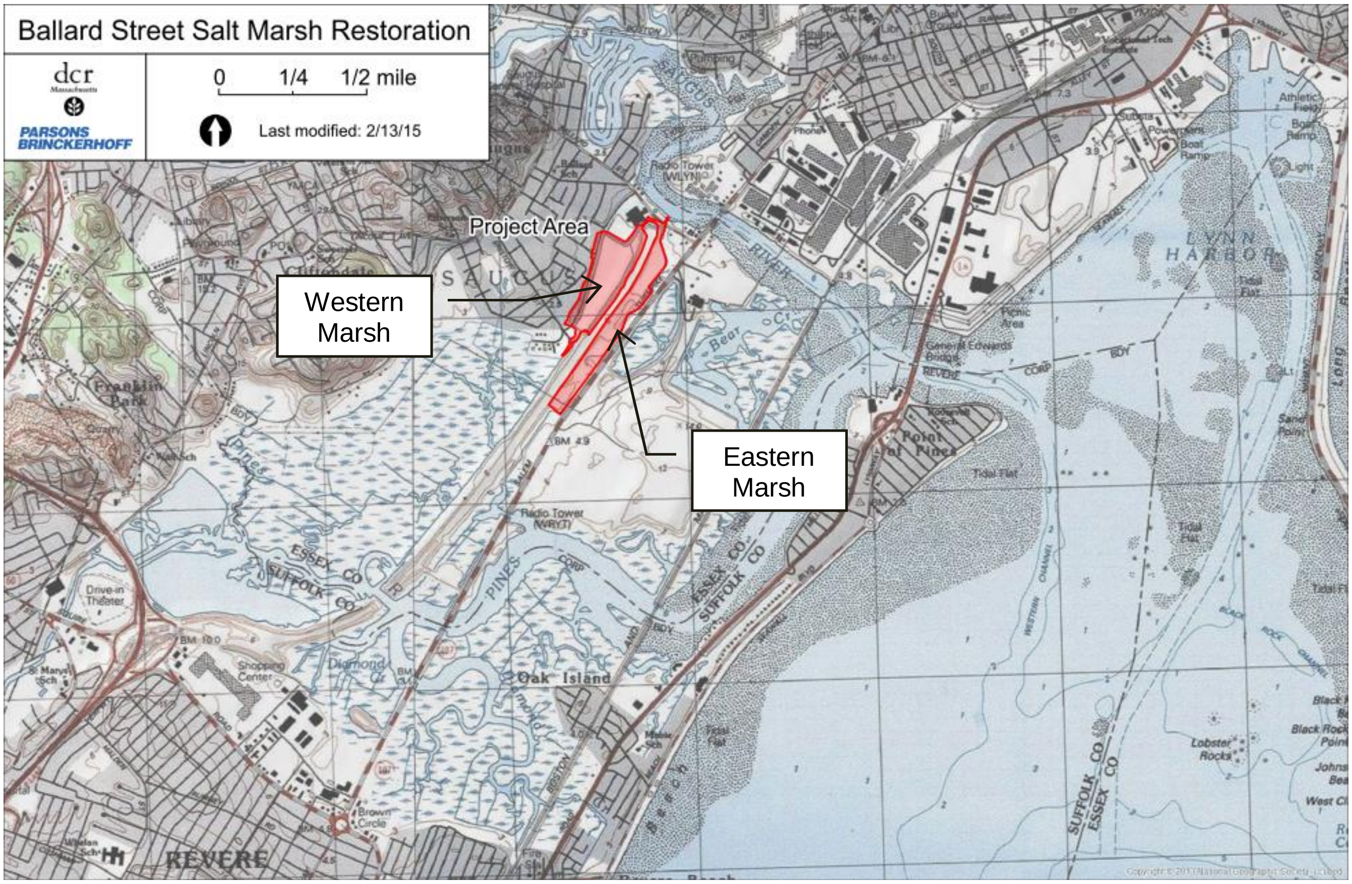

Fig. 1.02 USGS Project Locus

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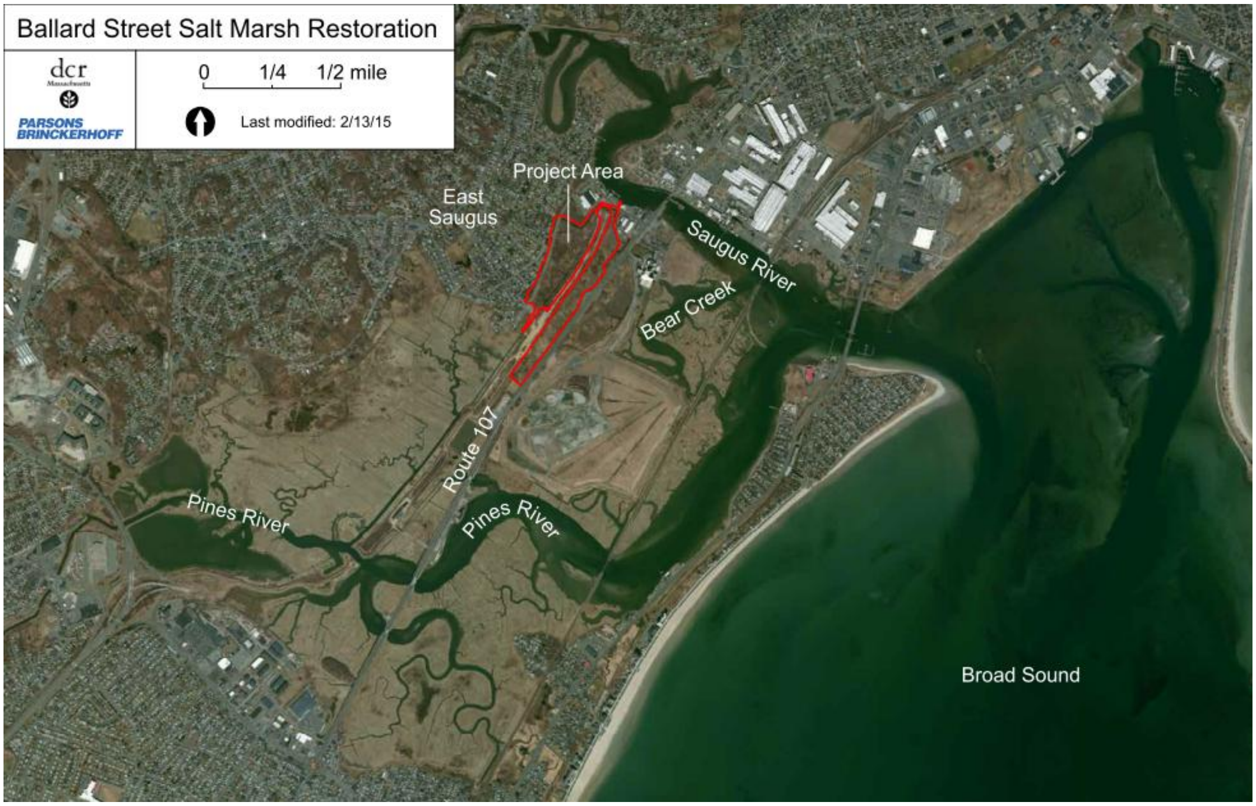

Fig. 1.03 Project Area in Relation to Overall Rumney Marsh

Fig. 1.04 Aerial Project Locus

1.3 Project Purpose and Need

1.3.1 History of Project Area

Historically, the Ballard Street salt marsh received tidal water from three sources: the Saugus River to the north, Bear Creek to the east, and the Pines River to the south (formerly the Chelsea River as seen in Fig. 1.05). See historic maps from 1829 and 1872 in Figs. 1.05 and 1.06. The Project Area was once contiguous to 150 acres of salt marsh, extending west from the present day Route 107 (Salem Turnpike) nearly to Lincoln Avenue at the fringes of the East Saugus drumlin. Evidence of construction of the Salem Turnpike (now Route 107), first emerges in the 1829 map. "South Street" is believed to be an early version of Bristow Street. Note that Ballard Street has not been built and a stream drains the Project Area into the Saugus River.

By 1872, Ballard Street was in place and the drainage pattern changed, with the link to the Saugus River not shown. In its place, a series of channels along the west side of the Turnpike drain the Project Area to the Bear Creek.

Development in the East Saugus neighborhood has filled in this area, as shown on Fig. 1.08.

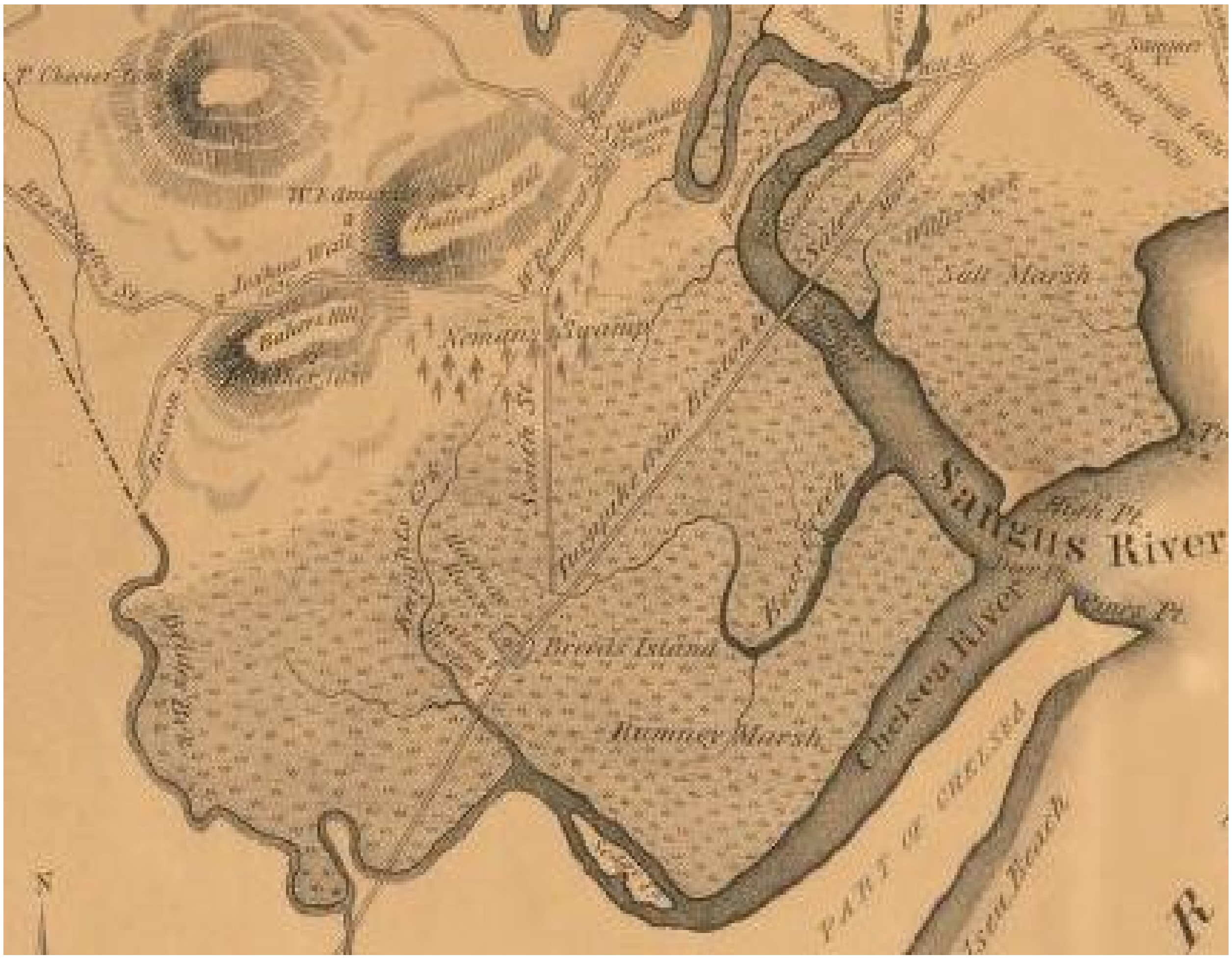

Fig. 1.05 1829 Historic Map of Project Area

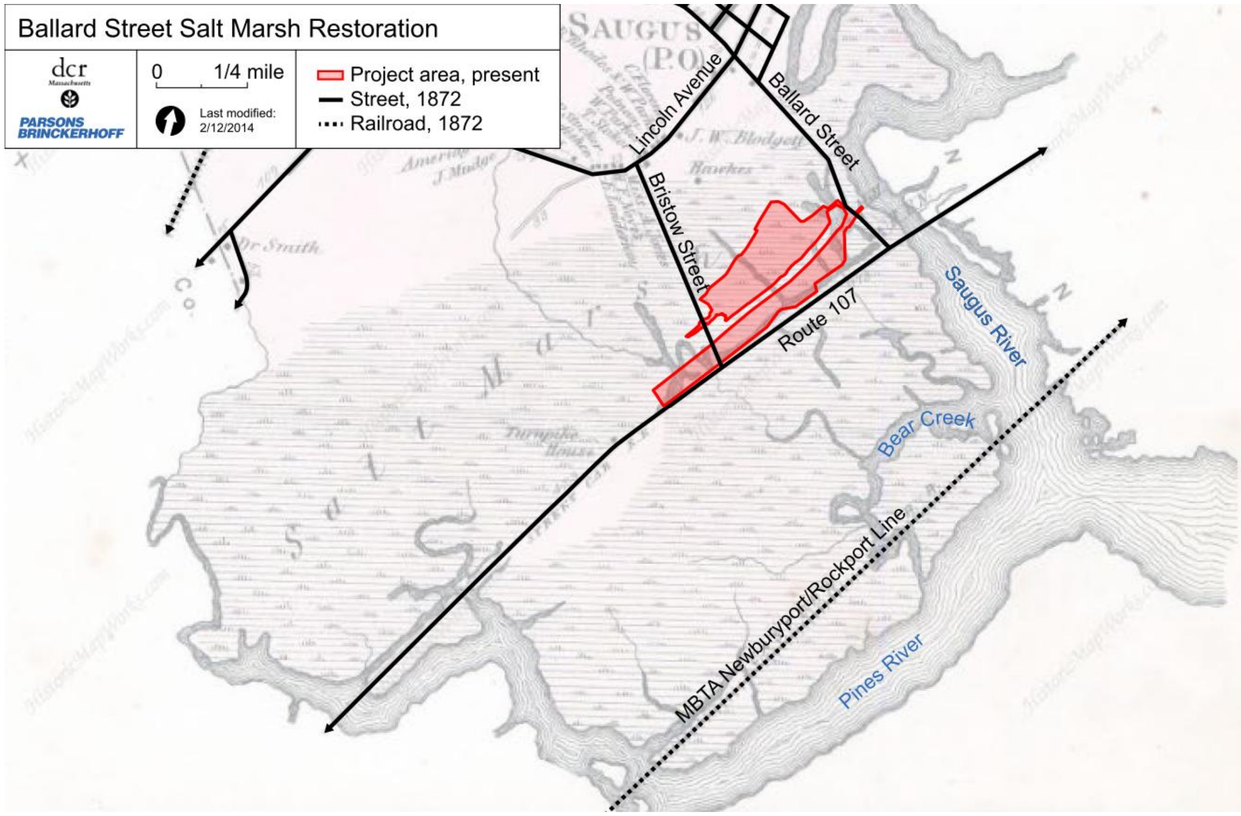

Fig. 1.06 1872 Historic Map of Project Area

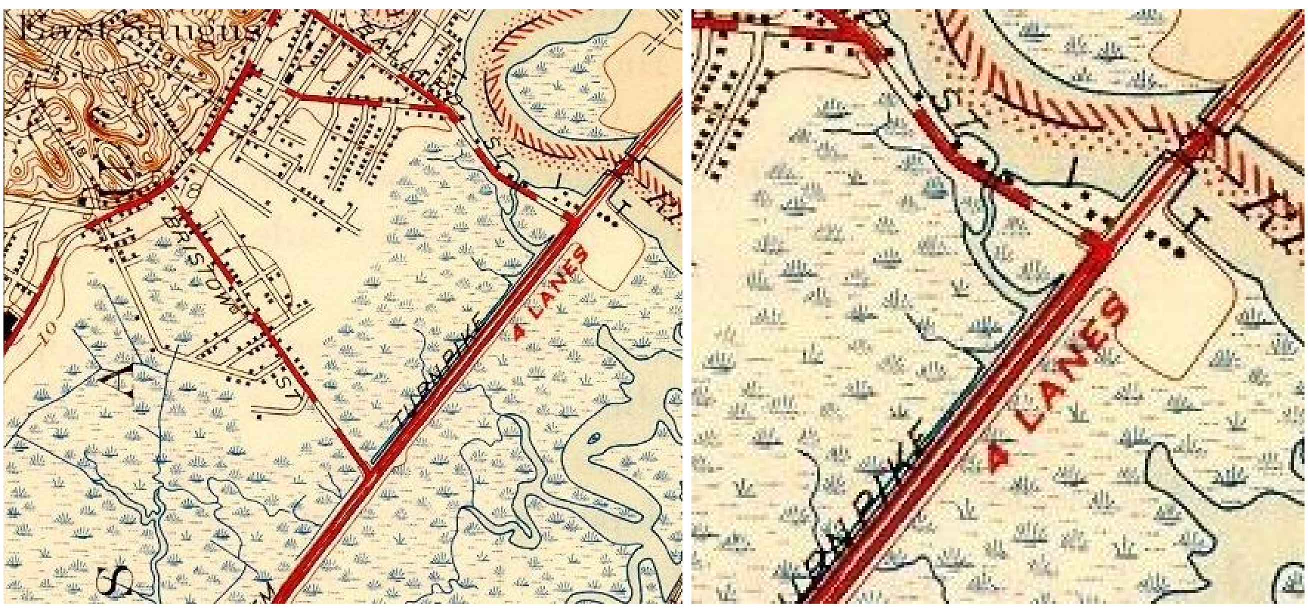

Fig. 1.07 USGS Map from 1943.
Left: Showing the Project Area with apparent culverts under Bristow Street, the Salem Turnpike (Rt. 107) and Ballard Street. Right: Close-up showing stream passing under Ballard Street with a symbol indicating a bridge.

Today, tidal exchange is limited within the salt marsh because of significant anthropogenic alterations including past installation of culverts, tide gates, and filling of salt marsh. The result is that a once contiguous area of salt marsh within the Rumney Marsh (see Fig. 1.05, 1.06 and 1.07) is now degraded and the remaining marsh is isolated as two tenuously connected but distinct marsh cells (referenced herein as the Eastern and Western Marshes – see Fig. 1.04) with severely restricted tidal connections due to five specific conditions:

1. The primary tidal restriction occurs at Ballard Street where an improvised tide gate (see Fig. 2.20) affixed to the downstream end of a 4-ft. diameter culvert under Ballard Street (culvert "BA-1") severely restricts flow from the Saugus River. While installed as a stop-gap measure to replace an historic tide gate and to provide some flood protection by blocking flow from the Saugus River into the Western Marsh, the improvised tide gate at Ballard Street leaks, allowing roughly only 30% of the Saugus River tidal range to pass through the culvert.

2. A second historic tidal connection along the Pines Creek, which once also functioned via a tide gate at Bristow Street (culvert "BR-1") (east of the I-95 embankment) providing flow to the Eastern Marsh, is now blocked entirely from tidal flow by a wooden board (Fig. 2.21).

3. A third tidal restriction occurs at the Western Marsh, where the absence of a culvert directly along the Pines River Channel occurs at Bristow Street (west of the I-95 embankment).

4. Directly east of the project area, an additional restriction is the result of past filling for the solid waste facility, where non-functioning culverts and Route 107 all block flows from Bear Creek.

5. Finally, the major contributor negatively affecting the quality of the salt marsh is the presence of the fill material associated with construction of the abandoned extension to I-95.

The combined result of these obstructions is a highly muted tidal flow and one that is not able to support a viable salt marsh to the extent that once existed in this now degraded system.

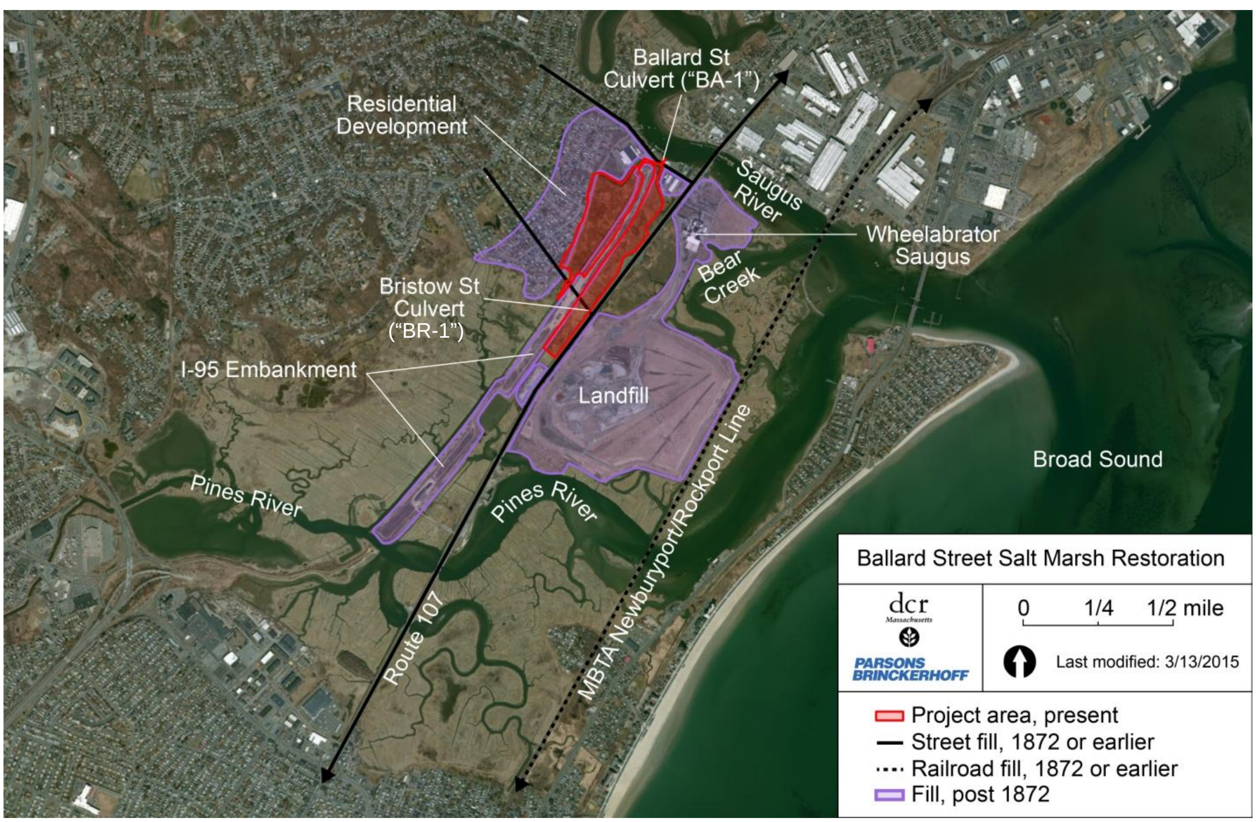

Fig. 1.08 Fill placement since 1872

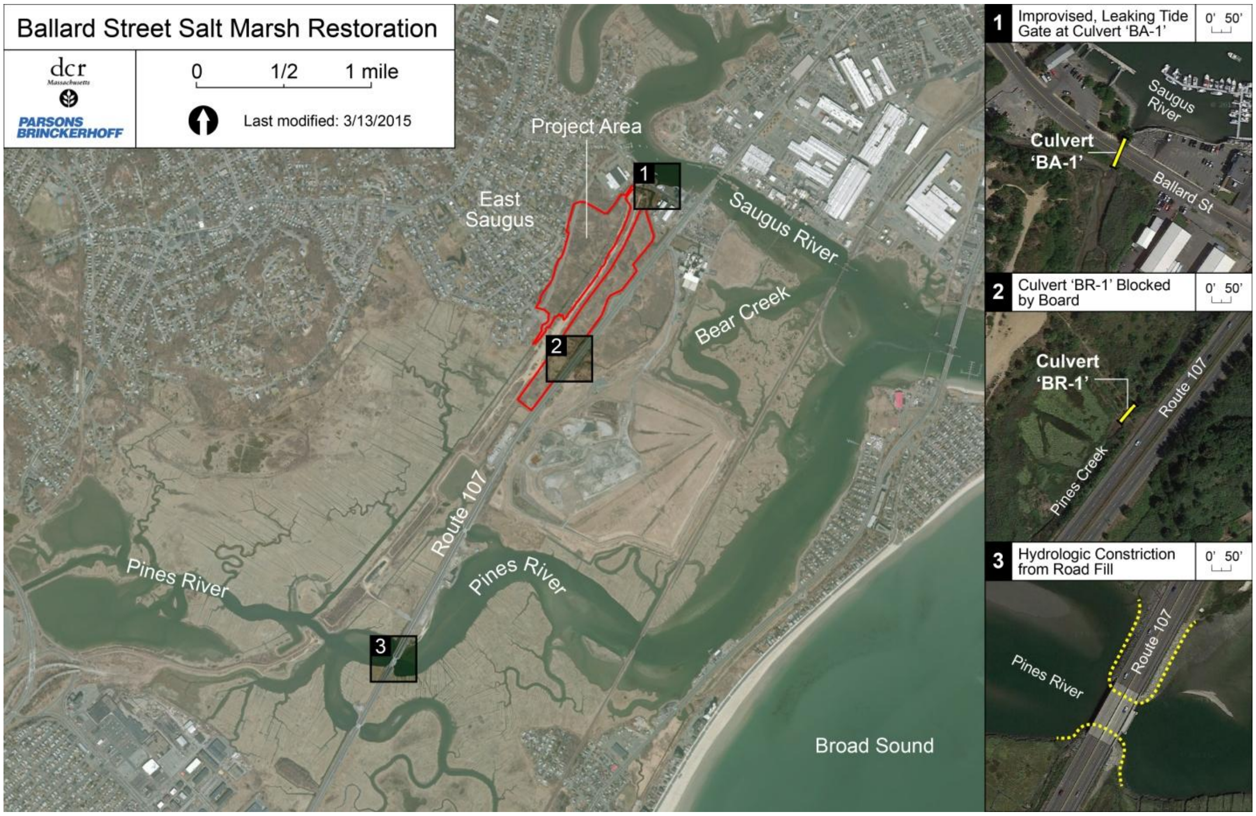

Fig. 1.09 Hydraulic Constrictions to Tidal Connectivity of the Project Area

1.3.2 Project Need

The restrictions in tidal exchange and physical obstructions contribute to the poor drainage of freshwater from the flood-prone East Saugus neighborhood to the Saugus River. As a result, the area has poorly functioning salt marsh and the adjacent residential neighborhood experiences exacerbated flooding. The cumulative effect of these alterations is the significantly reduced coverage of salt marsh resource in the vicinity of the Project Area from more than 54 acres to the present estimate of approximately 9 acres. The remaining 45 acres have converted to either freshwater marsh dominated by non-native and invasive common reed (*Phragmites australis*), or have begun the process of succession to forested upland. The monotypic coverage of *Phragmites* is the dominant visual and structural feature of the Project Area covering more than 75% of the remaining wetland and greatly limiting its function and value.

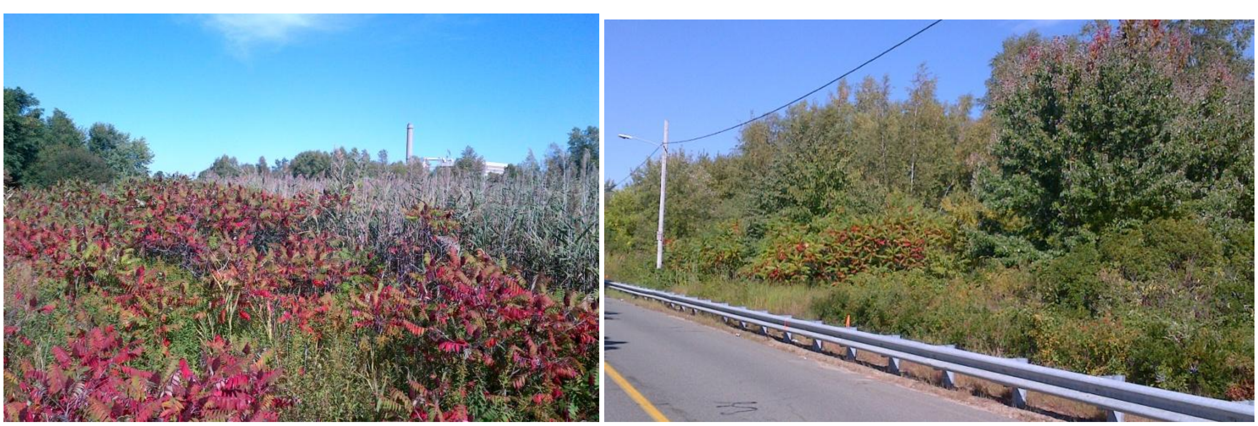

Fig. 1.10 Photos from Eastern Avenue showing freshwater invasives (left) and succession to forested upland (right)

1.3.3 Project Purpose

The Project is proposed in order to accomplish two primary goals:

1) The restoration of former and degraded salt marsh in an Area of Critical Environmental Concern (ACEC), thereby improving wildlife, fisheries, and potential shellfish habitat; and

2) Enhancement of flood control and storm damage prevention for area residents through improved drainage providing for better control of water levels from coastal and inland storm events.

The Division of Ecological Restoration (DER) of the Massachusetts Department of Fish & Game has determined this Project to be the highest priority project within the Rumney Marsh given the extent of potentially restorable salt marsh and the potential improvements to flood control, water quality, and other ecological benefits for fisheries and wildlife (Rumney Marshes Area of Critical Environmental Concern Restoration Plan, WRP, 2002). The Project is also a federal Coastal America Project based on a "Resolution to Restore Massachusetts Wetlands," which the Executive Office of Environmental Affairs (EOEA), the Mass. Department of Transportation, and six federal agencies representing the federal Coastal America Partnership signed in 1994. As such the Project has benefitted significantly from the past input of the United States Environmental Protection Agency (EPA), the United States Department of Agriculture's Natural Resource Conservation Service (NRCS), and the United States Army Corps of Engineers (ACOE).

1.4 Project History

The Project has developed from multiple past collaborative efforts among many federal, state, and municipal stakeholders including ACOE, EPA, NRCS, the Town, the MA Department of Conservation and Recreation (DCR, formerly known as the MDC), and DER.

1.4.1 Early Versions of the Project with NRCS as Proponent

Recurrent flooding during and following inland storm events in the adjacent East Saugus neighborhood led to initial investigation by NRCS (USDA NRCS, 1999). The other stakeholders recognized the Project's simultaneous potential to provide significant wetland restoration of the degraded salt marsh in the Project Area.

Between 1999 and 2007, NRCS, in conjunction with the Town, EPA, DER, and others, advanced the design of improvements to address flood control and salt marsh restoration. This work included the filing of an ENF for which the Secretary issued a Certificate under EOEA #12889, dated December 30, 2002. Construction was proposed in three phases:

- Phase 1 included the installation of a new culvert and tide control gates at the I-95 embankment terminus near Ballard Street (about 200 ft. upstream of the culvert under Ballard Street). These gates would control the tidal range in the Western Marsh;
- Phase 2 included excavation to lower the marsh plain and create stormwater storage in the Western Marsh between the I-95 embankment and Eastern Avenue; and
- Phase 3 provided for tidal restoration via removal of objects that obstruct flow at Ballard and Bristow Street culverts ("BA-1" and BR-1," respectively) and simultaneous operation of the culverts and tide gates previously installed in Phase 1.

Subsequently, the Town, with support from NRCS, submitted a Phase 1 waiver request under EEA #13993 on April 20, 2007. Refer to Appendix 4 for copies of the ENF Certificates for EOEA[1] #12889 and EEA #13993.

NRCS advanced the design to secure the permits required to implement Phase 1, but the final two phases required further design before permits could be secured to allow that work. Even though Phase 1 permitting was partially completed, its implementation was put on hold for several reasons:

1) Uncertain funding for design/construction of remaining phases;
2) Errors discovered in the original ground survey which caused NRCS to withdraw the original permitted Phase 1 construction designs; and
3) The need for additional tidal data and updated modeling capability on the flow dynamics of the existing marsh system, work that would ultimately lead to the development of the current design.

The project never advanced to Phase 1 installation.

1.4.2 Role of the Winthrop Beach Restoration and DCR as Project Proponent

In 2010 DCR, which had undertaken the Winthrop Beach Nourishment Project (included in EEA #10113) Investigations by DCR determined that sand and gravel embankment installed in the late 1960s to support large portions of the I-95 extension immediately adjacent to the Project Area would be suitable for nourishment. The US Army Corps of Engineers used material from this embankment for the successful beach nourishment of Revere Beach in the 1990s. DCR proposed extracting the sand and restoring portions of the underlying salt marsh which had been buried by the I-95 embankment. The Winthrop Beach Nourishment Project proved an opportunity to revive the dormant salt marsh restoration and flood control enhancement project.

DCR recognized that the restoration of wetland acreage underlying the I-95 embankment, to be exposed by the extraction of sand for the Winthrop Beach Nourishment Project could and should be beneficially combined with reviving efforts at the Ballard Street salt marsh to ensure coordinated design and construction of each. In fact, the Superseding Order of Conditions (DEP File # 067-1001) issued for DCR’s sand removal requires such coordination prior to commencement of the salt marsh restoration under the embankment. This synergy, combined with the realization of significant new project funding via a USFWS National Coastal Wetland Conservation Grant awarded to DCR and DER made the Project feasible.

DCR and DER secured new ground survey data along with more complete tidal flow data within the Project Area, including data from tide gauges and salinity testing at multiple site locations, as described in a report prepared by Woods Hole Group, Inc. (2014, see Appendix 1). DCR, through Applied Coastal Research and Engineering, Inc. in 2014-2015, performed additional hydraulic and hydrologic modeling of the Project Area to test and predict tidal dynamics of the Project Area under a range of conditions and design alternatives, described in Appendix 2.

The current design was developed based upon its ability to balance complicated site conditions and (at times) competing interests in order to provide the maximum amount of salt marsh restoration with as natural a tidal flow as possible while also mitigating flooding effects to the adjacent residential neighborhood. This proactive salt marsh restoration project is the single largest restoration opportunity

[1] EOEA, or Executive Office of Environmental Affairs, is the predecessor of the current EEA (Executive Office of Energy and Environmental Affairs).

within Rumney Marsh and is consistent with the *Rumney Marshes Area of Critical Environmental Concern Salt Marsh Restoration Plan* (May, 2002).

For description, see Section 4.0.

1.5 MEPA Review Thresholds

Under current MEPA review thresholds the Project requires an ENF and a mandatory EIR for alteration of one or more acres of salt marsh or bordering vegetating wetlands [301 CMR 11.03(3) (1) (a)], and alteration of ten or more acres of any other wetlands [301 CMR 11.03(3) (1) (b)]. The Project also triggers an ENF and other MEPA review, if the Secretary so requires, as it is within a designated ACEC [301 CMR 11.03(11) (b)], and because the Project will result in direct alteration of 25 acres or more of land [301 CMR 11.03(1) (b) (1)].

This application will demonstrate that construction of the Project described in this EENF, meets the standards for a waiver of the mandatory EIR, as described in 301 CMR 11.11 (1-3). The standards and demonstration of compliance with the waiver criteria are described in Section 8.0.

1.6 Greenhouse Gas Emissions Compliance

The project is believed to qualify for a de minimus exemption from the MEPA Greenhouse Gas Emissions Policy and Protocol as an ecological restoration project.

1.7 Vertical Datum

All vertical elevations in this report refer to the North American Vertical Datum of 1988 (NAVD88), unless otherwise noted.

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2.0 Existing Conditions

The 54-acre Project Area, located within the 2,363-acre Rumney Marsh system (see Fig. 1.01), is shown in Fig. 2.01. The Project Area is located within East Saugus and is generally bordered by Eastern Avenue on the west, Ballard Street on the north, Salem Turnpike (Route 107) on the east and the abandoned Bristow Street right-of-way on the south. The Project Area contains two areas of degraded salt marshes, hereafter referred to as the Eastern and Western Marshes, which are bifurcated by a large linear embankment of sand and gravel fill placed in the late 1960s for the layout of I-95.

Fig. 2.01 Project Area

2.1 Wetland Resources

The Project Area formerly contained a thriving salt marsh. Today it is a low-quality brackish/freshwater marsh dominated by the non-native and invasive common reed (*Phragmites australis*). The salt marsh resource in the Project Area is 31.8 acres, based on field delineation. The Western Marsh contains 15.4 acres of poorly functioning *Phragmites* marsh. The monotypic coverage of *Phragmites* is the dominant visual and structural feature of the Project Area covering more than 75% of the remaining wetland and greatly limiting its function and value. The Eastern Marsh contains 16.4 acres in a similar condition.

Wetlands subject to Section 404 of the Clean Water Act, the Massachusetts Wetland Protection Act (MGL Ch. 131 S. 40) and Regulations, and the Saugus Wetland Bylaw, Article 508 have been delineated several times within the Project Area. In 2002, the Saugus Conservation Commission approved the boundaries for Phase 1 of the NRCS proposed project under DEP File #67-806, which has been periodically extended by the Saugus Conservation Commission and remains current. Wetlands were again delineated in June 2005 by GeoSyntec and most recently in August 2012 by Rimmer Environmental

Consulting (REC) for the sand extraction project, approved under a Superseding Order of Conditions (DEP File #67-1001). Additional flagging along Eastern Avenue and historic peat stockpiles in the Eastern Marsh were delineated by REC in September 2014. The extent of the wetland resources within the Project Area has been compiled from the delineations as described above and is depicted on the Wetland Resource Map, Fig. 2.02.

Fig. 2.02 Wetland Resource Map

Wetland Resource Areas (WRAs) subject to the Massachusetts Wetlands Protection Act present within and immediately adjacent to the Project Area include Salt Marsh, Riverfront Area, and Land Subject to Coastal Storm Flowage.

2.1.1 Salt Marsh

The Project Area contains primarily areas of former salt marsh that are converting from brackish to freshwater marsh due to the lack of adequate tidal exchange. Approximately 15.4 acres of salt marsh are located west of the I-95 embankment and 16.4 acres to the east. These figures are based on field delineation, as described in Section 2.1. Species composition is similar on both sides of the embankment. Dominant vegetation within both the Eastern and Western Marshes is *Phragmites*. However, interspersed within the *Phragmites* stands are small pockets of salt marsh species such as *Spartina alterniflora, Spartina patens, Juncus gerardii, Salicornia europaea, Sueada linearis,* and *Atriplex patula*. Several ditched channels are present within the salt marsh. The wetland areas closest to Ballard Street reflect the larger concentration of coastal wetland plants, as these are closest to the limited tidal exchange at the failed tide gate.

Though delineated as the Salt Marsh (310 CMR 10.32), the Western Marsh is now functioning mostly as a freshwater Bordering Vegetated Wetlands (BVW) with some tidal influence confined mostly to the main channel along the northern edge. The Western Marsh is dominated by *Phragmites australis*, and several ditched channels are present. A large fill pile of peat excavated from under what is now the I-95 embankment is present within the Eastern Marsh.

Nearest the upland areas the salt marsh transitions to a scrub shrub wetland including species such as grey birch, sweet gale, swamp rose, purple loosestrife, and sensitive fern occurring near the base of the I-95 embankment.

2.1.2 Riverfront Area

The Saugus River and portions of an unnamed tributary to the Saugus River near Ballard Street are indicated on the USGS topographic quadrangle as perennial streams and are therefore presumed under 310 CMR 10.58 to contain a 200-ft. Riverfront Area extending from mean high water. A small portion of the northern part of the Project Area is within the Riverfront Area to the Saugus River and a larger portion is within Riverfront Area to the on-site unnamed tributary. See Fig. 2.02.

2.1.3 Land Subject to Coastal Storm Flowage (LSCSF)

This resource is defined under 310 CMR 10.04 as, "land subject to any inundation caused by coastal storms up to and including that caused by the 100-year storm, surge of record or storm of record, whichever is greater." The current Flood Insurance Rate (FIRM) maps for this area, depicted as Fig. 2.03 indicate that the 100-year storm extends up to elevation +9.0 ft. and encompasses virtually the entire Project Area.

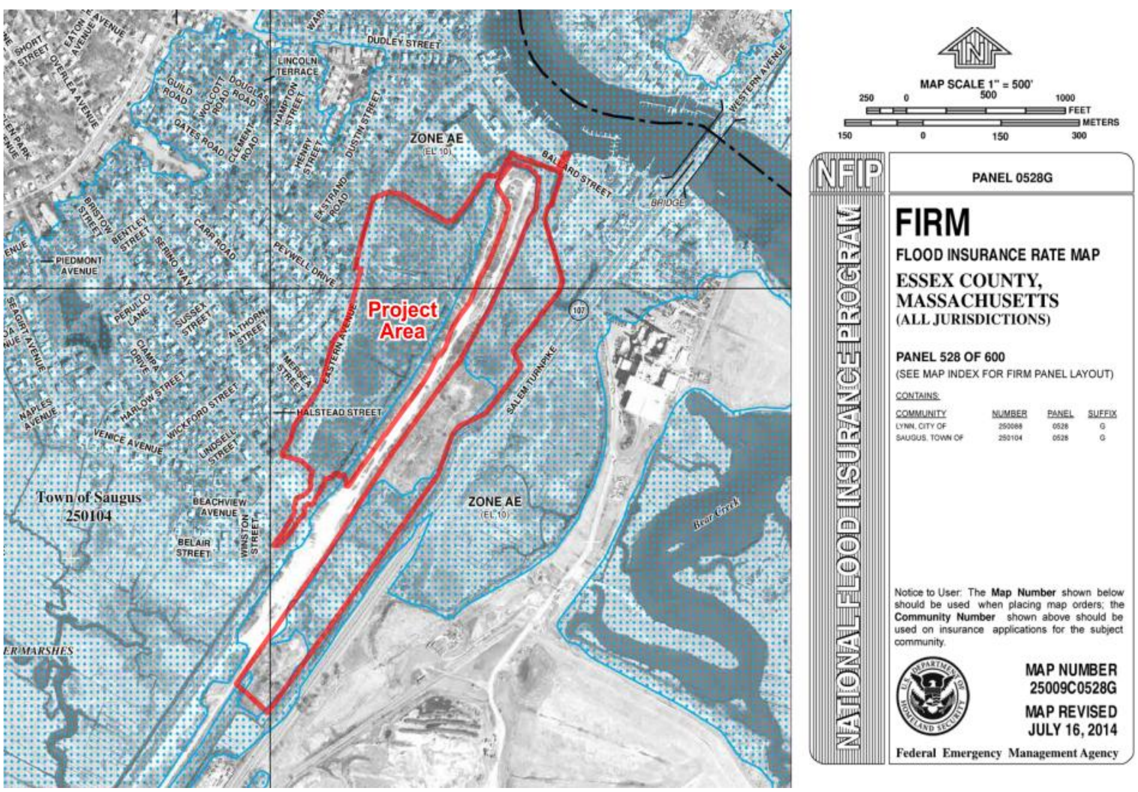

Fig. 2.03 FEMA Flood Map

Based upon a survey profile, Saugus River tidal elevations greater than +7.1 ft. will overtop Ballard Street and enter the marsh. This would occur with a frequency greater than the 10-year tidal flood of 8.4 ft.. The southeast end of the Project Area at Bristow Street is subject to tidal flooding from the Pines River at approximately the same frequency. The intersection of Bristow Street and Eastern Avenue is just barely above elevation +7 ft. Eastern Avenue varies in elevation up to elevation +10 ft. Surface flooding of the residential properties in the upgradient East Saugus neighborhood currently begins at elevation +5.4 ft.

2.2 Wildlife/Fisheries Habitat

The wildlife habitat functions of the existing marsh are severely restricted by the lack of adequate tidal exchange and the subsequent colonization of a majority of the area by non-native and invasive plant species, especially *Phragmites*. The tendency of *Phragmites* to grow in mono-typic stands, greatly limits other native plant species as demonstrated by the Project Area's low diversity of vegetative cover. Low plant species diversity reduces the range of ecological niches for native wildlife, given the limited variety of forage, cover and overwintering sites. The result is a corresponding drop in wildlife diversity. While still found in small numbers, many of the shore birds, waders and waterfowl typically inhabiting New England salt marshes are largely absent from this Project Area. The lack of tidal exchange limits opportunities for fish to enter into the ditches located through the Project Area and for shellfish to occupy tidal flats, pannes, and pools that are typically present in an undisturbed salt marsh. In the Western Marsh, there is no tidal access (i.e., inundation at MHW) to the marsh other than immediately adjacent to the tidal stream along the northerly boundary. Overall, there is presently tidal access only to 3 acres for the remaining 31.8 acres in the Eastern and Western Marshes.

2.3 Water Quality

Because the Project is located within the Rumney Marshes ACEC, its wetlands and water bodies are designated as Outstanding Resource Waters (ORW) per 314 CMR 4.06. This protection reflects the waters' outstanding socio-economic, recreational, ecological, and/or aesthetic values. Protection of the existing water quality is required, and a new or increased discharge is generally prohibited.

2.4 Rare Species

The Project Area is not located within the Estimated Habitat of Rare Wetlands Wildlife or within Priority Habitat, as identified by information provided by the Mass. Division of Fisheries and Wildlife, Natural Heritage and Endangered Species Program available on MassGIS.

2.5 Soils

GeoSyntec Consultants conducted soil testing in the Western Marsh with a hand-held steel auger in 2005. Probes extended 3 ft. in depth. Testing indicates that the southern two thirds of the Western Marsh contain a higher water table elevation and is dominated by *Phragmites*. The sediment is dark brown peat to a depth of at least 1 ft. underlain by fine to medium sand. The north section is primarily covered by trees, shrubs and grasses with sediment consisting of about 1 ft. of black to dark brown peat underlain by brown sand to sandy silt. Boston Blue Clay appears below the peat layer at one of the sampling stations (S-11). See Appendix 6.

2.6 Parklands and Open Space

2.6.1 Rumney Marsh Reservation

The Project Area is located within the DCR's Rumney Marsh Reservation, which consists of a 600+ acres reservation within the Saugus and Pines River estuary. See Fig. 2.04. The reservation provides recreational opportunities such as boating, fishing, walking, and bird watching. While most of the reservation is undeveloped, there is an existing gravel parking lot located at the corner of Eastern Avenue and Bristow Street. As part of the Winthrop Beach Nourishment Project, the DCR will construct an additional small parking lot at Ballard Street that will be the trailhead of a walking path traversing the embankment to a point just south of Bristow Street. See Fig. 2.05

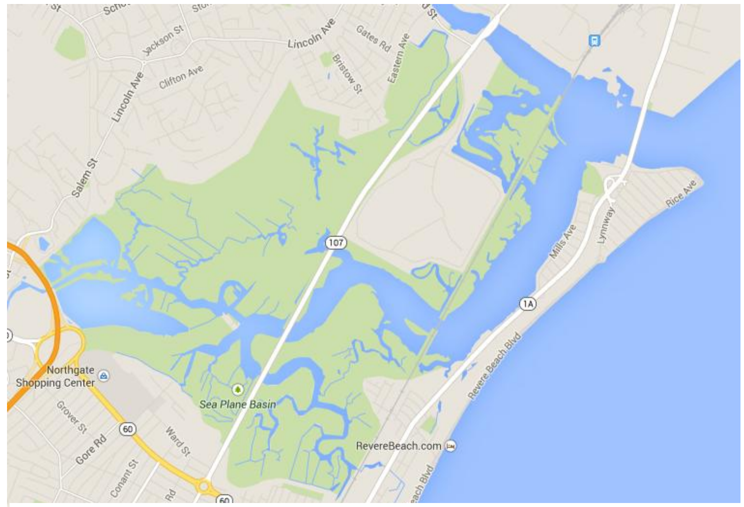

Fig. 2.04 DCR Rumney Marsh Reservation

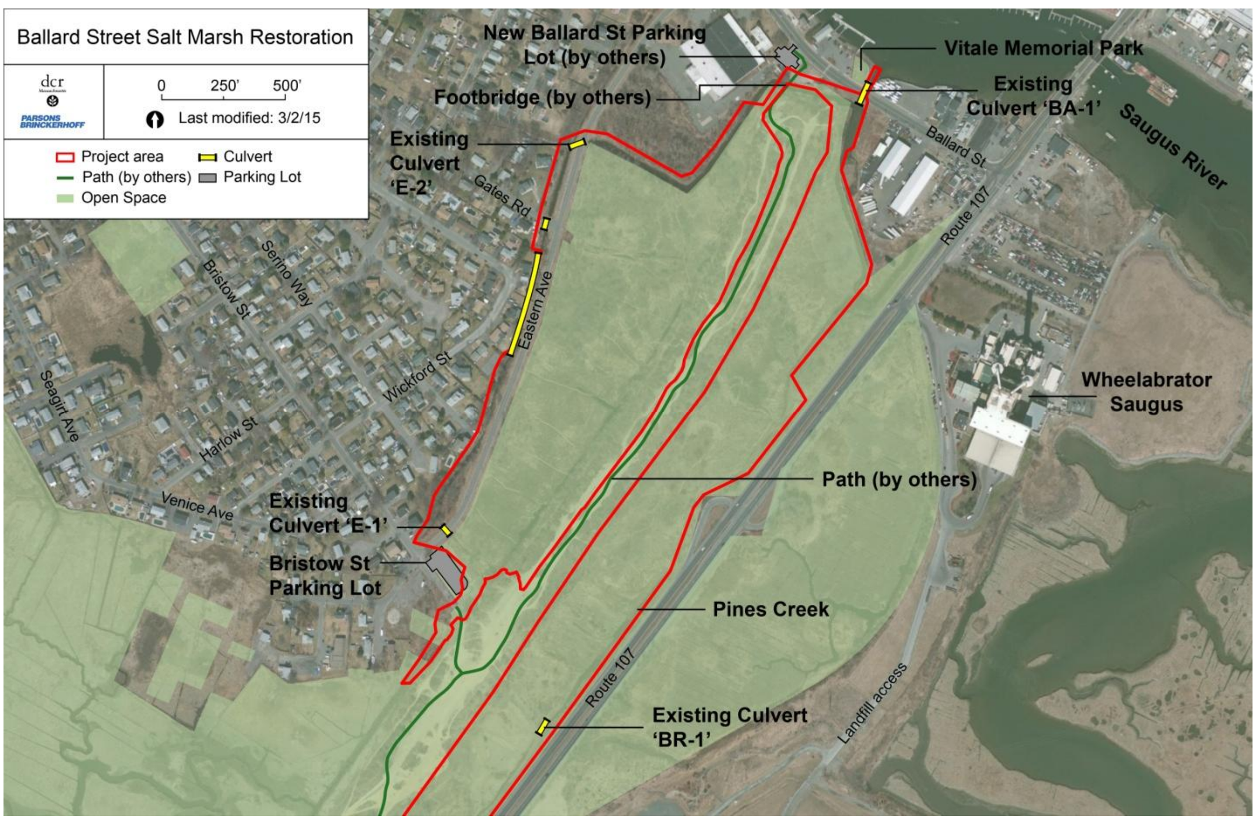

Fig. 2.05 A linear path will be constructed along the length of the embankment from Ballard Street to a point south of Bristow Street.

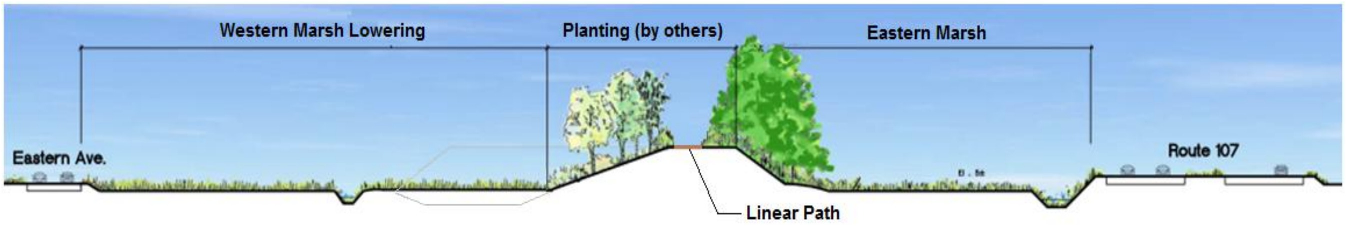

Fig. 2.06 Cross section showing the location of the linear path along the embankment

2.6.2 Harold L. Vitale Memorial Park

Adjacent to the Saugus River and directly north of the DCR reservation at Ballard Street is the Town of Saugus' Harold L. Vitale Memorial Park. The park includes benches, picnic tables, pathways, and a memorial statue. It also includes a parking lot, docks, and a small building.

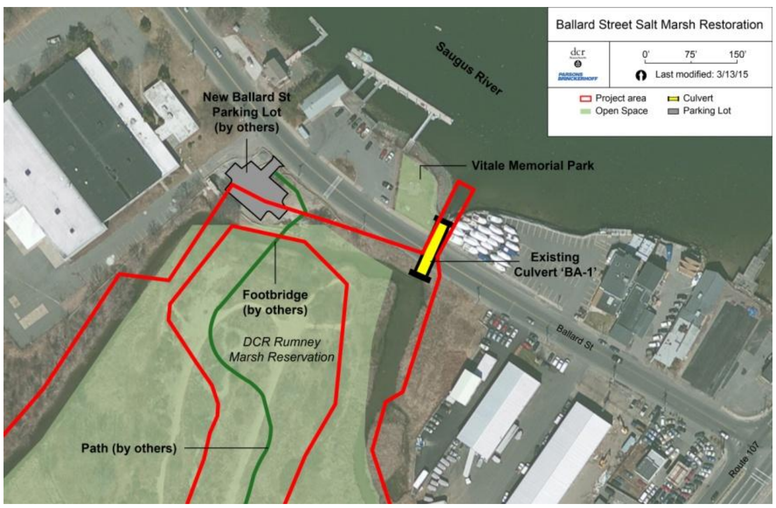

Fig. 2.07 The Ballard Street culvert ("BA-1") is immediately adjacent to recreational facilities, including Vitale Memorial Park, the new parking lot at Ballard Street, and the footbridge over the tidal stream upstream of the culvert. For a discussion of the hazards of the existing culvert, see Section 2.8.4.

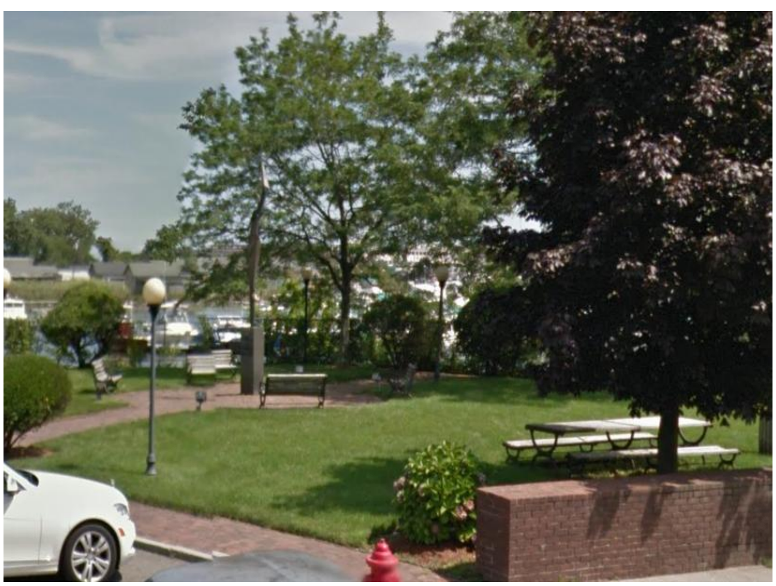

Fig. 2.08 Vitale Memorial Park includes benches, picnic tables, pathways, and a memorial statue.

2.7 Stormwater Runoff Patterns and Drainage Facilities

Two upland and two wetland watersheds - totaling 144 acres - contribute stormwater runoff to the Ballard Street culvert. These are delineated as Watersheds 2 and 4 for the uplands and 6 and 8 for the wetland watersheds, as delineated in the 1999 NRCS analysis and shown in Fig. 2.09. These watersheds contribute respectively to the North Segment and South Segment of the Eastern Avenue Ditch, as described in Section 2.7.1.

The two upland watersheds include densely developed residential areas in East Saugus. West of Lincoln Avenue, Fig. 2.09 indicates that the upper reaches of Watersheds 2 and 4 extend to the easterly portion of the East Saugus drumlin. East of Lincoln Avenue, are low-lying neighborhoods that are prone to frequent flooding during rain events. These areas are also subject to coastal flooding contributed by both the Saugus and Pines Rivers. For these reasons, most of this neighborhood is within the 100-year floodplain (see Fig. 2.03). Portions of these low-lying areas were originally marsh, as can be seen by comparing Figures 1.05 and 1.06 with Fig. 1.07.

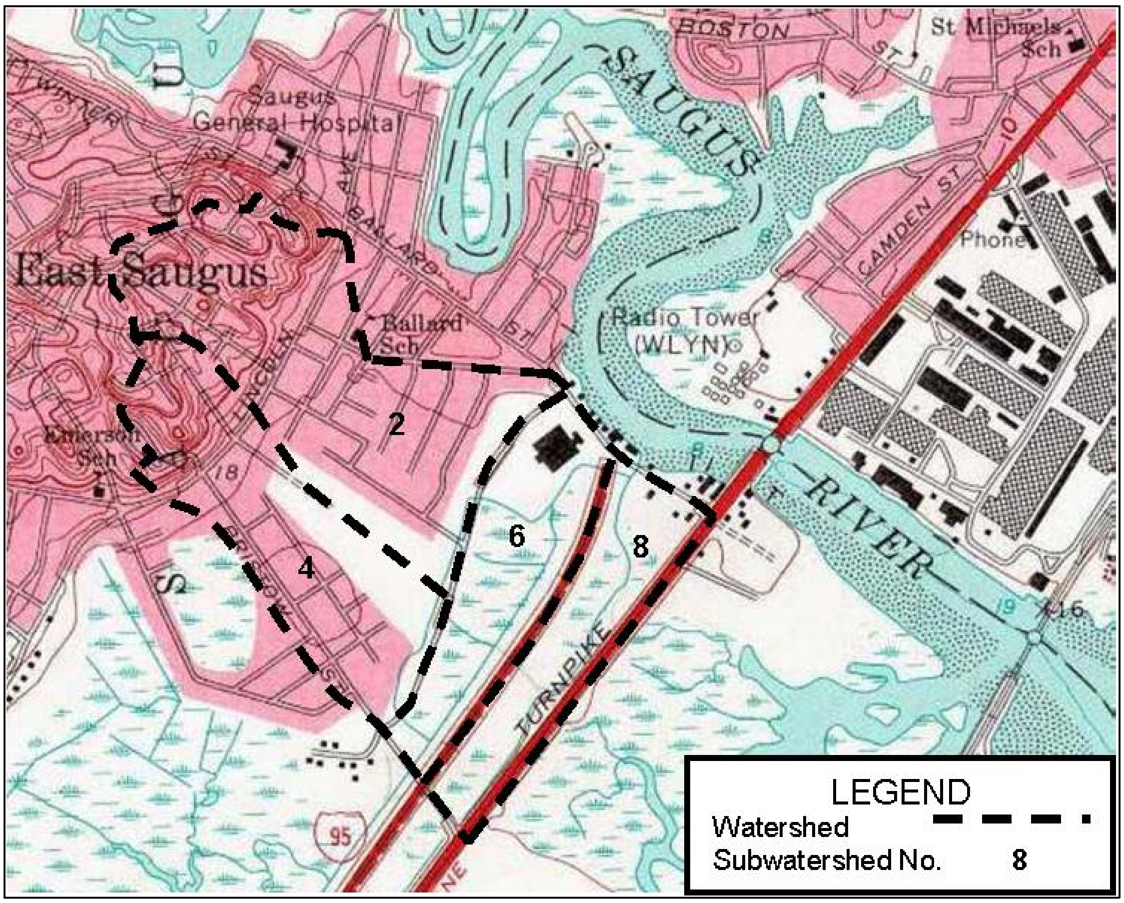

Fig. 2.09: Watershed delineation from the 1999 NRCS Ballard Street Marsh analysis

Watersheds 6 and 8 represent the Western and Eastern Marshes in the NRCS delineation (Fig. 2.09). Each of these areas is defined by bordering fills for roadways:

- Watershed 6 – Western Marsh: Ballard Street (north), Eastern Avenue (west), Bristow Street (south) and abandoned I-95 embankment (east)
- Watershed 8 – Eastern Marsh: Ballard Street (north), abandoned I-95 embankment (west), abandoned Bristow Street embankment (south) and Route 107 (east)

2.7.1 Eastern Avenue Drainage Ditch

Currently runoff from East Saugus (Watersheds 2 and 4) flows overland and through closed drainage systems to a drainage ditch over which the Town of Saugus maintains an easement along the west side of Eastern Avenue. The ditch was constructed along with Eastern Avenue as part of the I-95 embankment project. There are multiple outfalls of the Town storm drainage system that discharge to this ditch. The Eastern Avenue ditch consists of two segments, a connecting culvert and a spur:

- **North Segment** extends from 150 ft. south of Gates Road to approximately 800 ft. north of Gates Road. This segment flows to a 72-in. culvert under Eastern Avenue (henceforth referred to as culvert "E-2"), located 300 ft. north of Gates Road. (See Fig. 2.10.) As seen in Fig. 2.11, north of Gates Road the ditch is an open, tidally influenced waterway. However, south of the 60-in. concrete pipe culvert at Gates Road ("E-4"), the ditch is overgrown with invasive vegetation.
- **South Segment** extends from Bristow Street to Mersea Street. (See Fig. 2.10.) This segment of the ditch is overgrown by invasive vegetation and a repository for discarded items. (See Fig. 2.12.) This segment drains into the existing Western Marsh via a 24-in. culvert under Eastern Avenue (henceforth referred to as culvert "E-1"), located about 150 ft. north of Bristow Street. Four storm drain outfalls discharge into the southern segment. Given the overgrown condition and poorly defined outlets, improved stormwater capacity is needed in this segment of the Eastern Avenue ditch.
- **Connecting Culvert:** The two segments of the Eastern Avenue ditch are connected by a 400-ft. long "perched" culvert – a culvert which has inverts higher than the inverts of the ditch. This culvert, designated "E-5," can function as an equalizer, allowing flow from one segment to the other, depending on the relative water elevations at a particular point in time. The culvert appears to have been built to allow for construction on residential subdivision lots.
- **Spur Channel:** An open "spur" channel tributary to the Eastern Avenue drainage ditch extends to the west, about 100 ft. north of Gates Road. (In Fig. 2.10 this is labeled as the Spur Channel.)

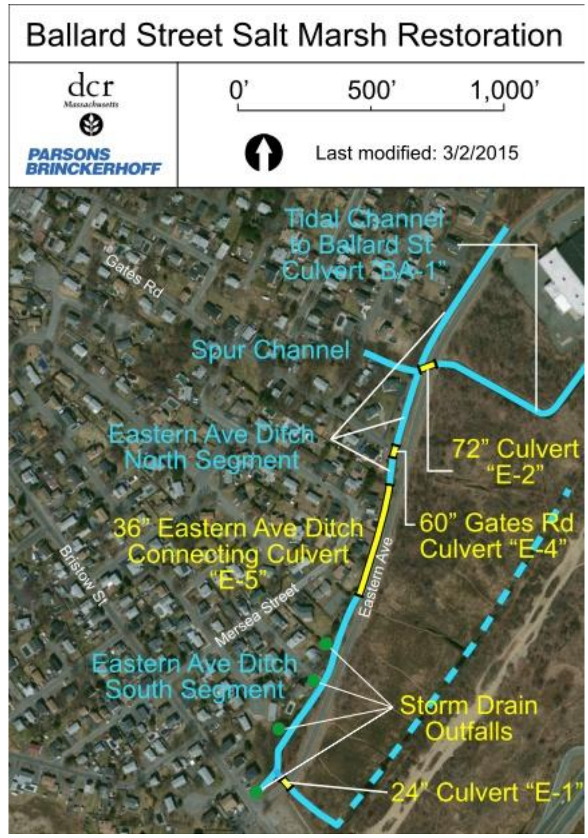

Fig. 2.10 Eastern Avenue Ditch and Related Culverts

Runoff from the East Saugus neighborhood reaches the Eastern Avenue ditch via surface flow and through storm drain pipes. It then drains through the two culverts under Eastern Avenue into the Western Marsh (Watershed 6 in Fig. 2.09).

- Watershed 2 in Fig. 2.09 drains to the North Segment, which, in turn, drains to the 72-in. culvert ("E-2") located about 300 ft. north of Gates Road. For continuation, see Section 2.7.2.
- Watershed 4 in Fig. 2.09 drains to the South Segment. This would generally drain to the 24 in. culvert ("E-1") located about 150 ft. north of Bristow Street. See Fig. 2.10. However, it could also drain towards the North Segment via the Connecting Culvert ("E-5"). For further discussion, see Section 2.7.3.

Fig. 2.11 Eastern Ave. Drainage Ditch – North Segment
Left: Looking north from Gates Road; Right: Looking south from Gates Road

Fig. 2.12 Eastern Ave. Drainage Ditch – South Segment –
Left: Overgrown with invasive vegetation; looking north from Bristow Street;
Right: Items dumped in ditch. (Photo credit Woods Hole Group, Inc., Appendix 1)

Fig. 2.13 Downstream end of Eastern Avenue Ditch Connecting Culvert "E-5"
(Photo by Woods Hole Group, Inc., Appendix 1)

2.7.2 Downstream of Culvert "E-2"

The North Segment drains through the 72-in. culvert "E-2" and via a defined tidal channel towards the Ballard Street culvert ("BA-1"), where it then flows into the Saugus River. See Fig. 2.14. The improvised tide gate affixed to the down gradient or northern side of the Ballard Street culvert ("BA-1") (shown in Fig. 2.20) allows passage of freshwater runoff from the Project Area but only a very limited flow of salt water into the marsh.

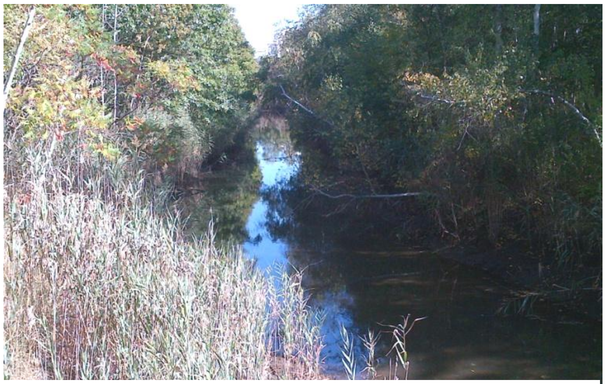

Fig. 2.14 Channel downstream of the 72-in. culvert ("E-2") on Eastern Avenue, looking towards Ballard Street.

2.7.3 Downstream of Culvert "E-1"

Stormwater entering the Southern Segment of the Eastern Avenue ditch may be discharged through 24-in. culvert "E-1" to the Western Marsh. Within this area, there is a series of poorly defined ditches, some partially filled. There is no direct connectivity of these ditches to the defined channel (shown in Fig. 2.14), located at the northerly end of the Western Marsh. This lack of direct connectivity may be, in part, a cause of poor drainage during rain events in the residential neighborhood.

2.8 Tidal Hydraulics

Factors influencing the current tidal hydraulics in the Eastern and Western Marshes include the impact of prior filling and the existing sizes, configurations, and improvised modifications of the two culverts connecting the marshes to adjacent tidal waters.

2.8.1 Impact of Prior Marsh Filling on Current Tidal Flows

Prior to roadways and other development altering the natural drainage patterns, the Project Area contained tidal estuaries and a salt marsh system, which linked the Saugus River to the north, with the Pines River (formerly the Chelsea River) to the south and Bear Creek to the east. This can be seen in the 1829 map (Fig. 1.05) and the 1872 map (Fig. 1.06). Based on the 1829 map, the Project Area was contiguous with approximately 150 acres of the Rumney Marsh, west of Route 107 and between Bristow Street (noted as "South St." on the map) and the Saugus River. At that point in time, the Project Area had unrestricted tidal exchange with the Saugus River.

In the 1872 map, Ballard Street (not shown on the 1829 map) is shown, and the map shows a series of waterways within the Project Area. Ballard Street separates the Project Area salt marsh from the Saugus River, so after the street was constructed, the river could no longer provide unrestricted tidal exchange with the marsh. This map is not detailed enough to indicate if there were culverts or bridges allowing some degree of tidal connection. The 1943 USGS map (Fig. 1.07) appears to indicate a tidal connection under Ballard Street, close to or at the current culvert location. This map also shows the beginning of residential development in the western fringes of what was salt marsh in the 1829 and 1872 maps.

Today, tidal connections are now severely restricted, due to the past filling of salt marsh for transportation and land development. Filling has extended the East Saugus neighborhood eastward from beyond the limits shown in the 1943 USGS map (Fig. 1.07) to Eastern Avenue, which was built at the time of the filling for the I-95 embankment. Industrial development has filled in land along Ballard Street and Route 107. The I-95 embankment also significantly alters drainage patterns and bifurcates the remaining unfilled marsh into two cells. Fig. 2.15 illustrates the extent of post-1872 filling in the Saugus section of the Rumney Marsh.

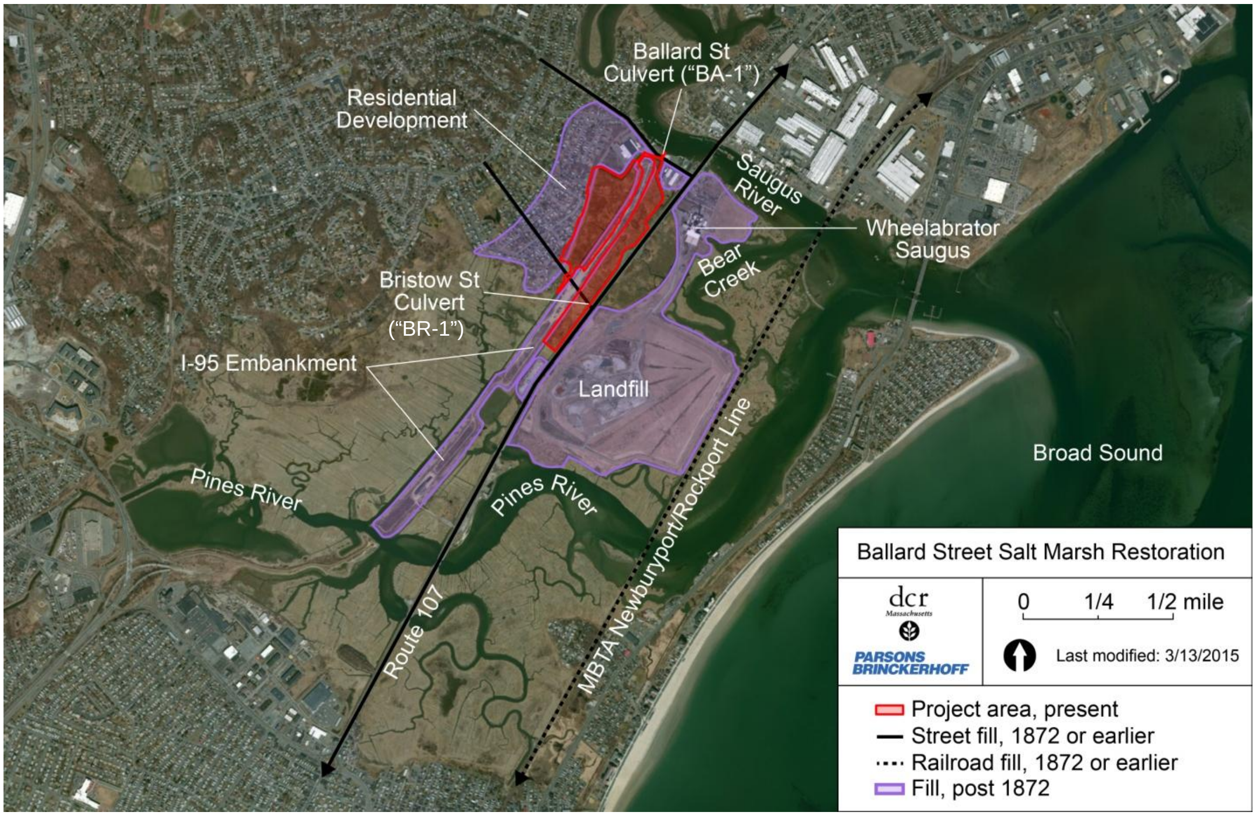

Fig. 2.15 Constraints to Tidal Flows

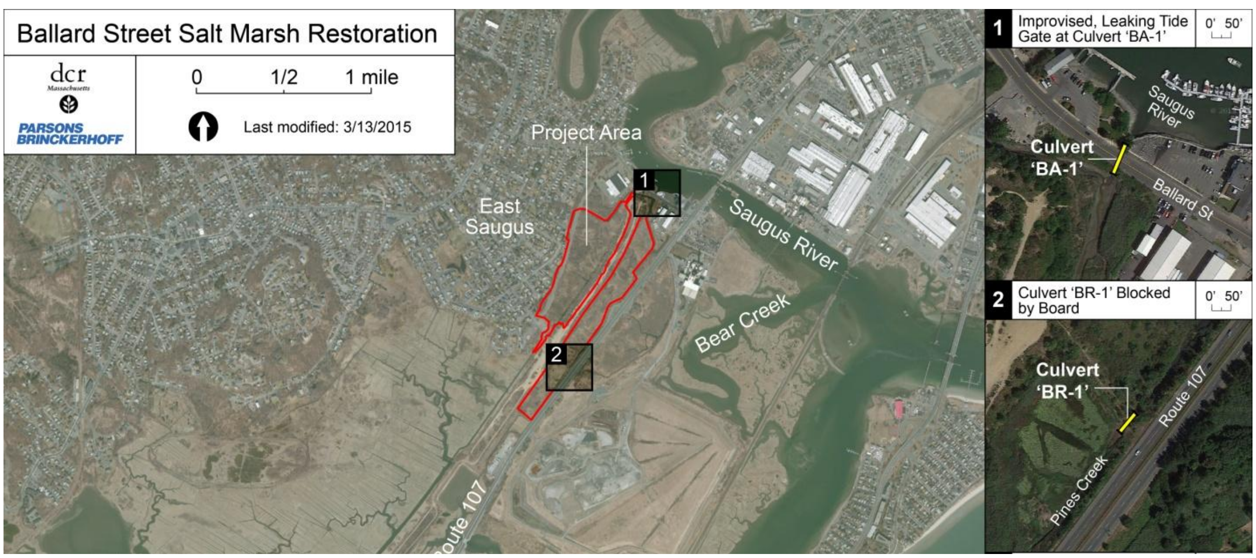

Fig. 2.16 Location of Culverts at Ballard Street ("BA-1") and Bristow Street east ("BR-1")

2.8.2 Tidal Connections to the Eastern and Western Marshes

Today the Eastern and Western Marshes have two tidal connections via culverts, one to the north at Ballard Street ("BA-1") (currently restricted) and one to the south on the east side of the I-95 embankment at Bristow Street ("BR-1") (currently blocked). The current configuration and improvised modifications of these culverts are the keys to understanding the present-day tidal hydraulics.

2.8.2.1 Ballard Street Culvert ("BA-1")

The northern tidal connection to the Eastern and Western Marshes is the 4-ft. diameter concrete culvert under Ballard Street. See Fig. 2.16 for key plan and Fig. 2.17 for site plan. Also see Fig. 2.19 for photographs showing the ends of the culvert.

This culvert is set low in the tidal range with its invert at -3.14 to -3.23 ft. based on a survey by Bryant Associates in 2014, which is shown in Fig. 2.17. Therefore the culvert is submerged for nearly half of the tidal cycle.

The culvert passes under seven underground utility pipes in Ballard Street including an 18-in. MWRA (Massachusetts Water Resources Authority) water main, a gravity sewer, a sewer force main, a 12-in. water main and two gas lines. See Fig. 2.18, which illustrates the culvert in relationship to the other utilities in Ballard Street.

The Ballard Street culvert presently has a poorly functioning improvised tide gate, consisting of a corroding steel plate affixed at the Saugus River end, as shown in Fig. 2.20. The flap does not close properly, and under current conditions the leaking flap allows some water in to the Eastern and Western Marshes on a flooding tide. Previously, this culvert was fitted with a round hinged tide gate that completely closed, thus only allowing outflow, and therefore preventing the flooding tide from entering the Project Area. The current plate was hung to replace the original hinged gate, which fell off.

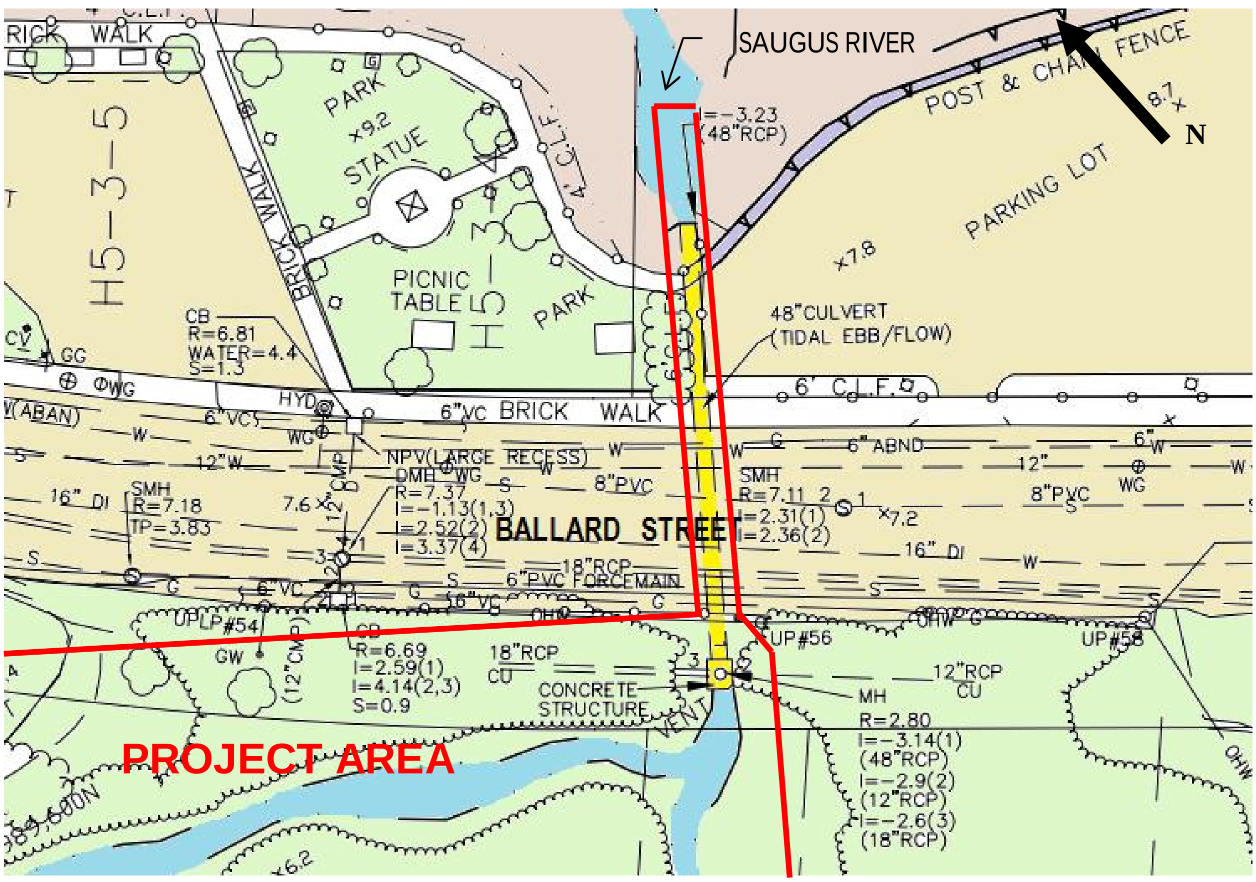

Fig. 2.17 Ballard Street Culvert ("BA-1") – Survey Plan

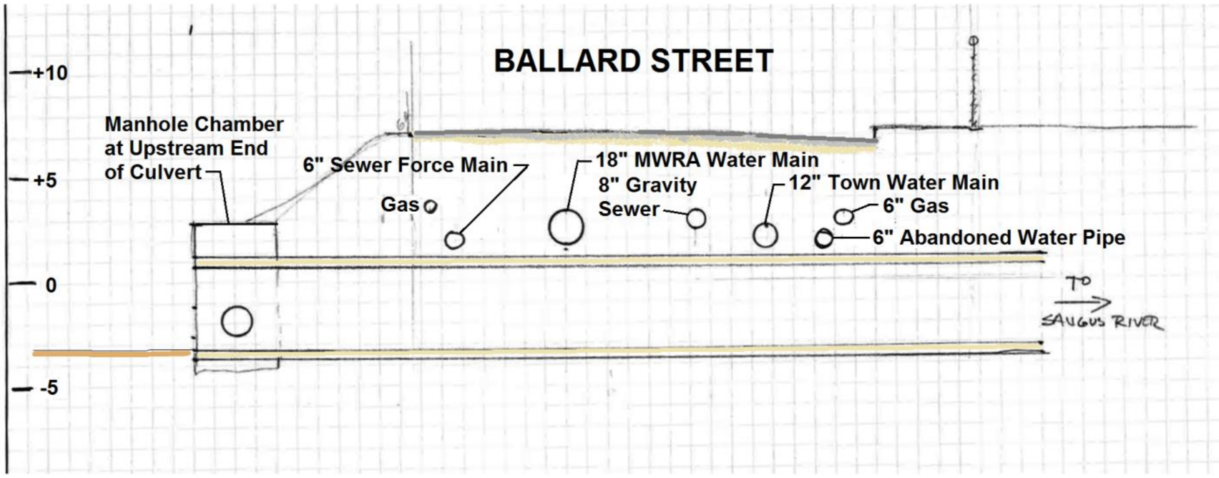

Fig. 2.18 Profile of Ballard Street Culvert ("BA-1") Showing Utility Pipes Below Roadway

Fig. 2.19: Ballard Street Culvert ("BA-1")
Upper Left: Flap Gate on Downstream End of Ballard Street Culvert
Upper Right: View of 48-In. pipe in Upstream Manhole
Lower Left and Right: Rectangular Manhole at Upstream End of Ballard Street Culvert

Fig. 2.20 Enlarged View of Improvised Tide Gate on North End of Ballard Street Culvert (“BA-1”)

2.8.2.2 Bristow Street Culvert (East) (“BR-1”)

In addition to the connection of the Ballard Street culvert to the Saugus River, there is also a connection to the south from the Pines Creek via a 7.3 ft wide by 4.5 ft. high[2] culvert under the abandoned portion of Bristow Street (between the I-95 embankment and Route 107). See Fig. 2.21. Observations made by Woods Hole Group, Inc. (Appendix 1) indicated that the invert has an accumulation of sediment. Most of the tidal influence of the Pines Creek is prevented by a board that blocks the culvert at Bristow Street. There are metal remnants of a flow control structure within the culvert, indicating that at one time a gate was deemed necessary for flow control.

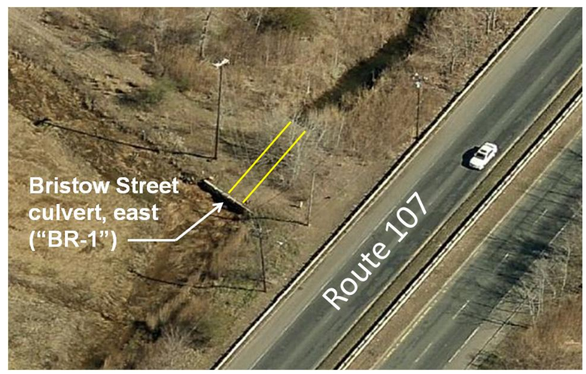

Fig. 2.21 Bristow Street Culvert (East) (“BR-1”) Adjacent to Route 107. The existing board on the south end is shown at below at left. The north end is shown on the right

[2] Measurements were made by Woods Hole Group, Inc. (Appendix 1).

2.8.3 Tide Data Collection

Tidal data is necessary as input to the hydrodynamic model developed to simulate the proposed restoration alternatives for the Ballard Street Salt Marsh. Tidal data within the Eastern and Western Marshes were collected by Woods Hole Group, Inc. in May through June, 2010. (See Appendix 1 and Fig. 2.22)

Fig. 2.22 Tide gauge deployment by Woods Hole Group, Inc., May through June, 2010. (Source: Appendix 1)

Supplemental tide data were collected at three locations in the Pines River and associated estuaries between May 15 and May 29, 2014 by Applied Coastal Research & Engineering, Inc. See Fig. 2.23. The new data were needed in order to:

- determine if the tide range in the Pines River immediately west of Route 107 was damped by the highway bridge, and
- collect concurrent additional tide data in the two channels that potentially could be used to connect the Pines River to the Eastern and Western Marshes:
    - Pines River Channel (west of the I-95 embankment)
    - Pines Creek (east of I-95 embankment)

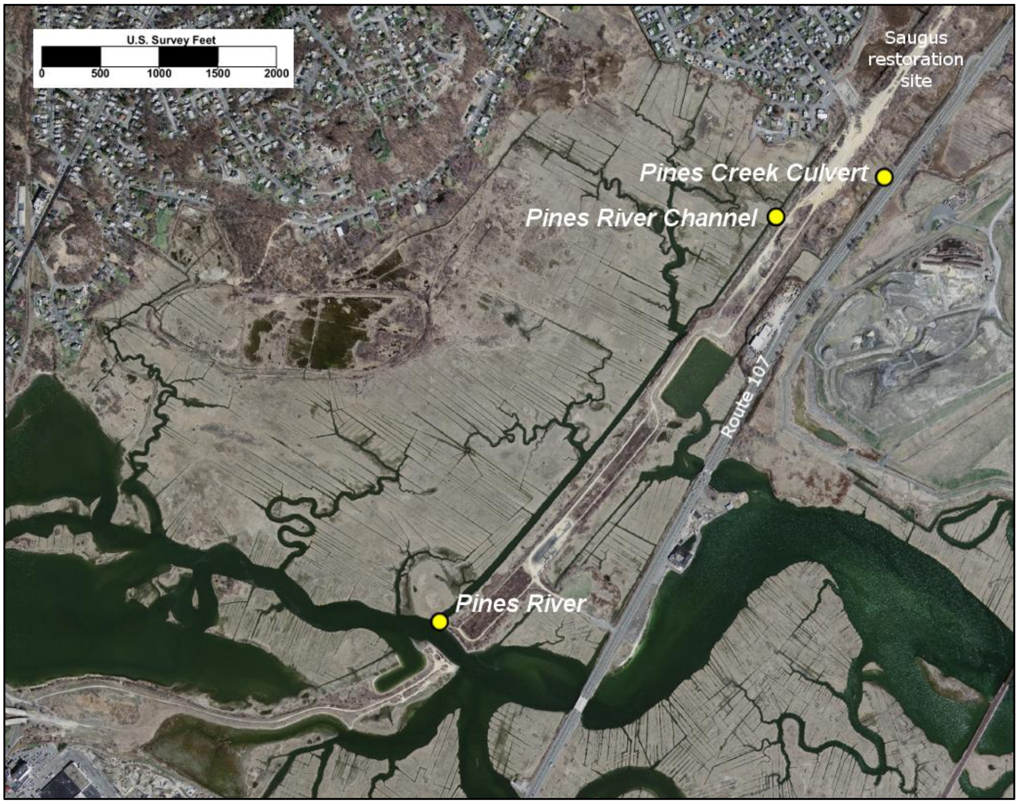

Fig. 2.23 Map of the tide gauge locations used for the May 2014 deployment in the Project Area

Fig. 2.24 Pines River Channel, along the west side of the I-95 embankment
Left: Looking north from a point south of the tide gauge location. Right: Looking south from Bristow Street

Plots of the tide data from the three gauges are shown in Fig. 2.25 for the 15-day deployment. The spring-to-neap variation in tide range is visible in these plots. The data record begins during a period of spring tides. A week later there is a period of neap tides, which occurs around the time of the half moon on May 21. Following this neap tide is a return to a period of spring tides around the time of the new moon on May 28. The minimum neap tide range in the Pines River record is 9.5 ft. (May 23), while the maximum spring tide range is 11.7 ft. (May 17).

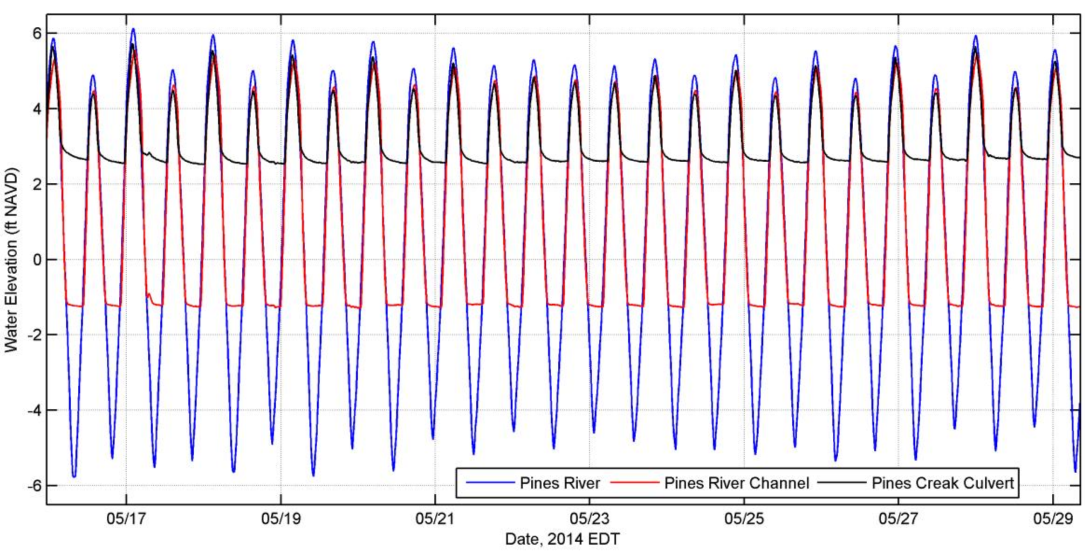

Fig. 2.25 Tide data from the May 2014 deployment in the Pines River

Table 2.01 presents the standard tide datums and computed tidal harmonics determined for the three gauge records. The tide datums presented in Table 2.1 show how the tide range is attenuated by the marsh channels. The mean tide range in the Pines River is 10.4 ft., while in the Pines River Channel the range is reduced by nearly one half. The reduction of the tide range is caused by the minimum elevation of the channel. Greater attenuation of the tide occurs in the Pines Creek at the Bristow Street east culvert ("BR-1," referred to as "Pines Creek Culvert" in Fig. 2.25), which has a mean range only slightly greater than 2 ft.

Table 2.01
Tide Datums Computed from 30-Day Records Collected
Pines River Marsh System in May 2014.

Tide Datum	Pines River	Pines River Channel	Pines Creek at Bristow St. east culvert ("BR-1")
Maximum Tide	6.1	6.3	5.7
MHHW	5.7	5.9	5.3
MHW	5.3	5.6	4.9
MTL	0.1	2.6	3.7
MLW	-5.1	-0.4	2.6
MLLW	-5.3	-0.5	2.6
Minimum Tide	-5.8	-0.5	2.5
Mean Range	10.4	6.0	2.3

Additional tide gauge measurements were within the Pine River Channel by Normandeau Associates, Inc. (July 1, 2014 through August 1, 2014 – See Appendix 5).. The data collected by Normandeau Associates within the Pines River channel exhibited a similar tide range as that measured by Applied Coastal.

2.8.4 Dampened Tidal Range in the Project Area

Fig. 2.26 illustrates the dampened tidal range in the Project Area, namely the Eastern and Western Marshes. This dampening is a result of the conditions at the two existing culverts at Ballard Street ("BA-1") and Bristow Street east ("BR-2").

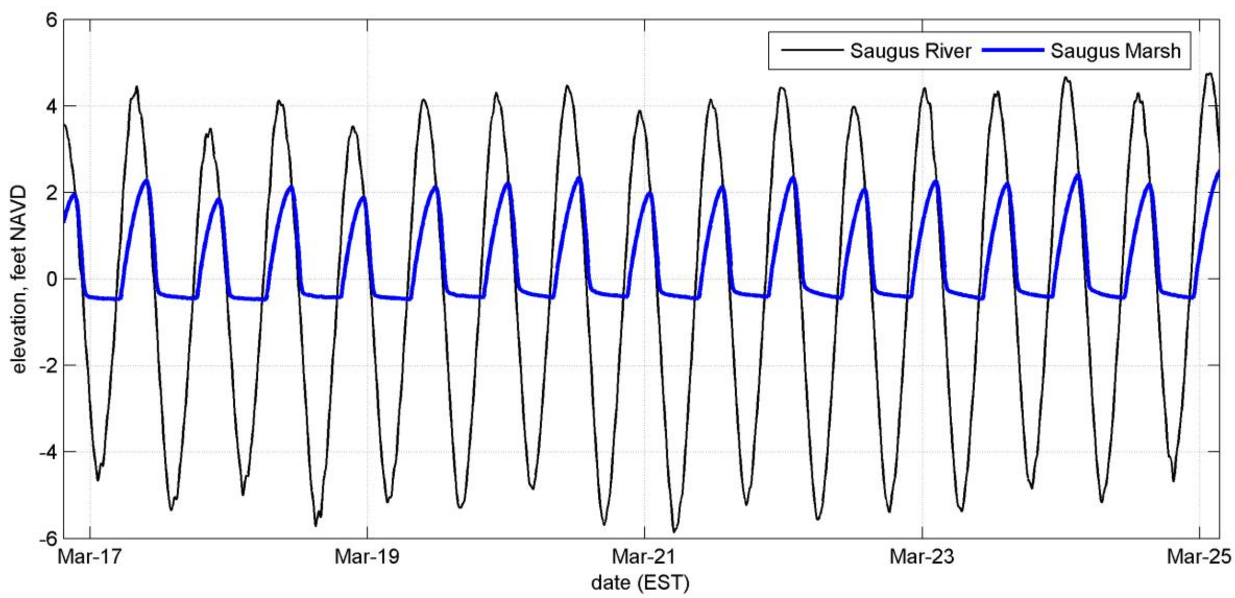

Fig. 2.26: Tidal Hydrograph upstream of the Ballard Street Culvert ("BA-1")

Most of the tidal influence of the Pines Creek is prevented by a plywood board that blocks the culvert at Bristow Street ("BR-1"). In addition, the blocked flow at this location has facilitated deposition of sediment on the south side of the culvert over time, further dampening the potential tidal range. Woods Hole Group, Inc. identified three locations where significant shoals and blockages are present in the channel north of this culvert. See Fig. 2.27. Therefore, effectively, the Pines Creek does not contribute to the tidal exchange in the Project Area.

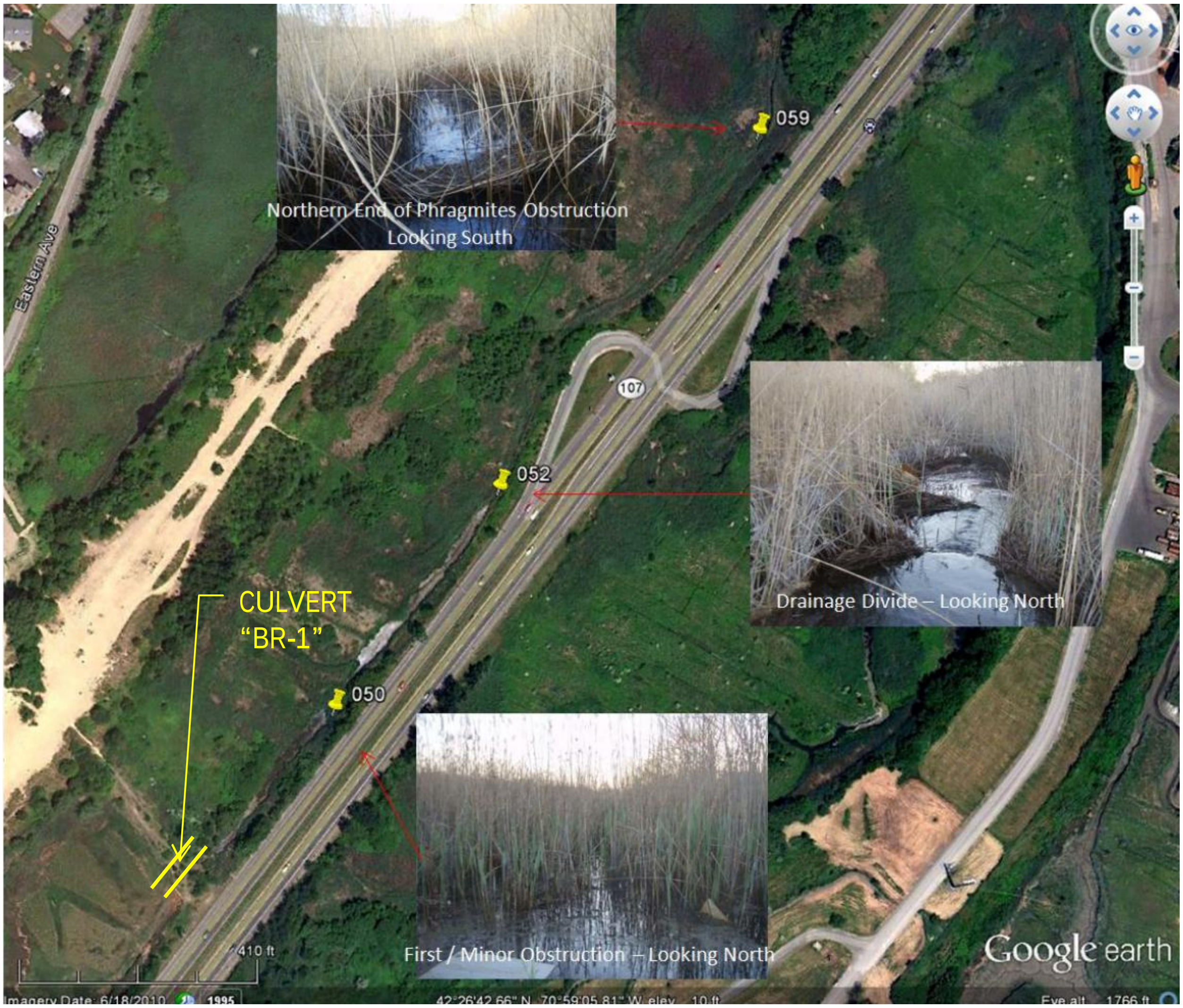

Fig. 2.27: Obstructions in Pines Channel (Eastern Channel) North of Bristow Street East Culvert ("BR-1")
(Source: Woods Hole Group, Inc., 2013, Fig. 6-3 – See Appendix 1)

Therefore, tidal flow only enters the Project Area from the Saugus River through the Ballard Street culvert ("BA-1"), with its poorly functioning improvised tide gate. (See Fig. 2.20) Both Woods Hole Group, Inc. in 2013-2014 and Applied Coastal Research & Engineering, Inc. in 2014-2015 conducted detailed hydrodynamic studies and modeling of the Project Area. (See Appendices 1 and 2.) These studies confirmed that if the flap were functioning correctly, it would only allow water to discharge from the Eastern and Western Marshes to the Saugus River. However, under current conditions the leaking flap allows some water into the Eastern and Western Marshes on a flooding tide.

As a result, while the Saugus River has a mean tide range of approximately 9.4 ft., it is only 3.7 ft. in the marsh just upstream of the Ballard Street culvert. The hydrograph in Fig. 2.26 illustrates the reduced tidal range of salt marsh in blue compared with that of the Saugus River in black. The net result is an approximately 70% reduction in tide range caused by the Ballard Street culvert and flap gate.

Once the limited tidal flow reaches the Project Area, high tide water levels are fairly uniform throughout, with only slightly higher high tides upstream in the system due to freshwater runoff entering from the surrounding watershed.

2.8.4 Tidal Flows and Public Safety Issues at the Ballard Street Culvert ("BA-1")

Another result of its low elevation and being undersized are safety concerns with the operations of the Ballard Street Culvert ("BA-1"). The two concerns are the following:

- high flow velocities during conditions when the culvert runs full
- lack of "head room" in the culvert under maximum flow conditions (i.e., minimum top clearance for a person to travel through the culvert with their head above water)

2.8.4.1 Public Safety with High Velocities

Many studies on safe flow velocities demonstrate a critical relationship between flow velocities, water depth and human safety. For example, Cox, *et al*. (2010) developed a plot illustrating potentially dangerous conditions for both adults and children, as shown in Fig. 2.29. This shows how different combinations of flow depth and flow velocities present different levels of hazard to children and adults.

Note that the chart indicates that about 1.2 m (about 3.9 ft.) is the limiting flow depth for adults. This means that when the culvert is running full (i.e., at 4 ft. depth), it is not a safe condition for adults. For children, the maximum safe depth is 0.5 m (about 1.7 ft.), which is less than half full flow for this culvert.

2.8.4.2 Public Safety with Limited Headroom

The safety issue with limited head room occurs when the culvert is flowing full or within 1 ft. of flowing full. Under these conditions, should a person be swept into the culvert, there is no opportunity to get one's head above the water and breathe. Fig. 2.28 shows the Ballard Street culvert flowing full with no headroom at mid-tide. The culvert is completely submerged at high tide.

Fig. 2.28 Ballard Street Culvert ("BA-1") flowing full with no headroom at mid-tide.

2.8.4.3 Evaluation of Public Safety Based on Hydraulic Modeling

Modeling by Woods Hole Group, Inc. and Applied Coastal Research & Engineering, Inc. has determined the anticipated depths of flow and velocities for the culvert under various flow conditions. These results were evaluated in the context of Fig. 2.29. For existing conditions, the conclusions with regard to the hazards for children and adults are summarized in Table 2.02. For a further discussion of the analysis, see Appendix 7.

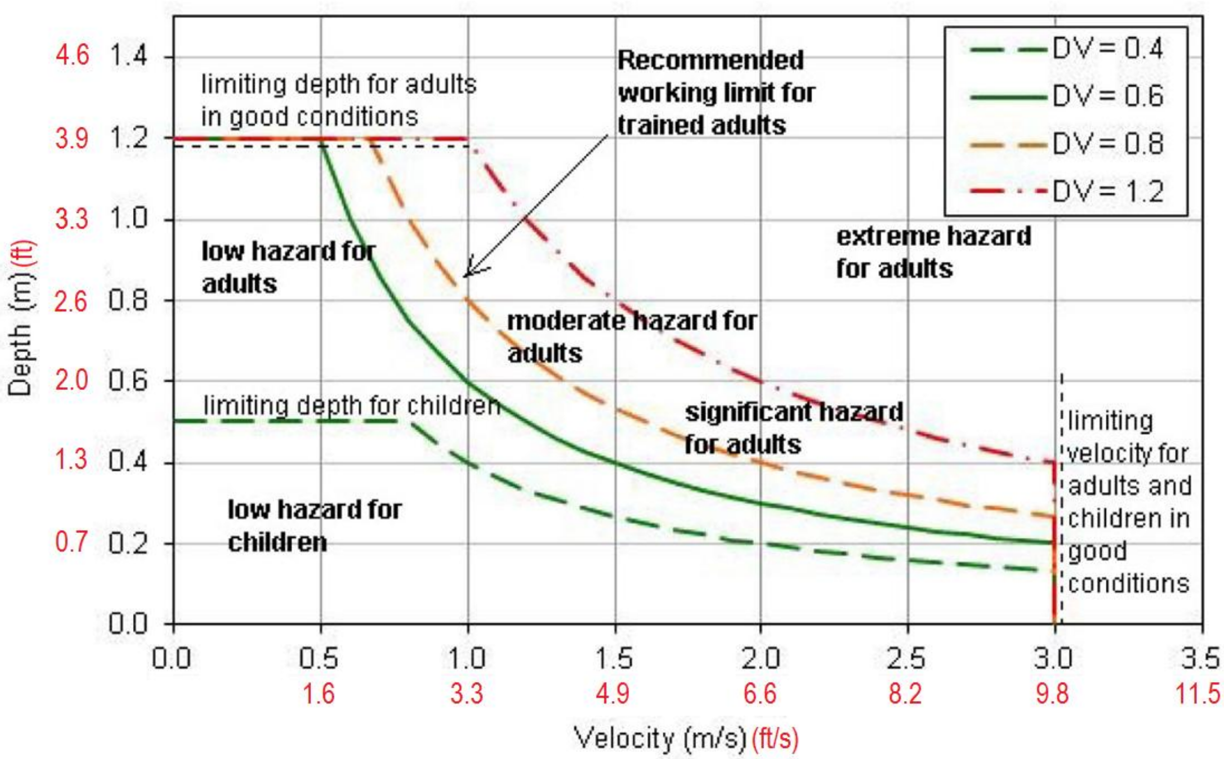

Fig. 2.29 Flow velocities versus depth indicating safe flow conditions associated with both adults and children (plot from Cox *et al.*, 2010).
(Note: velocities in black are in meters per second and depths in black are in meters.
Values in red for velocity in feet per second and depth in feet have been added by Parsons Brinckerhoff.)

Table 2.02
Hazard for Adults & Children as Portion of Tidal Cycle
Ballard Street Culvert ("BA-1")

	Hazard for Adults	Hazard for Children
	Approx. Hrs. per 12-hr. Tide Cycle	Approx. Hrs./12-hr. Tide Cycle
Culvert with flap	4 hrs. (33%)	9 to 10 hrs. (80%)

The summary in Table 2.02 must be viewed in the context of the proximity of the culvert to existing DCR and Town parklands, as show in Fig. 2.07. These parklands are places where the public is invited. The high velocity ebb flows with a single submerged outlet represent a public safety issue if a child or adult were to accidentally fall into the tidal waterway near the culvert.

It is not acceptable from an engineering perspective to either exacerbate or even accept a known public safety hazard as part of the Project. This consideration will be included in the evaluation of all alternatives. Any modification to this culvert, as well as any proposed structure, must meet minimum safety requirements relative to flow velocities and "head room." The project engineers cannot move forward with a design that does not meet minimum standard safety requirements, and the Commonwealth cannot accept an alternative that does not rectify the currently unsafe conditions.

2.8.5 Existing Ebb-Dominant Tidal Exchange

In addition to having a reduced tidal range, the single inefficient culvert at Ballard Street results in a slow filling of the Eastern and Western Marshes during the incoming tide. However, modeling shows that as the tide recedes, flow rates increase resulting in an ebb-dominant as opposed to flood-dominant tidal regime. Higher velocity ebb flows generally result in a net export of sediment and nutrients from the marsh rather than a gradual accumulation of sediment that would occur in a flood-dominant system. A flood dominant tidal regime is generally considered to be a favorable, natural New England salt marsh tidal regime (Friedrichs and Perry, 2001).

A significant ebb dominant flow, such as that which currently exists, can limit the ability of a salt marsh to continue to accrete sediment and outpace sea level rise by raising the marsh plain. Rates of sea level rise are expected to vary regionally and are estimated to range from 0.43-2.08 ft. within the next 50 years according to various combined sources as described in Appendix 1, section 4.5.4.

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3.0 Alternatives Analysis

This section presents a summary of alternatives considered to achieve and maximize the dual Project goals of:

1) Salt marsh restoration and
2) Enhancement of flood control and storm damage protection

3.1 Development of Alternatives

DCR's engineering team evaluated a number of potential project designs to develop a concise yet representative list of alternatives to be evaluated. The development of this list of alternatives included consideration of previous investigations as well as hydrodynamic modeling to evaluate how each would meet the stated Project goals of enhancing tidal flowages so as to create sustainable salt marsh as well as handling stormwater runoff to enhance flood control and storm damage prevention for the adjacent East Saugus neighborhood.

The previous designs evaluated included the project developed by NRCS in 2002 and analysis on behalf of DER included in Woods Hole Group Inc.'s October 2014 report (Appendix 1). Both of these approaches depend primarily on tidal flushing and stormwater discharge as provided by the undersized and low culvert at Ballard Street ("BA-1") with some limited additional drainage through the Bristow Street east culvert ("BR-1"). Review of the modeling performed by NRCS and Woods Hole Group, Inc. revealed that reliance on the Ballard Street culvert results in a project with the following limitations:

- The existing 4-ft diameter Ballard Street culvert ("BA-1") does not have the capacity to provide enough tidal exchange and stormwater discharge if the Western Marsh plain is significantly lowered (2 to 3 ft. lower than the existing marsh plain elevation.
- The lowered marsh plain requires the manipulation of the tide signal by regulation with tide gates. This is needed to sustain a dampened mean high water (MHW) elevation in the Western Marsh. (MHW should be below the marsh plain, with only the spring tides inundating the marsh plain).
- Lowering the plain of the Western Marsh is not sustainable in consideration of anticipated sea level rise. With sea level rise, the tide gates would be required to be closed more and more of the day, limiting habitat connectivity to the Saugus River. A 1 ft. sea level rise would require the gates to be closed an additional 2 hrs. per tidal cycle, or 4 hrs. per day.
- The low invert of the Ballard Street culvert results in an ebb-dominant tidal flow, in contrast to the desired flood-dominant flow recommended by Friedrich and Perry (2001). A flood-dominant flow allows the marsh to accrete, and therefore raise itself in the face of sea level rise.
- The existing 4-ft diameter Ballard Street culvert ("BA-1") experiences high velocities for several hours of every tide cycle when the culvert runs full, resulting in a public safety concern. (See discussion in Section 2.8.4.)

With these concerns identified, additional alternatives were considered. The first and most-obvious approach was to consider replacing the inadequate existing Ballard Street culvert with a larger culvert, one at a higher invert elevation, or even removing the culvert and reconstructing Ballard Street with a bridge so as to eliminate any tidal restriction. Historic maps (e.g, the 1943 USGS map, Fig. 1.07) suggest a bridge existed at this location at one time.

However, a significant amount of underground utility infrastructure is located in Ballard Street directly above the culvert, including an MWRA transmission water main, a gravity sewer, a gas line, other water mains, and other utilities (see Fig. 2.18). In addition to the MWRA, some utilities are owned by the

Town of Saugus, while others are owned by private utility companies. Based on a 2014 survey and record plans from the respective utilities, the MWRA water main and other pipes appear to be immediately above the culvert. To construct a bridge or a culvert at the ideal invert elevation, many (if not all) of these utilities would need to be relocated. These relocations would be complicated by the requirement to retain service to customers during the relocation. In addition, a taller culvert or a bridge would interrupt the profile of the gravity sewer, likely resulting in the need for a pump station. As a result, the Project proponent concluded that scope and cost of these improvements far exceeded DCR's jurisdiction and available funding. Therefore this alternative was rejected without advancing to the level of further modeling.

As a result of this initial evaluation, the following designs were selected for further evaluation:

- Alternative 1 - No Action
- Alternative 2 - Installation of a Self-Regulating Tide Gate (SRT) near Ballard Street
- Alternative 3 - Installation of SRT at Bristow –West ("BR-2" and BR-3) and Closing the Ballard Street Culvert ("BA-1")
- Alternative 4 - Installation of SRT at Bristow –West ("BR-2" and BR-3) and Install Dike With Culvert ("BA-2")

3.2 Evaluation Criteria

Similar to many urban marsh restoration programs, the Ballard Street Salt Marsh Restoration requires balancing multiple competing interests including: restoration of tidal flow to the degraded marsh system to enhance the overall ecological value; enhancement of flood protection for the East Saugus neighborhood; consideration of Sea Level Rise impacts and sustainability; and protection of public safety. Achieving balance between these competing interests involves exploring a wide range of marsh restoration options, followed by a screening process to select the most appropriate alternative.

To provide a baseline assessment of potential alternatives, typically a project team develops a series of exclusionary and discretionary criteria to provide an objective approach for screening alternatives. In general, this process follows the "Highway Methodology", developed by the U.S. Army Corps New England District in 1987, as a means of integrating design requirements and environmental permit regulations for the determination of the Least Environmentally Damaging Practicable Alternative (LEDPA). 3.2.1 Exclusionary Criteria

Exclusionary criteria reflect a regulatory prohibition regarding the specific option or a project that does not meet the engineering requirements of the project. For example, a project that increases the tide range within the marsh system, but also increases flooding potential in the adjacent neighborhood would not meet the engineering requirements for this Project.

Based on project-specific information available for the Ballard Street Salt Marsh system, the following exclusionary criteria were developed for the screening process:

Maximize Marsh Restoration Area – The purpose of the Ballard Street Salt Marsh Restoration Project is to restore tidal wetland functions and values historically lost with the placement of fill along the I-95 embankment and through past filling of the adjacent areas for residential and industrial development. Under existing conditions, there are two distinct wetland areas bifurcated by the remaining embankment, known as the Eastern Marsh and the Western Marsh, with significant wetland restoration potential. An existing U.S Fish and Wildlife funding grant for the Project requires a minimum tidal restoration area of 30 acres. Therefore, to meet the overall Project purpose, the restoration effort is targeting 30+ acres of restoration, where this area is defined as either improved (i.e. increased area of tidal inundation, primarily within the Eastern Marsh) or new tidal inundation (primarily within the Western Marsh). It is also understood that it may not be possible to achieve 30+ acres of tidal restoration; therefore, the exclusionary criteria is to maximize restoration to the extent practicable. A project that does not provide large-scale restoration to both the Eastern and Western Marshes would not meet the exclusionary criteria.

Safeguard Public Safety – The Project must meet minimum safety requirements for culverts and inlet structures. It is understood *a priori* that the existing 4-ft diameter Ballard Street culvert ("BA-1") – the direct connection of the existing degraded marsh system to the Saugus River – is dangerous due to the high flow velocities and flow depths (see Section 2.8.4), as entrainment in the culvert could lead to loss of life. Therefore, it is not acceptable from an engineering perspective either to exacerbate or even to accept a known public safety hazard as part of the restoration project. In addition, any proposed structure must meet minimum safety requirements relative to flow velocities and "head room" (minimum top clearance for a person to travel through the culvert with their head above water). The engineers cannot move forward with a design that does not meet minimum standard safety requirements, and the Commonwealth cannot accept an alternative that does not rectify the currently unsafe conditions.

Mitigation for this safety concern could be provided by a grate or "trash rack" over the culvert. See Fig. 3.01. In general guidance for trash racks produced by Urban Drainage and Flood Control District (UDFCD) (2001), a maximum safe flow velocity at the front of the trash rack was determined to be 2 feet per second at every stage of the flow entering the culvert. A principal concern in the use of trash racks is clogging, which can reduce hydraulic capacity. During the flood tide, clogging can reduce tidal exchange and rob the marsh of salinity. In the case of the ebb tide and rain events, loss of hydraulic capacity would lead to upland flooding.

Fig. 3.01 Blocked culvert grate ("trash rack") with wide bar spacing (*photo credit*: environment-agency.gov.uk).

Therefore the application of this mitigation should be limited to locations where clogging and loss of hydraulic capacity will not lead to a decrease in tidal exchange and/or lead to upland flooding.

Enhance Flood Control – Through a series of drainage ditches and culverts, the existing marsh system transmits stormwater runoff (associated with rain events) from the East Saugus residential neighborhood located west of the Western Marsh. This stormwater runoff discharges to the Saugus River via the 4-ft diameter Ballard Street culvert ("BA-1"). Upon re-introduction of significant tidal flow to the marsh system, there is a concern that the restored Ballard Street Salt Marsh area could not handle the anticipated stormwater runoff without other mitigating strategies. A project that exacerbates stormwater-related flooding would not meet the exclusionary criteria.

3.2.2 Discretionary Criteria

Discretionary criteria are those that meet secondary project goals, such as the protection and enhancement of fish and wildlife habitat. In this example, alternatives will be favored that enhance overall fish and wildlife.

The application of discretionary criteria is the main component of the screening process, and it is the process by which the alternatives are compared amongst themselves, using site-specific information to prioritize project appropriateness. For the purpose of this marsh restoration screening analysis, "appropriate" is defined as those alternatives that best meet the LEDPA standard, that are permittable under federal and state environmental law, that meet standard best-practices of engineering design, that are acceptable to the DCR and the Saugus community, and that are capable of being implemented at reasonable cost (both in the short- and long-term).

Based on project-specific information available for the Ballard Street Salt Marsh system, the following discretionary criteria were developed for the screening process:

Enhance and/or Maintain Fish and Wildlife Habitat – One of the primary reasons for restoring tidal marsh systems is to enhance fish habitat. As part of the planned restoration, there is an opportunity to improve the ecological habitat on a system-wide basis, where the increased tide range and improved water circulation will presumably create a broader range of higher quality fisheries habitat throughout the marsh system. The ecological salt marsh enhancement can be quantified based on the changes to the inundated area for each of the alternatives, with consideration of the source of tidal waters (i.e. the relative distance of these source waters[3] from Lynn Harbor). Both NMFS and Massachusetts DMF personnel have indicated that the direct hydraulic connection to Saugus River is important to marine fisheries. Specifically, the distance that fish need to travel through shallow estuarine and/or salt marsh creeks is an important consideration relative to habitat enhancement associated with the restored marsh, where the greater distance through the Pines River Channel is deemed less satisfactory than the partially blocked Ballard Street culvert that links directly to the Saugus River.

Minimize Mechanical Manipulation of the System – Due to the complexity of the interconnected channels/culverts, the historical upland drainage modifications and wetland infilling, and the alteration of the original tidal creeks by roadway/railroad construction, it is not possible to restore the Ballard Street Salt Marsh system to a functioning salt marsh and accomplish all of the other project requirements without some manipulation of the incoming tide during certain conditions. However, minimizing this manipulation is critical for developing a salt marsh that can emulate a natural marsh system. Specifically, the goal for this criterion is to minimize both the number of adjustable tide gates within the system and to also minimize the duration of gate closures during the tidal cycle.

Minimize Maintenance and Inspection Requirements – Similar to the system manipulation described above, system maintenance and inspection are required to some extent, as all solutions require structural modifications. For this criterion, the goal is to provide structures with relatively modest maintenance and inspection requirements. Specifically, the goal is to make onerous and potentially dangerous inspections/maintenance during storm events unnecessary.

Minimize Excavation Requirements – As part of all marsh restoration options being considered, excavation of the marsh plain within the Western Marsh is required to achieve all of the exclusionary criteria listed above. Approximately 40,000 cubic yards of excavation is required to lower the plain of the Western Marsh one foot. Minimizing the excavation while still achieving the marsh restoration and upland drainage enhancement goals will achieve other benefits:

- substantially reducing the project cost,
- avoiding or minimizing the need for off-site disposal,
- shortening the duration of the project, and

[3] "Source waters" refers to the river or stream providing the tidal inflow to the salt marsh.

- reducing inconvenience to area residents by minimizing construction duration and traffic impacts of off-site disposal.

Create a Sustainable Marsh System – A long-term goal of the Project is sustainability of the marsh system in response to sea-level rise. To this end, maintaining a marsh level at the highest elevation possible relative to the more natural surrounding marsh systems allows the Ballard Street Salt Marsh Restoration to provide the greatest longevity and resiliency.

In addition, maintaining typical 'flood dominance' within the marsh system will promote accretion to keep up with sea level rise. (Reference: Friedrichs and Perry, 2001) With flood-dominance sediment is imported into the salt marsh under the stronger incoming currents and it is deposited within the marsh system, as the outgoing tides are not of sufficient velocity to allow the sediments to exit the marsh. In general, this criterion is met by establishing a marsh system that mimics the surrounding natural marsh elevations and maintains a tidal regime that imports sediments to the extent practical.

3.3 Description of Alternatives

3.3.1 Alternative 1 - No Action

The No Action alternative maintains the existing culvert with its leaking improvised tide gate at Ballard Street ("BA-1") and the existing board at the Bristow Street east culvert ("BR-1"). Under this condition, the remnant salt marshes will continue to degrade because of restricted tidal flushing. Existing and extensive stands of *Phragmites* are likely to increase in height, vigor and density, and the remaining fragments of salt marsh vegetation will likely be completely overtaken by *Phragmites*. The dense rhizomes (shallow, spreading "roots" of *Phragmites*) will likely clog small creeks and impair drainage and the dead stems will become a fire hazard. The maintenance of the existing condition also results in continuing degraded estuarine function within the marsh creeks for fish, crabs, snails, and invertebrates.

3.3.2 Alternative 2 - Installation of a Self-Regulating Tide Gate (SRT) near Ballard Street

This alternative involves providing tidal exchange from the Saugus River by removing the improvised tide gate at the existing Ballard Street culvert ("BA-1") and from the Pines Creek by removing the board at the existing Bristow Street East culvert ("BR-1"). Tidal exchange to the Western Marsh would be regulated by the installation of a dike with two SRTs in the creek channel approximately 200 ft. upstream of the existing Ballard Street culvert. (This SRT arrangement is similar to that proposed by the NRCS design in 2002, as well as similar to the alternative identified in Section 7.0 in the WHG report included in Appendix 1).

This alternative lowers the existing western marsh plain by 2-3 ft. to accommodate the lower invert at Ballard Street. Tidal flow would be provided from the Saugus River via an unrestricted Ballard Street culvert and from the Pines River via the Bristow Street east culvert ("BR-1") on the Pines Creek. However, existing blockages (see Fig. 2.27) north of this culvert within the eastern channel (i.e., Pines Creek) would remain, thereby restricting the tidal contribution from the Pines River to the south. This alternative is depicted graphically in as Fig. 3.02, as well as in Appendix 1, Fig. 7-10.

This alternative requires complicated tide gate operation to maintain tidal flows 2-3 ft. below high tide in the Saugus River to ensure that the restored marsh ground surface is only submerged during spring tides. At least one of the two tide gates would require closing during portions of each tide. Therefore the operation and maintenance of structures associated with this alternative is more complex than that for other alternatives. Also the tidal regime created would be muted and strongly ebb-dominant as under current conditions, therefore offering no improvement over existing tidal regime conditions.

This alternative includes grates (trash racks) over each end of the Ballard Street culvert ("BA-1") to address the safety considerations due to flow velocity and depth. (See Appendix 7.)

Fig. 3.02 Alternative 2 with SRT at Ballard Street

3.3.3 Alternative 3 - Installation of SRT at Bristow –West ("BR-2" and BR-3) and Closing the Ballard Street Culvert (BA-1)

This alternative involves providing tidal exchange from the Pines River Channel to the south by a new open-topped culvert ("BR-2") and SRT at Bristow Street west of the I-95 embankment. It also includes closing the Ballard Street culvert ("BA-1") to incoming tides, while still allowing for the outflow of tidal and storm waters. This alternative includes removing the board blocking the existing Bristow Street east culvert ("BR-1").

This alternative lowers the Western Marsh by approximately 1-1.5 ft. Since the new culvert at Bristow Street west ("BR-2") can be set at an optimal elevation for tidal exchange, a larger tide range could be accommodated. Therefore the required lowering of the marsh plain is less than in Alternative 2, which depends on tidal exchange from the lower elevation of the existing Ballard Street culvert ("BA-1").

An additional 4 ft. by 4 ft. culvert will be installed adjacent to the proposed Bristow West ("BR-2") to serve as additional egress for waters during tidal events. This culvert ("BR-3") will be outfitted with a duckbill to allow water to escape the marsh, but not add additional inflow to the system. In order that this culvert will not induce ebb-dominant tidal flows, this culvert will have a drop inlet with a weir set above the normal high tide elevation in the Western Marsh. This will ensure that during normal tide cycles it does not convey water out of the Western Marsh.

Fig. 3.03 Alternative 3 with SRT at Bristow ("BR-2" and "BR-3") and Ballard Street Closed

This alternative includes flood control enhancement features at Eastern Avenue:

- The two existing culverts under Eastern Avenue ("E-1" and "E-2") would be fitted with one-way duck-bill valves to prevent tidal flow into the Eastern Avenue ditch from the Western Marsh, while still allowing stormwater runoff from rain events to discharge into the Western Marsh.
- A new auxiliary culvert ("E-3") under Eastern Avenue will be added to improve drainage from the residential neighborhood via the South Segment of the Eastern Avenue ditch.

A schematic of this alternative is shown in Fig. 3.03 as well as in Fig. 5 of Appendix 2.

3.3.4 Alternative 4 - Installation of SRT at Bristow –West ("BR-2" and "BR-3") and Install Dike

This alternative (shown in Fig. 3.04 and in Fig. 6 in Appendix 2) includes all of the components of Alternative 3 above but also entails the removal of the improvised tide gate at Ballard Street ("BA-1") as described in Alternative 2 to allow unrestricted tidal flow to the Eastern Marsh. It includes installation of an earthen dike across the stream channel near the north end of the I-95 embankment. This dike separates the Eastern and Western Marshes, allowing each to experience full tidal flow, but each operating in a slightly different tidal regime.

Fig. 3.04 Alternative 4 with SRT at Bristow-West ("BR-2" and "BR-3") and Install dike in East Channel which includes the 12-inch culvert through the dike ("BA-2").

Full tidal flow is provided to the Western Marsh by a new open-topped culvert ("BR-2") and SRT at Bristow Street west allowing tidal flow via the Pines River Channel to the south. The SRT will control the high tide elevation in the Western Marsh to be approximately 1 ft. lower than in the Eastern Marsh. This alternative significantly reduces the amount of excavation to lower the Western Marsh when compared to Alternative 2. This is because Alternative 4 establishes a higher tide range in the Western Marsh than Alternative 2, so that, in Alternative 4, the marsh plain can be set at a higher elevation.

Unlike Alternative 3, this alternative maintains the connection between the Saugus River and the Western Marsh at a level that would not affect flood protection. This is achieved by the inclusion of a 1-ft. diameter culvert ("BA-2") through the proposed dike. A culvert at a diameter greater than 1-ft. (or multiple 1-ft. culverts) will affect flooding as well causing increased velocities in the Ballard Street Culvert ("BA-1").

Alternative 4 also results in some minor additional impact for the placement of 1400 square ft. of fill material within an existing stream channel to construct the dike. However, this impact is more than offset by the additional salt marsh created.

This alternative also provides for the excavation of small ditches within the restored Western Marsh to improve tidal flushing in all areas of the marsh.

Finally, this alternative includes grates (trash racks) over each end of the Ballard Street culvert ("BA-1") to address the safety considerations.

3.3.5 Summary of Design Alternatives

Table 3.01 presents a summary of the proposed work of each alternative at each marsh and at each culvert location.

Table 3.01
Summary of Work for Each Alternative

Alt.	Alteration of Marshes		Work at Culverts							
	Eastern Marsh	Western Marsh	"BA-1"	"BA-2"	"BR-1"	"BR-2"	"BR-3"	"E-1"	"E-2"	"E-3"
1	--	--	--	N/A	--	N/A	N/A	--	--	N/A
2	--	Lower 2-3 ft.; add channels	Remove tide gate; Add trash racks	Dike with 2 culverts w/SRTs	Remove board	N/A	N/A	--	--	N/A
3	--	Lower 1-1.5 ft.; add channels	Closed	N/A	Remove board	Open top culvert w/SRT	Out only culvert	Add duck bill	Add duck bill	Out only culvert
4	--	Lower 1-1.5 ft.; add channels	Remove tide gate; Add trash racks	Dike w/ 12 in. culvert	Remove board	Open top culvert w/SRT	Out only culvert	Add duck bill	Add duck bill	Out only culvert

Note: "--" = No action proposed at this location
"N/A" = This location is not applicable

3.4 Evaluation of Alternatives

For the Ballard Street marsh restoration, development of a long-term sustainable marsh system with substantial engineering and ecological constraints is complex. To the extent possible, a series of objective criteria were developed to assess a series of four alternatives. Within this context, both exclusionary and discretionary criteria were utilized to evaluate each alternative. Consistent with the Highway Methodology approach promoted by the U.S. Army Corps of Engineers, the exclusionary criteria consisted of a pass/fail grading. A more diverse set of evaluations was provided for the discretionary criteria, where the assessment included the following ratings: poor, fair, and good.

3.4.1 Summary of Evaluation

The exclusionary and discretionary criteria were applied to each of the alternatives. This process was aided by the results from hydrodynamic modeling. These results were used to compute overall restoration area achieved by each alternative, variations in both tidal currents and water elevations throughout the marsh system, and potential flood levels for selected alternatives. Along with existing tidal conditions, the existing conditions model and preferred alternative were evaluated for the 50-year extreme rainfall event based on data from the Northeast Regional Climate Center (NRCC), to ensure that proposed conditions would not exacerbate upland flooding.

The results of the alternatives analysis is summarized in Table 3.02.

Table 3.02
Comparison of Modeled Alternatives

Alternative	Exclusionary Criteria			Discretionary Criteria				
	Maximize Restoration Area	Safeguard Public Safety	Enhance Flood Control	Enhance Fish Habitat	Minimize Mechanical Manipulation	Minimize Maintenance and Inspection	Minimize Excavation	Create a Sustainable Marsh
1	Fail	Fail	Fail	N/A	N/A	N/A	N/A	N/A
2	Pass	Fail	Pass	Fair	Poor	Poor	Poor	Poor
3	Pass	Pass	Pass	Poor	Good	Good	Good	Good
4	Pass	Pass	Pass	Good	Good	Fair	Good	Good

Table 3.02 indicates that Alternatives 3 and 4 pass the exclusionary criteria. In the discretionary criteria, Alternative 4 scores the highest and is the preferred alternative for the Project.

Section 3.4.2 presents details of the application of the exclusionary criteria, while Section 3.4.3 presents the details of the application of the discretionary criteria.

3.4.2 Application of Exclusionary Criteria

3.4.2.1 Maximize Marsh Restoration Area

Table 3.03 compares the alternatives in terms of parameters that measure salt marsh restoration. The “maximum wetted area” represents the acreage that is inundated by tidal flow at spring high tide. The “maximum tide elevations” indicate the highest water elevations during normal (non-storm) conditions. The values in Table 3.03 are based on hydraulic modeling that is presented in Appendices 1 and 2.

Table 3.03
Results of Modeled Restoration Alternatives

Maximum wetted areas and maximum tide elevations are provided for spring tide conditions.

Alternative	Maximum wetted area (acre)			Maximum tide elevation (ft.)		Rating
	Eastern Marsh	Western Marsh	Total	Eastern Marsh	Western Marsh	
Alternative 1	1.6	1.4	3.0	2.4	2.4	Fail
Alternative 2	5.1	19.6*	24.7*	1.9	1.8	Fail
Alternative 3	9.1	20.7	29.8	5.3	5.3	Pass
Alternative 4	10.5	26.4*	36.9*	5.6	4.8	Pass

*Alternatives 2 and 4 include additional excavation of the marsh plain associated with the 'footprint' of the embankment removal that was used for Winthrop Beach Nourishment.

As depicted in Table 3.03 above, Alternative 4 maximizes salt marsh restoration potential

i. *Alternative 1* – This alternative only maintains 3 acres of inter-tidal and sub-tidal area; therefore, this option does not achieve minimal potential restoration goals.

   Rating based on evaluation criteria: **Fail.**

ii. *Alternative 2* – This alternative creates a salt marsh system with 24.7 acres of inter-tidal and sub-tidal area which represents an increase of over 21 acres of salt marsh area compared to existing conditions. However only 3.5 acres of new marsh is restored in the Eastern Marsh, and the restoration goal of 30+ acres is not achieved.

   Rating based on evaluation criteria: **Fail**

iii. *Alternative 3* – This alternative creates a salt marsh system with 29.8 acres of inter-tidal and sub-tidal area which represents an increase of over 26 acres of salt marsh area compared to existing conditions. It provides full tidal restoration to 9.1 acres in the Eastern Marsh, which is more than five times the area of the existing Eastern Marsh intertidal and sub-tidal marsh system. The restoration goal of 30+ acres is not achieved; however, this alternative is very close to the restoration area goal, where the difference is within the margin of error associated with the analysis.

   Rating based on evaluation criteria: **Pass**

iv. *Alternative 4* – This alternative creates a salt marsh system with 36.9 acres of inter-tidal and sub-tidal area which represents an increase of over 33 acres of salt marsh area compared to existing conditions. Due to the full tidal restoration to the Eastern Marsh, this alternative restores a substantial area of the higher quality marsh associated with the Eastern Marsh. The 10.5 acres of marsh restored in the Eastern Marsh is six times the area of the existing Eastern Marsh intertidal and sub-tidal marsh system. In addition, the restoration goal of 30+ acres is achieved.

   Rating based on evaluation criteria: **Pass**

3.4.2.2 Safeguard Public Safety

The criterion is applied to the culvert or culverts that provide tidal exchange to the Eastern and Western Marshes. This includes the Ballard Street Culvert ("BA-1") as well as the new Bristow Street west culvert ("BR-2"). As noted in Appendix 7, both culverts have flow velocity and flow depths that present hazards to adults and/or children. In addition, both culverts are near public open spaces and the parking lots where the public can access them. Therefore both culverts were evaluated for each of the alternatives.

It should be noted that the existing Bristow Street east culvert ("BR-1") was not evaluated. This was due to the presence of blockages in the Pines Creek north of the culvert. (See Fig. 2.27.) These blockages would prevent full flow through this culvert. Removal of these blockages is not part of this Project.

Measures can be taken to mitigate the hazard:

- If the culvert is short in length (40 ft. or less) and with headroom (at least 1 ft. between water elevation and the crown of the culvert), a person can safely pass through the culvert. No other mitigation measures are needed.
- If the culvert is longer or does not have headroom, a grate (trash rack) could be installed.

A grating or trash rack is considered practicable in only those locations where it is not the sole conduit for tidal exchange and stormwater discharge. A summary of this evaluation is presented in Table 3.04.

Table 3.04
Mitigation for Flow Conditions at Culverts

Alternative	Ballard Street - ("BA-1")		Bristow Street west - ("BR-2")		Rating
	Short culvert with headroom?	Grating ("trash rack") practicable?	Short culvert with headroom?	Grating ("trash rack") practicable?	
Alternative 1	No	Not existing	N/A	N/A	Fail
Alternative 2	No	No (see discussion)	N/A	N/A	Fail
Alternative 3	(closed)	(closed)	Yes	Not required	Pass
Alternative 4	No	Yes (see discussion)	Yes	Not required	Pass

N/A = not applicable. The culvert is not part of the alternative.

i. *Alternative 1* – Flow conditions in the Ballard Street culvert ("BA-1") indicate the need for mitigation. The culvert runs full without headroom for much of the tidal cycle, as well as during storm events. As noted in Section 2.8.4, this is a public safety hazard.

Rating based on evaluation criteria: **Fail**.

ii. *Alternative 2* - Flow conditions for Alternative 2 are less safe than Alternative 1 at the Ballard Street culvert ("BA-1"). There are substantially higher velocities than existing conditions at the culvert. Due to the fact that the culvert runs full for a significant portion of the tidal cycle, the danger associated with the flow velocities is substantially increased for a baseline that is already a public safety hazard. (See Section 2.8.4.) This fails the exclusionary criteria.

Mitigation of the safety concern by installation of a grate (trash rack) would introduce a concern of clogging under high flow conditions, the very time that the full hydraulic capacity is needed. (See Fig. 3.01.) Since this culvert provides the principal discharge of stormwater during rain events, the reduction in hydraulic capacity due to a clogged grating could lead to upland flooding.

Rating based on evaluation criteria: **Fail**.

iii. *Alternative 3:*

Ballard Street culvert (“BA-1”) – Alternative 3 results in closure of the Ballard Street culvert (“BA-1”), mitigating many of the safety concerns. High velocity flows through a completely submerged culvert do not exist as part of this scenario.

Bristow Street Culvert west with SRT (“BR-2”) – Although flow velocities (see Appendix 7) are high in relation to the safety criteria shown in Fig. 2.29, this culvert is short (~40 ft. in length) and does not run full. Therefore, a person can safely float through the culvert and there is no need for a trash rack to mitigate for public safety hazards.

Rating based on evaluation criteria: **Pass**.

iv. *Alternative 4:*

Ballard Street culvert (“BA-1”) – This alternative has similar safety concerns to Alternative 2 due to high velocity flows through the completely submerged culvert at Ballard Street. For this alternative, the use of gratings is practicable. The reason is that Alternative 4 provides an alternative outlet for stormwater runoff from East Saugus, namely, via the two new culverts at Bristow Street west: the 4-ft. open-topped culvert and the SRT (“BR-2”) and the “out only 4-ft. diameter culvert (“BR-3”). Therefore, if the grating at the culvert at Ballard Street (“BA-1”) were clogged, it would not result in upstream flooding as the Western Marsh would drain to the south through culverts “BR-2” and “BR-3.”

Bristow Street Culvert west (“BR-2”) – Although flow velocities (Fig. 5 in Appendix 7) are high in relation to the safety criteria shown in Fig. 2.29, this culvert is short (~40 ft. in length) and does not run full. Therefore, a person can safely float through the culvert and there is no need for a trash rack to mitigate for public safety hazards.

Dike with Culvert (“BA-2”) – The dike placed in the existing tidal channel near Ballard Street will have a one-foot diameter culvert installed to allow for fish passage. The size of this culvert does not create any additional public safety issues, as it is too small for people to pass through. No trash rack would be needed as mitigation

Rating based on evaluation criteria: **Pass**.

3.4.2.3 Enhance Flood Control

i. *Alternative 1* – The existing conditions provides no improvements for the poor existing upland drainage conditions that are caused by the inability of the existing Ballard Street culvert (“BA-1”) to adequately convey flows generated by severe rainfall events.

Rating based on evaluation criteria: **Fail**.

ii. *Alternative 2* – Alternative 2 provides substantial improvements to upland drainage as the modeling included in Appendix 1 demonstrates. The modeling indicates that the upland structures will not flood during a 50-year rainfall event. Under existing conditions, the neighborhood floods during much more frequent rainfall events; therefore, Alternative 2 represents a significant improvement. However, a major concern for the Project remains the potential mitigation for the above safety concerns as previously noted. Mitigation of the safety concern by installation of a grate (trash rack) would introduce a concern of clogging under high flow conditions, the very time that the full hydraulic capacity is needed. (See Fig. 3.01) The reduction in hydraulic capacity could lead to upland flooding if the culvert is completely, or even partially, blocked during a high freshwater inflow event.

Rating based on evaluation criteria: **Pass**.

iii. *Alternative 3* – Alternative 3 provides substantial enhancement to flood control, through the incorporation of duckbill gates at the seaward limit of the drainage culverts running under Eastern Avenue to prevent tidal surges from flooding upstream into the residential neighborhood. In addition, the installation of larger culverts will facilitate more rapid drainage from the residential neighborhood when offshore tide elevations are lower than the marsh water level. This includes a new 4-ft. culvert under Eastern Avenue ("E-3") as well as two new culverts under Bristow Street west of the I-95 embankment: the new 4-ft. open-topped culvert and the SRT ("BR-2") and the new out-only 4-ft. diameter culvert ("BR-3").

Rating based on evaluation criteria: **Pass**

iv. *Alternative 4* – Similar to Alternative 3, Alternative 4 provides substantial improvements to upland drainage, both through the incorporation of duckbill gates at the seaward limit of the drainage culverts running under Eastern Avenue and the installation of larger culverts to facilitate rapid drainage of the upland when offshore tide elevations are lower than the marsh water level. This includes a new 4-ft. culvert under Eastern Avenue ("E-3") as well as two new culverts under Bristow Street west of the I-95 embankment: the new 4-ft. open-topped culvert and the SRT ("BR-2") and the new out-only 4-ft. diameter culvert ("BR-3").

Rating based on evaluation criteria: **Pass**

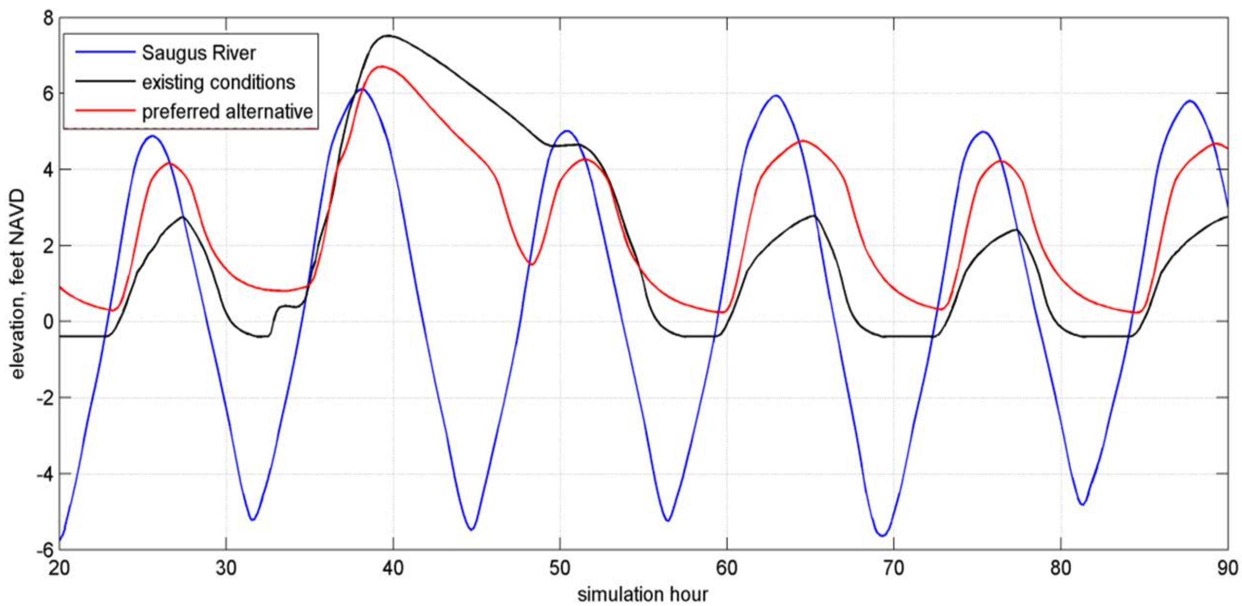

Fig. 3.05 Comparison of modeled tides in the Western Marsh for existing conditions and the preferred alternative (Alternative 4) during the simulation of the 50-year rainfall event. The peak water elevations are nearly 1 ft lower for Alternative 4 relative to existing conditions, and the additional culverts for the preferred alternative allow more rapid draining of floodwaters.

3.4.3 Application of Discretionary Criteria

The Discretionary Criteria are only applied to the "action" alternatives, namely Alternatives 2, 3 and 4.

3.4.3.1 Enhance and/or Maintain Fish Habitat

The measures used for this criterion include the increase in inundated tidal area at spring tide (based on values in Table 3.03), and connectivity with tidal waterways, with connection to the Saugus River as the most important connection related to marine fisheries. These measures are presented in Table 3.05.

Table 3.05
Comparison of Fish Habitat Enhancements

Alternative	Maximum wetted area during spring tide (acre)	Connectivity to Saugus River		Connectivity to Pines River Marsh System		Rating
		Eastern Marsh	Western Marsh	Eastern Marsh	Western Marsh	
Alternative 2	24.7	Direct	Through SRTs at dike (“BA-2”)	Limited due to blockages in Pines Channel north of Bristow Street	No direct connection	Fair
Alternative 3	29.8	Blocked	Blocked		New connection (“BR-2”)	Poor
Alternative 4	36.9	Direct	Through 1-ft. culvert at dike (”BA-2”)		New connection (“BR-2”)	Good

i. – *Alternative 2:*

Connectivity to Saugus River: The removal of the flap at the Ballard Street culvert (“BA-1”) allows for unrestricted tidal flow in the Eastern Marsh.

However, unrestricted tidal flow in the Eastern Marsh necessitates closure of the SRTs leading to the Western Marsh for several hours every tide cycle, based on modeling. This will inhibit fish passage during certain tidal conditions. As the Western Marsh contains nearly 80% of the restored salt marsh area for this alternative, mechanical restriction of tidal flow to a majority of the restored marsh diminishes the enhancement to fish habitat.

Rating based on evaluation criteria: **Fair**.

ii. *Alternative 3:*

Connectivity to Saugus River: The connectivity is eliminated by closing the Ballard Street culvert..

Connectivity of Western Marsh to Pines River: This is added by a new culvert with SRT.

Rating based on evaluation criteria: **Poor**

iii. *Alternative 4:*

Connectivity to Saugus River: The removal of the flap at the Ballard Street culvert (“BA-1”) allows for unrestricted tidal flow in the Eastern Marsh.

Connectivity to the Western Marsh is provided via a 1-ft. culvert through a dike separating the Eastern and Western Marshes.

Connectivity of Western Marsh to Pines River: This is added by a new culvert with SRT.

Rating based on evaluation criteria: **Good**

3.4.3.2 Minimize Mechanical Manipulation of the System

Measures employed for this criterion are minimizing the number of adjustable tide gates and minimizing the duration of gate closures. See Table 3.06.

Table 3.06
Comparison of Mechanical Manipulation of the System

Alternative	No. of SRTs to Control Tide Signals		Frequency of Operation of SRTs (Tidal Cycles per 30-Day Month)		Rating
	Eastern Marsh	Western Marsh	Eastern Marsh	Western Marsh	
Alternative 2	0	2	N/A	60	Poor
Alternative 3	1	1	4	4	Good
Alternative 4	0	1	N/A	4	Good

i. *Alternative 2* – Alternative 2 will initially require manipulation of one of the two installed tide gates to artificially attenuate the tide signal from the Saugus River into the Western Marsh. This manipulation will require that the tide gate operate continuously, where failure of the gate will either lead to long-term inundation of the marsh plain or no flooding of the marsh plain. Therefore, failure or partial failure of the tide gate will lead to loss of the restored salt marsh resources.

   Rating based on evaluation criteria: **Poor**

ii. *Alternative 3* – With the introduction of tidal flow through an open-topped culvert at Bristow West ("BR-2"), manipulation of tide gates is no longer required except during infrequent storm surge events. The proposed tide gate on the Bristow West culvert will only operate to close the culvert once the water level in the Pines River marsh system has exceeded +5.0 ft. Overall, this alternative represents a low level of tidal manipulation.

   Rating based on evaluation criteria: **Good**

iii. *Alternative 4* – With the introduction of tidal flow through an open-topped culvert at Bristow West ("BR-2"), manipulation of tide gates is no longer required except during infrequent storm surge events. The proposed tide gate on the Bristow West culvert will only operate to close the culvert once the water level in the Pines River marsh system has exceeded +5.0 ft. As the Eastern and Western Marshes are hydraulically separated for Alternative 4, no tide gates will exist within the Eastern Marsh, allowing full tidal exchange for all conditions. Overall, this alternative represents the minimum tidal manipulation of all scenarios evaluated.

   Rating based on evaluation criteria: **Good**

3.4.3.3 Minimize Maintenance and Inspection Requirements

The measures employed include the number of items requiring inspection and maintenance, the frequency of that inspection, and the criticality of performing maintenance, particularly onerous and potentially dangerous maintenance during storm events. See Table 3.07.

Table 3.07
Comparison of Inspection & Maintenance Requirements

Alternative	Maintenance Items			Rating (See Narrative)
	Duckbills	SRTs	Grates (Trash Rack)	
Alternative 2	0	2	2	**Poor**
Alternative 3	4	1	0	**Good**
Alternative 4	4	1	2	**Good**

i. *Alternative 2:*

SRTs: The operation of SRTs are critical to maintaining the tidal range in the Western Marsh during each tidal cycle. Failure of the SRTs could deprive the Western Marsh of adequate salinity from tidal exchange as well as cause upstream flooding either from failure to close during tidal surges or failure to open to discharge stormwater events. Therefore, maintenance of the SRTs has a high criticality.

Culvert Gratings: As the only means of floodwater exiting the marsh, it is critical that both the proposed tide gates and the Ballard Street culvert remain fully open during inland flooding events to prevent flooding of the neighborhood. Therefore frequent inspection and maintenance will be necessary. Debris removal will be necessary, both on a periodic basis and potentially also emergency cleaning during hazardous high-flow conditions if the grating becomes clogged during a major storm event.

Rating based on evaluation criteria: **Poor**

ii. *Alternative 3:*

Duckbills: As duckbills are self-cleaning and low maintenance, they are rated as a low criticality.

SRTs: The SRT only needs to function in tidal surges. With the duckbills on the culverts under Eastern Avenue, failure of the SRT would not lead to upstream flooding, as it would in Alternative 2. Therefore, maintenance of the SRTs has a moderate criticality.

Rating based on evaluation criteria: **Good**

iii. *Alternative 4:*

Duckbills: As duckbills are self-cleaning and low maintenance, they are rated as a low criticality.

SRTs: The SRT only needs to function in tidal surges. With the duckbills on the culverts under Eastern Avenue, failure of the SRT would not lead to upstream flooding, as it would in Alternative 2. Therefore, maintenance of the SRTs has a moderate criticality.

Culvert Gratings: In Alternative 4, the Ballard Street culvert is not critical to providing stormwater discharge in order to prevent flooding of the neighborhood. Rather, the stormwater can be discharged via the culverts at Bristow Street west ("BR-2" and "BR-3"). Therefore the inspection and maintenance of the gratings has a low criticality.

Rating based on evaluation criteria: **Good**

3.4.3.4 Minimize Excavation Requirements

The measures employed include the volume of material excavated to lower the Western Marsh plain and the volume of excess material that cannot be disposed on site. See Table 3.08.

Table 3.08
Comparison of Excavation Requirements

Alternative	Volume of Excavation (CY)	Volume of Off-Site Disposal	Rating
Alternative 2	120,000	45,000	Poor
Alternative 3	50,000	0	Good
Alternative 4	50,000	0	Good

i. *Alternative 2* – As part of all marsh restoration options being considered, large-scale excavation of the marsh plain is required. Alternative 2 requires the maximum excavation of any of the evaluated options (total excavation volume of 120,000 cubic yards), creating the maximum excavation cost.

Rating based on evaluation criteria: **Poor**

ii. *Alternative 3* – As part of all marsh restoration options being considered, large-scale excavation of the marsh plain is required. Alternative 3 requires excavation of the marsh plain to finished elevation of between +3.5 and +4.5 ft., requiring a total excavation volume of 50,000 cubic yards. The excavation volumes required for Alternatives 3 and 4 are identical.

Rating based on evaluation criteria: **Good**

iii. *Alternative 4* – As part of all marsh restoration options being considered, large-scale excavation of the marsh plain is required. Alternative 4 requires excavation of the marsh plain to finished elevation of between +3.5 and +4.5 ft., requiring a total excavation volume of 50,000 cubic yards. The excavation volumes required for Alternatives 3 and 4 are identical.

Rating based on evaluation criteria: **Good**

3.4.3.5 Create a Sustainable Marsh System

The measures employed include the elevation of the lowered Western Marsh plain relative to the marsh plain surrounding the Project Area and whether the restored marsh has a flood-dominant tidal exchange. See Table 3.09.

Table 3.09
Comparison of Sustainability of Alternatives

Alternative	Elevation of Lowered Western Marsh Plain Below Adjacent Marsh Plain	Flood Dominance	Rating
Alternative 2	2.8 to 3.6	No	Poor
Alternative 3	0.5 to 1.5	Yes	Good
Alternative 4	0.5 to 1.5	Yes	Good

i. *Alternative 2:*

Relative marsh elevation: For Alternative 2, the excavated marsh plain elevation varies between +1.4 and +2.2 ft. This elevation is substantially below the adjacent Pines River marsh plain (approximately +5.0 ft.) and would require substantial manipulation of the tide gates to allow a marsh to exist at this low elevation.

Flood or Ebb Dominance: As shown in Fig. 3 of Appendix 7, the tidal currents through the Ballard Street culvert ("BA-1") for Alternative 2 are substantially greater during the ebbing portion of the tide. Therefore, the marsh system created by Alternative 2 would export sediment and not be able to keep up with sea level rise or be sustainable in the long-term.

Rating based on evaluation criteria: **Poor**

ii. *Alternative 3:*

Relative marsh elevation: For Alternative 3, the excavated marsh plain elevation varies between +3.5 and +4.5 ft. This elevation is slightly below the adjacent Pines River marsh plain (approximately +5.0 ft.).

Flood or Ebb Dominance: As shown in Fig. 4 in Appendix 7, the tidal currents through the Bristow West culvert ("BR-2") for Alternative 3 are substantially lower during the ebbing portion of the tidal cycle. Therefore, the marsh system created by Alternative 3 would import sediment and facilitate the marsh in keeping up with sea level rise and have a higher likelihood of being sustainable in the long-term.

Rating based on evaluation criteria: **Good**

iii. *Alternative 4:*

Relative marsh elevation: For Alternative 4, the excavated marsh plain elevation varies between +3.5 and +4.5 ft. This elevation is slightly below the adjacent Pines River marsh plain (approximately +5.0 ft.).

Flood or Ebb Dominance: As shown in Appendix 7, the tidal currents through the Bristow West culvert ("BR-2") for Alternative 4 are substantially lower during the ebbing portion of the tidal cycle. Therefore, the marsh system created by Alternative 4 would import sediment and facilitate the marsh in keeping up with sea level rise and have a higher likelihood of being sustainable in the long-term. Some flow will still exit the system via the Ballard Street culvert ("BA-1") via the 1-ft. diameter culvert ("BA-2") in the new dike, however the small size of this culvert negates any possible effects on sediment transport.

Rating based on evaluation criteria: **Good**

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4.0 Project Description

Alternative 4 is the preferred alternative and the basis of the Project. The Project elements are shown in Fig. 4.01 and include the following:

Modifications to the Western Marsh:

- The lowering of 15.4 acres of the Western Marsh plain by 1-1.5 ft., representing approximately 50,000 cubic yards of material.
- Placement of this spoils material to backfill the over-excavated portions of the western side of the I-95 embankment (“Area C”) as well as over existing mounds located east of the embankment (designated as “Fill Area 1” and “Fill Area 3” in Fig. 4.01).
- Excavation of new auxiliary channels within the restored marsh will facilitate full tidal flow to all areas of the Western Marsh.

Modifications to the Eastern Marsh:

- No excavation of the Eastern Marsh is proposed. Cleaning of the existing channel, which runs parallel to Route 107, is not included this Project, but is anticipated to be performed in the future through a Northeast Mosquito Control project. Modeling described in Appendix 2 indicates that the Ballard Street and Bristow East culverts provide enough tidal exchange within the Eastern Marsh to raise the high tide level above the observed blockages in the channels. It is anticipated that the larger tidal flow and higher salinity may also “naturally” clear some of the observed channel shoaling.

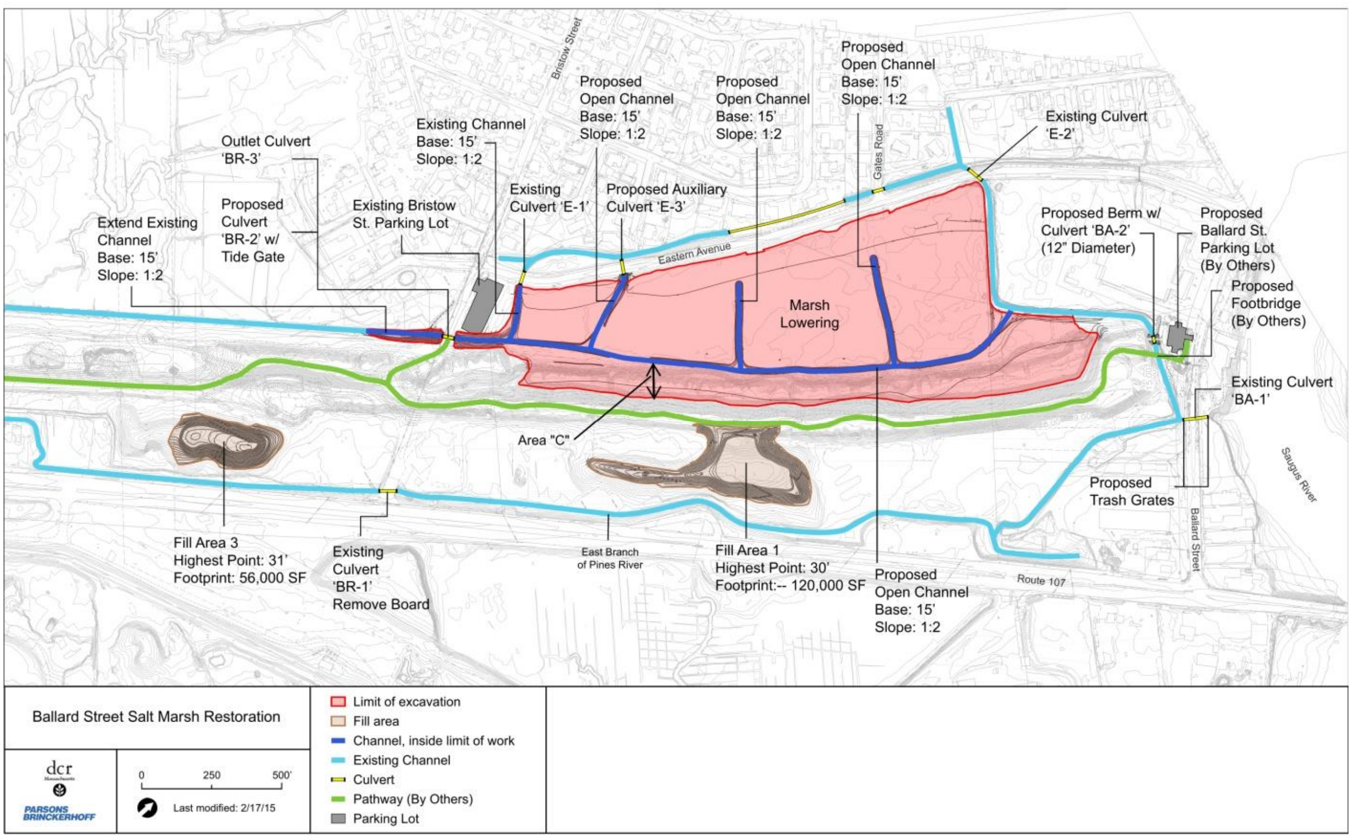

Fig. 4.01 Overview of Preferred Alternative

New Culverts and SRTs:

- Installation of a pair of new culverts at Bristow Street west of the I-95 embankment at the location of an historic channel. The existing Pines River Channel (See Fig. 2.24) will be extended north to this location.
    - A new open-topped culvert ("BR-2") and SRT to provide the primary source of tidal flow for the Western Marsh from the Pines River Channel.
    - An auxiliary "out only" 4-ft. culvert ("BR-3") with a one-way duckbill valve to prevent tidal flow into the Western Marsh. This culvert is intended to enhance stormwater discharge from the Western Marsh to the Pines River Channel. It also provides an emergency fail-safe to allow tidal and stormwater discharge in the event that the primary culvert and SRT ("BR-2") fails in the closed position.
- Installation of a new auxiliary culvert ("E-3") under Eastern Avenue in the vicinity of Mersea Street, to improve drainage from the residential neighborhood. The new culvert would be fitted with a one-way duckbill valve to prevent tidal flow into the Eastern Ave. ditch.
- Construction of a 8-ft. high earthen dike across the channel on the west side of the northerly terminus of the I-95 embankment, approximately 200 ft. upstream of the Ballard Street culvert. This dike would contain a 1-ft. diameter culvert ("BA-2") to allow restricted flow to the Western Marsh from the Saugus River.

Modifications to Existing Culverts:

- Removal of the existing improvised tide gate at the Ballard Street culvert ("BA-1") to allow unrestricted flow into the Eastern Marsh.
- Removal of board and remnants of internal flow controls from the Bristow Street culvert east ("BR-1") to allow flow from the Pines Creek into the Eastern Marsh (see Fig. 4.02).
- Installation of one-way duckbill valves on the two existing Eastern Avenue culverts (24-in. "E-1" and 72-in. "E-2") to prevent tidal flow into the Eastern Avenue ditch.

4.1 Description of Project Elements

This section provides additional detail of the Project elements necessary to achieve the Project goals.

4.1.1 Lowering of Western Marsh Plain and Material Handling

4.1.1.1 Lowering of Marsh Plain

The Project will lower approximately 15.4 acres of the Western Marsh plain by 1-1.5 ft. to create tidal conditions suitable to restore salt marsh vegetation. The resultant marsh plain will coincide with the range of high tide conditions, allowing full inundation only in spring high tides.

4.1.1.2 Material Handling and On-Site Disposal

The contractor would move approximately 50,000 cubic yards of this material to backfill three areas:

- The additional excavation of the western side of the I-95 embankment ("Area C" in Fig. 4.01).
- Two of the existing mounds located east of the embankment (designated as "Fill Area 1" and "Fill Area 3" in Fig. 4.01).

A total of five on-site locations were considered for on-site disposal:

- Area C, which is proposed to be excavated to elevation -1.0 by the Winthrop Beach Nourishment – Northern Segment (DCR Project No. P11-2686-C4A)
- Fill Areas 1 to 4: These are existing upland areas east of the I-95 embankment, identified by Geosyntec and shown in Fig. 4.02.

Area C

Presently, Area C has been excavated only to elevation +5.0 ft. as part of the extraction associated with the Winthrop Beach project. This is pursuant to a condition of the Superseding Order of Conditions (DEP File #67-1001). This condition does not allow the excavation below elevation +5.0 to occur until it can be done concurrent with the Ballard Street Western Marsh lowering. When the Ballard Street Project is underway, Area C will be excavated from elevation +5.0 to -1.0 ft., providing for the on-site disposal of approximately 25,000 cubic yards of material from the Western Marsh lowering to achieve a level marsh plain.

Fill Areas 1 to 4

In 2009, Geosyntec identified 4 locations where spoils of marsh lowering could be placed. See Fig. 4.02. All the areas were upland (above the marsh plain) and all but Area 2 are existing mounds of peat and other spoils that date back to the original embankment placement. These areas were identified in consideration of the long range plans for marsh restoration. There is considerable material in each mound, and removal and disposal would be prohibitedly expensive. Therefore, placement of spoils atop these existing mounds was considered acceptable.

Fig. 4.02 Potential On-Site Disposal Locations. (Geosyntec, 2009)

Two other fill areas were considered and rejected:

- Fill Area 2, immediately north of Bristow Street, is a potential location for future marsh restoration, as it is only a few feet higher than the current desired marsh plain. It has the potential to be lowered at a future time so it can be restored to salt marsh.
- Fill Area 4, immediately south of Area 3, was rejected in that it is under a power transmission line. Filling on top of the mound would violate the power company's required vertical clearance under high voltage transmission lines.

Material containing *Phragmites* will be handled to minimize the potential for further spread into areas of restored marsh, including burial at least 5 ft. below final grade.

Fill Area 1 is closer to the Western Marsh and would be the first choice to place the excess 25,000 cubic yards of material that could not be placed in Area C. "Fill Area 3" is located south of Bristow Street. It is included as a contingency on-site location. Though fill will be placed on these existing mounds, fill placement will not alter existing salt marsh as the footprint of each mound will not increase.
No material will be taken off-site for disposal.

4.1.1.3 Channels within the Lowered Western Marsh

New auxiliary channels within the restored marsh will facilitate full tidal flow to all areas of the Western Marsh. See Fig. 4.03. The design of these auxiliary channels will be completed prior to final permitting of the Project. The concept will include a system of primary new channels with auxiliary ditches:

- New primary channels/creeks will be created in the Western Marsh to ensure tidal flow reaches the entire restoration area.
- Additional secondary creeks may be added as a field adjustment during the construction or restoration process if determined to be necessary to ensure full restoration. Similarly tidal flow restrictions caused by slumping channel banks within the existing marsh channels in the Eastern Marsh may be removed as inspection deems necessary.

Material removed from channel improvements will be placed on site in the same locations as the spoils from marsh lowering. See Section 4.1.1.2 above.

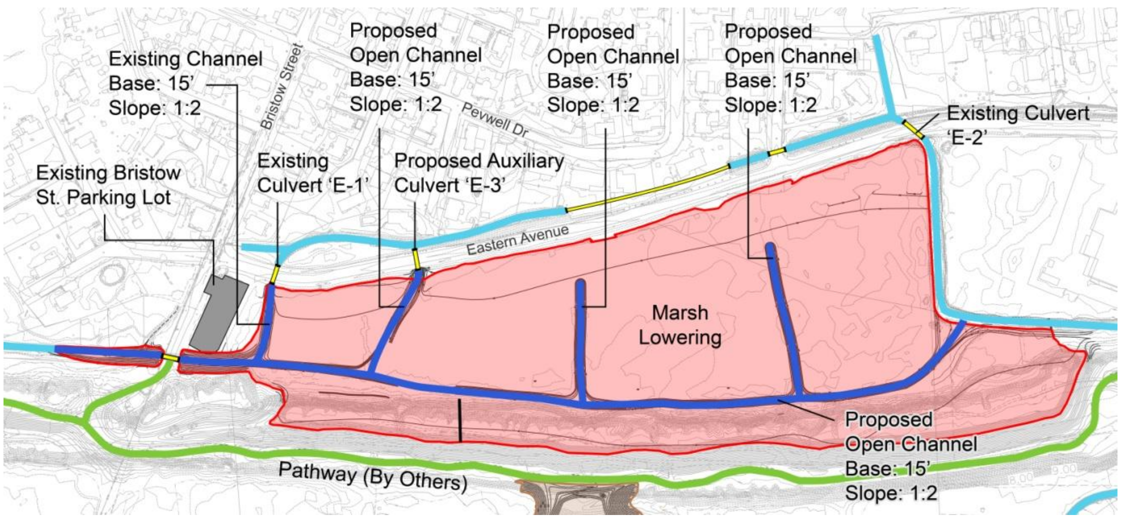

Fig. 4.03 Conceptual layout of channels and auxiliary ditches for the lowered Western Marsh

4.1.2 New Culverts at Bristow Street West ("BR-2" & "BR-3")

4.1.2.1 New Culvert for Tidal Exchange

The Project will add a new open-topped culvert ("BR-2") and SRT at Bristow Street west of the I-95 embankment. The culvert invert will be set at elevation 0.0 to optimize hydraulic performance, as this elevation corresponds to the typical marsh channel elevations south of the proposed culvert in the Pines River marsh system. The culvert will be rectangular in shape, 4 ft. wide and be open topped. The height will be set to ensure it never runs full under tidal and storm conditions.

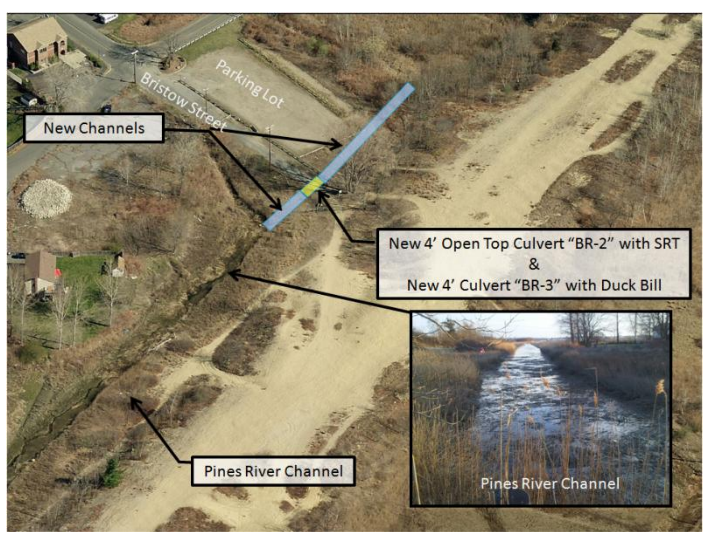

Fig. 4.04 New culvert "BR-2" & "BR-3" at Bristow Street west, near the parking lot

The new culvert will cross the end of Bristow Street, just east of the existing parking lot. New channels will be excavated north and south of the culvert. To the south, the channel will extend the Pines River Channel and provide tidal exchange (See Fig. 4.04). To the north, it will connect to the lowered Western Marsh via a series of channels and auxiliary ditches (as shown in Fig. 4.03).

The SRT is a float-activated tide gate that allows the passage of normal tidal flows and is fully adjustable to limit the passage of extreme tides or flood surges. See sequence of operation in Fig. 4.05.

If flows exceed the set elevation, counter floats automatically close the tide gate, which then remains closed during the flood event. The SRT automatically re-opens as the tide or flood event recedes. The SRT will be installed within a 4 ft. wide open topped concrete culvert with an invert elevation of 0 ft. A typical SRT is shown in Fig. 4.06.

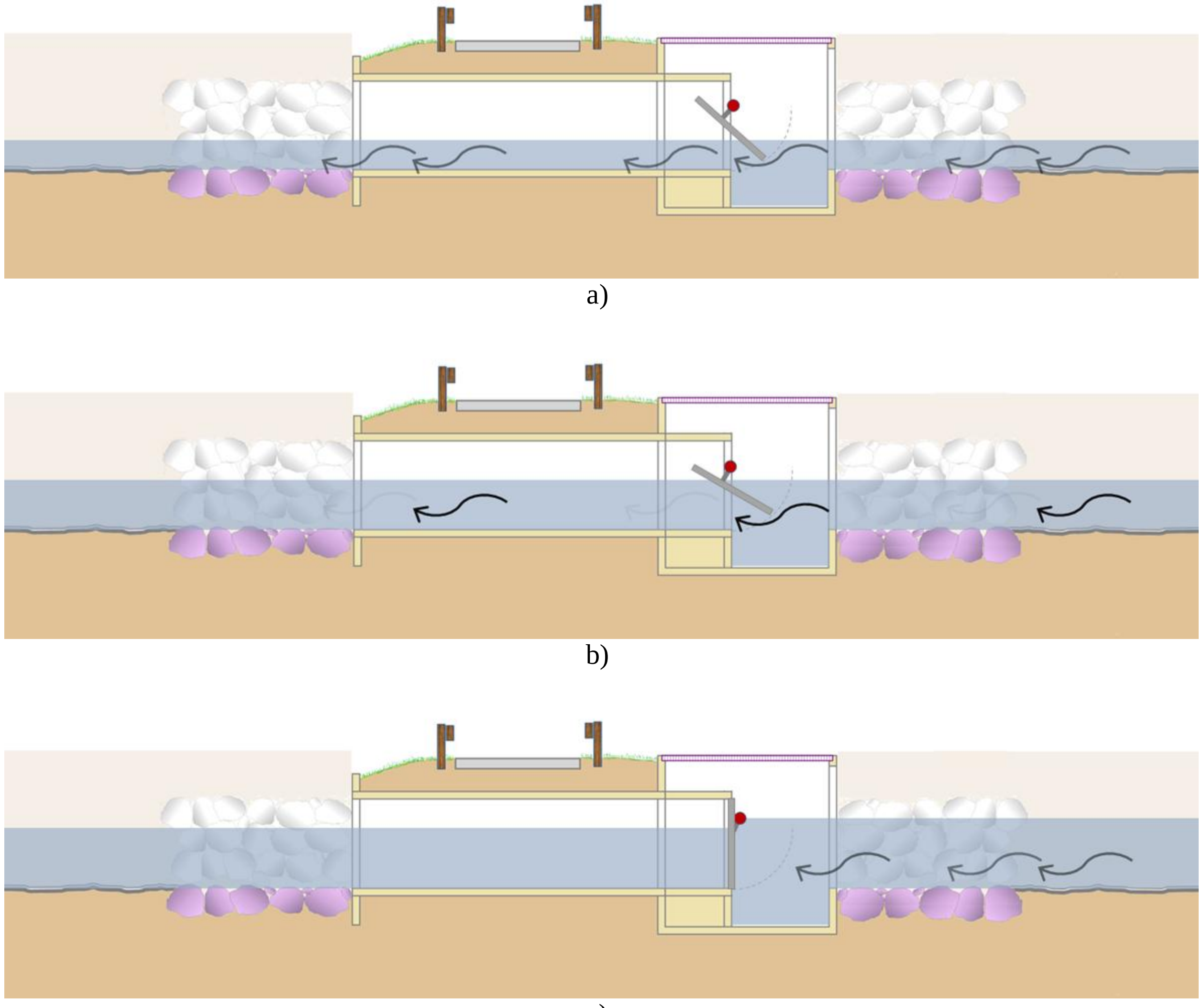

Fig. 4.05 Sequence of Operation of SRT
a) Gate floats open to let tide in
b) Gate stays open during rising tide
c) Gate closes when tide is above a set elevation

Fig. 4.06 Photographs of Typical SRT, installed (at left) and prior to installation (right)

4.1.2.2 Auxiliary Culvert for Stormwater Discharge

An auxiliary "out only" 48 in. culvert ("BR-3") will be provided with a one-way duckbill valve to prevent tidal flow into the Western Marsh. This culvert is intended to enhance stormwater discharge from the Western Marsh during major rain events.

4.1.3 New Dike and Culvert ("BA-2")

The new dike would serve the purpose of separating the Eastern Marsh and Western Marsh, allowing for maximum salt marsh restoration overall. It would allow for different tidal ranges in the Eastern and Western Marshes. The Eastern Marsh can operate with unrestricted tidal flow without causing the flooding of properties at high spring tides and without detrimental effect of the ebb-dominate flow under the influence of the low Ballard Street culvert.

However, hydraulic modeling has indicated that it is necessary to restrict the hydraulic influence of the Ballard Street culvert in order to establish the desired flood-dominant flow in the Western Marsh. While ideally a solid dike would completely eliminate the influence of the Ballard Street culvert, a small culvert can be provided to provide habitat connectivity between the Saugus River and the Western Marsh. Modeling shows that a 12-inch culvert can provide the connectivity without significant degradation of flood-dominant flow. Modeling also shows that adding a second culvert shifts the operation of the Western Marsh to ebb-dominant, as the greater hydraulic capacity results in a greater influence of the ebb-dominant operation of the Ballard Street culvert.

The dike also reduces the amount of Western Marsh plain excavation otherwise required because of the low invert at the Ballard Street culvert. The dike height is set to match the elevation of Ballard Street and therefore the dike would overtop during a coastal storm surge associated with an approximate 2-year storm event (or 50% probability of occurring in a year). In the event that the new dike would be overtopped, a second line of flood control is provided by the provision of one-way duckbill tide valves on the Eastern Avenue culverts. These duckbills would keep spring tides and storm surges from backflowing into the residential neighborhoods west of Eastern Avenue. See further discussion in Section 4.1.4.

4.1.4 Eastern Avenue Culverts ("E-1," "E-2," and "E-3")

The proposed design utilizes Eastern Avenue to serve as a barrier against tidal flows and storm surges, so as to protect the residential East Saugus neighborhood located west of Eastern Avenue from associated flood damage. To ensure this objective while also allowing stormwater runoff to pass through the Western Marsh, the Project will add one-way duckbill valves on the existing Eastern Avenue Culverts. This includes the 24 in. culvert ("E-1") just north of Bristow Street and the 72 in. culvert ("E-2") north of Gates Road.

The duckbill valves are made of rubber and remain closed when there is not stormwater flow from upstream. As the Western Marsh receives tidal flow, the valve remains closed. However, under the force of stormwater from upstream, the duckbill opens up, allowing stormwater to enter the Western Marsh. For photographs of typical duckbill valves, see Fig. 4.07.

Fig. 4.07 Photographs of Typical duckbill Tide Valves

The Project also includes construction of a 48-inch diameter auxiliary culvert ("E-3") under Eastern Avenue in the vicinity of Mersea Street (see Fig. 4.08). This would improve the conveyance of inland floodwaters and stormwater runoff from the residential neighborhood along Eastern Avenue into the newly created salt marsh area. This culvert will also be fitted with a one-way duckbill to prevent flooding from coastal storm events from backing up into the culvert and then into the drainage ditch along Eastern Avenue, as currently occurs. This will alleviate some of persistent flooding in this area.

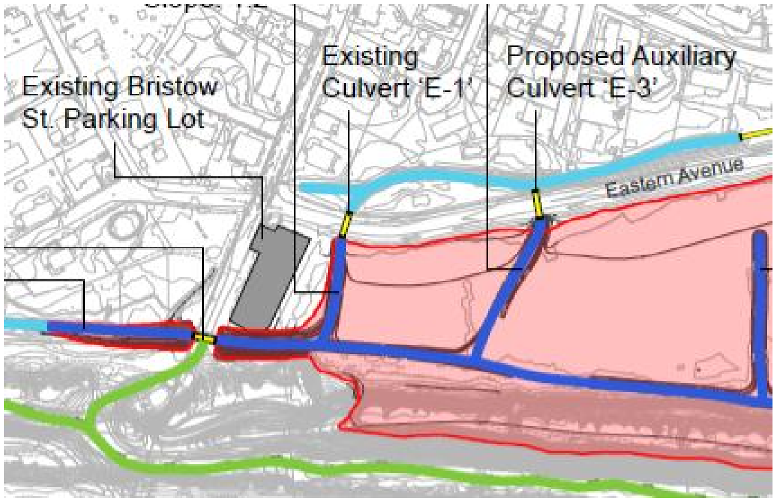

Fig. 4.08 Location of Proposed Auxiliary Culvert "E-3"

4.1.5 Removal of Culvert Obstructions

Obstructions will be removed at the existing culverts at Ballard Street ("BA-1") and Bristow Street east of the I-95 embankment ("BR-1"). For culvert locations, see Fig. 4.09.

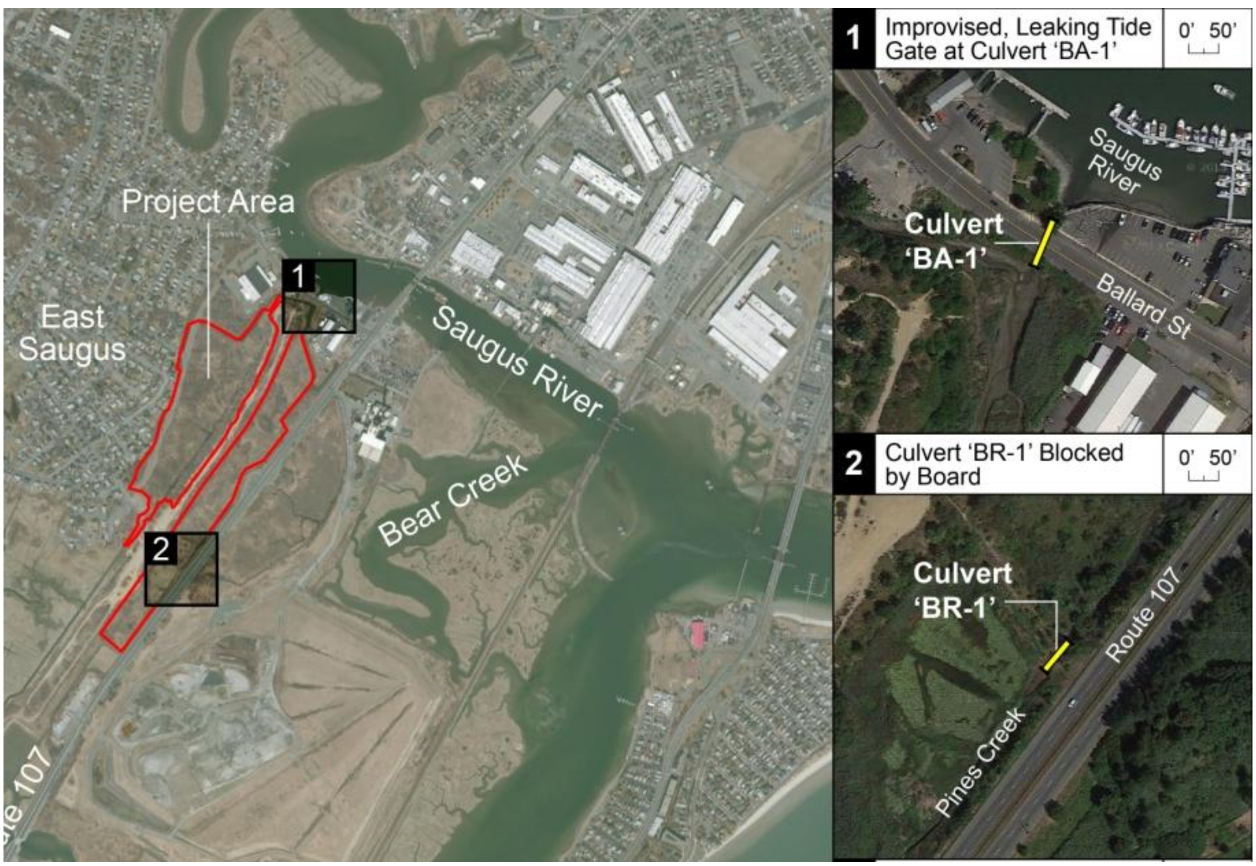

Fig. 4.09 Location of Obstructed Culverts at Ballard Street ("BA-1") and Bristow Street east ("BR-1")

4.1.5.1 Ballard Street Culvert ("BA-1")

At Ballard Street, the poorly functioning improvised tide gate (a corroding steel plate affixed to the end of the culvert) will be removed, allowing full tidal exchange, to the extent of the culvert's capacity.

Hydrological modeling has indicated that excessive velocities will occur at this culvert with the improvised tide gate removed. Combinations of flow depth and velocity can be strong enough to knock over a person standing in the stream, as illustrated in Fig. 2.28. As this culvert is adjacent to state and town parklands, this safety hazard must be mitigated. One approach would be to install a grate at such a distance from the culvert ends that the velocities would be under 2 fps.

Fig. 4.10 Enlarged View of Improvised Tide Gate on North End of Ballard Street Culvert

4.1.5.2 Bristow Street Culvert East ("BR-1")

The board blocking this culvert will be removed. See Fig. 4.11. This will provide an additional source of tidal flushing from the Pines River, south of the Project Area.

Fig. 4.11 Enlarged View of board on North End of Bristow Street Culvert

4.2 Flood Control Benefits

The Project provides for the enhancement of flood control and storm damage protection during both rain events and coastal tidal surges in the following ways:

- Stomrwater drainage from the Eastern Avenue ditch – southern segment is significantly improved by providing enhanced downstream capacity:
    - New 48-in. culvert ("E-3") under Eastern Avenue.
    - New channel from this culvert through the Western Marsh
    - New culverts at Bristow Street west ("BR-2" and "BR-3")

- Stormwater drainage from both segments of the Eastern Avenue ditch is significantly improved by the improved channels and lowering of the marsh plain in the Western Marsh. For the design storm (50-yr. storm), these improvements lower the peak water elevation in the Western Marsh by nearly 1 ft. when compared to existing conditions. See Fig. 4.12.

- The Project will prevent the backup of tidal surge waters from reaching the Eastern Avenue ditch and Town storm drains upstream of the ditch during spring high tides and storm surges up to the low point of Bristow Street (elevation +7, equivalent of the 2-year storm),. This will keep these surges from backflowing into the East Saugus neighborhood. However, should severe coastal flooding overtop Ballard Street with wind or wave-driven storm surges, and overwhelm tide gates at any location in the Project Area, local flooding will reach the neighborhood directly from the Saugus River and from the marsh south of Bristow Street. Though the Project is unable to fully protect the adjacent East Saugus neighborhood from flooding caused by extreme coastal storm surge, there will be a reduction in frequency and severity of flooding in the neighborhood.

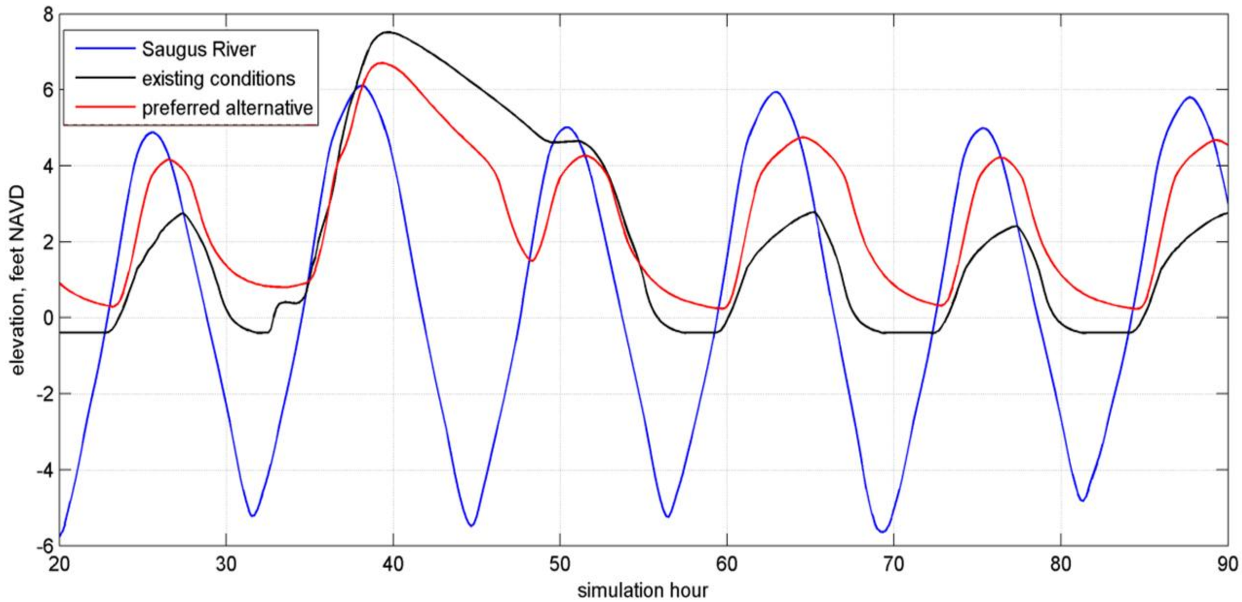

Fig. 4.12 Comparison of modeled tides in the Western Marsh for existing conditions and the preferred alternative (Alternative 4) during the simulation of the 50-year rainfall event.
The peak water elevations are nearly 1 ft lower for Alternative 4 relative to existing conditions. The peak flows of the 50-yr. storm occurs during simulation hours 35 to 55. The peak runoff occurs at simulation hour 39..

4.3 Proposed Project Schedule and Costs

Construction of the Project is currently anticipated to commence late in 2015 or early 2016. The proposed construction sequencing and methodology is presented in Section 6.1. The Project will likely require approximately 12 to 18 months to complete, at an estimated cost of $2.2 million. See Table 4.01.

Table 4.01
Construction Cost Estimate

Items of Work	Estimated Costs
Culverts & Structures	$657,000.00
Material Extraction & On-Site Disposal	$1,054,000.00
Paving, Site Restoration, and General Requirements	$505,000.00
Total	**$2,216,000.00**

Note: Costs are for mid-2015

4.4 O&M Considerations

Future maintenance of the culverts and tide gate will be the responsibility of the DCR in accordance with an Operation and Maintenance (O&M) Plan prepared as part of a Notice of Intent to be filed for this Project. Appendix 3 contains a sample O & M Plan showing typical measures to maintain structures included in the design. Upon completion of the SRT specifications, a final plan will be developed. The tide gate proposed has a minimum of moving parts and manual controls both to reduce monitoring requirements and the potential for unintended adjustments or vandalism. The design will allow for adjustments as necessary in order to calibrate for changing field conditions, including sea level rise.

DER will conduct post-construction tidal hydrology monitoring of the salt marsh and coordinate additional post-restoration monitoring with the project proponent as appropriate. Given the restoration area's size re-planting is not practical. The plan will rely upon establishment of suitable coastal hydrology in order to promote and encourage the growth of native coastal salt marsh species. This monitoring will include evaluation of encroachment by non-native plants, especially *Phragmites*.

4.5 Attachment 4-1: Plan of Proposed Conditions

A plan of proposed conditions is included as Attachment 4-1 following this page.

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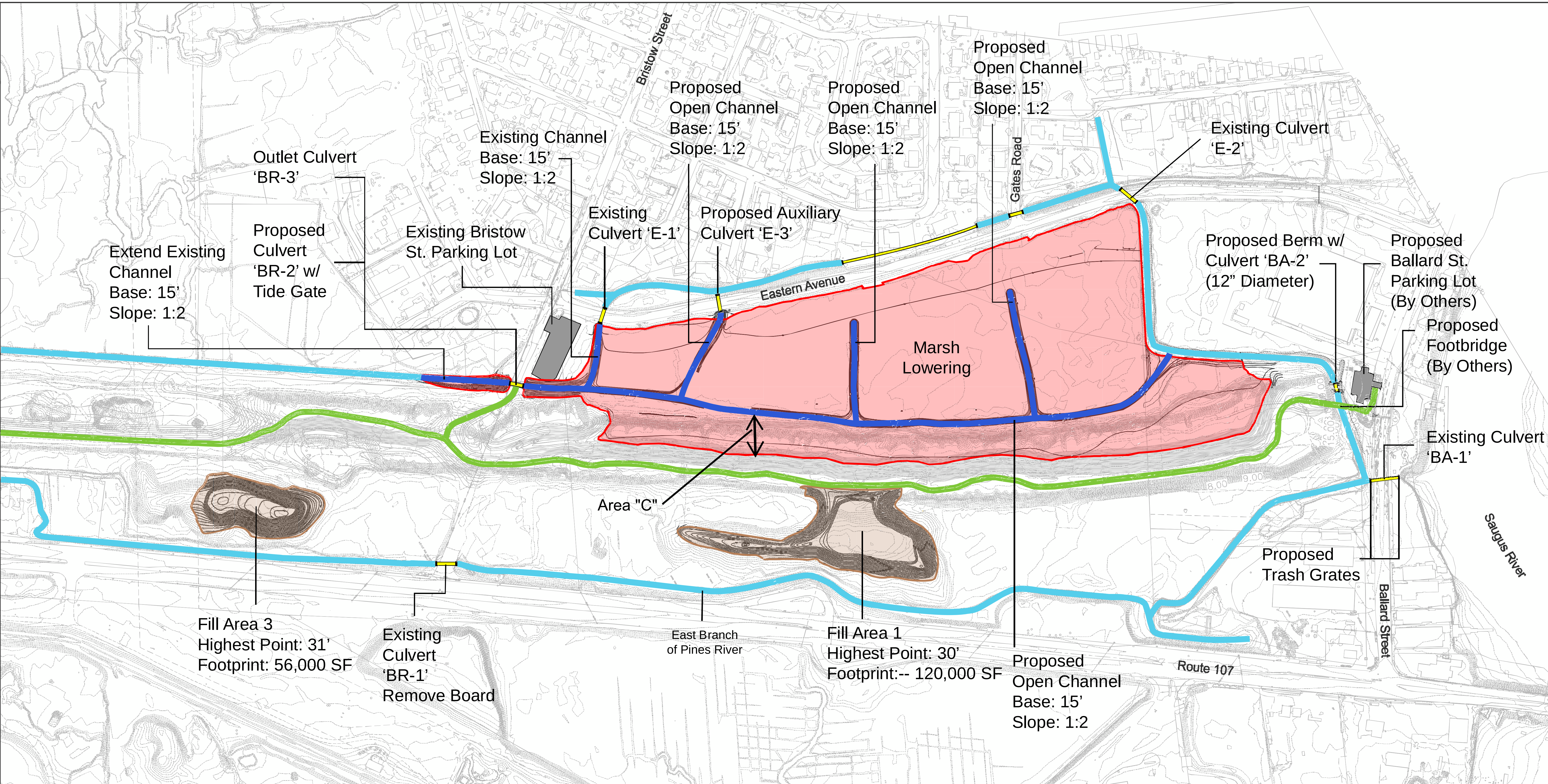

Ballard Street Salt Marsh Restoration

dcr Massachusetts

PARSONS BRINCKERHOFF

0 250 500'

Last modified: 2/17/15

- Limit of excavation
- Fill area
- Channel, inside limit of work
- Existing Channel
- Culvert
- Pathway (By Others)
- Parking Lot

5.0 Potential Environmental Effects of the Project

5.1 Wetlands and Waterways

The total area of wetland to be restored is estimated to be 36.9 acres, which includes improving the existing 3.0 acres of degraded salt marsh. This includes temporary alteration to the existing 31.8 acres of the presently delineated wetland resource, (which includes only an estimated 9 acres of presently viable native salt marsh habitat) as well as an additional 5.1 acres of restoration to be created by the removal of the I-95 embankment.

Most of the impacts to wetland resources associated with the construction of this project are temporary and will be fully restored upon project completion and restoration of tidal flow to support a new salt marsh. These temporary impacts include excavation to create a lowered marsh plain and channel construction. This includes temporary impacts to 15.4 acres of existing degraded marsh in the western marsh. Approximately 5.9 acres of formerly filled marsh will also be included in the new marsh plain consisting of 5.1 acres of the I-95 embankment and 0.8 acres of new channels to culverts “BR-2” and “BR-3”

Some minor permanent impacts will be required for the construction of the dike at the northern end of the project site, as well as culvert and headwall installation. The total area of permanent impacts is expected to be approximately 4,000 square feet or 0.1 acre. These impacts are necessary in order to provide the necessary tidal flow to support the new salt marsh.

Approximately 2.9 acres of the proposed restoration activities are located within Riverfront Area. All of those impacts will also be temporary, with the exception of approximately 2,400 square feet for installation of structures.

These impacts are offset by the Project’s capacity to create or restore up to 36.9 acres of salt marsh.

Measures will be employed to minimize adverse impacts to wetland resources during construction. These include preparation of a Stormwater Pollution Prevention Plan (SWPPP) by the selected site contractor which will detail measures proposed to control runoff, and to minimize soil erosion and sedimentation of wetland resource areas. Tidal flow will be blocked from the Project Area during the period of construction, in particular, the marsh lowering activities. Other impact mitigation measures include use of standard erosion and sedimentation controls at the wetland/upland interface, use of low ground pressure equipment within the restoration area to minimize compaction, as well as stockpiling of materials and equipment outside of wetland areas wherever possible. Construction will be sequenced as described in Section 6.1.2 in order to minimize the potential for downstream impacts to other wetlands.

Table 5.01
Summary of Salt Marsh Restoration for the Project

	Maximum wetted area (acre) for spring tide conditions		
	Eastern Marsh	**Western Marsh**	**Total**
Existing Conditions	1.6	1.4	3.0
Net increase	+8.9	+25.0	+33.9
After Project completion	**10.5**	**26.4**	**36.9**

5.2 Flood Protection

While the Project will not be capable of completely solving the flooding issues plaguing the East Saugus neighborhood during coastal, wind-driven storms (as discussed in Section 4.2), the Project does include a number of features for enhancing flood protection. For example, the inclusion of one-way duck bill devices on the culverts connecting the Eastern Avenue drainage ditch ("E-1", "E-2" and "E-3") will prevent tidal waters (e.g., spring tides, tidal surges up to approximately elevation +7[4] from backflowing from the Western Marsh into the Eastern Avenue ditch.

The project enhances flood protection during rain events by improving the drainage path from the Eastern Avenue ditch through the Western Marsh. A new 4-ft. culvert ("E-3") is added under Eastern Avenue to drain the southern segment of the Eastern Avenue ditch. Presently this segment drains only through a 24-inch culvert "E-1" and then through a series of poorly defined and partially filled channels through the Western Marsh. From this point today, the stormwater runoff has to reach the existing channel along the northern edge of the Western Marsh. This condition will be greatly improved by new channels from both culverts "E-1" and "E-3" that will direct stormwater runoff to the two new culverts at Bristow Street West ("BR-2" and "BR-3"), which will significantly shorten the drainage path through the Western Marsh.

These improvements will enhance the current standard of flood control that the neighborhood experiences. The level of improvement is illustrated in Fig. 4.12 which shows that during the design 50-year storm, the peak water elevations in the Western Marsh and Eastern Avenue ditch are approximately 1 ft lower for preferred alternative relative to existing conditions. In addition, with the project, the peak water elevation will be below the low point (elevation +7.0 ft.) at Eastern Avenue and Bristow Street. See also Table 5.02.

Table 5.02
Reduction in Flood Elevation for 50-Yr. Design Storm

	Peak Water Elevation in Western Marsh (ft.)
Existing Conditions	+7.5
With Project	+6.5

5.3 Water Quality

The Project will improve water quality by reestablishing regular tidal flushing and salinity supportive of salt marsh vegetation. Healthy salt marshes filter pollutants from stormwater contained within non-point source runoff from developed areas and promote the growth of micro-fauna that also filter both fresh and salt water.

Proper construction methods deployed during construction will minimize erosion and siltation of adjacent undisturbed resource areas. Most work can be done without interference from the daily tidal cycle. The Western Marsh will be isolated by temporary dikes from the existing channel to the north (connecting culvert "E-2" to "BA-2" and a new channel to the south connecting culvert "E-1" to the new Bristow Street west culvert "BR-2"). This approach will maintain upstream stormwater water discharges while protecting the channels and downstream wetland resources from sediment-laden runoff from the excavation operations.

[4] Above elevation +7, tidal surges in the Saugus and Pines Rivers will overtop Ballard and Bristow Streets.

Re-use of the excavated organic material as cover or topsoil on the remaining portions of the I-95 embankment will also promote improved growth of vegetation providing stabilization to side slopes and reducing the potential for erosion. Such re-use will occur with attention to minimizing the potential spread of *Phragmites* onto the restored embankment.

5.4 Wildlife and Protected Species

Salt marshes are regarded as one of the most productive ecosystems in the world, and provide habitat for many species of fish, shellfish, invertebrates, birds, and other terrestrial and aquatic species. Re-establishment of viable salt marsh will enhance and improve ecological functions and values for numerous species. The Project Area will shift however, from its present state of a largely terrestrial ecosystem to a wetland ecosystem over time. This will involve loss of some scrub-shrub and tree cover leading to a temporary disruption of the wildlife community. Upon completion, however, the species and habitat diversity provided by the restored salt marsh should be significantly greater than current conditions.

Fish access to the site is currently limited to the few able to pass beyond the broken flap gate at Ballard Street culvert (“BA-1”). Upon Project completion, fish passage will be fully restored between the Saugus River and the Eastern Marsh through the Ballard Street culvert, and between the Pines River and the Eastern and Western Marshes through the new Bristow Street west culvert (“BR-2”). In addition, the one-foot diameter culvert (“BA-2”) proposed through the dike will provide a passage between the Saugus River and the Western Marsh. Table 5.01 shows the increase in fish habitat area, represented by the acreage that is inundated by tidal flow at spring high tide.

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6.0 Proposed Mitigation Measures

6.1 Construction Sequencing and Methodology

As noted in Section 4.3, construction will likely require 12 to 18 months.

6.1.1 Sequencing Constraint based on SOC DEP File No. 67-1001

Per Conditions #37, 38 and 39 of Superseding Order of Conditions for DEP File No. 67-1001, the salt marsh restoration must dovetail with the on-going I-95 sand extraction efforts related to the Winthrop Beach Nourishment Project. DEP sought to guarantee completion of the salt marsh restoration work by recognizing the overlap of the footprint of these two projects at the western edge of the I-95 embankment. Therefore a 5-acre section of the western portion of the extraction footprint (Area C in Fig. 4.01) will be excavated below the elevation of the adjacent salt marsh. This area will accommodate spoils from the lowering of the Western Marsh. As designed, the Project will not haul spoils for off-site disposal.

This constraint is incorporated into Stage 3 of this Project, as described below.

6.1.2 Proposed Construction Sequencing

The following outline construction sequence was developed based on the experience gained with the extraction and marsh restoration work performed as part of the Winthrop Beach Nourishment Project. The final construction sequence, pending completion of final design, construction plans and specifications will be determined in conjunction with the contractor and interested parties, and may vary from the general order of events described below. Proper construction sequence and methods will result in minimization of potential adverse impacts to wetland resources.

Prior to the start of construction, erosion and sedimentation controls will be installed to protect those wetland resources that will not be disturbed by this Project.

Stage 1: Culverts "BR-2" and "BR-3"
These culverts at Bristow Street will be constructed to allow flow from the southerly Eastern Ave. culvert ("E-1") to drain into the marsh south of Bristow Street. Culvert "BR-2" will initially have the SRT locked and closed, while Culvert "BR-3" will be installed with the one-way duckbill tide valve preventing tidal flow into the Project Area during construction. This work also includes the relocation of a Town water main and a telephone ductbank in Bristow Street.

Stage 2: Site Preparation and Isolation of the Marsh Plain
The Project will then hydraulically isolate the Western Marsh to allow excavation "in the dry." Temporary dikes would be constructed along the channels at the north and south ends of the marsh. These temporary dikes will be built high enough so that, during rain events, stormwater discharges from west of the Project Areas would pass through without inundating the excavation area. This would also allow tidal surges to pass through the construction area without flooding the marsh lowering work area.

Stage 3: Marsh Plain Lowering and Material Handling
With the majority of the Western Marsh isolated from the two channels, the area will be first cleared and grubbed of the upland and invasive vegetation. Organic topsoils will be segregated. Soils with *Phragmites* rhizomes will be separated for deep burial to prevent re-propagation. This work may require low ground pressure equipment.

Spoils will be initially backfilled into "Area C" in close coordination with the contractor performing the extraction as part of the Winthrop Beach Nourishment Project. (See discussion above in Section 6.1.1.) The remaining spoils will be placed in "Fill Area 1" and/or "Fill Area 3."

The channels and auxiliary ditches will be constructed through the lowered marsh.

Stage 4: Eastern Avenue Culverts
The new auxiliary culvert "E-3" will be constructed and the duck bills added onto the existing culverts "E-1" and "E-2."

Stage 5: Marsh Flooding
The dike and 12-in. culvert ("BA-2) near the Ballard Street parking lot will be installed. The temporary dikes isolating the lowered marsh plain will be removed, and the SRT on culvert "BR-2" will be activated. This will result in tidal flooding of the Western Marsh.

Stage 6: Other Culvert Work
The new grates will be installed at the Ballard Street culvert ("BA-1"). The flap will be removed from the Ballard Street culvert and the board removed from Bristow Street culvert east ("BR-1").

Stage 7: Completion
All disturbed upland areas will be stabilized. Upland areas will be seeded with a native mix. Pavement will be restored in areas where it was removed (e.g., for the utility relocations in Bristow Street and for the new culvert ("E-3") in Eastern Avenue). The site will be cleaned and the contractor will demobilize.

6.2 Construction Traffic, Access and Staging

6.2.1 Construction Access and Staging

Access to the Project Area will be off Bristow Street and from the Route 107 access to the I-95 embankment. The access off Route 107 is currently used for the DCR contractor performing the material extraction from the embankment for the Winthrop Beach Nourishment Project. It is assumed this temporary access would be maintained during the Ballard Street Salt Marsh Restoration. After both projects are completed, the access will be restored to pre-construction conditions.

The Bristow Street parking lot may be used for staging and stockpiling of materials and equipment as needed. Other staging areas within the Winthrop Beach project's extraction area may be allowed. After both projects are completed, all staging areas will be restored. Areas within the embankment will be restored per the final planting plans for the Winthrop Beach project (DEP File #67-1001). The Bristow Street parking lot will be restored to pre-construction conditions, including the existing gravel surface.

6.2.2 Construction Traffic

6.2.2.1 Construction Traffic – Remaining Embankment Excavation
The material associated with the remaining excavation below elevation +5.0 in "Area C" is planned to be transported off site for beneficial reuse at Winthrop Beach by the contractor working on that project. Some material that is unsuitable for the beach may remain on site. This truck traffic will continue to use the direct access to and from Route 107 and these trucks will not traverse the residential area to the west. This associated truck traffic has been accounted for in EEA #10113 for the Winthrop Beach Project, and, as such, is not part of this Project. This removal will be a relatively minor operation compared to the peak of trucking to Winthrop Beach from last summer, when approximately 20 trucks per day made two to three round trips. The additional removal will involve approximately 10 trucks per day making two to three round trips for 3 to 6 weeks.

6.2.2.2 Construction Traffic – Ballard Street Marsh Restoration

As the Project will not be exporting material, there will be limited daily construction traffic to and from the Project Area. The daily project workforce is estimated at 5 to 10 workers.

Construction traffic to the site will include the following:

- Mobilization of earth moving equipment
- Temporary construction materials:
  - Erosion control materials
  - Temporary fencing
  - Temporary signage and traffic control devices
- Materials for the culverts:
  - Precast concrete pipe and box culvert sections
  - Estimated 5 to 10 truckloads of concrete
  - Stone for culvert ends
  - SRTs and duck bills
  - Gratings
  - Pipe, fittings, conduit, and related materials to relocate the utilities in Bristow Street
- Restoration materials:
  - Pavement materials to restore Bristow Street and
  - Loam and seed to restore disturbed upland areas
  - Miscellaneous other material to restore site to pre-construction conditions
- Removal of unreusable materials (e.g., old water main pipe, rubbish and debris found on site, etc.)
- Demobilization of earth moving equipment

Daily construction traffic to and from the site is estimated at 5 to 10 trucks, with many days of no truck trips, and possibly up to 10 days of over 10 truck trips. In general, this truck traffic will be directed to the direct connection to Route 107, so as to avoid travel through the residential neighborhood. Truck traffic associated with the work on the new and existing culverts under Eastern Avenue would need to traverse that roadway. Note that these trips are in addition to any truck trips associated with the embankment excavation, as described in Section 6.2.2.1.

Work activities will be coordinated with local police and fire departments.

6.3 Erosion and Sedimentation Control

Erosion and sedimentation control procedures will be implemented prior to and during construction to minimize sedimentation of adjacent wetlands and waterways during construction. A SWPPP developed by the contractor will be implemented prior to construction. Hydrologic connections between the excavation areas and tidal creeks will be made gradually, while the excavated area is stabilized so risk of downstream turbidity is minimized. The suggested sequence would involve deploying a flexible cofferdam in the waterway while the bank is breached. Once the channel excavation work is completed, the cofferdam would be removed and the area flooded.

6.4 Dust Control

During excavation the contractor will deploy measures necessary to control fugitive dust. Dust control measures include only wet suppression consisting of sprinkler pipelines, tanks, tank trucks, or other devices capable of providing regulated flow, uniform spray, and positive shut-off. Several such applications may be necessary each day, depending upon meteorological conditions and work activity.

Hydroseeding for dust control may be used to produce a temporary stand of grass that will effectively control dust.

6.5 Noise Control

During excavation of the marsh plain, construction operations will result in temporary, localized impacts to ambient noise levels. Mitigation measures such as the following will be used to minimize noise impacts resulting from construction:

- Using appropriate mufflers on equipment;
- Turning off idling equipment;
- Shielding equipment from or locating at a distance from sensitive receptors; and
- Scheduling operations to keep average noise levels low and uniform.

Every effort will be made to minimize construction related noise associated with the Project out of respect for Project Area neighbors. Should additional noise control measures be required during the course of the Project, DCR, its contractor and its engineer will work with local authorities to implement these measures.

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7.0 Regulatory Permitting

7.1 Environmental Review and Required Permits

DCR anticipates the Project will require permits from federal, state and local permit authorities.

Table 7.01
Regulatory Permits and Reviews

Regulatory Permits and Reviews	
Agency	Permit or Review
Federal Permits	
Army Corps of Engineers	Amendment or modification to existing Massachusetts Programmatic General Permit II – Section 404 of the Clean Water Act for the Winthrop Shores Reservation portion of the Project Area Individual Permit– Section 404 of the Clean Water Act.
Environmental Protection Agency	National Pollutant Discharge Elimination System (NPDES) Stormwater Permit for Construction Activities
State Permits and Reviews	
Massachusetts Environmental Policy Act (MEPA)	Expanded Environmental Notification Form (EENF)
Massachusetts Office of Coastal Zone Management	Federal Consistency Certification
Department of Environmental Protection – Waterways Regulation Program	Chapter 91 Waterways License and Permit *(not anticipated, see Fig. 7.02)*
Department of Environmental Protection – Division of Wetlands and Waterways Office of Watershed Management	401 Water Quality Certification (WQC)
Mass. Historical Commission	Project Notification
Mass. Underwater Archaeological Research Board	Project Notification
Massachusetts Department of Transportation	Temporary Access Permit *(Existing Permit 4-2014-128 will be extended for use in construction)*
Department of Environmental Protection – Wetlands Program	Order of Conditions: Wetlands Protection Act
MA Department of Conservation and Recreation	Access and Construction Permit

DCR avers that the Project fully complies with Mass CZM Coastal Program Policies and will result in significant enhancements to coastal resources. This will be demonstrated in DCR's request for consistency concurrence which will be filed along with the US Army Corps permit application.

Fig. 7.01 and Fig. 7.02 depict the extent of Chapter 91 jurisdiction estimated within the Project Area, based upon reference to the most recently available data from Mass GIS. This information indicates that very little of the Project Area is within flowed or historic tidelands, with the exception of the east channel which is not proposed to be altered as part of this current Project.

Fig. 7.01 Chapter 91 Jurisdiction

A 401 Water Quality Certificate will be required given the salt marsh alteration required to excavate the marsh plain in the Western Marsh. Some dredging of channels, such as at the new structures proposed at Bristow Street ("BR-2" and "BR-3") and other locations are anticipated to trigger a 401 Dredge Permit. Other excavation is mostly above the current mean high water line and therefore not considered dredge.

The Massachusetts Historical Commission commented on the ENF filed in 2002 for Phase I of this Project and indicated that while there was a Native American site within or near the Project site, there are likely not any significant archaeological resources remaining following the alterations from the construction of the I-95 embankment. MHC's comments from 2002 are included in Appendix 3. The Army Corps of Engineers Section 404 review will require notification to Native American Tribes. DCR will submit a copy of this EENF to the Underwater Archaeological Research Board for review and comment.

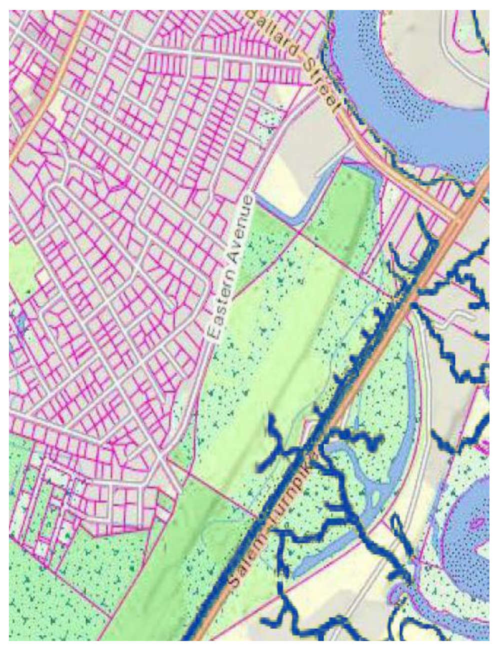

Fig. 7.02 Chapter 91 Jurisdiction within Project Area

Also, DCR continues to discuss the Project progress with the Saugus Conservation Commission and will file a Notice of Intent with the Commission after the filing of this EENF.

The Project exceeds the area thresholds of 0.5 acres of tidal areas necessary to qualify under Massachusetts General Permit 22 for ecological restoration activities and is presumed at this time to require an Individual Permit. Work associated with the final grading of the I-95 embankment area will require a modification to the existing 404 Authorization for the Winthrop Beach Nourishment Project.

7.2 Initial Agency Consultation

Prior to the development of this EENF, a series of meetings was held between the proponent, project consultant team, and various agencies that will have a role in the project reviews and permitting. At each meeting, the project team presented the project objectives and a description of project elements. Discussions followed and comments were received regarding the details of the project, issues of concern to the various agencies, and which permits would be required. Table 7.02 presents a list of these meetings

Table 7.02
Initial Agency Consultation

Date	Location	Agencies Attending
8/3/14	DCR Boston	EPA
8/10/14	DCR Boston	EPA
8/19/14	Saugus Town Hall Annex	Saugus ConCom
9/23/14	DCR Botume House, Stoneham	Saugus ConCom
9/23/14	DCR Botume House, Stoneham; Project Areas, Saugus	NMFS, DMF, EPA
9/24/14	ACOE, Concord	ACOE, EPA
10/9/14	Parsons Brinkerhoff, Boston	MEPA, ACOE, DEP (Ch. 91 & WQC), CZM, EPA, NMFS, DMF
10/29/14	MEPA	MEPA, ACOE, DEP (Ch. 91 & WQC), CZM, EPA, NMFS, DMF

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8.0 Request for Waiver

The Ballard Street Salt Marsh Restoration Project entails alteration of one or more acres of saltmarsh or bordering vegetating wetlands, cited in 301 CMR 11.03(3)(1)(a) as an example of a project requiring an ENF and Mandatory EIR. It also causes alteration of ten or more acres of other wetlands cited in 301 CMR 11.03(3) (1) (b) which also triggers an ENF and Mandatory EIR. Further, the Project location within the Rumney Marshes ACEC triggers an ENF and other MEPA review if the Secretary so requires pursuant to 301 CMR 11.03(11) (b). It will cause direct alteration of 25 acres or more of land which triggers the same ENF and other MEPA review if the Secretary so requires pursuant to 301 CMR 11.03(1) (b) (1).

According to 301 CMR 11.11 (1) Standards for all Waivers, "the Secretary may waive any provision or requirement in 301 CMR 11.00 not specifically required by MEPA and may impose appropriate and relevant conditions or restrictions, provided that the Secretary finds that strict compliance with the provisions would:

- Result in an undue hardship for the Proponent, unless based on delay in compliance by the Proponent; and
- Not serve to avoid or minimize Damage to the Environment."

8.1 Hardship

Not only the Proponent, but also the general public will experience hardship should an EIR be required. Such an action would delay a worthwhile and long-anticipated project and impose additional cost both for EIR preparation and the loss of anticipated savings from DCR's coordination of this effort with other nearby salt marsh restoration endeavors. Given the extent of environmental analysis already undertaken for this Project, the ongoing collaboration with local, state and federal officials, and the thoughtful coordination of project officials on this effort with the adjacent restoration by others, an EIR will not generate more environmental protection, but will delay the onset of the Project benefit. East Saugus residents and Rumney Marsh visitors will lose confidence in the Commonwealth's ability to ever undertake this eagerly anticipated salt marsh restoration, and the neighborhood will continue to have flood protection concerns. Finally, DCR, and the Commonwealth for that matter, cannot afford to lose the cost-benefit and potential cost savings from coordinating two high profile jobs in the area.

DCR intends to use the contractor already on site for the sand extraction related to the Winthrop Beach Nourishment Project, thereby saving time and money in procurement. Should an EIR be required, its preparation/review would necessitate a separate procurement process with added costs. This would also delay implementation of flood control measures sought by East Saugus residents. This imposes undue hardship not only on DCR but the surrounding community.

DCR is eager to proceed. The proposed Project, its impacts and benefits have already been detailed in this EENF. An EIR will not provide new information and will only add cost as well as significant delay to project implementation. This in turn could slow other nearby salt marsh restoration efforts and the Winthrop Beach Nourishment Project. The Project will provide immediate potential flood protection to the residents of the East Saugus neighborhood in the event of failure of the existing leaking tide gate at Ballard Street. Delay in onset of Project improvements would postpone such flood protection.

8.2 Damage to the Environment

Rather than causing damage to the environment, the Project will address damage to the environment resulting from previous human disturbance including construction of the I-95 embankment and tidal obstructions on Ballard Street and Route 107. Delaying this restoration work only extends the proliferation of *Phragmites* and resulting diminution of the salt marsh resource.

Habitat Enhancement: The Project will support the enhancement of fish and wildlife habitat by reducing the height, vigor, and density of the dominant common reed and by promoting the recolonization or spread of salt marsh vegetation. The expansion of salt marsh vegetation will provide food, cover, and nesting/breeding areas for a variety of native species and, potentially, rarer salt marsh species such as sharp-tailed sparrow (*Ammodrammus caudacutus*) and seaside sparrow (*Ammodrammus maritimus*).

Scenic Enhancement: Currently hikers and others enjoying the scenic open space find their views obscured by tall (>10'), dense stands of common reed. The salt marsh restoration activities, specifically the restoration and enhancement of tidal flushing, will decrease the height, vigor, and density of these tall monotypic stands, allowing improved views of the remaining marsh. They will also expand salt marsh vegetation of marsh areas and the diverse wildlife afforded by that vegetation.

Public Safety Benefits: The Project will increase tidal flushing which will, in turn, reduce mosquito habitat along with odors typically associated with stagnant water in obstructed drainage ditches. Restoration activities will increase habitat for killifish (*Fundulus* sp.) in the marsh. This breed feeds on mosquito larvae and is an essential component to mosquito population control.

As noted, the majority of the Ballard Street salt marshes are dominated by tall and dense stands of common reed. Common reed stands are highly productive, tend to accumulate significant litter layers, and their dry, dead stems tend to remain upright for several years. Common reed stands burn fiercely, especially during the non-growing season, thereby posing a significant risk of fire damage in urban areas. The preferred Alternative 4b will provide the greatest measure of control of common reed on both the Route 107 and Eastern Avenue sides of the Ballard Street Salt Marsh.

The salt marsh restoration activities, specifically restoration and enhancement of tidal flushing, will decrease the height, vigor, and density of these tall monotypic stands. Increasing tidal flushing will also regularly saturate the surface of the marshes, further reducing the risk of fire damage to the adjacent East Saugus residential neighborhood.

Salt marshes in an urban landscape are critical for ecological and public health/safety reasons. Salt marshes provide attenuation of peak run-off velocities, water quality improvement, flood storage, and maintenance of fish and wildlife habitat. Of the Project alternatives identified in Section 4.0 above, only Alternative 4 allows for the restoration of a significant acreage of salt marsh while improving local flood protection.

The construction components outlined in Section 3.0 along with the methodology and measures to minimize impacts provided in Section 6.0 demonstrate the considerable analysis already undertaken to ensure the overriding environmental benefit of this salt marsh restoration/flood control improvement project. For the reasons stated in Section 7.0 and the information provided in this EENF, DCR avers that the Project meets the standard for all waivers pursuant to Section 11.11.(1).

Based on this, DCR believes that an EIR is not needed to provide necessary protection of the environment during the course of Project construction and urges the Secretary to conclude similarly. If there are any questions, DCR would be pleased to meet with you or your MEPA staff to address them.

9.0 References

Cox, R J, Shand, T D and Blacka, M J (2010), *Appropriate Safety Criteria for People in Floods, WRL Research Report 240.* Report for Institution of Engineers Australia, Australian Rainfall and Runoff Guidelines: Project 10. 22p.

Friedrichs, Carl T. and J.E. Perry, 2001. *Tidal Salt Marsh Morphodynamics: A Synthesis.* Virginia Inst. Marine Science, College of William and Mary. Gloucester Point, Virginia.

Hoyte, James S., Massachusetts Secretary of Environmental Affairs. August 22, 1988. *Designation of Portions of the Cities of Boston, Lynn, and Revere, and the Towns of Saugus and Winthrop as the Rumney Marshes Area of Critical Environmental Concern, with Supporting Findings.* Boston, Massachusetts.

Massachusetts Wetlands Restoration Program and the Massachusetts Department of Environmental Management. May 2002. *Rumney Marshes Area of Critical Environmental Concern Salt Marsh Restoration Plan.* Boston, Massachusetts.

Reiner, Edward. United States Environmental Protection Agency. February 17, 1995. *Town of Saugus, Massachusetts Ballard Street Tidegate and Salt Marsh Restoration.* Boston, Massachusetts.

UDFCD (2001). *Drainage Criteria Manual (V.2),* Urban Drainage and Flood Control District, Denver, Colorado.

United States Department of Agriculture, Natural Resources Conservation Service. March 1999. *Hydrologic and Hydraulic Analysis: Wetlands Restoration Investigation, Ballard Street Salt Marsh, Saugus, Massachusetts.* Prepared for Town of Saugus in Cooperation with Essex Conservation District. Amherst, Massachusetts.

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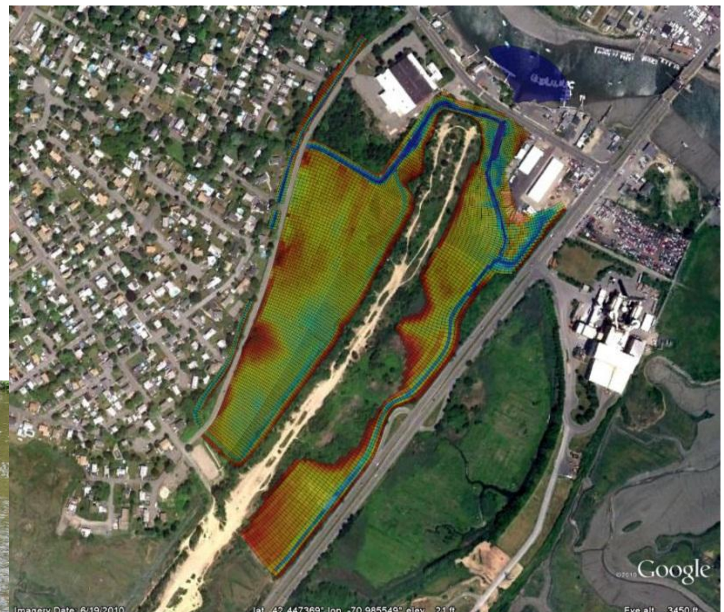
Appendix 1 Ballard Street Restoration Project
Woods Hole Group, Inc.
October 2014

Ballard Street Restoration Project
Saugus, Massachusetts



Prepared For:
Commonwealth of Massachusetts
Division of Ecological Restoration
251 Causeway Street, Suite 400
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Prepared By:
Woods Hole Group, Inc.
81 Technology Park Drive
East Falmouth, MA 02536

October 2014

BALLARD STREET RESTORATION PROJECT
SAUGUS, MASSACHUSETTS

October 2014

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Division of Ecological Restoration
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1.0 INTRODUCTION

The Ballard Street salt marsh is a tidally restricted subsystem of the Rumney Marsh Reservation, located within the Town of Saugus, MA. The approximately 57-acre project area is encapsulated by Eastern Avenue on the west, Ballard Street on the north, Route 107 on the east, and the abandoned Bristow Street right-of-the-way to the south. The marsh system is heavily anthropogenically influenced, including the separation of the natural marsh by a large linear berm of sand and gravel fill, a remnant from former I-95 construction activities abandoned in 1972. The marsh system is connected to the Saugus River via a four foot inner-diameter pipe fitted with a steel sheet metal "tide gate", which has been reinforced with rebar and chained to the culvert entrance. This hydraulic connection significantly inhibits natural tidal exchange to and from the estuary system.

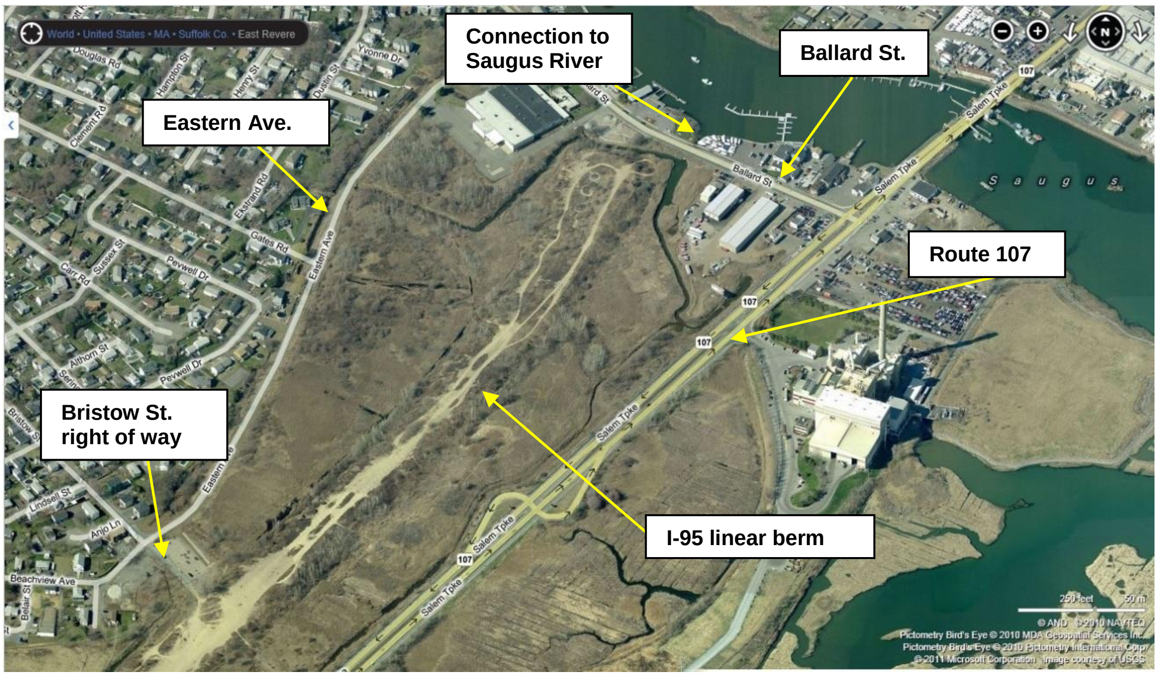


Figure 1-1. Ballard Street marsh site overview.

The potential restoration of the Ballard Street salt marsh has been under consideration for the last few decades (Reiner, 2010 personal communications). Significant steps towards the restoration were earnestly undertaken in the mid-to-late 1990s, when the National Resources Conservation Service (NRCS) conducted a Hydrologic and Hydraulic study (NRCS, 1999) of the system to evaluate the hydrologic and hydraulic effects of alternatives for replacing the temporary tide gate at Ballard Street and potentially provide for salt marsh restoration consistent with flood protection needs for the Town of Saugus. Between 2001 and 2007, the Ballard Street Salt Marsh Restoration Project was further advanced with the development of engineering plans and acquisition of project permits. However, due to a significant lack of funding for project construction, the project stagnated.

Subsequently, Woods Hole Group Inc. (WHG) was contracted by the Massachusetts Division of Ecological Restoration (DER) to further advance the restoration project. In support of the restoration project, Woods Hole Group Inc. (WHG) conducted a hydrodynamic assessment and study of the Ballard Street salt marsh estuarine system with emphasis on the evaluation of potential restoration alternatives, including previous recommendations and new opportunities to expand the restoration area. The study, presented herein, consists of a field data collection component, which was used to support the development of the hydrodynamic model component. The field data collection component primarily consisted of water surface elevation observations and topographic measurements throughout the estuarine system to assess the level of tidal restriction, and support calibration of the hydrodynamic model. The hydrodynamic modeling component, following model development and calibration, was then used to assess a variety of potential restoration alternatives. The primary goals of the restoration project include restoration of former and currently degraded salt marsh areas in the system and improved flood protection for the communities surrounding the Ballard Street marsh, especially those areas just west of Atlantic Avenue. Specifically, the goal of the restoration, as specified by DER, was to maximize the restoration of the system while providing comprehensive flood storage for an extreme precipitation event for adjacent communities.

The study, which evolved as the project itself evolved, consisted of numerous, sometimes unanticipated phases. For example, the final alternatives evaluate the marsh system with a portion of the I-95 embankment removed for use in an off-site beach re-nourishment project; however, this was not considered in the original restoration alternatives. Newly released analysis methodology related to projected increased precipitation levels due to climate change, also resulted in modified model input conditions at different stages of the modeled alternatives development. In addition, the model was continually updated as new data were acquired, and new information was obtained over the progression of the project. For example, new data collected during the study process (e.g., unique topographic features within creek streams), as well as new project directives (e.g., improving public safety compared to existing conditions) and alternative ideas, resulted in ongoing development of the technical work and the report herein. As such, this document presents a number of alternatives that evolved in concert with the model itself and as the project elements changed. This adaptable nature of the modeling effort results in a continually improving and adapting model effort.

This report describes the methods used to collect and process the various types of data, and provides a brief assessment of the tidal conditions in the Ballard Street salt marsh. This report also presents the development of the hydrodynamic model for the Ballard Street salt marsh system. The report is divided into the following sections:

- Section 2.0 presents the results of the initial field data collection effort, including the tide and salinity data collection and supplemental topographic survey.

- Section 3.0 presents the proposed model approach, identifying the major tasks within the modeling scope and identifies key discussion points for evaluation of the modeling performance and progress.

- Section 4.0 presents the development of the hydrodynamic model for the Ballard Street salt marsh system. The purpose of the model is to aid in planning for tidal restoration of the estuary by predicting time dependent water levels, velocities, and salinity levels for various restoration alternatives. This section of the report describes how the model was calibrated and validated to existing conditions within the system, and then presents the use of the calibrated model to evaluate some initial alternatives. The report presents the results of a number of simulations with the estuary in its existing restricted state to aid in understanding of the current behavior of the system and to provide a baseline for comparison with future alternative simulations. These existing conditions simulations include: simulation of normal tidal conditions, a storm surge event, an extreme rainfall event, and 50 years of projected sea level rise.

- Section 5.0 presents the initial alternative simulations for evaluating changes at the Ballard Street marsh system, focusing on the proposed NRCS design(s). The alternatives are evaluated for similar conditions (e.g. normal tidal conditions, storm surge, precipitation events).

- Section 6.0 presents further investigation into the proposed restoration project, including some additional data observations, updated assessment and methodologies for evaluation of extreme precipitation events, additional model validation, and the development of a refined (preferred alternative).

- Section 7.0 evaluates another set of alternatives that integrates the proposed Massachusetts Department of Conservation and Recreation's project to extract sand from the old I-95 road embankment for replenishment of Winthrop Beach into the proposed Ballard Street marsh restoration project. The proposed sand extraction project increases the amount of restored acres within the western branch of the Ballard Street marsh, while also providing additional flood storage area during extreme rainfall events. A number of restoration alternatives were considered that incorporated the sand extraction design into the restoration, ultimately arriving at a preferred alternative for the restored marsh. This section presents the development of the modified model grid, as well as the hydrodynamic results for the proposed phased excavation and the final recommended marsh restoration design.

- Section 8.0 presents the conclusions and a brief overall summary of the study.

- The report also includes an addendum that documents some additional technical tasks focused on specific system components in greater detail.

2.0 FIELD DATA COLLECTION

2.1 TIDE AND SALINITY

In order to determine the existing conditions at the Ballard Street salt marsh, Woods Hole Group deployed three SeaBird Electronics SBE37 Microcat instruments to measure conductivity, temperature, and pressure. The deployment locations are shown in Figure 2-1. Station WHG1 was positioned in the ditch that runs parallel to Eastern Avenue, station WHG2 was deployed on the upstream side of the culvert that connects the marsh with the Saugus River, and station WHG3 was deployed in the Saugus River. The Woods Hole Group gauges were deployed from May 20th, 2010 to June 20th, 2010, a period of 31 days, to characterize tidal conditions over a full lunar tidal cycle.

Additionally, the Massachusetts DER deployed three Onset HOBO data loggers in the Ballard Street marsh system to record water levels. A fourth HOBO logger was deployed to record barometric pressure for post-deployment corrections to the observed water levels. The HOBO loggers were deployed on May 17th, 2010. One of the HOBO water level loggers (DER3), which was initially positioned (DER3 Initial) in the Saugus River as a back-up system to WHG3, was inadvertently place in the intertidal zone (dry at low tides). However, this system was subsequently moved to a new location (DER3 Final), in the adjacent Pines marsh system as shown in Figure 2-1 on June 3rd, 2010 for the remainder of the study period. The HOBO loggers were recovered on June 22nd, 2010. Station DER1 was deployed in the ditch along Eastern Avenue, approximately 800 feet upstream from WHG1, and Station DER2 was deployed in the Pines Channel on the southeastern edge of the marsh system, adjacent to Route 107. The deployment locations of the three DER water level loggers are also shown in Figure 2-1.

Prior to deployment, the WHG instruments were synchronized with a universal atomic clock and programmed to autonomously record a time-stamped data point (salinity, pressure, and temperature) every 6 minutes. The Seabird gauges were attached to pipe anchors and fastened with hose clamps to a vertical member and driven into the sediment with the pressure port on the gauge located as close to the bottom as practical. Figure 2-2 shows the instruments and their deployment configurations prior to deployment, while Figure 2-3 shows the station WHG2 in the marsh at low tide.

The DER HOBO loggers were attached to a fence post housed inside a PVC stilling well. The PVC section about 10-inches in length, and the pressure port of the logger sat at the bottom of the well. Figure 2-4 shows the DER logger configuration. The DER loggers collected pressure only, while the WHG gages also collected temperature and conductivity.

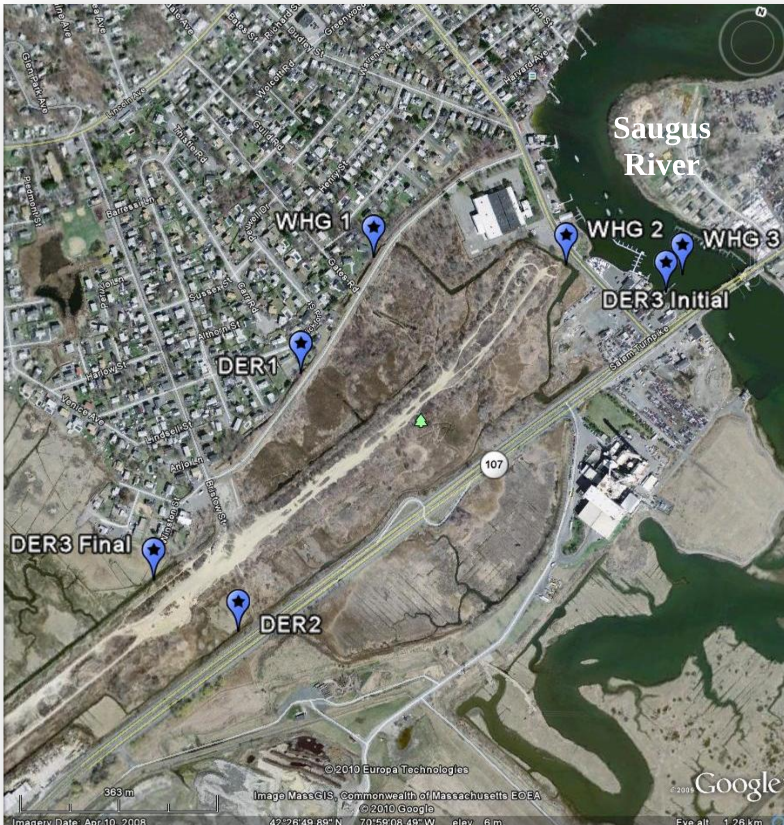


Figure 2-1. Tide gauge deployment locations.

Figure 2-2. Seabird Electronics SBE37 Microcats prior to deployment.

Figure 2-3. Seabird Electronics SBE37 Microcat deployed in Ballard St. marsh.

Figure 2-4. DER-deployed Onset HOBO Water Level Data Logger in Ballard St. marsh.

2.2 SUPPLEMENTAL GROUND SURVEY

Although existing topographic data had been collected within the system (NRCS, 1999), Woods Hole Group conducted a supplemental ground survey to provide increased spatial resolution on the former Ballard Street marsh plains and capture more detailed information for some of the systems culverts. The survey was conducted using a Trimble® R7 GPS total station, a Real-Time Kinematic Global Positioning System (RTK-GPS), and provided additional data for the hydrodynamic modeling effort. The RTK-GPS equipment provides centimeter-level geodetic positioning, allowing the user to navigate to established benchmarks, establish temporary benchmarks, and collect topographic data. Woods Hole Group used the Trimble R-7 in conjunction with a base station network for the survey. The base station network consists of continuously running base stations strategically positioned to provide wide geographic coverage. Each base station feeds real-time network corrections to a central computer allowing for a network solution to be generated for the coverage area that is more robust than RTK-GPS systems employing only a single base station. Woods Hole Group used the KeyNetGPS network operated by Keystone Precision Instruments (KPI). KeyNetGPS operates on the NAD83 horizontal datum and the NAVD88 vertical datum. The network allows the RTK-GPS to achieve its peak performance with an accuracy of 10 mm in the horizontal and 20 mm in the vertical.

2.2.1 Tide Gauge Survey

During the supplemental ground survey, the elevations of the tide gauges were surveyed to a local datum (NAVD88, feet). This allows the depths measured by the instruments to be translated to water surface elevations. The elevations of the tide gauges' pressure ports in the NAVD88 vertical datum (in feet) used in the conversion of pressure to elevation (Section 2.3), as well as their positions in Mass State Plane Mainland NAD83 Horizontal Coordinates, are provided in Table 2-1.

Table 2-1. Tide gauge locations and elevations.

Tide Gauge	Location Description	Northing State Plane Coordinates (ft)	Easting State Plane Coordinates (ft)	Pressure Port Elevation (NAVD88-ft)
DER 1	Eastern Ave Ditch	2988484.835	794347.964	1.052
DER 2	Pines Channel	2986883.179	794412.94	2.484
DER 3 Initial	Saugus River	2989561.363	796341.425	-2.302
DER 3 Final	East Saugus Marsh	2987042.162	793834.261	0.113
WHG 1	Eastern Ave Ditch	2989278.456	794579.525	-0.289
WHG 2	Main Culvert	2989553.467	795713.593	-2.475
WHG 3	Saugus River	2989689.773	796407.322	-6.169

2.2.2 Culvert Survey

In addition to the culvert connecting the Saugus River to Ballard Street marsh, there are a number of additional culverts and pipes that interconnect various areas within the system.

These structures may restrict the flow of water throughout the system. Figure 2-5 shows the locations of the culverts (red lines) that were included in the WHG survey, while Table 2-2 provides a brief description of each culvert's location and their surveyed positions and elevations. Culvert C, which is surrounded by heavy vegetation that created RTK satellite interference, was only surveyed for elevation with a standard rod and staff surveying technique. In addition, culvert invert elevations are provided in Table 2-3. In all cases, the nomenclature used for culverts was further landward into the marsh represents the upstream side, while the downstream side is closer to the Saugus River, regardless of the slope of the culvert.

Figure 2-5. Surveyed culvert locations (Red lines indicate actual culvert location).

The primary tidal connection to the Ballard Street marsh is a culvert that runs under Ballard Street connecting to the Saugus River (Culvert G). The culvert is a four foot inner-diameter pipe which has been fitted with a makeshift "tide gate" on the downstream end (i.e. on the Saugus River side) consisting of a steel plate reinforced with rebar and chained to the culvert entrance. In the closed position, it is intended to control the flow of water from the Saugus River into the marsh system. However, the tide gate is not fully functionally and does allow a fair amount of tidal water to enter the system (see section 2.3). A photograph of the downstream end of the Ballard Street culvert and the tide gate is shown in Figure 2-6. Just downstream of the culvert, significant scour has occurred from ebb velocities exiting the Ballard Street marsh system.

Table 2-2. Culvert locations and elevations from culvert survey.

Culvert ID	Location Description	Point of Measurement	Northing State Plane Coordinates (feet)	Easting State Plane Coordinates (feet)	Elevation (NAVD88-feet)
A	Southeastern Marsh limit	Top of concrete, downstream	2987036.13	794518.713	7.06
		Top of concrete, upstream	2986986.224	794481.047	7.14
B	Southwestern Marsh limit	Top of concrete, downstream	2987797.256	794134.271	5.07
		Top of concrete, upstream	2987837.725	794090.346	4.40
C	Parallel Culvert	Top of concrete, upstream	South End		3.46
		Top of concrete, downstream	North End		3.27
D	Gates Rd Culvert	Top of concrete, downstream	2989091.979	794526.111	5.45
		Top of concrete, upstream	2989035.839	794512.556	5.42
E	Large Culvert across Eastern Ave	Top of concrete, downstream	2989391.163	794682.691	6.66
		Top of concrete, upstream	2989376.991	794624.373	6.87
F	Small culvert across Eastern Ave	Top of concrete, downstream	2989899.506	794941.539	3.48
		Top of concrete, upstream	2989870.921	794986.413	4.09
G	Ballard Street Culvert, main culvert from Marsh to Saugus River	Below pipe, downstream	2989644.713	795842.483	-4.59
		Scour hole, downstream	2989648.399	795844.065	-6.78
		Top of pipe, downstream	2989643.767	795841.747	0.50
		Invert, upstream	2989541.972	795786.399	-3.54
		Top of box culvert, upstream	2989541.778	795787.158	2.59

The upstream side of the Ballard Street culvert consists of a concrete junction box that is formed around the upstream end of the pipe that opens to the marsh. Two 12-inch storm drains also feed into the sides of the junction box. The junction box has spalling concrete, shows exposed rebar and evidence of wear. A photograph of the upstream, marsh end of the culvert is provided in Figure 2-7.

Culvert E is a concrete arch culvert running under Eastern Avenue that is effectively eight feet wide and four feet tall under current conditions. However, past investigations (Reiner, 2010) indicate that the culvert may be a three-side arch structure or have a deeper invert. This culvert connects the northwestern end of the Ballard Street marsh to a ditch that runs parallel to Eastern Avenue. This culvert appears in good condition and the more than adequate size of the culvert indicates that flow remains relatively unimpeded at this location. Figure 2-8 shows a photograph of the downstream, marsh-side end of the culvert.

Table 2-3. Measured culvert inverts.

Culvert ID	Upstream/Downstream	Invert Elevation (ft-NAVD88)
A	Upstream (Pines Marsh Side)	Not Measured+
	Downstream	1.14
B	Upstream	1.25
	Downstream	1.97
C	Upstream	0.52
	Downstream	0.36
D	Upstream	-1.21
	Downstream	-1.05
E	Upstream	-0.75
	Downstream	-0.36
F	Upstream	Not included in model
	Downstream	Not included in model
G	Upstream	-3.54
	Downstream	-3.72

+ = Plywood covered culvert opening, was inaccessible during this survey (was subsequently measured in later surveys [see section 6.0]).

Figure 2-6. Downstream end of Ballard Street culvert with tide gate (culvert G).

Figure 2-7. Upstream end of Ballard Street culvert (Culvert G).

Figure 2-8. Downstream end of large Eastern Avenue culvert (culvert E).

The Gates Road culvert (Culvert D) is a five foot diameter concrete pipe that runs under Gates Road, connecting two segments of the ditch that run parallel to Eastern Avenue. The culvert has experienced some siltation and detrital accumulation that may impede water flow. A photograph of the downstream end of the Gates Road culvert, provided in Figure 2-9, shows the accrual of material at the entrance to the culvert, which is expected to vary seasonally.

Figure 2-9. Downstream end of Gates Road Culvert (culvert D).

Culvert F is a smaller culvert that runs underneath Eastern Avenue north of Culvert E. Culvert F is a two foot inner diameter concrete pipe, the downstream end presented in Figure 2-10. Upstream of the culvert is an approximately 12" diameter storm drain and connects to a small storm water swale on the southwest side of Eastern Avenue. This connection, to a small area, was not included in the model domain.

Figure 2-10. Downstream end of small Eastern Avenue culvert (Culvert F).

Culvert C is a 300 foot long, three foot diameter corrugated steel pipe that runs in series with the Gates Road culvert (Culvert D) and connects segments of the ditch that spans parallel to Eastern Avenue. Culvert C is heavily corroded at the bottom of the pipe on both ends and appears to be partially clogged with sediment deposition. Figure 2-11 is a photograph of the downstream end of Culvert C. This culvert runs under a number of private properties on the northwest side of Eastern Avenue, is relatively inaccessible, and appears to be restrictive to flow.

Figure 2-11. Downstream end of parallel culvert (culvert C).

At the southern end of Eastern Avenue, a third culvert, Culvert B, connects the Eastern Avenue ditch back to the southernmost end of the Ballard Street marsh. This is a two foot diameter concrete pipe that runs underneath Eastern Avenue. Visual observations indicated that this culvert experiences limited tidal exchange and flow.

Culvert A lies at the southeastern limit of the Ballard Street marsh under the abandoned portion of Bristow Street. Culvert A consists of approximately a seven foot wide by three foot high steel and concrete box culvert (7.3 feet wide by 4.3 feet tall), which has been substantially modified and has experienced significant sedimentation. More details on this particular culvert are presented in Section 6.3. Originally, this culvert connected the Ballard Street portion of the Rumney Marsh with the Pines River portion of Rumney Marsh. The southern end (i.e., the Pines River side) is closed with a sheet of plywood (Figure 2-12). The southern end of the culvert has experienced sedimentation and some vegetation has started to grow across the entrance. Figure 2-13 shows a photograph of the northern end of Culvert A (i.e., the Ballard Street marsh side). In its present state, the plywood blockade prevents the tides in Pines River from entering the marsh at this location.

Figure 2-12. **Southern end of Pines Creek culvert (culvert A).**

Figure 2-13. **Northern end of Pines Creek culvert (culvert A).**

2.2.3 Supplemental Topographic Marsh Survey

The supplemental topography survey also included recording GPS coordinates and spot elevations for a number of points at the site. Survey points were taken on the marsh plain, in the channels and ditches, and at various locations surrounding the marsh. The primarily focus of the supplemental survey was to improve the details on the southeast side of the marsh where there were limited historical NRCS data. The location of the survey points and their approximate elevations (shown by the color bar) is presented in Figure 2-14.

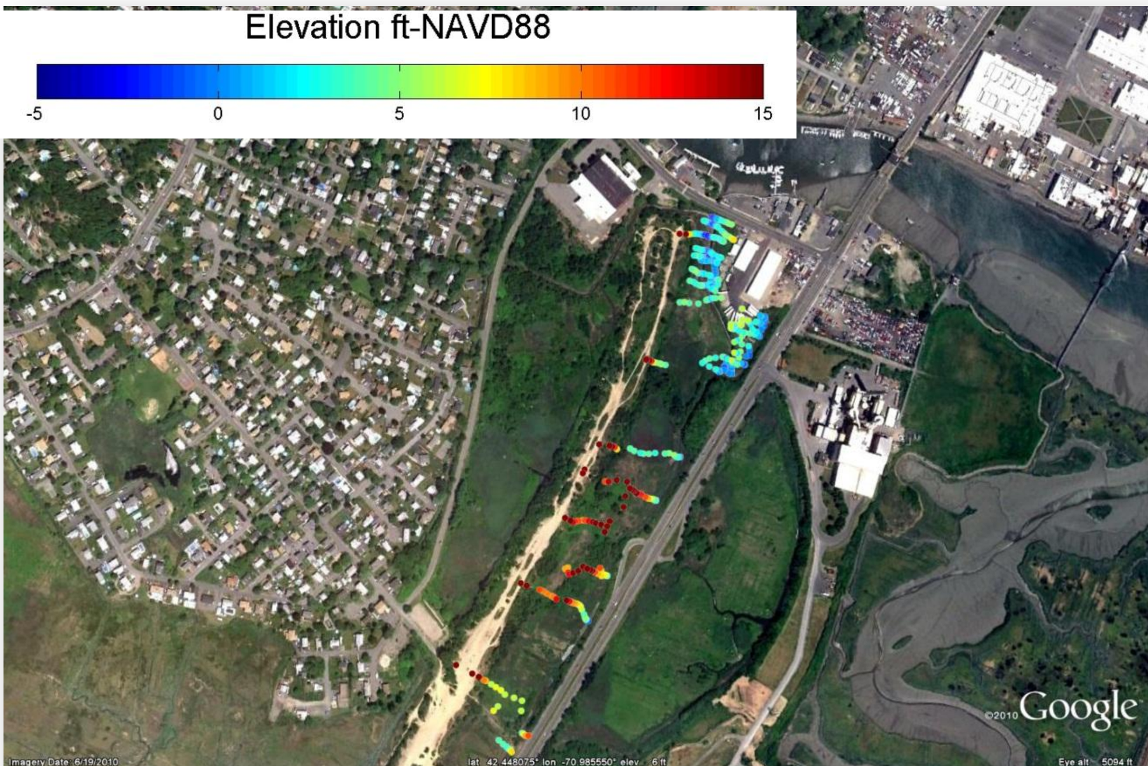


Figure 2-14. Supplemental topographic survey data collected by Woods Hole Group.

2.2.4 Additional Topographic Marsh Survey

During the process of completing the supplemental ground survey, anomalies in the historical topographic survey elevations collected by NRCS were discovered. Points occupied during both the NRCS survey and the WHG surveys were significantly different. As such, an independent third party survey was conducted and determined that the NRCS data were inaccurate due to an error in the original benchmark information provided to NRCS. Subsequently, NRCS has indicated that both their survey information and marsh restoration design are no longer supported (see Appendix A) and all NRCS data were discarded from this study. Therefore, DER requested an updated topographic survey of the area to support the revised modeling effort and potential project design and grading plans. New topographic and ground survey data were collected by Otte &

Dwyer, Inc. (O&D) of Saugus, MA. These data are shown in Figure 2-15. The data collected by O&D were required to provide creek cross-section and marsh plain elevations for the hydrodynamic model. The survey also attempted to re-occupy some of the same locations previously survey by NRCS. The final O&D survey plan is included in Appendix B, and includes both O&D and Woods Hole Group Survey points. The data presented on Figure 2-14 are included on those plans, including specific elevations.

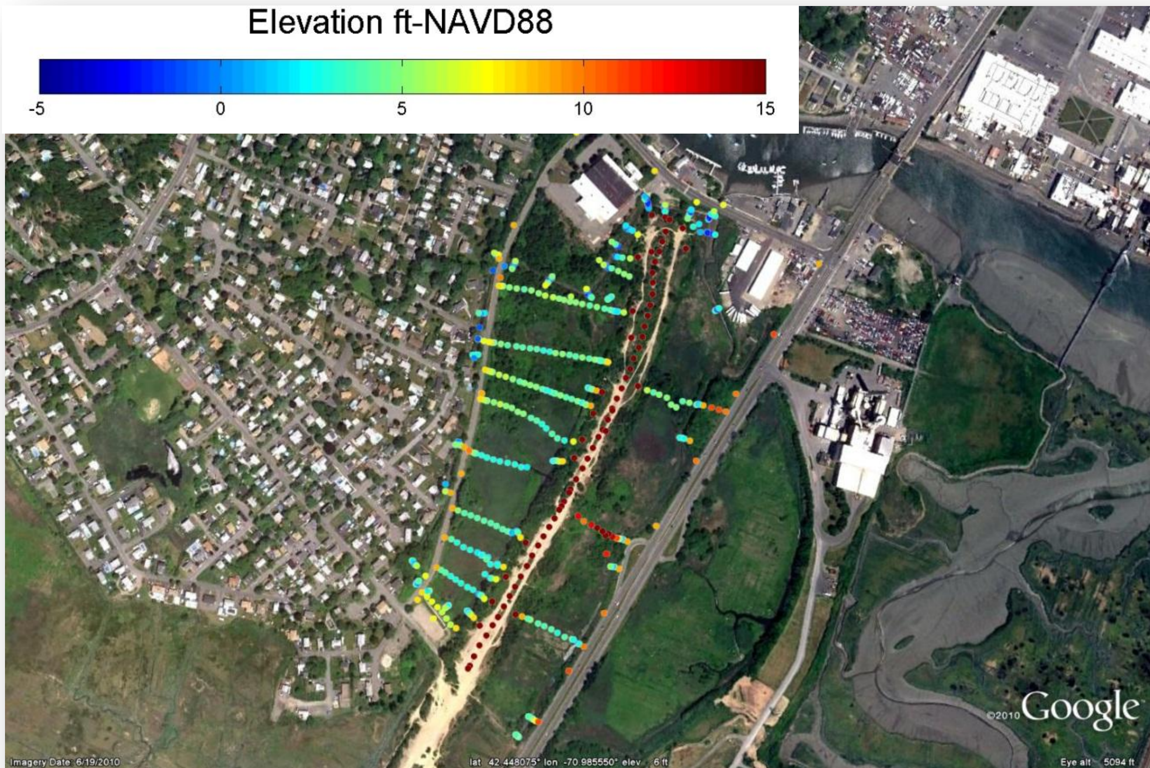


Figure 2-15. Topographic survey data collected by O&D.

2.3 DATA PROCESSING AND TIDAL ASSESSMENT

2.3.1 Data Post-Processing

The observed tide data were processed to account for changes in atmospheric pressure during the deployment time period, as well as to adjust the data to an appropriate datum. As discussed, the SBE37 tide gauges deployed for this study recorded conductivity, temperature, and pressure. The instruments are non-vented and therefore record the absolute pressure; a combination of the atmospheric pressure and the gauge pressure (i.e. the pressure from the weight of water above the instrument). Changes in atmospheric pressure during deployment may lead to significant error in the computed depth if the time varying atmospheric pressure is not accounted for; this is particularly true in shallow water. Site specific atmospheric pressure data recorded by a DER logger were used to correct the pressure data. Depth of water may be determined from the density and corrected pressure data. Using methods from Fofonoff et al. (1983), salinity was determined from the conductivity and temperature, and density was calculated from the salinity and temperature. Then, assuming the gauge pressure is hydrostatic, the depth was determined from the density and pressure. Finally, depth is translated to water surface elevation using the surveyed tide gauge elevations (Table 2-1). Figure 2-16 shows the barometric pressure observations and air temperatures recorded on-site. Impacts of local rainfall can also play an important role in the water surface elevations, especially in shallow water marsh systems. As such, local rainfall data were also obtained. Figure 2-17 presents the daily rainfall totals during the deployment period, recorded at Boston's Logan International Airport.

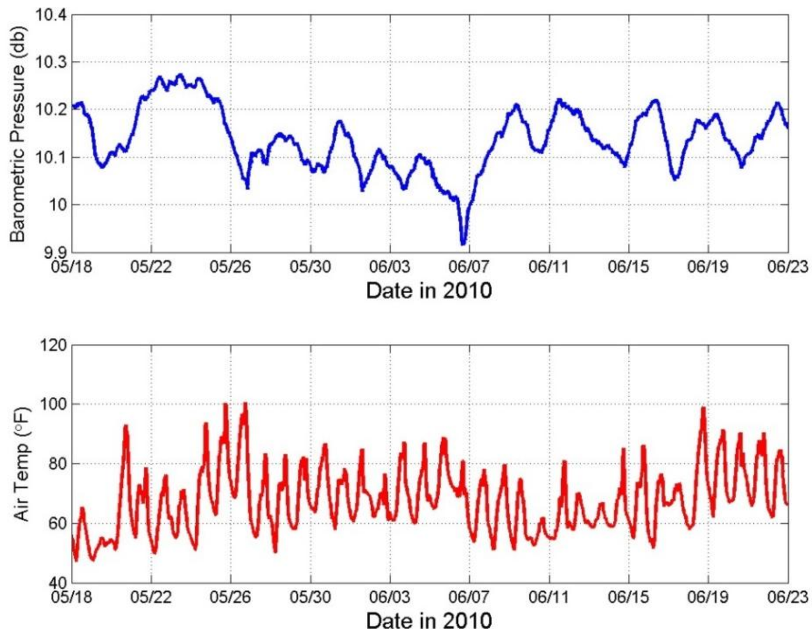


Figure 2-16. Barometric pressure and air temperature at Ballard Street marsh.

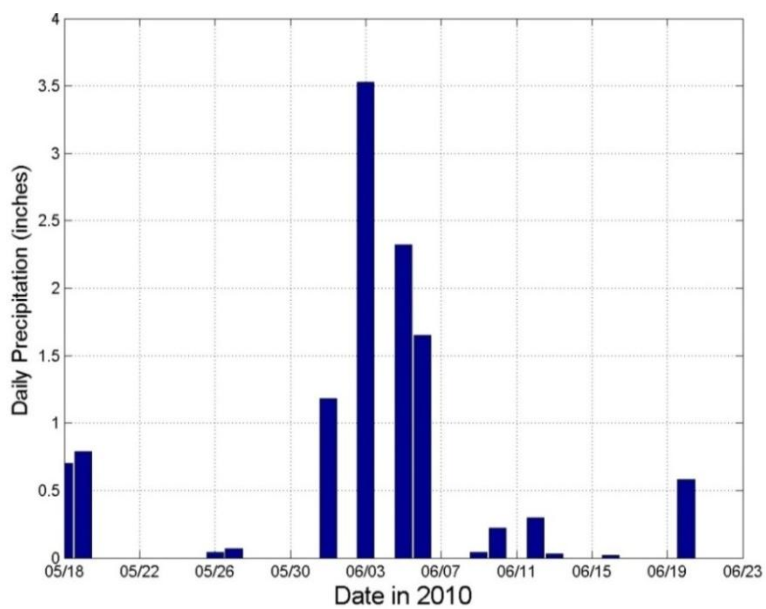


Figure 2-17. Daily rainfall totals from Logan Airport.

Time series of salinity, compiled from the Woods Hole Group data, are shown in Figure 2-18. The salinity data are vital to accurately determining the density and depth of the water at each location and are also an important parameter for wetland restoration. The DER HOBO data loggers do not record conductivity data. For processing, brackish water was assumed by DER. Salinity observations made in the ditch at the WHG1 location indicate that brackish water is a reasonable assumption. DER provided processed data for their stations directly to Woods Hole Group. Woods Hole Group did not process the DER data. The salinity observations at all three locations indicate adequate salinity levels to support a marsh restoration project. The time series of salinity does indicate drops in salinity levels with heavy rainfall events (between May 31st and June 6th) and during outgoing tides; however average salinity levels in the marsh are 20 psu or greater.

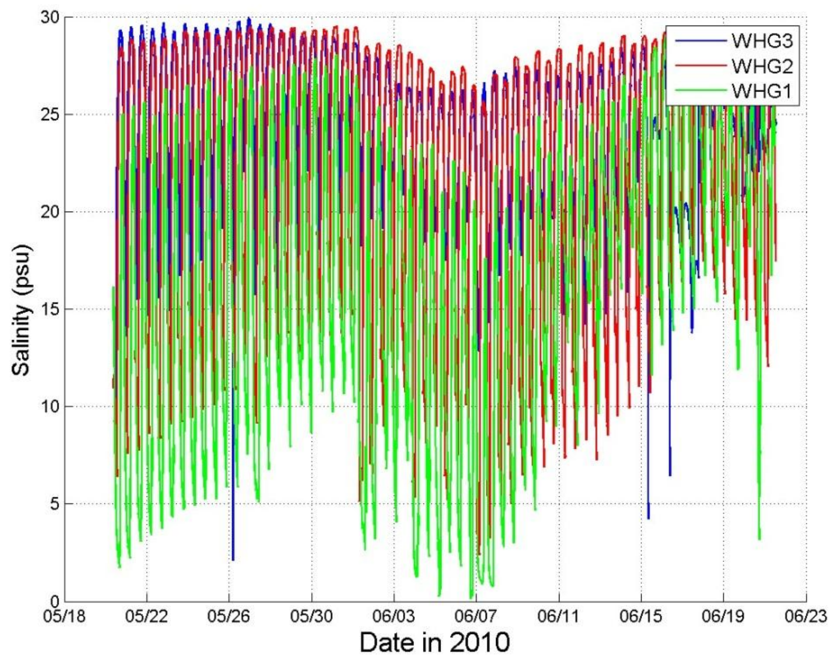


Figure 2-18. Salinity for Saugus River and Ballard Street marsh.

Time series of water surface elevation (WSE) from the WHG tide gauges and the DER HOBO loggers are shown in Figures 2-19 and 2-20, respectively. Time series of temperatures compiled from the WHG and DER instruments are shown in Figures 2-21 and 2-22, respectively. Temperatures at DER2 exceed 90 degrees in late May when air temperatures peaked at 94 degrees during that week, and the mean temperature was 15 degrees warmer than average for that week in May. Given the location of DER 2, which was in extremely shallow water or was directly exposed to the air during low tides (see figure 2-20 that shows the drying of DER2), it is feasible that the observations reached approximately 90 degrees during low tide. DER2 regularly was regularly exposed to the air temperatures. Also note that during high tides DER2 observes water temperatures similar to those in the Saugus River.

Figure 2-23 provides a shorter time period of the water surface elevation data (approximately May 28th to May 31st, 2010) in order to better visualize the details of the tidal signals observed at the WHG Stations. Due to the configuration of the DER HOBO instruments positioned vertically in PVC stilling wells, the instruments were sometimes out of water during lower tidal stages.

The tide gate blocking the culvert under Ballard Street (Culvert G) was removed from June 15, 2010 at approximately 8:15 am to June 18, 2010 at approximately 10:45 am. This is clearly shown in the data record at WHG Station 1. This allowed for a time period of data collection to assess the impact of tide gate removal on the Ballard Street marsh system and allow for comparison of physical processes within the system with and without the tide gate in place.

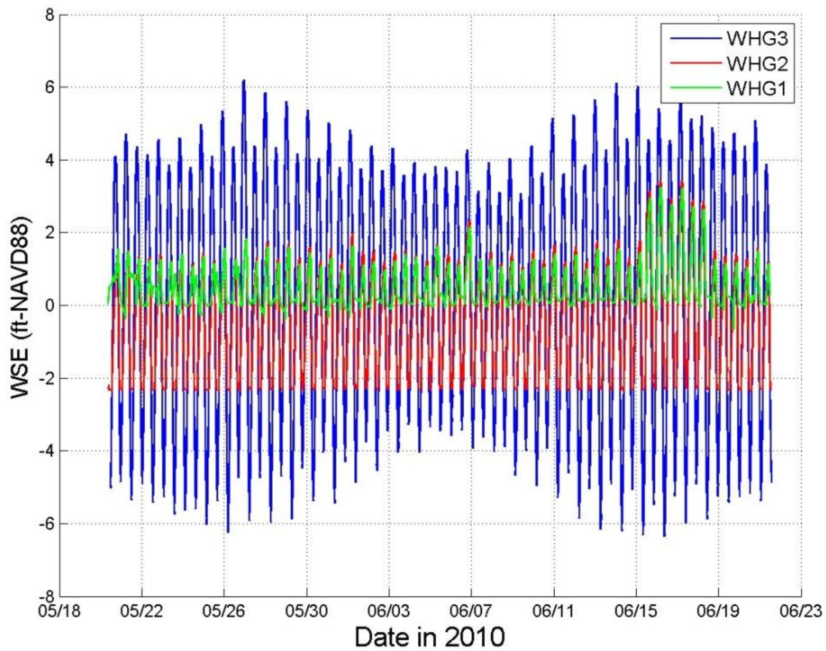


Figure 2-19. Water surface elevation (WSE) at WHG Stations.

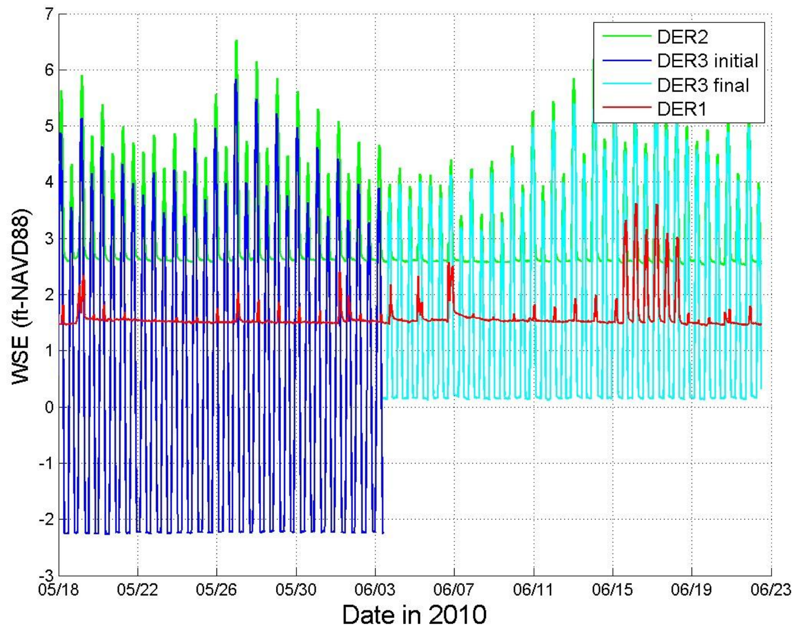


Figure 2-20. Water surface elevation (WSE) at DER Stations.

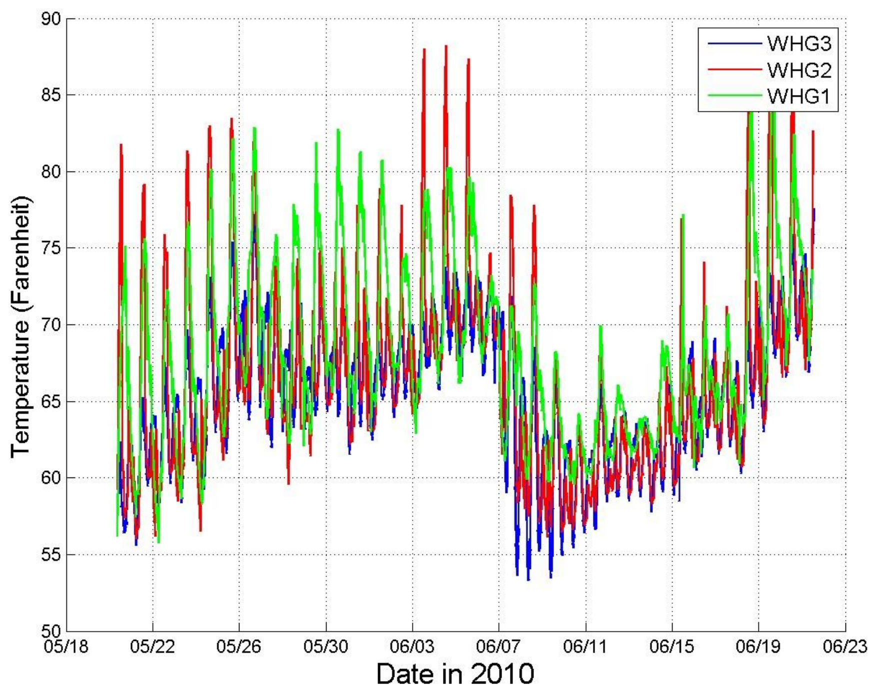


Figure 2-21. Water temperature at WHG Stations.

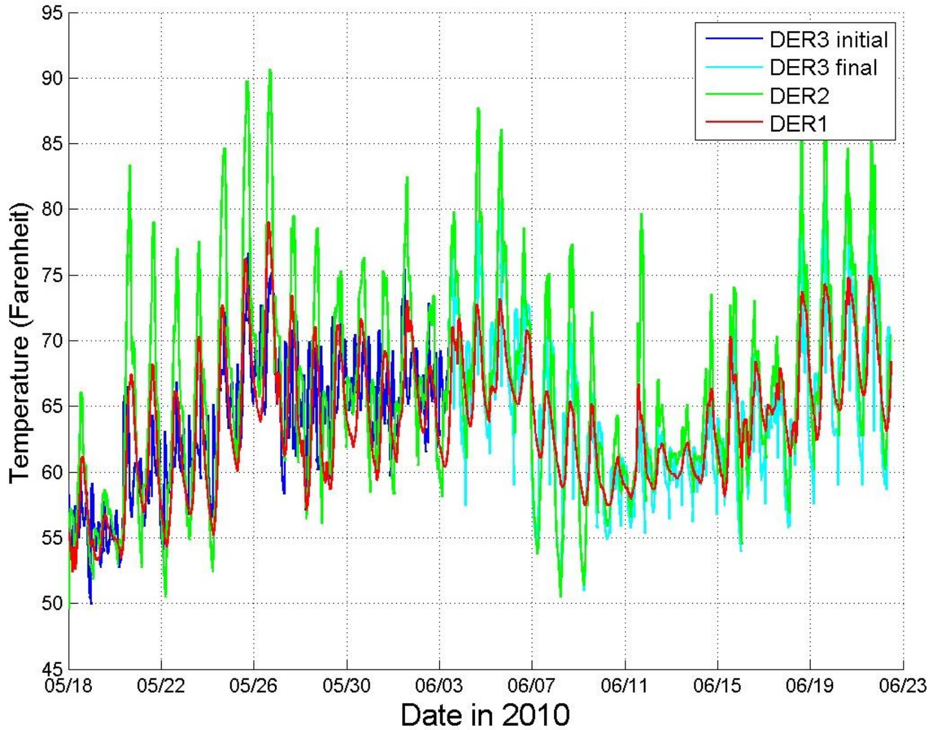


Figure 2-22. **Water temperature at DER Stations.**

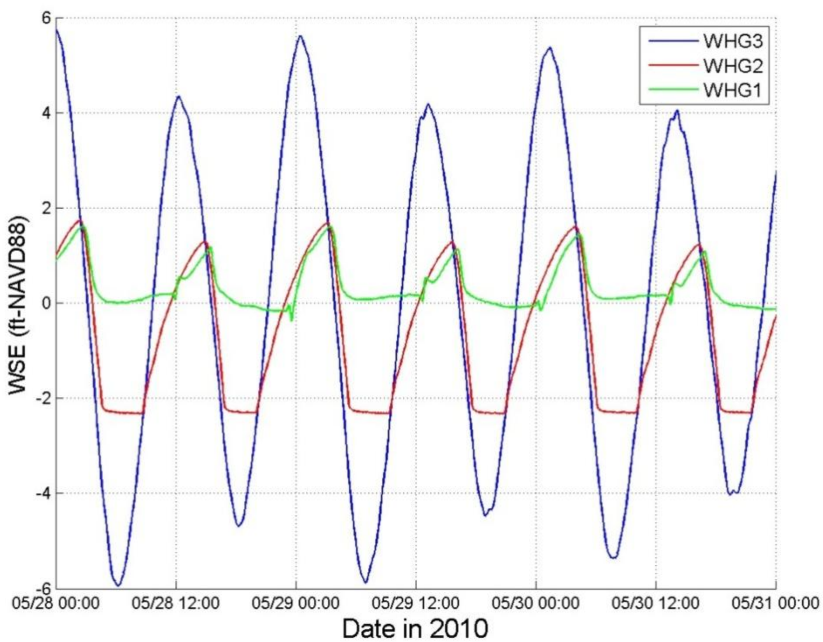


Figure 2-23. **Water surface elevation (WSE) at WHG Stations (from May 28, 2010 to May 31, 2010). WHG3 = Saugus River, WHG2 = upstream of Ballard Street culvert, WHG1 = Eastern Avenue Ditch.**

2.3.2 Tidal Assessment

With the current conditions of the Bristow Street culvert (A) being blocked by a temporary barrier, tides are only allowed to propagate into the Ballard Street marsh system from the Saugus River through the Ballard Street culvert (Culvert G), which is also fitted with a makeshift, flap tide gate. When functioning correctly, this flap is intended to only let water out of the system and block water from coming into the system. However, the tide gate is not fully functional and leaks water into the Ballard Street marsh system on a flooding tide. In addition, most of the tidal influence from the Pines Channel is prevented by the temporarily blocked culvert (A) at Bristow Street. Analysis of the observed water level data show mean tide ranges of approximately 9.4 feet in the Saugus River (WHG3) and approximately 3.7 feet in the Ballard Street marsh just upstream of the Ballard Street culvert (WHG2). This significant tidal attenuation is primarily caused by the Ballard Street culvert and flap gate, as well as the blockage of tidal flow from the Pines marsh system at the Bristow Street culvert. The high tide level within the marsh is lower than that in the river because the culvert is unable to convey enough water to allow the marsh system to fill completely during a typical flooding tide. The low tide level in the marsh is higher than in the river because the marsh system cannot drain below the invert elevation of the Ballard Street culvert. The net result is approximately a 60% reduction in tide range caused by the Ballard Street culvert and tide gate. Removal of the tide gate at Ballard Street, and/or removal of the temporary barrier at the Bristow Street culvert may also allow additional tidal exchange into the Ballard Street system, and this was further evaluated in Chapter 6.

Within the system, high tide water levels are fairly uniform throughout the system, with only slightly higher high tides upstream in the system (e.g., high tide at DER1 is typically higher than at WHG1) due to freshwater input from the watershed and possible backwater effects caused by poor drainage through Culvert C. Low tide water levels are at a higher elevation at upstream locations due to limiting culvert and bathymetric control elevations (e.g., low tide cannot fall below the channel bottom). This indicates that there is minimal tidal attenuation due to upstream culverts within the system under current conditions, and that the primary tidal restriction for the entire system is the Ballard Street culvert. Other culverts may be restrictive under full tidal exchange scenarios (i.e., if the there was a directly open channel connection to the Saugus River) or during freshwater discharge storm events (e.g., culvert C likely restricts discharge from the upper portions of the Eastern Avenue ditch and watershed). As such, culverts within the system may be restrictive for non-tidal phenomena such as a large runoff event or for tides if a greater range of tides were restored to the marsh by increased tidal exchange with the Saugus River or Pines Channel. For example, the ditch and culvert system along Eastern Avenue may not provide adequate drainage capacity during a larger rainfall event.

The salinity data show significant tidal fluctuation within the marsh system. This suggests that there is, in fact, tidal exchange between the river and marsh system, and that tidal fluctuations in water level in the marsh are primarily caused by tidal exchange (flooding tide), not by freshwater outflow backing up behind a closed tide gate. This also indicates that the makeshift flap gate system is relatively ineffective.

As evident in the full time series of water surface elevation, (Figures 2-19 and 2-20) the tide gate of the main Ballard Street culvert was opened on June 15, 2010 at approximately 8:15 am and closed on June 18, 2010 at approximately 10:45 am. The removal of the tide gate allowed approximately 1.5 feet of additional tidal range throughout the marsh system and also allowed tidal influence much further upstream. For example, with the gate closed, a tidal signal is apparent at the WHG1 ditch station, while upstream at the DER1 ditch station, the tide signal is minimal. However, during the three day period when the tide gate was opened, the DER1 ditch station showed a significantly larger tidal response. However, even with the tide gate removed, a tidal restriction remains with the tidal range attenuated by over 40% (from the Saugus River range). As such, the Ballard Street culvert by itself is a significant restriction to total tidal exchange, even without the tide gate in place. Even with the tide gate removed from the Ballard Street culvert, little attenuation is caused by the culverts within the system. Some small attenuation is observed due to the 300 foot long parallel culvert (culvert C) between WHG1 and DER1. However, friction and bathymetry in the ditch also contribute to the attenuation between these locations making it difficult to quantify the effect of the culvert alone.

To aid in the tidal assessment, some basic statistical values were calculated from the water surface elevation time series. The minimum, maximum, and mean tide levels during the deployment period were computed and are shown in Table 2-4. Elevations are provided for conditions with the tide gate in place and for the tide gate removed. The mean tide levels presented in Table 2-4 are only representative for the time period of data collection and are not comparable to the tidal benchmarks compiled over a 19-year tidal epoch (e.g., mean low water, mean high water, etc.). Therefore, within the marsh system under current conditions, the data indicate there is negligible tidal attenuation between different parts of the system (i.e. east marsh, west marsh, ditch). The existing culverts within the system are able to adequately convey water for the limited range of tides allowed in by the Ballard Street culvert (even with the tide gate removed). These culverts may, however, become restrictive for non-tidal phenomena (such as a large rainfall events) or if a greater tide range were restored (e.g., replacement of the Ballard Street culvert with a larger conduit, and/or unblocking of the Bristow Street culvert). Under current conditions (with the Bristow Street culvert blocked), the Ballard Street culvert (culvert G) is the primary restriction.

During the deployment period, the water surface elevation in the Saugus River reached a maximum elevation of approximately 6.19 feet (NAVD88) on May 26th. This maximum water level occurred during a spring high tide. Within the marsh, at both the WHG culvert and ditch station, the maximum water surface elevation during the deployment occurred on June 16th (3.44 and 3.26 feet, respectively), which understandably occurred during the period when the tide gate was removed. At this time, both the spring tide and open gate contributed to highest observed water level in the marsh during the deployment period. This illustrates that spring tides were approximately 1 foot higher in the marsh with the tide gate removed than with the tide gate in place. Even with the gate removed, the highest water surface elevations due to normal tides are significantly lower than critical infrastructure to the west of Eastern Avenue.

Table 2-4. Maximum, minimum, and mean tide elevations during deployment period.

Tide Gauge Station	Water Surface Elevation				
	Maximum (NAVD88-ft)	Minimum (NAVD88-ft)	Mean High Water (NAVD88-ft)	Mean Low Water (NAVD88-ft)	Mean Tide Level (NAVD88-ft)
WHG1 - Ditch (gate closed)	2.17	-0.67	1.24	-0.04	0.60
WHG1 - Ditch (gate open)	3.26	-0.14	2.92	0.023	1.47
WHG2 - Culvert (gate closed)	2.31	-2.35	1.43	-2.32	-0.45
WHG2 - Culvert (gate open)	3.44	-2.34	3.12	-2.30	0.41
WHG3 - Saugus River	6.19	-6.35	4.48	-4.92	-0.22
DER1 - Ditch (gate closed)	2.57	1.13	N/A	N/A	1.55
DER1 - Ditch (gate open)	3.62	1.48	3.30	1.50	2.40
DER2 - Pines Channel	6.52	2.52	4.66	2.59	3.63
DER3 - Saugus River	5.84	-2.27	4.20	-2.24	0.98
DER3 - East Saugus Marsh	5.65	0.12	4.41	0.14	2.27

The DER ditch station, DER1, also exhibited effects due to the opening of the tide gate. A tide signal can be clearly observed at DER1 during June 15th-18th when the tide gate was open. The difference between the peak water surface elevations at the two ditch stations (WHG1 and DER1) is likely a function of a number of possible effects, including attenuation caused by the 300 feet long corrugated steel culvert (Culvert C) parallel to Eastern Avenue and frictional effects of the ditch, which promotes poor drainage. The observed water levels at the DER1 location also indicate that water at this location is perched. For example, for the observations with the flap gate removed, the tidal range at DER1 is 1.8 feet, while the range at WHG1 is 2.9 feet. As such, the tidal range with the flap gate removed is much larger at WHG1 than DER1. The Gates Road culvert is also in between these gauge locations, however due to its relatively large diameter and short length it does not likely impose a significant restriction to flow along the ditch. The tide signal at the WHG1 gauge shows little attenuation in high tide when compared to the WHG2 gauge, evidence that the flow through the Eastern Avenue culvert is primarily uninhibited. The disparity between minimum water surface elevations at WHG1 and WHG2 can be attributed to channel depths as the tidal channel becomes nearly dry during low tides. The station in the Pines channel (DER2) illustrates relatively poor drainage at this location within the channel as MLW only lowers to 2.59 feet NAVD88. At this location in the channel, the current channel invert has shoaled and flow out of the system is restricted such that the channel cannot physically drain any lower. This is also observed in the additional data collection efforts presented in Chapter 6.

3.0 MODEL APPROACH

This section presents the overall model approach that was applied to develop the hydrodynamic model for the Ballard Street marsh system. The approach identifies the major tasks within the model development, and provides key points for evaluation of the modeling performance and progress. This allows for a flexible approach that can include the incorporation of new data, and/or a re-direction of the effort based on the results of the current modeling phase. This was critical given the evolution of the restoration project, which incorporated new, updated analysis methodology, and ultimately completely new restoration alternatives based on various stakeholder needs. The original scope of services for this contract consisted of the completion of the model development phase, including model calibration and validation, as well as an initial alternative simulation (the proposed NRCS design). Subsequently, the NRCS alternative was refined and eventually discarded in additional phases of the restoration. Eventually, a completely new restoration project was developed, integrating the extraction of a significant portion of the former I-95 embankment.

3.1 MODEL CALIBRATION

Model calibration is the process by which adjustments are made to the model parameters to ensure the model appropriately simulates measured water surface elevation, salinity, and other observed parameters. This requires conducting a series of iterative model simulations to ensure the model is stable, and results compare favorably with measured data. Calibration can be a lengthy process involving hundreds of model simulations. Specifically, the model coefficients are adjusted (within acceptable ranges) until the modeled water surface elevation, salinity, and temperature closely approximates the measured field observations.

In practice, hydrodynamic models require input of some physical parameters that are unknown or only known within a reasonable range. For example, bottom friction parameters, because their formulations, often account for a combination of frictional effects, leaving some freedom in choosing an appropriate value. The calibration process involves “tuning” the model by systematically adjusting some unknown parameters, such as bottom friction, so that its results match reasonably well to a set of observed data. Horizontal eddy viscosity is another parameter that can reasonably lay within a significant range, however for different models its effect on the results can be considerably different due to the use of different numerical methods. In addition, different models have numerous different parameters that can be tuned to achieve better model results. To accomplish this, the observed data set must provide both the necessary information outside the model domain to drive the boundaries, while also providing information within the model domain for comparison to model output. Once a set of parameters has been found that produces the best possible fit to the data and the selected parameters are reasonable compared to empirically defined values, the parameters are fixed for subsequent model simulations. The more extensive the calibration data set in terms of duration, spatial extent, and observed quantities, the better chance the model has at matching other independent sets of data and producing accurate predictions.

3.2 MODEL VALIDATION

Model validation is achieved by applying the calibrated model, with its fixed parameters, to one or more sets of observed data that are independent from the calibration data. Typically, sets of data for validation are collected at a different time and under conditions that differ from the calibration period. Results from validation simulations are quantitatively compared to the observed data in the same way as in the calibration process. However, during validations there is no freedom to tune parameters. This demonstrates that the model performs reasonably under a different set of conditions. As such, validation simulations act as a check to see how well the model is capable of predicting accurate results under conditions that differ from calibration. A model must be satisfactorily verified before it can be used for forecasting (e.g., alternative simulations or different forcing conditions).

3.3 EXISTING CONDITIONS SIMULATIONS

Once the model has been calibrated and validated, further simulations using the unmodified model provide a better understanding of the behavior of the system over a broader range of forcing conditions. In addition to elucidating the present state of the Ballard Street marsh system, these existing conditions simulations will also provide a baseline for comparison to proposed restoration alternatives in order to provide a gauge of the potential benefits and/or risks associated with different components of the restoration design.

3.3.1 Normal Tidal Conditions

While the calibration and validation results ensure the accuracy of the model, they represent the behavior of the system during specific time periods and may not be fully representative of the normal function of the estuary. Evaluating the existing system under normal conditions will allow for assessment of the flushing characteristics, the overall hydrodynamics, and the regular volume flux that occurs between Saugus River and the marsh system.

3.3.2 Storm Scenarios

Perhaps one of the biggest risks involved in restoring tidal flow to the Ballard Street marsh is the increased potential for upland flooding associated with storm events. Therefore, simulation of storm events is important. Storm surge elevations were developed from historical records in the U.S. Army Corps of Engineers (USACE) New England Coastline Tidal Flood Survey of 1988, as well as the Federal Emergency Management Agency (FEMA) Flood Information Study for Saugus, MA. In addition, winds associated with large storms can have a significant impact on water levels; therefore wind forcing is included in these model scenarios. Understanding how the existing system responds to storm forcing, will be critical in assessing the potential impacts/risks that will be involved with each potential restoration scenario. Finally, extreme rainfall events will be simulated to determine the drainage potential, or lack thereof, of the system. The proposed extreme rainfall event simulated was developed by

NRCS (1999), and subsequently modified using new information developed at the Northeast Regional Climate Center at Cornell University during some of the later alternative simulations.

3.3.3 Sea Level Rise

The current degraded state of the Ballard Street estuary is the result of a century of anthropogenic modifications. With restoration, in another century, the state of the estuary may be significantly improved. However, progression into the 21st century and beyond, it is feasible that other long-term processes may have a significant effect on the state of the system. While the topic of accelerated sea level rise is still heavily debated, the Intergovernmental Panel on Climate Change (IPCC) has undergone a considerable effort to analyze and review the current state of the knowledge and provide an estimated range of predicted sea level rise into the next century. In the current scope of work, model simulations are conducted for predicted sea level rise using projected 50-year sea levels based on the United States Corps of Engineers (USACE) guidance on incorporating sea level change considerations in civil works projects (USACE, 2009). Sea level rise simulations are conducted for existing conditions, as well as the final preferred alternative.

3.4 ALTERNATIVE SIMULATIONS

Following simulation of existing conditions, Woods Hole Group simulated a number of potential restoration alternatives. These alternatives evolved throughout the project and included various modifications to the original WHG scope of work. The primary alternatives simulated included:

- The proposed design as presented in the Ballard Street Salt Marsh Restoration Project Design Plans (culvert and excavation) produced by NRCS (1999) in their report. These results should verify the relative performance of the proposed alternative and determine if it will function as anticipated. This alternative simulation, along with the existing conditions simulations, were intended to assist in determining what, if any, additional alternatives should be considered in future assessments. This design alternative is simulated using the calibrated hydrodynamic model under normal tidal conditions to gain an estimate of the maximum possible area of restoration that could be attained, and storm conditions to assess performance during a storm. It was anticipated that the proposed NRCS alternative will not perform as originally expected since the topographic data were inaccurate in the NRCS study (1999).
- A modified NRCS design, presented in subsequent permitting documents and memorandums that utilized the same excavation and culvert concepts, but modified the tidal control structures at the newly proposed I-95 embankment culverts.
- A refined NRCS alternative developed following the existing conditions model and the required modifications to the original NRCS concept to ensure the restoration would function as intended. This alternative attempted to closely follow the original NRCS design (e.g., the marsh layout and channels) and primarily modified the (1) excavation amount, (2) tidal control structures, and (3)

storm water drainage from the system. The NRCS alternative was also refined based on improved modeling approaches than used by NRCS and newer precipitation methodologies. This was the preferred alternative prior to the inclusion of the DCR excavation from the abandoned I-95 embankment.

- The Ballard Street marsh system with phased excavation stages proposed by DCR. These alternatives evaluated the condition of the marsh system following the two proposed stages of embankment removal to determine potential, temporary detrimental impacts to the hydraulics of the system following extraction and prior to full restoration.
- The final restored layout for the Ballard Street marsh system following the DCR extraction effort. This alternative includes a new marsh gradation and layout, new marsh creek locations, the reconsideration of all culverts and flow control structures, and the required excavation for flood storage during storm water events. This is the preferred alternative for restoration of the Ballard Street marsh system.

4.0 MODEL DEVELOPMENT

This section describes the development of the hydrodynamic model for the Ballard Street marsh system. In addition to describing the configuration, calibration, and validation of the model, this section presents the results of a number of simulations for the existing system. These simulations, with the estuary in its existing restricted state, aid in developing an understanding of the current behavior of the system, and provide a baseline for comparison with alternative simulations. It is not critical that the reader be familiar with the development, equations, and /or concepts presented in this chapter and associated appendix C in order to understand the results of the hydrodynamic model.

4.1 THE ENVIRONMENTAL FLUID DYNAMICS CODE

After careful consideration of a number of hydrodynamic, numerical models, the Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1996), originally developed at the Virginia Institute of Marine Science (Hamrick, 1992), was selected as the most appropriate tool for modeling the Ballard Street marsh system. EFDC has been applied to numerous aquatic systems including Chesapeake Bay (Hamrick, 1994), Mobile Bay in Alabama, Cape Fear River in North Carolina, the Suwannee River in Florida, and the Herring River in Massachusetts (Woods Hole Group, 2009). The model has been applied to studies of circulation, discharge dilution, water quality, TMDL, and sediment transport. EFDC is capable of predicting hydrodynamics and water quality in multiple dimensions and is a widely accepted EPA approved model. EFDC was chosen because of its ability to meet all necessary requirements for the Ballard Street Estuary model including the ability to simulate (in two-dimensions) time dependent water levels, current velocities, salinity, wetting and drying, and hydraulic control structures. Appendix C presents further details on EFDC.

4.2 MODEL CONFIGURATION

The development of the Ballard Street marsh system hydrodynamic model required configuration so that this particular application of EFDC would best approximate the form and function of the real system (i.e., the Ballard Street marsh system). Model configuration involves compiling observed data from the actual estuarine system into the format required for the execution of EFDC. This can be broken down into three major steps that are described below.

First, topographic and bathymetric data are used to generate the computational grid on which EFDC's finite difference calculations are performed.

Second, observed water levels, salinity, and atmospheric conditions are used to define boundary conditions for driving the model. The development of boundary conditions also includes the assignment of bottom friction for the various types of marsh substrate throughout the estuary system.

Third, for this application, additional subroutines were applied within the EFDC code to dynamically compute discharge through the different types of hydraulic control structures that are present in the estuary and have a significant effect on the hydraulics. Thus, the methods used to compute discharge through flap gates, and culverts, and their parameterization in the hydrodynamic model are also described.

Appendix C presents detail on the setup of the model, including the explicit steps followed to generate the grid, input boundary conditions, and determine flow dynamics at control structures. A brief summary of model setup is presented in this chapter. Following model setup, the governing equations are solved at each grid point through an iterative method. The model is then able to calculate the water surface elevation, velocity, and salinity at each time step. Once a certain level of accuracy is attained, the model advances to the next time step in the simulation and repeats the calculations. This methodology is continued until the model has simulated the entire time period of interest.

4.2.1 Grid Generation

The first step in building the model is constructing the model grid. The grid is a digital abstraction of the prototype's (Ballard Street marsh system) geometry that provides the spatial discretization on which the model equations are solved. Different numerical methods require different types of grids, each having unique geometrical requirements. The grid building process involves using geo-referenced digital maps or aerial photos to define the model domain, then the grid is generated within this domain providing the desired degree of spatial resolution, and topographic data are incorporated by interpolation of elevation values to grid nodes or cells within the domain.

Topographic data collected by Woods Hole Group, Inc. were combined with topographic data collected by Otte and Dwyer, Inc. and used in constructing the Ballard Street model grid. In addition, Woods Hole Group collected topographic and geometric information required to accurately define all the systems culverts. The combined topographic data are shown in Figure 4-1 from the original sets of surveys. As the project continued to evolve, additional data were added to the model domain and integrated into the grid (section 6.0).

Due to the complex shape of the Ballard Street marsh system and the need for higher grid resolution in certain areas, it was convenient to generate a number of separate grids for different portions of the system and then combine them to create the final model grid. Figure 4-2 shows the domain boundaries for the four portions of the system that were gridded separately. Areas of overlap were deleted or merged carefully to preserve orthogonality of the final grid. The final grid is shown in Figure 4-3 and a close up of the grid which shows individual grid cells more clearly is shown in Figure 4-4. The final grid has a total of 10,387 computational cells ranging in size from approximately 4 feet to approximately 60 feet.

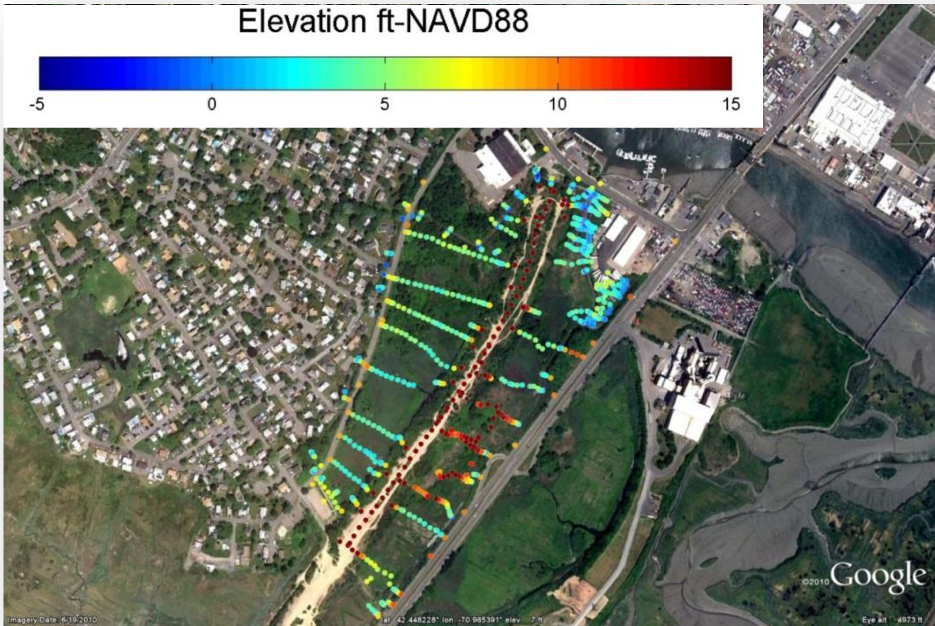


Figure 4-1. Combined topographic data used to construct EFDC model grid.

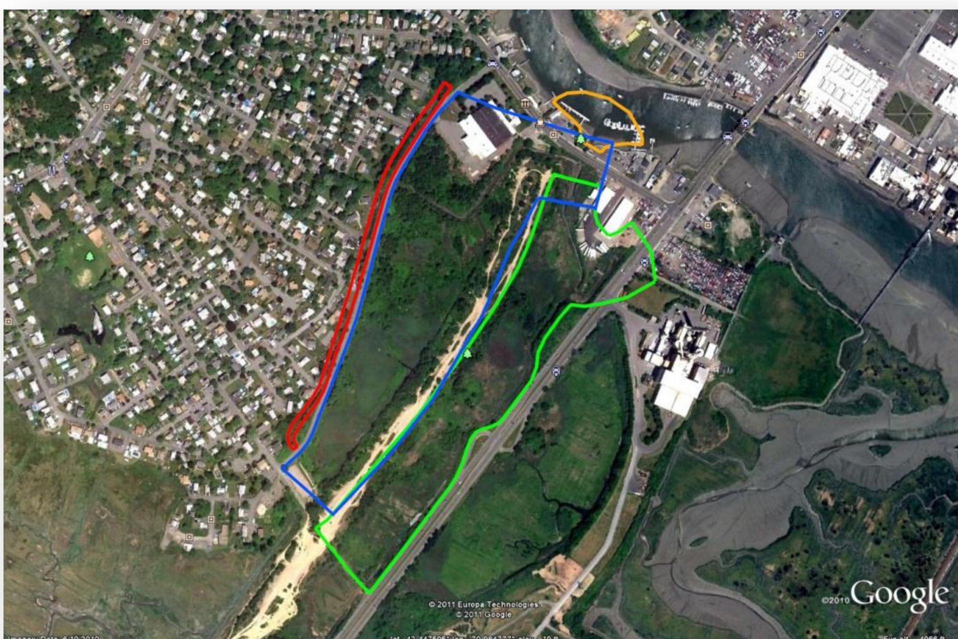


Figure 4-2. Domain boundaries for generation of grid portions.

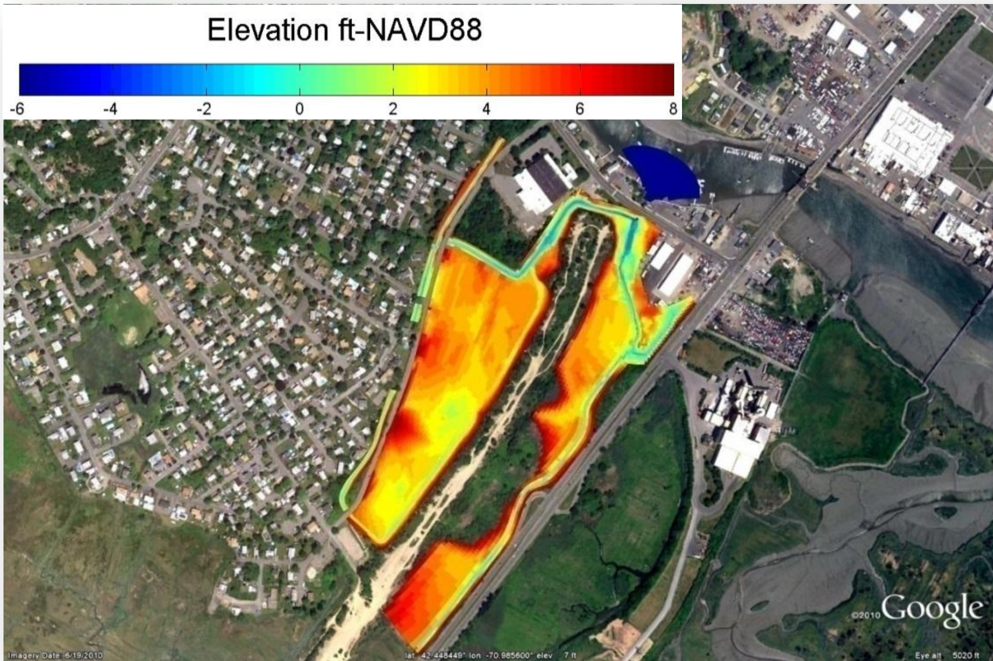


Figure 4-3. Ballard Street marsh EFDC model grid.

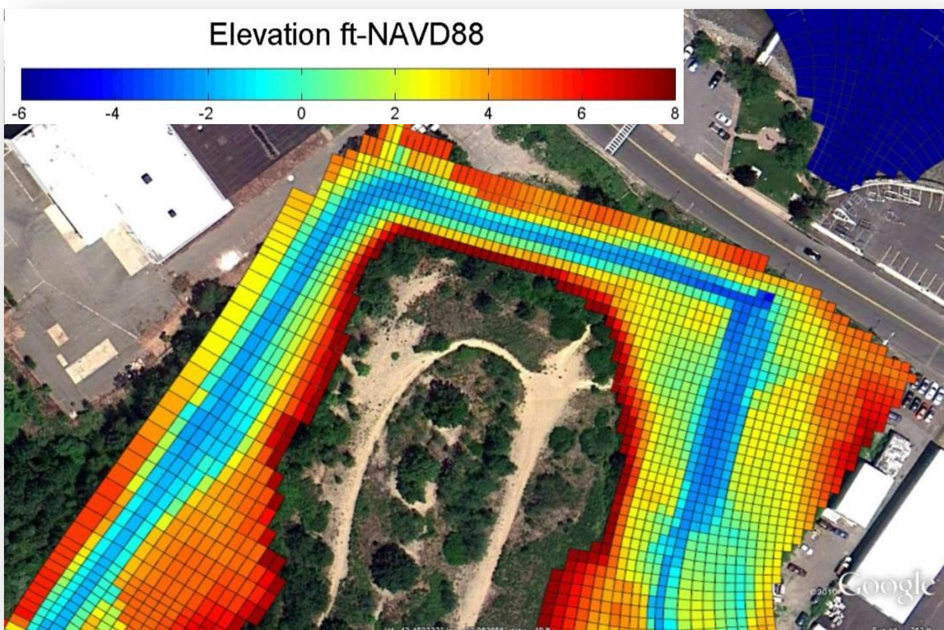


Figure 4-4. Close up of Ballard Street marsh EFDC model grid.

4.2.2 Boundary Conditions

The assignment of model specific boundary conditions allows EFDC to compute a unique solution for a given model scenario. Most of the Ballard Street marsh system is bounded by roadways or high ground. The minimum elevation at which water can flow over Ballard Street and into the marsh is approximately 7.7 feet NAVD88 (subsequently found to be 7.1 feet NAVD88 by more recent survey efforts, section 6.0), according to the previous study (NRCS, 1999). In addition, a lower elevation of 7.3 feet NAVD88 was reported by NRCS between Bristow Street and the Ballard Street System. Without overtopping Bristow or Ballard Street, tidal flow may currently only enter and exit the marsh system through the Ballard Street culvert and tide gate. The Ballard Street marsh hydrodynamic model was designed to simulate water levels in the marsh below 7.7 ft-NAVD88 elevation (the highest elevation before the culvert becomes inconsequential). Therefore, the roadways and high ground bounding the marsh system were defined as land boundaries. Along land boundaries water is constrained to flow parallel to the boundary and there is no restriction on the water surface elevation. This initial model domain was also modified following incorporation of the DCR extraction proposal (section 7.0).

Tidal forcing for the model is applied on an open boundary in the Saugus River. Figure 4-5 shows the location of the open boundary. Along the open boundary there is no restriction on the current velocity, however both water surface elevation and salinity must be specified. Data collected in the Saugus River at the WHG3 location (see Figure 2-1) were used to specify the water surface elevation and salinity for model calibration and validation. A secondary forcing boundary condition was also available at the Bristow culvert to consider modifications at this location (e.g., removing the plywood); however, for calibration the model has this boundary closed as currently the case in the real system.

Freshwater input to the model can be specified as a uniform input over the entire domain representing rainfall, as well as volume sources at individual model grid cells. Rainfall input used for model calibration and validation is based on rainfall observations made at Logan Airport as shown in Figure 2-17. Although no stream flow data are available to quantify actual freshwater flow into the Ballard Street marsh System, a relatively small base flow of approximately 1 cfs was distributed between three cells in the ditch along Eastern Ave. This base flow volume is relatively insignificant when compared with the tidal flux in the system. Also, the observation of primarily brackish water in the ditch along Eastern Ave. suggests that minimal freshwater input occurs except during and immediately after rainfall events. The locations of these freshwater input cells are shown in Figure 4-6.

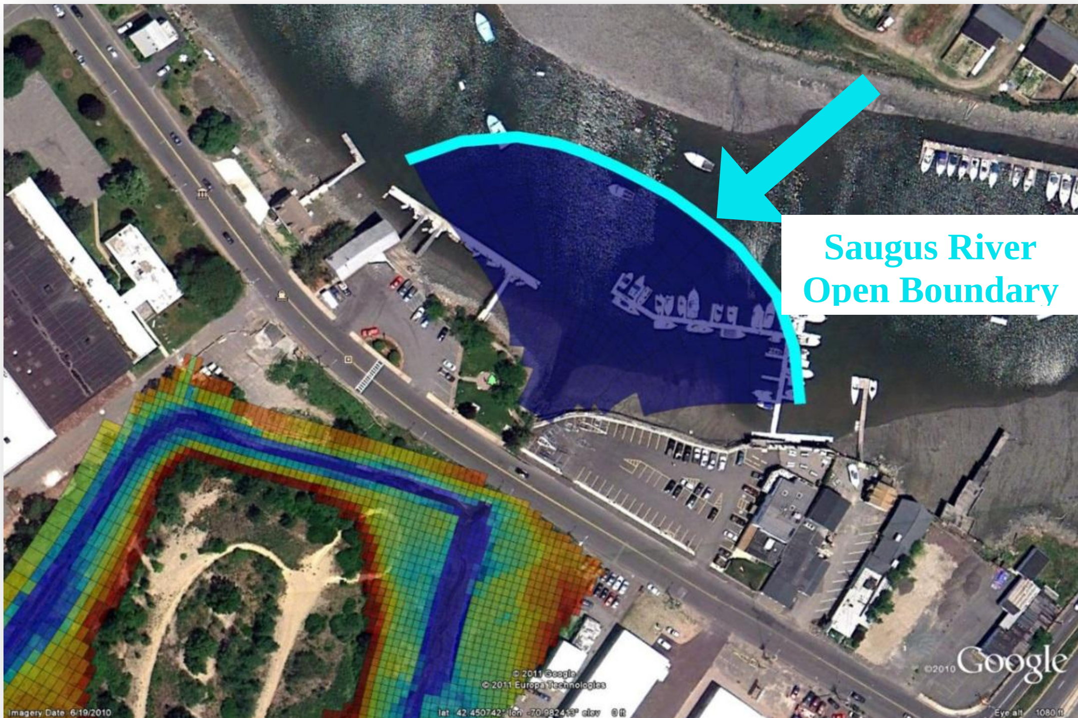


Figure 4-5. Location of the open boundary in the Saugus River.

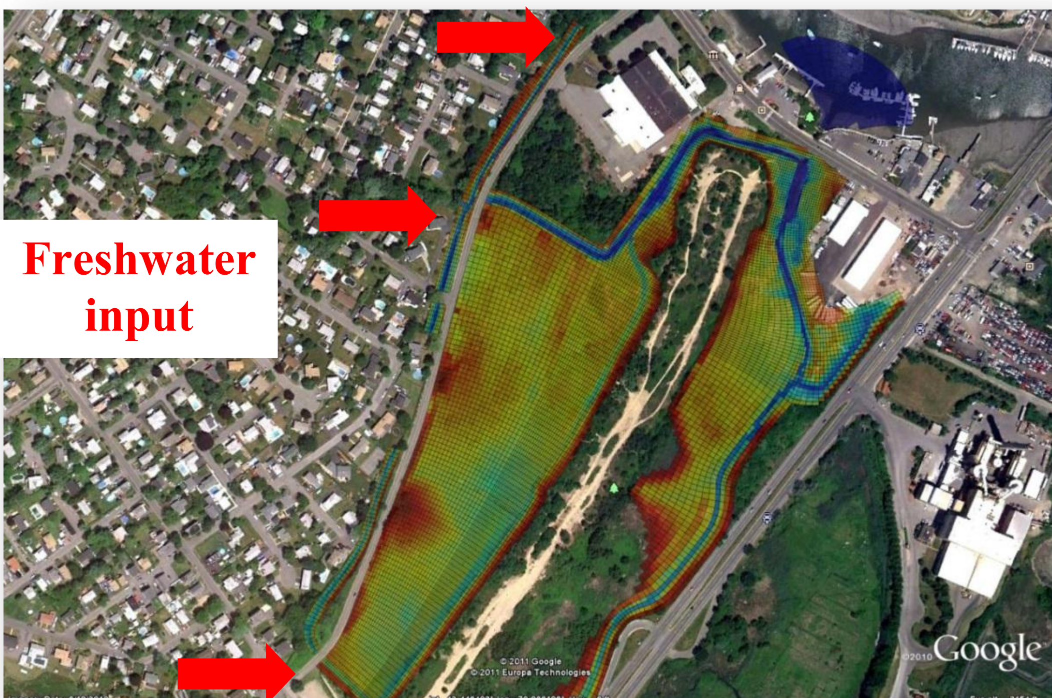


Figure 4-6. Approximate location of freshwater input cells in the ditch along Eastern Avenue.

4.2.3 Flow Control Structures

A total of seven culverts have been identified within the Ballard Street marsh system. The location of these culverts was shown in Figure 2-5. Of the seven culverts in the system, six have been included in the Ballard Street marsh hydrodynamic model. The small culvert under Eastern Avenue at the northern end of the Eastern Avenue ditch (culvert F) is also not include because it drains only a relatively small swale on the east side of Eastern Avenue and does not contribute significantly to the hydraulics in the larger marsh system. Details on the model specifications of the culverts and flow characterization are presented in Appendix C.

4.3 MODEL CALIBRATION

Model calibration is the process in which model parameters are systematically adjusted through a range of acceptable values and results are examined using standard measures of error to determine the configuration of model parameters that provides the best agreement between modeled variables and observed measurements. The Ballard Street marsh hydrodynamic model was calibrated to water level observations collected from June 15, 2010 to June 18, 2010. During this time period the steel plate acting as a flap gate on the Saugus River side of the Ballard Street culvert was removed allowing increased tidal influence in the system. Although only a short time period, this time period was chosen for model calibration because the greater degree of tidal influence in the system ensures the model accurately reproduces the tidal dynamics in a larger portion of the marsh. This timeframe also is the only data that were available with the tide gate removed. Subsequent validation was conducted over a longer observed time frame (two weeks), and a second validation was conducted for tide observations from a completely different data set (section 6.0).

The model performance is evaluated by comparing time series output from the model at to the observed time series of both water surface elevation and salinity. The results are presented visually as time series plots and scatter plots. The time series plots allow for a direct visual comparison of how the observed and modeled variables evolve through time and provide a "first glance" at the performance of the model. On the scatter plots, points are plotted showing the modeled values corresponding to each discrete observed value. If the model has perfect agreement with the observed data, the points would lie on a line with slope of 1 passing through the origin. The vertical distance between a point on the scatter plot and the line of perfect agreement represents the model error for that particular observation. Figures 4-7, 4-9, and 4-11 show the time series comparisons, while Figures 4-8, 4-10, and 4-12 show the scatter plots for the WHG2, WHG1 and DER1 gauges, respectively.

In addition to the visual comparison, statistical model errors were also computed. Model error for a given observation time series is quantified by computing the Bias and Root Mean Square Error (RMSE) based on each discrete observation in the time series. The Bias and RMSE are calculated as:

$$Bias = \frac{\sum_{1}^{n} \left(p_{\mathrm{mod}} - P_{obs} \right)}{n} \quad (1)$$

$$RMSE = \sqrt{\frac{\sum_{1}^{n} \left(p_{\mathrm{mod}} - p_{obs} \right)^2}{n}} \quad (2)$$

Where P_{mod} and P_{obs} are the modeled and observed values respectively and *n* is the number of discrete measurements in the time series. The bias provides a measure of how close on average the modeled results are to the observed data. A positive value indicates that the model is over-predicting the observation, while a negative value indicates that the model is under-predicting the observations; a bias of zero indicates that the on average the model reproduces the observations. As such, a low bias value indicates the model is simulating the observed data reasonably. The RMSE is an average of the magnitude of the error. RMSE is always positive with smaller values indicating better model performance. Both the Bias and RMSE are measures of absolute error having the same units of the measured quantity from which they are computed. Overall for the calibrated Ballard Street marsh system model, the RMSE is less than 4 inches and the magnitude of the bias less than 2 inches for all three observation time series. Relative errors for the RMSE and bias are determined by relating absolute error to the range of water levels observed at each gauge. The relative RMSE for all three locations is less than 15% and the magnitude of the relative bias is less than 7%. The U.S. EPA gives technical guidance on error statistic criteria for calibrating estuarine water quality models (EPA, 1990). In these guidelines, relative errors computed for hydrodynamic model variable (e.g. water surface elevation) should be less than 30% in order to achieve adequate calibration. The relative errors associated with the Ballard Street marsh system are well below these EPA guidelines. Overall, the model sufficiently simulates the hydrodynamics of the Ballard Street marsh system. The error statistics satisfy EPA standards, and the model compares well to observed data. Error statistics are summarized in Table 4-1.

Parameters adjusted during calibration of the Ballard Street marsh model include bottom roughness lengths and pipe culvert roughness coefficients (Manning's n). The best model performance results with bottom roughness values of 3 cm for open channels in the east and west portions and 10 cm for the ditch parallel to Eastern Ave. For some culverts, it was found that different roughness coefficients were required for flooding versus ebbing tides. This is reasonable considering that the roughness coefficients for culverts must account for entrance and exit losses in addition to friction losses within the culvert barrels. These additional losses are highly dependent on the geometry and flow characteristics at the culvert entrance and exit and thus will be different on a flooding tide than on an ebbing tide, as the culvert entrance becomes the exit and vice-versa. For example, consider the Ballard Street culvert with the tide gate removed. On a flooding tide, flow entering the Ballard Street culvert is perpendicular to the main flow in the Saugus River. To enter the culvert barrel the flow must accelerate (i.e. change direction). This causes an additional head loss at the entrance of the pipe when compared to the observed head in the main stream of the river where observations were made. Whereas on an ebbing tide, the flow entering the culvert is largely parallel to the culvert barrel and the entrance losses may be significantly less. Table 4-2 presents the various roughness values used in the calibrated model.

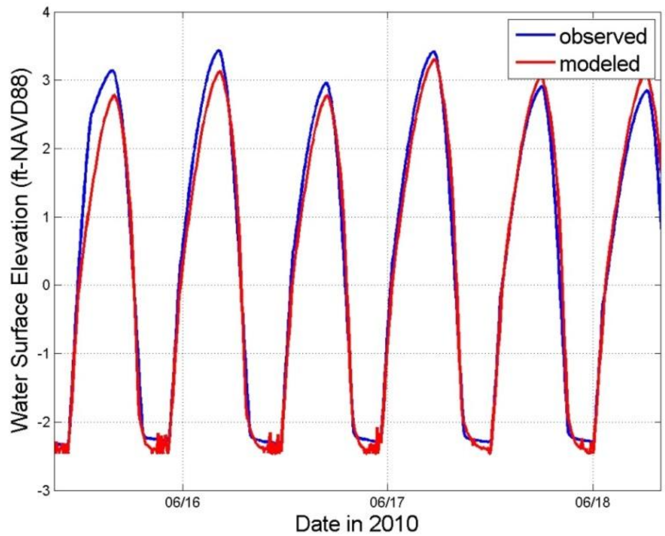


Figure 4-7. Water surface elevation time series comparing model results to observed values at WHG2 station.

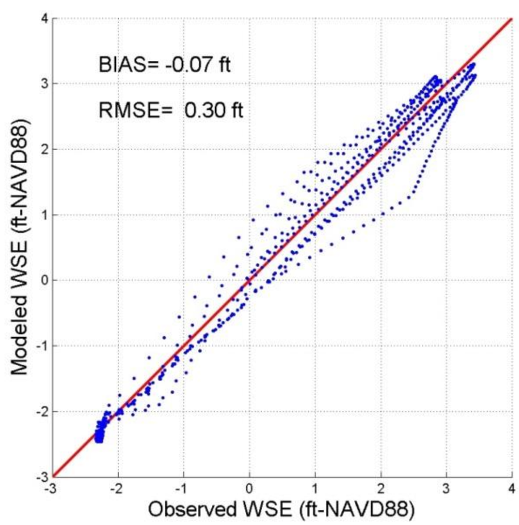


Figure 4-8. Water surface elevation (WSE) scatter plot for WHG2 station.

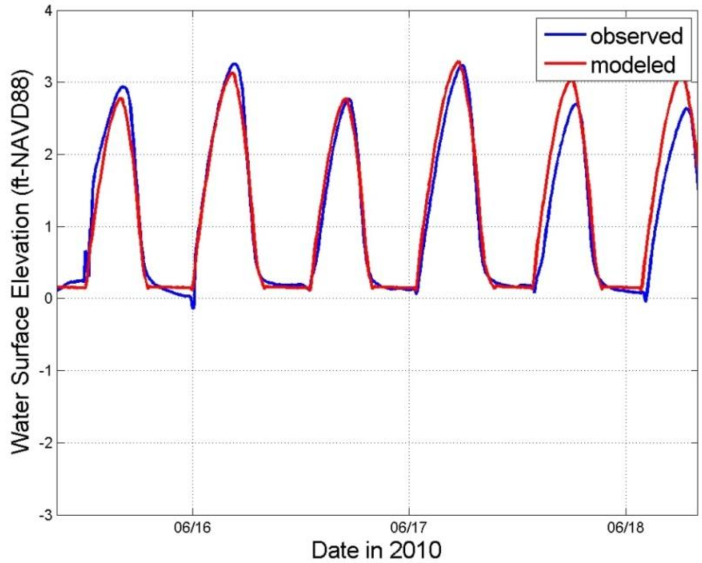


Figure 4-9. Water surface elevation time series comparing model results to observed values at WHG1 station.

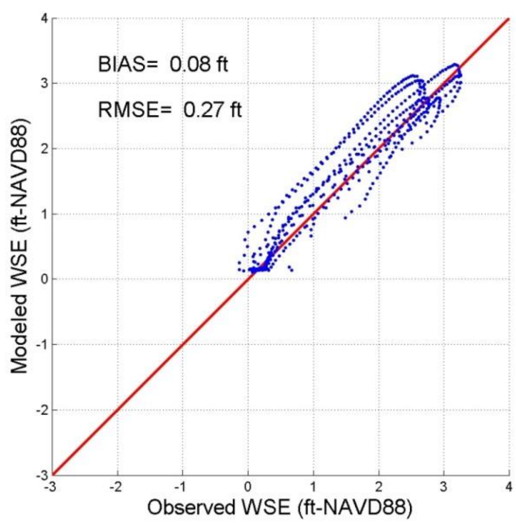


Figure 4-10. Water surface elevation (WSE) scatter plot for WHG1 station.

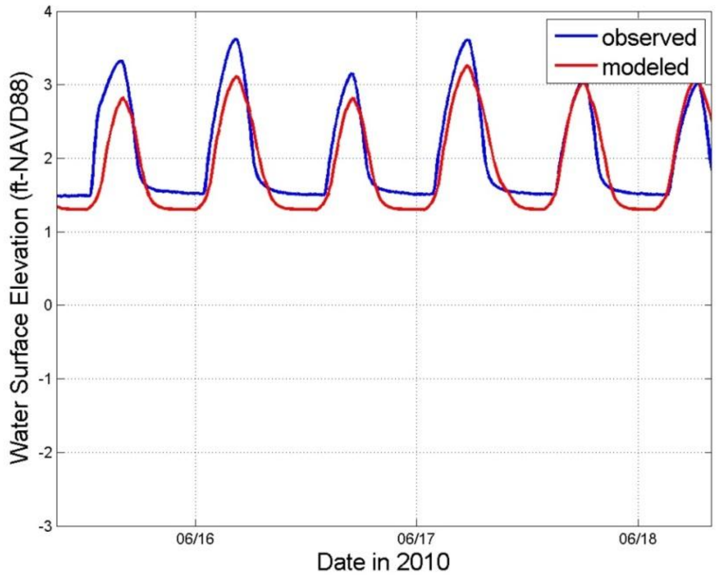


Figure 4-11. Water surface elevation time series comparing model results to observed values at DER1 station.

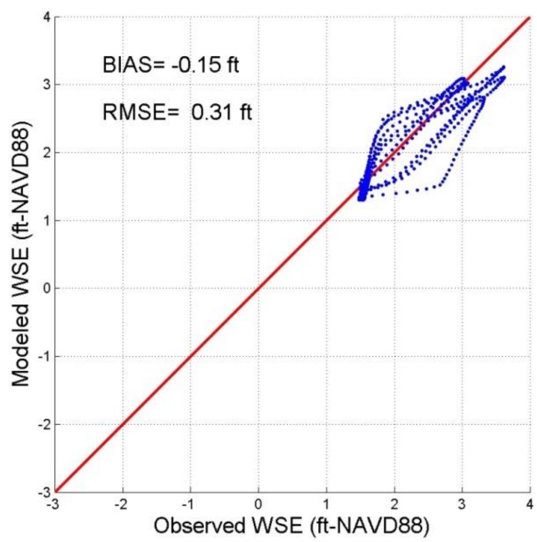


Figure 4-12. Water surface elevation (WSE) scatter plot for DER1 station.

Table 4-1. Water surface elevation error statistics for model calibration.

Gauge ID	Absolute Error (ft)		Observed Range (ft)	Relative Error (%)	
	RMSE	BIAS		RMSE	Bias
WHG2	0.30	-0.07	5.8	5.2	-1.2
WHG1	0.27	0.08	3.9	6.9	2.1
DER1	0.31	-0.15	2.2	14.1	-6.8

Table 4-2. Manning's n values for culverts applied in the calibrated model.

Culvert ID	Manning's n	
	Ebbing flow	Flooding flow
B	0.08	0.08
C	0.06	0.03
D	0.025	0.025
E	0.03	0.03
G	0.04	0.08

4.4 MODEL VALIDATION

Prior to using a hydrodynamic model as a predictive tool it is common practice to validate the model to confirm the model's applicability to a reasonable range of conditions. The Ballard Street marsh system model was validated to data collected when the tide gate was in place, while it was calibrated to data collected when the tide gate was removed. Additional model validation was also conducted for a completely independent data set (section 6.0). Validation involves applying the calibrated model to a set of observed data that are independent from the calibration data set without changing the model configuration or parameterization. However, because during the validation period the tide gate on the Ballard Street culvert was in place, it was necessary to use a slightly different model parameterization at the Ballard Street culvert to simulate the effects of the tide gate. Inspection of the tide gate, as well as analysis of the observed water level and salinity data, clearly shows that a significant amount of seawater enters the marsh system through the Ballard Street culvert during a flooding tide even when the tide gate is in place. To simulate the leaking gate it is assumed that the gate imposes an additional restriction to the culvert, which is accounted for by increasing the Manning's n value used for flooding flow. A series of simulations were conducted with increasing values until the simulated water levels in the marsh matched the observed values. A Manning's n value of 0.3 ultimately produced the best agreement. All other model parameters (e.g., marsh and channel friction, other culverts, etc.) were maintained at the calibrated values for the validation simulation.

The Ballard Street marsh system model was validated with observations made between May 26th, 2010 and June 9, 2010. During this timeframe the tide gate was in place. The water surface elevation observed in Saugus River during the validation period is shown in Figure 4-13. This time period captures a full fortnightly spring-neap cycle in the river. During this period the tide range varies from nearly 12 feet during the spring tide to less than 8 feet during the neap. The spring high of 6.2 ft-NAVD88 observed at 10:46 pm on May 26th was the highest water level recorded during the 30-day observation period. Validation during this period ensures the model can accurately simulate the range of water levels experienced in the Ballard Street marsh during normal tidal conditions, and combined with the calibration, ensures the model can simulate the system with and without the tide gate in place.

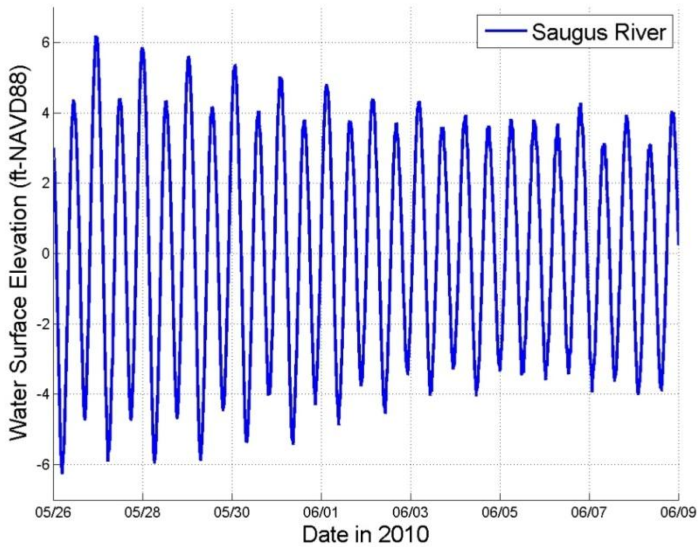


Figure 4-13. Saugus River water surface elevation observed during model validation period.

The results of the validation simulation are presented in the same fashion as the calibration results, and error statistics are calculated in the same way. Figure 4-14 shows a comparison of the observed and modeled water surface elevation time series at the WHG2 station, while Figure 4-15 shows the water surface elevation scatter plots. The error statistics for all stations are summarized in Table 4-3. The RMSE is less than 4 inches at all locations, while the magnitude of the bias is less 3 inches and the relative errors are less than 10% at all gauge locations. The model slightly under predicted freshwater input during rainfall events, but simulated the tidal processes well. Overall, the validated model performs well in reproducing the observed water levels, and the required error statistic is well within criteria established by EPA (1990).

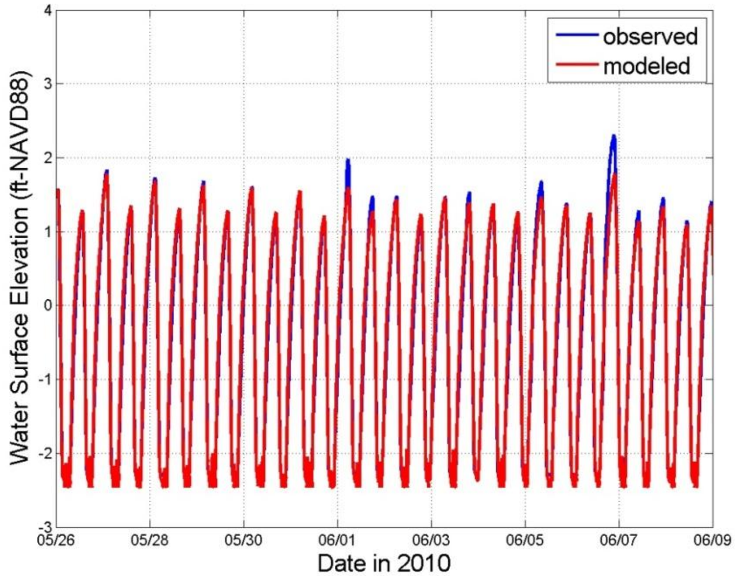


Figure 4-14. Water surface elevation time series comparison between model results and observations at WHG2 station.

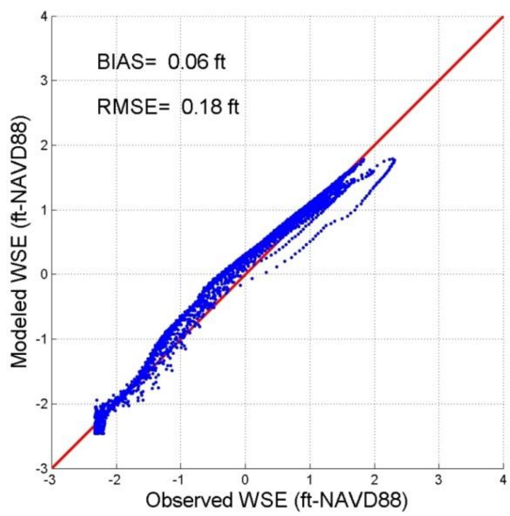


Figure 4-15. Water surface (WSE) elevation scatter plot at WHG2 station.

Table 4-3. Water surface elevation error statistics for model validation.

Gauge ID	Absolute Error (ft)		Observed Range (ft)	Relative Error (%)	
	RMSE	BIAS		RMSE	Bias
WHG2	0.18	0.06	5.8	3.1	1.0
WHG1	0.28	0.00	3.9	7.2	0.0
DER1	0.22	-0.18	2.2	10.0	-8.2

4.5 EXISTING CONDITIONS SIMULATIONS

The calibrated and validated model was further applied to simulate a number of scenarios to aid in understanding the behavior of the Ballard Street marsh system in its existing state. In addition to providing better understanding of the current system, these simulations also provide a baseline for comparison to future alternative simulations to help determine the impacts of proposed restoration alternatives. These simulations include simulations of normal tides, a significant rainfall event, a tidal flood event, and projected Sea Level Rise (SLR). Water surface elevation boundary conditions for these simulations were created by modifying the water surface elevation time series observed in the Saugus River. Rainfall input was determined using standard methods developed by the National Resources Conservation Service (NRCS) and the Soil Conservation Service (SCS), and subsequently modified by newer approaches provided by the Northeast Regional Climate Center at Cornell University. Additionally, six stations within the system were chosen to aid in comparison of model output for the various scenarios and alternative simulations, as shown in Figure 4-16.

4.5.1 Normal Tides

Boundary conditions for the normal tides simulation were based on observations of a fortnightly spring-neap cycle beginning on May 26th 2010. The normal tides simulation, therefore, is similar to the validation period simulation, but without meteorological forcing (observation specific rainfall, winds, etc.). This time period captures both spring and neap portions of a normal tidal cycle with the tide range in the Saugus river ranging from nearly 12 feet during a the spring tide to less than 8 feet during the neap tide.

Figure 4-17 shows the water surface elevation results for all six output locations, as well as the forcing boundary condition in the Saugus River (dotted line). A number of basic tidal statistics were determined from the time series output including: Mean High Water (MHW), Mean Low Water (MLW), Mean Tide Level, tidal range, and the minimum and maximum water levels. MHW is the average of all high tide elevation during the simulation period, MLW is the average of all low tide elevations during the simulation period, MTL is the average elevation of MHW and MLW, and the tidal range is the difference between MHW and MLW. These computed tidal benchmarks are only representative of the 14 days simulated in the model and are not necessarily the same as the tidal benchmarks that would result from a complete 19-year tidal epoch. The tidal statistics are listed in Table 4-4. The maximum and minimum water surface elevations during the normal tides simulation (the highest and lowest water surface elevation in the simulated spring-neap cycle) were also determined for each cell in the domain. Figure 4-18 graphically shows these values as contours of the maximum and minimum extent of inundation within the marsh for normal tides. The blue contours shows the minimum extent of inundation and the red contour shows the maximum extent of inundation. From these data, the area of inundation was also computed separately for both the west and east portions of the marsh.

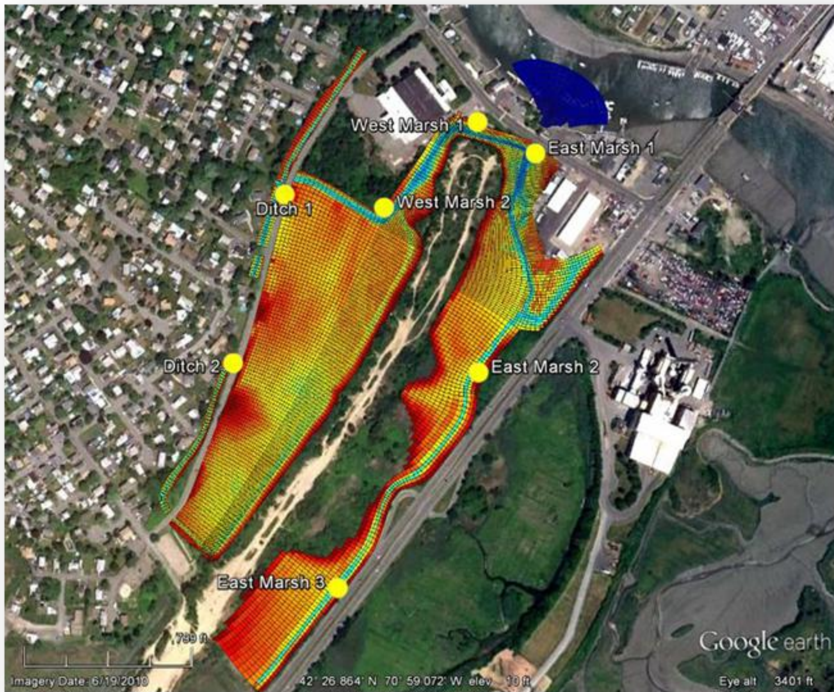


Figure 4-16. **Ballard Street marsh hydrodynamic model time series output stations used for comparing various scenarios.**

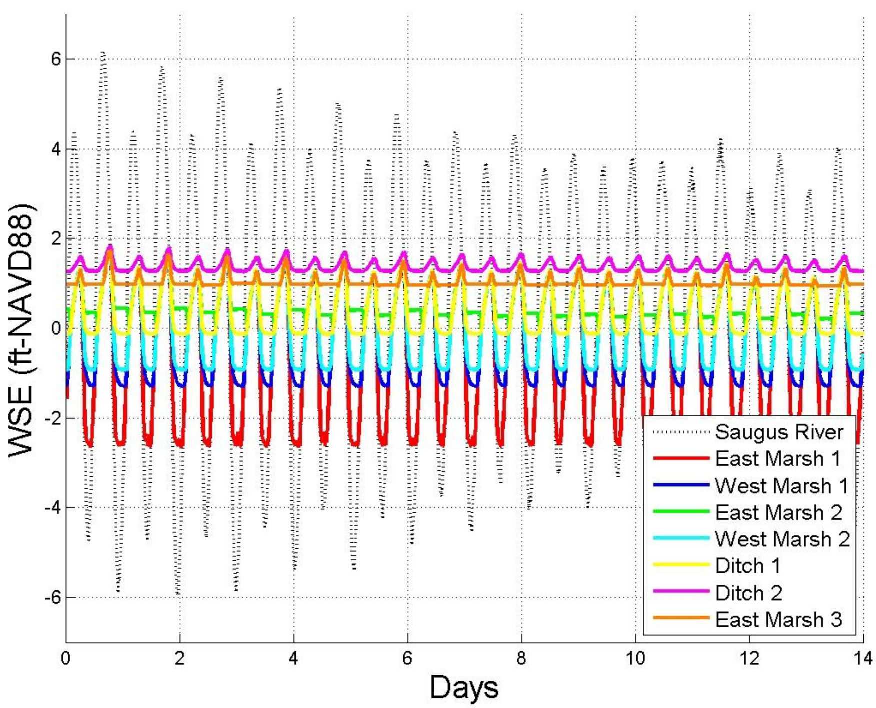


Figure 4-17. **Water surface elevation time series for existing conditions normal tides simulation.**

Table 4-4. Tidal statistics for existing conditions in the Ballard Street marsh (elevations in ft-NAVD88.)

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	4.2	-4.3	-0.1	8.5	-5.9	6.2
East Marsh 1	1.4	-2.6	-0.6	4.0	-2.6	1.8
West Marsh 1	1.4	-1.3	0.0	2.7	-1.3	1.8
East Marsh 2	1.4	0.0	0.7	1.4	0.0	1.8
West Marsh 2	1.4	-0.9	0.2	2.3	-0.9	1.8
Ditch 1	1.4	-0.1	0.6	1.5	-0.1	1.8
Ditch 2	1.6	1.3	1.5	0.3	1.3	1.9
East Marsh 3	1.4	0.9	1.2	0.5	0.9	1.7

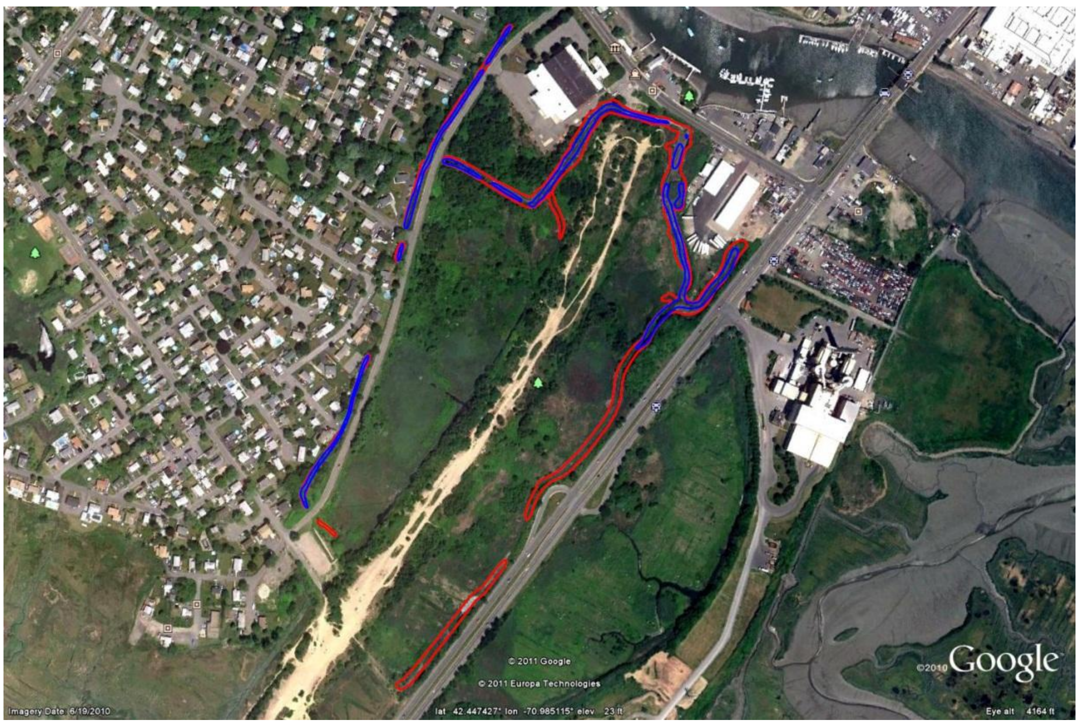


Figure 4-18. Contours of tidal maximum (red) and minimum (blue) water surface elevation during normal tides for existing conditions. Disconnects in the water surface elevation contours represent culverts and/or areas that are shallow water.

The difference between the maximum and minimum inundated area provides an estimate of the intertidal area in the marsh for normal tidal conditions. The results for inundated area and intertidal area are listed in Table 4-5. The maximum and minimum intertidal represent the area inundated over the time period when the model was simulated (a typical spring/neap tidal cycle). Therefore, the maximum inundated area is close to the area inundated by a monthly high tide, while the minimum inundated area is close to the area inundated by a monthly low tide. These intertidal areas are used as a general proxy as the level of restoration that may be expected for each alternative. The exact distribution of wetland classification zones (e.g., high marsh, low marsh, mudflat, etc.) is not presented; however the intertidal areas are expected to correspond to primarily restored high and low marsh regions.

Table 4-5. Inundated marsh area and intertidal area for existing conditions (with the tide gate in place) under normal tides. Maximum and Minimum inundated areas include ponded regions that are not presented in Figure 4-22.

Site	Maximum Inundated Area (acres)	Minimum Inundated Area (acres)	Intertidal Area (acres)
East Marsh	5.0	4.1	0.9
West Marsh	6.0	5.3	0.7

Figure 4-19 also provides a graphical summary of existing conditions at Ballard Street marsh. The figure shows the extent of water within the marsh system during a typical Mean Low Water elevation and a Spring High Water elevation. Figure 4-19 also shows some areas within the marsh that regularly pond water and have limited tidal exchange. These areas either fill with water during precipitation events, and/or receive intermittent tidal water during higher spring tides. Culverts within the system are color coded (shown in the key) as open (green), blocked (red), or gated (yellow) and the subpanel in the left hand corner shows the tide range in the Saugus River and in the Ballard street marsh for existing conditions.

Under existing conditions, the culvert and tide gate at Ballard Street impose a significant restriction on tidal flow as mean tide range is reduced by about 4.5 feet between the river and the upstream side of the culvert, and approximately 6 feet reduction between the Saugus River and the marsh. The existing tide gate is also somewhat effective in reducing the tide levels in the marsh. Although flooding tides regularly enter the marsh through the leaky tide gate, the mean tide level is reduced by 0.5 feet and the maximum water level within the marsh is limited to less than 2 feet-NAVD88, approximately 4 feet less than the spring high observed in the Saugus River. Within the marsh system, MHW is nearly constant suggesting that tidal flow within the system may be relatively unrestricted (once the tide propagates beyond the Ballard Street culvert), and tidal range differences are controlled by invert elevations of channels or culverts. MHW is slightly higher at the Ditch 2 location due to the inflowing freshwater and restricted drainage imposed by the long culvert parallel to Eastern Avenue (Culvert C). Observations show that water levels in this portion of the ditch are primarily non-tidal when the tide gate is in place and fluctuations in the water surface elevation are more dominated by rainfall events. A comparison of the minimum water levels with the bottom elevation shows that the minimum water levels are primarily controlled by the channel depth in the system. This suggests that drainage within the marsh could be enhanced by clearing and/or deepening the various channels and ditches within the marsh. The restriction on the flooding tide caused by the Ballard Street culvert and tide gate keeps the water primarily within the system's channels and ditches and limits the intertidal area in the marsh to less than 2 acres under normal tidal conditions. This illustrates the degraded nature of the system and indicates the system has been significantly impacted by anthropogenic activities. This also indicates that the current altered marsh plain elevation is too high to allow for significant restoration and that some level of re-grading may be required. Finally, the blockage of the Bristow Street culvert under current conditions eliminates another significant source of tidal exchange to the Ballard Street system.

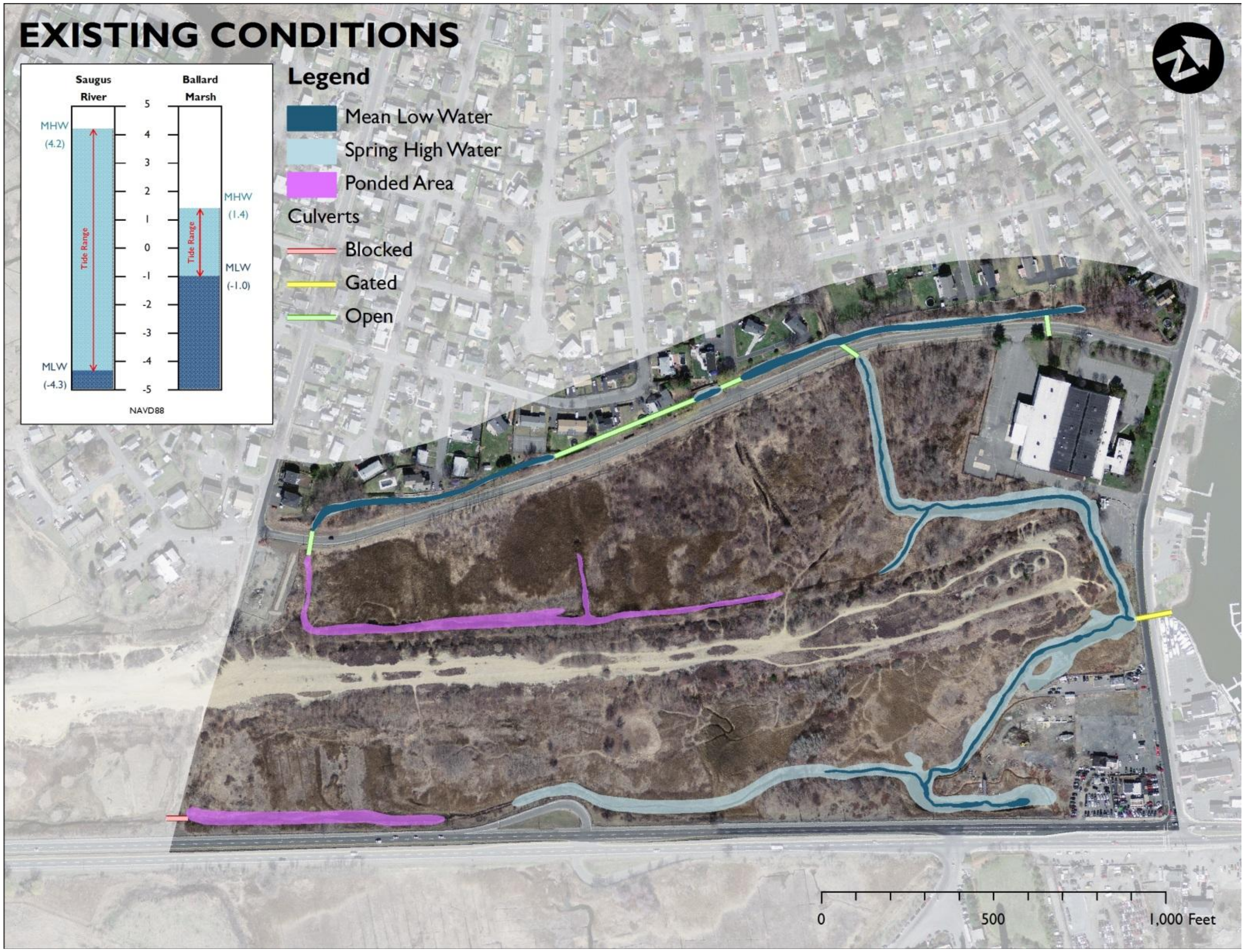


Figure 4-19. **Graphical representation of MHW and MLW water levels within the Ballard Street marsh system for normal tidal conditions (results from model simulation).**

4.5.2 Tidal Flood Event

A tidal flood event was simulated to show how the existing system might respond to a storm surge in the Saugus River. A water surface boundary condition was generated by adding a storm surge to the observed water surface elevation time series in the Saugus River. The peak of the surge was made to coincide with a spring high tide resulting in a storm tide with a peak water level of 7.7 feet-NAVD88, which was determined to be the low point at Ballard Street in the vicinity of the culvert (NRCS, 1999)[1]. This storm surge level corresponds to approximately a 10-year return period storm according to the New England Tidal Flood Profiles (USACE, 1988). A storm tide above this elevation would overtop Ballard Street rendering the Ballard Street culvert inconsequential, since significantly larger volumes of water would be flowing directly over Ballard Street. Figure 4-20 shows the storm tide boundary condition that was used to simulate the storm surge event.

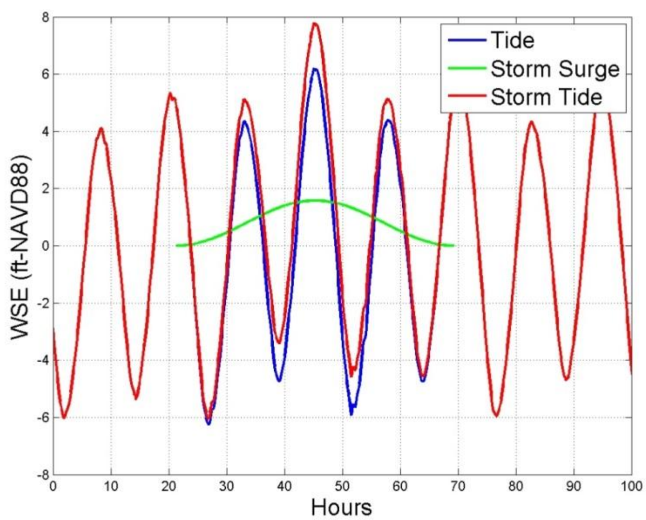


Figure 4-20. Tide, storm surge, and storm tide hydrograph for tidal flood event simulations. Peak water surface elevation of 7.7 feet NAVD88.

Water surface elevation time series results are presented in Figure 4-21 for the simulated storm surge event. Table 4-6 lists the maximum water levels simulated at the output locations. The results indicate that the combined restriction imposed by the Ballard Street culvert and tide gate is effective in preventing significant flooding from a tidal flood event that does not overtop Ballard Street. However, once Ballard Street is overtopped, then more significant flooding of the Ballard Street marsh system could be expected.

[1] Subsequently, more detailed topography indicated that the low point in the road was actually 7.1 feet-NAVD88 (section 6.0)

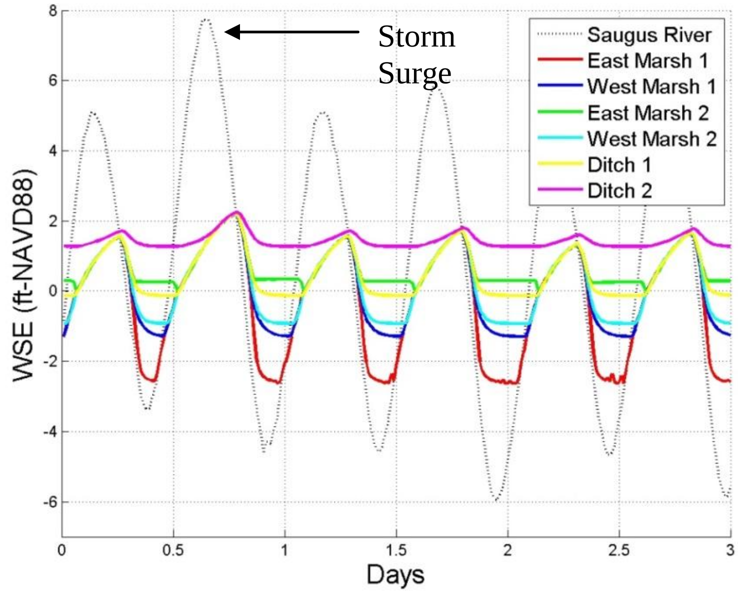


Figure 4-21. Water surface elevation (WSE) time series for existing conditions tidal surge simulation. The storm surge occurs in the second tidal cycle in the simulation between 0.5 and 1 days (water surface elevation reaches 7.7 feet NAVD88).

Table 4-6. Maximum water levels for existing conditions tidal surge simulation.

Location	Maximum Water level (ft-NAVD88)
Saugus River	7.7
East Marsh 1	2.2
West Marsh 1	2.2
East Marsh 2	2.2
West Marsh 2	2.2
Ditch 1	2.2
Ditch 2	2.2

Figure 4-22 provides a graphical summary of a storm surge condition at Ballard Street marsh for existing conditions for cases with and without the existing flap at the Ballard Street culvert. Although the Ballard Street marsh system and surrounding area is certainly vulnerable to flooding due to a storm surge event (primarily due to the low surrounding topography at Ballard Street), significant flooding will likely only occur when Ballard Street is overtopped. Even with no tidal control (tide gate removed as simulated in section 5.0); the limited size of the existing culvert does not allow enough water to enter the system to produce any significant infrastructure flooding (Figure 4-22). As described below (section 4.5.3), a greater threat to local flooding is heavy precipitation events. Therefore, any proposed restoration should ensure that there is an improved flood storage capacity, as well as the ability to provide improved storm water drainage from the system.

4.5.3 100 Year 24 hour Rainfall Event

Boundary conditions for the 100-year, 24-hour precipitation event were generated using methodologies developed by the NRCS and its precursor, the U.S. Soil Conservation

Service (SCS). For the Ballard Street marsh, the 100-year 24-hour precipitation event is an event with an annual 1% chance of occurrence in which 6.65 inches of effective rainfall occurs within a 24 hour period (Hershfield, 1961)[2]. At the time when these scenarios were being develop, Woods Hole Group assumed this rainfall amount was reasonable and has not completed any analysis to assess this level of rainfall event. However, subsequent analysis was completed as the project continued to evolve (section 6.0). Figure 4-23 shows the sub-watersheds that drain into the Ballard Street marsh system, as determined by NRCS (1999). Rainfall into sub-watersheds 6 and 8 is accounted through direct rainfall input. Rainfall into watersheds 2 and 4 is accounted for via freshwater inflow into source cells at the locations shown in Figure 4-6.

A rainfall hyetograph, generated using the NRCS type III rainfall intensity distribution, is shown in Figure 4-24(A). This hyetograph is used to specify rainfall input to sub-watersheds 2 and 4, and to generate the runoff hydrograph from sub-watersheds 6 and 8. A runoff hydrograph was developed using the SCS dimensionless unit hydrograph method. This method reduces to a one-parameter model with the time of concentration, t_c, as the single parameter that can be related to the watershed geometry (Singh, 1992). The variable t_c is related to the lag time, t_l, for the watershed and is estimated using the Snyder method:

$$t_l = C_t (LL_c)^{0.3} \tag{8}$$

$$t_c = \frac{t_l}{0.6} \tag{9}$$

Where L is the length of the main stream of the watershed in miles, L_c is the distance in miles from the outlet of the watershed to a point in the main stream near the center of the watershed, and C_t is a constant, which is taken as 2.0 for this application (Singh, 1992). L and L_c were estimated from the sub-watershed map as roughly the length, 0.7 miles, and half the length, 0.35 miles, of sub-watershed 2 resulting in a time of concentration of 2.4 hours. The duration and time to peak of the dimensionless unit hydrograph are then determined from time of concentration, and the runoff hydrograph is computed as the convolution of the rainfall hyetograph and dimensionless unit hydrograph. The resulting runoff hydrograph is show in Figure 4-24(B). The total runoff volume over the duration of the hydrograph is approximately 60 acre-ft which is equivalent to the runoff volume used in the previous modeling effort by the NRCS (1999). At the time of this portion of the study, Woods Hole Group had assumed that the amount of rainfall runoff is reasonable and has not completed any analysis to assess this runoff volume. Subsequently, additional analysis on the precipitation events were completed (section 6.0) that resulted in modification of the precipitation event. Timing of the model input was generated such that the timing of the peak runoff coincides with a spring high tide in the marsh system observed over the monitoring period such that conservative estimates of potential flooding could be determined.

[2] The return period precipitation values were subsequently modified using a new methodology as presented in Chapter 6.

Figure 4-22. **Graphical representation of water levels within the Ballard Street marsh system for storm surge conditions (results from model simulation).**

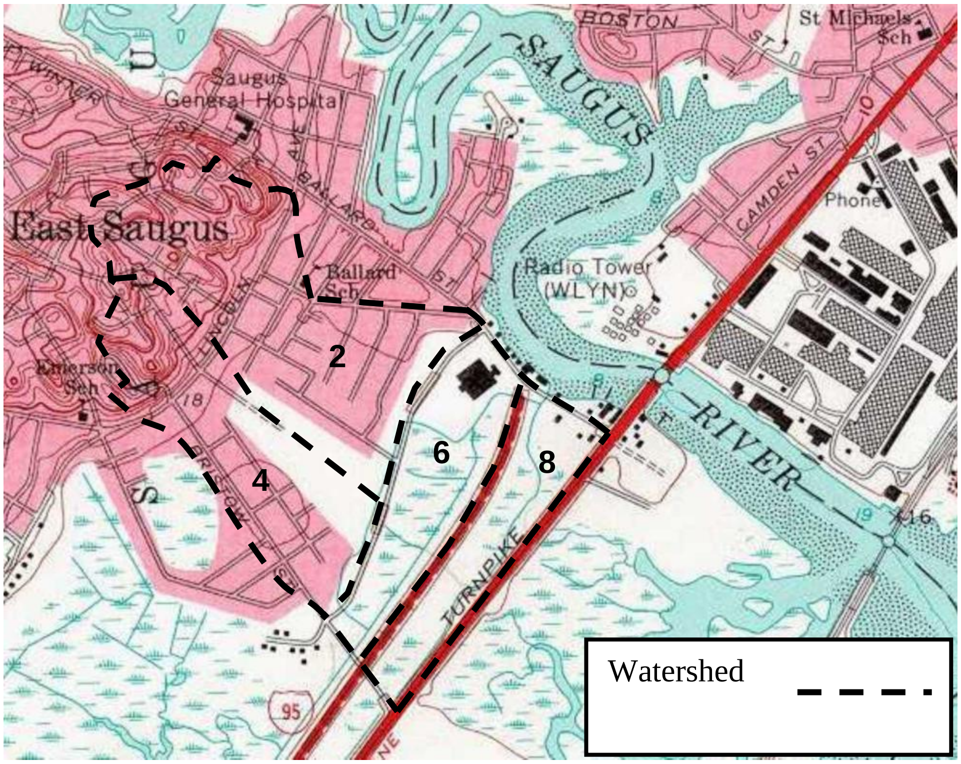


Figure 4-23. Watershed and sub watershed map taken from NRCS report (1999).

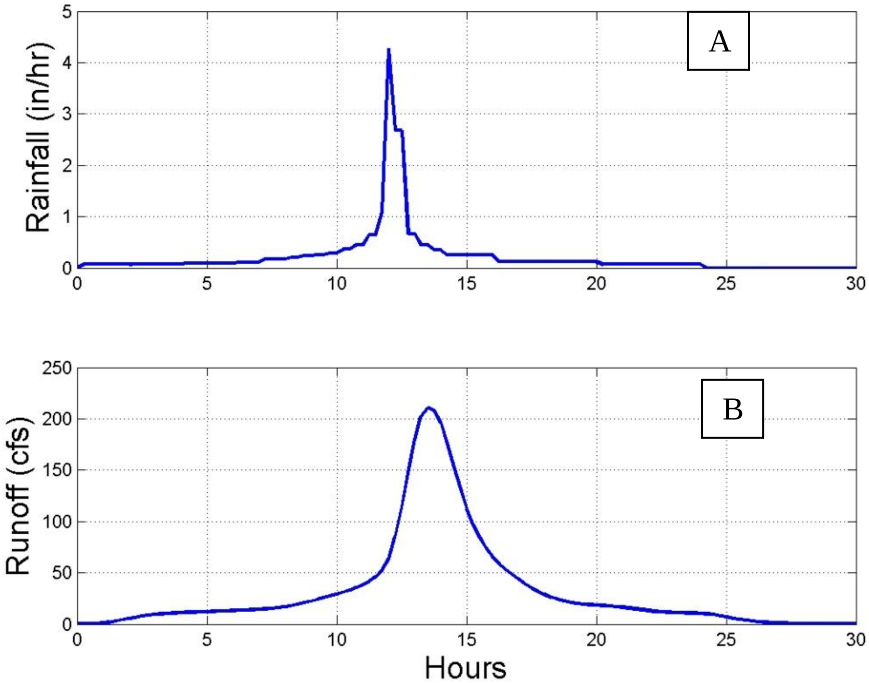


Figure 4-24. Rainfall hyetograph (A), and runoff hydrograph (B) for the 100-year return period 24 hour precipitation event.

Water surface elevation time series results are shown in Figure 4-25 and maximum water levels during the passage of the rainfall event are listed in Table 4-7. The results show a significant increase in water levels within the entire marsh system resulting from the precipitation and runoff inputs. The time series results indicate that water levels take approximately 24 hours to return to normal (drain from the system). The water level peaks at approximately the same elevation, 5.8 feet-NAVD88, throughout the main portion of the marsh. At the Ditch 1 location, just upstream of the large Eastern Avenue culvert, the peak water level is only slightly higher at 5.9 feet-NAVD88. These peak water levels are slightly above 5.6 feet-NAVD88, the elevation at which NRCS (1999) assumed damage to local infrastructure would occur[3]. The peak water level at the Ditch 2 location is significantly higher at approximately 7 feet-NAVD88 and would result in significant flooding of the local community. This significant increase in water level is likely due to the restrictions imposed by the ditch culverts (e.g., Culvert C) that connect this portion of the ditch to the rest of the marsh system and the watershed discharge that enters this area of the system. As such, under current conditions, if a rainfall event of this magnitude occurred, significant flooding could be expected regardless of any restoration project. The current marsh system lacks adequate storage capacity and there is poor drainage from the ditch network that runs parallel to Eastern Avenue.

Figure 4-26 provides a graphical summary of an extreme precipitation condition (100-year return period) at Ballard Street marsh for existing conditions. It should be noted that the shaded areas represent areas where water would reside; however this is only for within the modeling domain (Figure 4-3) and does not provide graphical representation of the areas outside of the modeling domain that would be flooded under this scenario. For example, the neighborhood to the west of the Eastern Avenue ditch would experience flooding up to an elevation of approximately 7.0 feet NAVD88. The key indicates the elevation of storm water that occurs throughout the system. The figure also indicates the poor drainage capacity of certain culverts that cause significant drainage concerns in the ditch that parallels Eastern Avenue.

Table 4-7. Maximum water levels for existing conditions 100-year rainfall event simulation.

Location	Maximum Water level (ft-NAVD88)
East Marsh 1	5.8
West Marsh 1	5.8
East Marsh 2	5.8
West Marsh 2	5.8
Ditch 1	5.9
Ditch 2	7.0

[3] This was the lowest elevation measured by NRCS. Subsequent additional survey of the infrastructure west of the Ballard Street Marsh identified the lowest structural (house) elevation at 5.25 feet NAVD88 (see section 6.0).

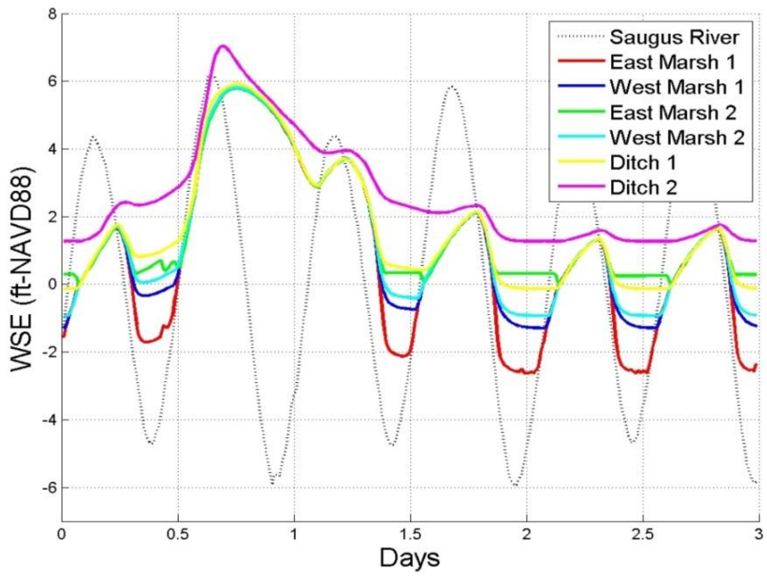


Figure 4-25. Water surface elevation (WSE) time series for existing conditions 100-year, 24-hour rainfall event.

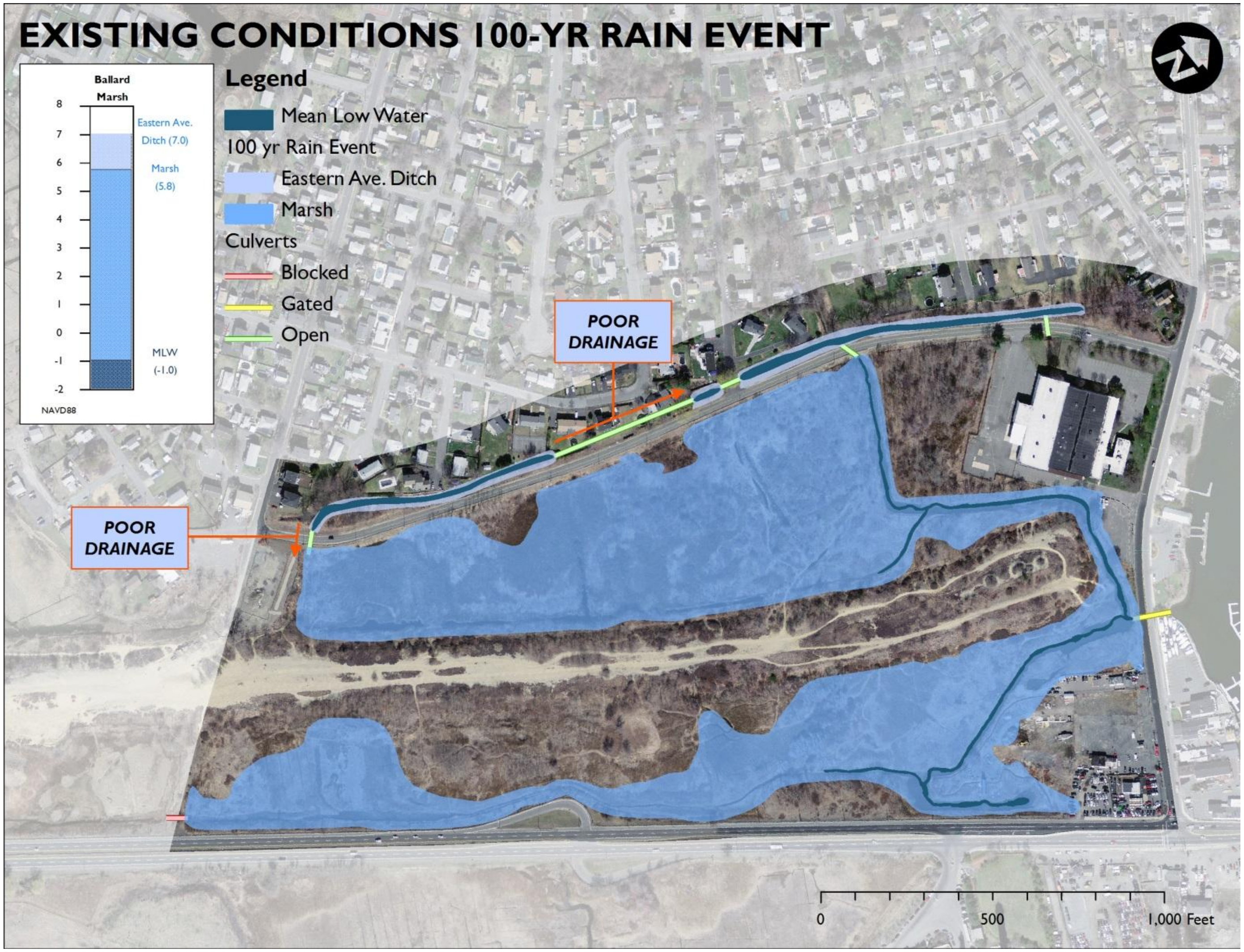


Figure 4-26. Graphical representation of water levels within the Ballard Street marsh system for an extreme rainfall scenario (results from model simulation).

4.5.4 Sea Level Rise

The potential impacts of sea level rise present another scenario to consider in evaluating the restoration potential of the Ballard Street marsh system. The topic of accelerated sea level rise (SLR) in the 21st century and beyond has been the subject of much debate. The Intergovernmental Panel on Climate Change (IPCC) has spent considerable time and energy reviewing and analyzing the current state of knowledge of past and future changes in sea level in relation to climate change. Taking this information, the United States Army Corp of Engineers (USACE) has developed guidance for incorporating sea-level change considerations in civil works programs (USACE, 2009). Under this design guidance, the USACE provides three predicted rates of sea level rise (high, intermediate, and low) to use in the design of civil works projects. The Corps guidance uses current local sea level rise rates based on historic tide data to form projections for the "low" scenario, and a combination of these local rates with IPCC (2007) scenarios and the National Research Council's (1987) equations for the "intermediate" and "high" scenarios for accelerated sea level rise. This method derives locally specific estimates for sea level rise that span a broader range of scenarios than the IPCC estimates alone. Sea level change values for the three scenarios at 50 years from now based on these methods for the Boston area are listed in Table 4-8. These values were added to the normal tides boundary condition to produce boundary conditions for the sea level rise scenarios. It is important to consider, however, that as global and regional sea level changes the tidal hydrodynamics outside the Saugus River will likely result non-uniform changes in sea level within the river. Thus, the assumption that sea level will rise uniformly in the Saugus River, in addition to the inherent uncertainty in sea level rise prediction alone, leads to a significant amount of uncertainty in the results of sea level rise simulations.

Table 4-8. Sea level rise scenarios for Boston, sea level increase from 2011 (feet).

Future Year	Low	Intermediate	High
2061	0.43	0.82	2.08

Simulations were conducted corresponding to the low and intermediate scenarios for 50 years into the future. The high scenario was not simulated because an increase in more than 1.6 feet in relative sea level would cause overtopping of Ballard Street and Bristow Street on the spring high tide. A comparison of water surface elevation time series for the SLR simulations at the East Marsh 1 output location is shown in Figure 4-27. Tidal statistics for the SLR simulations are listed in Tables 4-9 and 4-10 for the low and intermediate scenarios, respectively. The results show a uniform increase in the MHW and maximum water levels within the marsh with no corresponding increase in MLW or the minimum water levels. For the low SLR scenario, MHW and the maximum water levels increase about 0.1 feet. For the intermediate SLR scenario, MHW and the maximum water levels increase about 0.25 feet. For both scenarios, the increase in MHW and the maximum water level within the marsh system is roughly 25% of the increase in Saugus River. Table 4-10 shows some increase in the low tide elevations during the neap portion of the tidal cycle. This increase occurs when the neap low tides no longer drop below the invert elevation of the Ballard Street culvert. As such, flow is controlled by the low tide elevation in the Saugus River rather than the invert elevation of the culvert.

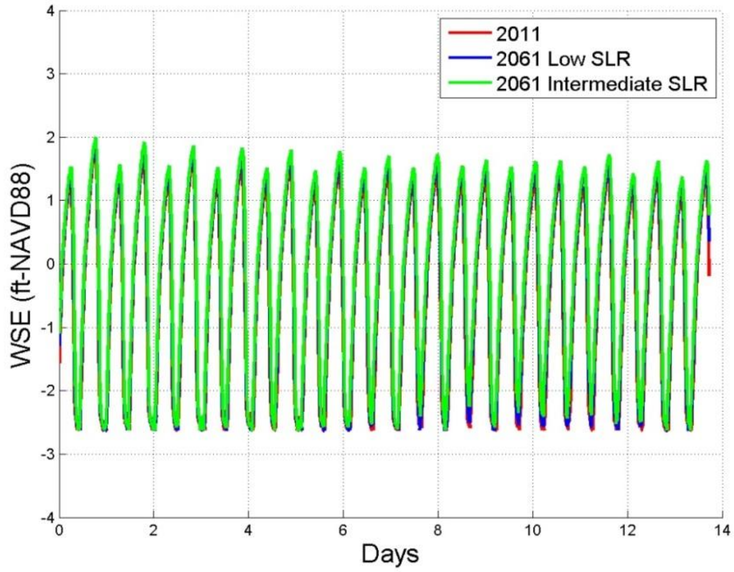


Figure 4-27. Water surface elevation (WSE) time series at East Marsh 1 output location for sea level rise scenarios.

Table 4-9. Tidal statistics for the low SLR scenario (elevations in ft-NAVD88).

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	4.7	-3.9	0.4	8.6	-5.5	6.6
East Marsh 1	1.5	-2.6	-0.5	4.1	-2.6	1.9
West Marsh 1	1.5	-1.3	0.1	2.8	-1.3	1.9
East Marsh 2	1.5	0.0	0.8	1.5	0.0	1.9
West Marsh 2	1.5	-0.9	0.3	2.4	-0.9	1.9
Ditch 1	1.6	-0.1	0.7	1.7	-0.1	1.9
Ditch 2	1.7	1.3	1.5	0.4	1.3	2.0

Table 4-10. Tidal statistics for the intermediate SLR scenario (elevations in ft-NAVD88).

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	5.1	-3.5	0.8	8.6	-5.1	7.0
East Marsh 1	1.6	-2.5	-0.5	4.1	-2.6	2.0
West Marsh 1	1.6	-1.3	0.2	2.9	-1.3	2.0
East Marsh 2	1.7	0.0	0.8	1.7	0.0	2.0
West Marsh 2	1.7	-0.9	0.4	2.6	-0.9	2.0
Ditch 1	1.7	-0.1	0.4	1.8	-0.1	2.0
Ditch 2	1.8	1.3	1.5	0.3	1.3	2.1

Overall, the SLR results suggest the Ballard Street culvert and tide gate may somewhat mitigate the effect rising relative sea levels on high tide elevations within the marsh. However, as low tide elevations increase with rising sea levels the ability of the tide gate to reduce mean water levels within the marsh diminishes. As such, due to the uncertainty associated with projected SLR, it is recommended that some form of tidal control is still provided as part of the restoration design. This will allow for adaptive management of the marsh restoration project, the ability to control non-linear flow capacity (e.g., allowing more water out of the system than into the system), and preparedness for unforeseen projected sea level rise or storm conditions.

5.0 PRELIMINARY ALTERNATIVE SIMULATIONS

Using the calibrated and validate hydrodynamic model, a number of potential alternatives were evaluated and are presented in the following sections. These alternatives evolved throughout the project and included various modifications to the original WHG scope of work. The alternatives are presented as sets, corresponding to the ongoing project evolution. The alternatives are categorized into 3 distinct alternative sections as follows:

- This section (section 5.0) presents a preliminary subset of restoration alternatives considered for the Ballard Street marsh system. This included the pre-existing NRCS alternative(s), as well as some investigative alternatives that evaluated minimal changes to the existing system to provide potential low cost alternatives. Specifically, this subset of alternatives included (1) the originally documented NRCS alternative (NRCS, 1999); (2) a modified NRCS alternative that was adjusted based on comments from the Environmental Protection Agency (EPA), DER, and other stakeholders; and (3) an alternative that evaluated simple modifications to the Ballard Street culvert (e.g., removal of the existing tide gate). These simulations also include limited information about the eastern marsh (topography, tides, etc.), and therefore, overpredict the restoration in the eastern marsh. Subsequently, new information was collected in the eastern marsh for the subsequent model runs.
- Section 6.0 presents a refined NRCS alternative developed by Woods Hole Group using updated information (e.g., new precipitation data, new topographic data, dynamic simulations of storm events, etc.). The intent of this alternative was to keep the same concept as the NRCS proposed restoration project, but update the components of the restoration (e.g., excavation amounts, culvert sizes, tide gate implementation, etc.). This was the preferred alternative prior to the inclusion of the DCR excavation from the abandoned I-95 embankment.
- Section 7.0 evaluates restoration alternatives integrated with the proposed DCR extraction effort. The final preferred alternative includes a new marsh gradation and layout, new marsh creek locations, reconsideration of all culverts and flow control structures, and the required excavation for flood storage during severe precipitation events. This section also presents the components of the final preferred alternative for restoration of the Ballard Street marsh system.

The previous wetlands restoration investigation undertaken by the NRCS (1999) recommended a preliminary design that allowed for restoration of a portion of the salt marsh, while also improving local flood protection. This design involves excavation in the western portion of the marsh to create a large storage area for storm water, the construction of a new tide gate separating the east and west portions of the marsh, and the construction of a new culvert under Eastern Avenue (NRCS, 1999). The two dimensional Ballard Street salt marsh hydrodynamic model presented herein, along with updated survey data (tide and topographic), were used to assess the initial NRCS proposed design (presented in NRCS, 1999), as well as a modified NRCS design developed by EPA, the Town, and the Massachusetts Division of Ecological Restoration (DER) in concert with NRCS.

The proposed NRCS design, which was based on inaccurate survey information, may have been overly conservative with respect to the amount of excavation required for flood storage. The incorrect survey elevations were artificially high, indicating that more significant excavation would be required to meet the NRCS flood storage requirement (Appendix A). Additionally, limited data observations and utilization of a simplified 1-D model may have created further uncertainties. DER recognized some of these potential shortcomings, and desired a re-evaluation of the NRCS proposed design.

This section describes modifications made to the Ballard Street marsh hydrodynamic model to simulate the NRCS preliminary and modified proposed concepts and presents results of simulations of the proposed design under the same scenarios evaluated for existing conditions (normal tides, a storm surge event, and a 100-year, 24-hour rainfall event)[4]. A simple alternative, primarily for comparison purposes, that considered the replacement of the Ballard Street tide gate with a new structure that would allow for better control of tides in the system was also evaluated. This alternative eliminated the new culvert and tide gate structure that was being proposed at the I-95 embankment area and that would separate the east and west basins of the marsh system, but also likely limited the restoration area. Finally, the final preferred NRCS alternative, developed after the initial NRCS design following discussions with DER and the Town of Saugus, was simulated.

5.1 PRELIMINARY NRCS ALTERNATIVE

Modifications were made to the existing conditions Ballard Street marsh hydrodynamic model to simulate the preliminary NRCS alternative. The modifications are based on the recommended components obtained directly from the NRCS investigation (1999). These recommend measures include:

- a new culvert and flap tide gate at the northern end if the I-95 fill berm separating the east and west portions of the marsh,
- an excavated storage area in the western portion of the marsh,
- an auxiliary culvert connecting the ditch on the west side of Eastern Avenue to the storage area, and
- drainage channel construction and maintenance.

Figure 5-1 shows the modified EFDC grid, modified elevations, and recommended NRCS alternative measures. To implement the preliminary NRCS recommended I-95 culvert and flap tide gate, this proposed flow control structure was to be placed at the north end of the I-95 berm and allow only flow out of the system. This effectively separated the east and west portions of the marsh. An 8 feet wide by 4 feet tall box culvert with a length of 30 feet and an invert elevation of -2.9 feet-NAVD88 was to be placed and configured so that water could only flow from the west to east (i.e. toward the Saugus River) as proposed by the preliminary NRCS design (1999). The excavated storage area was created by modifying grid cell elevations in the western marsh area

[4] Sea level rise scenarios were only conducted for the final preferred alternative. If the alternative was not optimal for normal tidal conditions, or storm conditions, there was no need to simulate sea level rise scenarios.

between the I-95 fill and Eastern Avenue. The modified area is approximately 17 acres, slopes from an elevation of 1.7 feet-NAVD88 at the southern end to an elevation of 0.7 feet-NAVD88 at the northern end, and is intersected by a system of meandering drainage channels with an invert elevations of -2.4 feet-NAVD88. Based on the geometry of the existing conditions model grid (created from the updated survey), the recommended excavation would require a cut volume of 97,000 cubic yards from the western marsh. An auxiliary Eastern Avenue culvert was implemented by creating an additional 56 ft long, 4 ft diameter pipe culvert connecting the ditch on the west side of Eastern Avenue to the western branch of the marsh. This culvert connects the west marsh directly to the portion of the ditch south of Culvert C, with the intent to improve conveyance to the marsh. Drainage channel maintenance was implemented by ensuring a consistent downward sloping surface from the excavated storage area to the culvert at Ballard Street. In addition to these modifications, the existing tide gate on the Ballard Street culvert was removed.

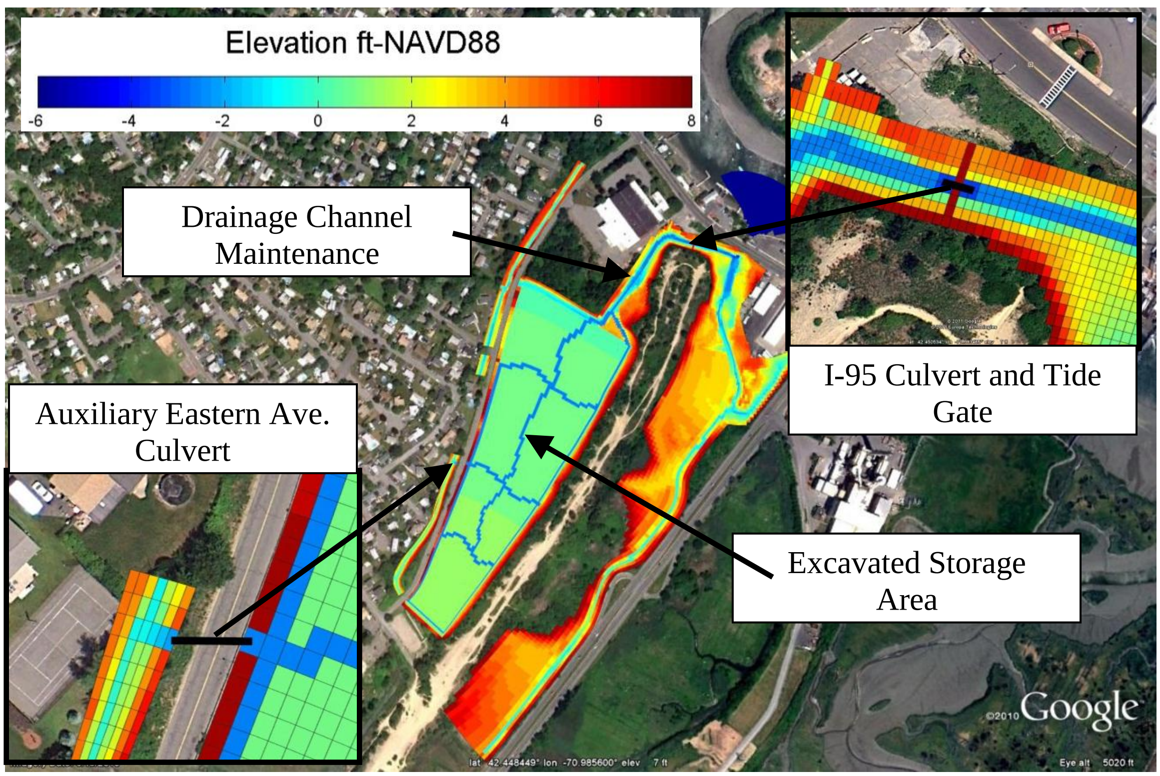


Figure 5-1. Components of the preliminary NRCS recommended alternative.

5.1.1 Normal Tides

Normal tides were simulated for the preliminary NRCS alternative using the same boundary conditions applied to the existing conditions model (described in section 4.5.1). Figure 5-2 shows water surface elevation time series for the model output stations. Comparisons to the water surface elevation time series for existing conditions at the East Marsh 1, West Marsh 1, and Ditch 1 locations are shown in Figures 5-3 thru 5-5, respectively. Mean tidal water levels and the minimum and maximum water levels at all output stations are presented in Table 5-1. Since in this preliminary NRCS design, the I-95 culvert and tide gate completely closes during the flooding tide, the west marsh and ditch along Eastern Avenue become non-tidal environments. Therefore, tidal statistics could not be computed for these locations. Although small water level fluctuations do occur west of the I-95 culvert and tide gate, they result from freshwater flow from the ditch and upland areas periodically backing up behind the closed flap gate. The tide range in the Eastern Marsh increases by approximately 1.75 to 2 feet under the preliminary NRCS design. Figure 5-6 shows the maximum and minimum inundation contours for this alternative during normal conditions. Minimum and maximum areas of inundation (between monthly maximum and monthly minimum water levels during the simulated time period, which is similar to the area between Spring High Tides and Spring Low Tides) are listed in Table 5-2 and can also be compared to existing conditions results.

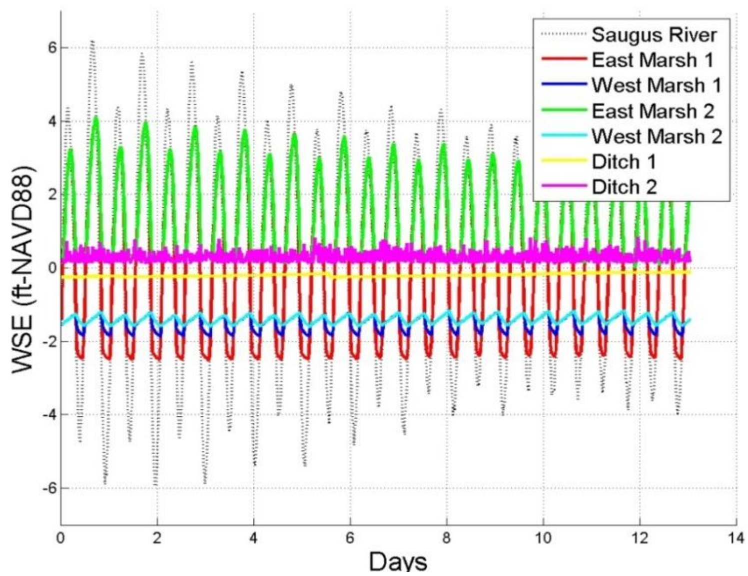


Figure 5-2. Water surface elevation (WSE) time series for the preliminary NRCS alternative, normal tides simulation.

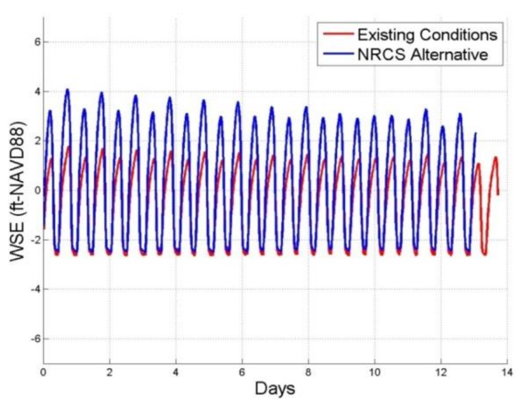


Figure 5-3. Comparison of water surface elevation (WSE) time series at East Marsh 1 for existing conditions and the preliminary NRCS alternative; normal tides.

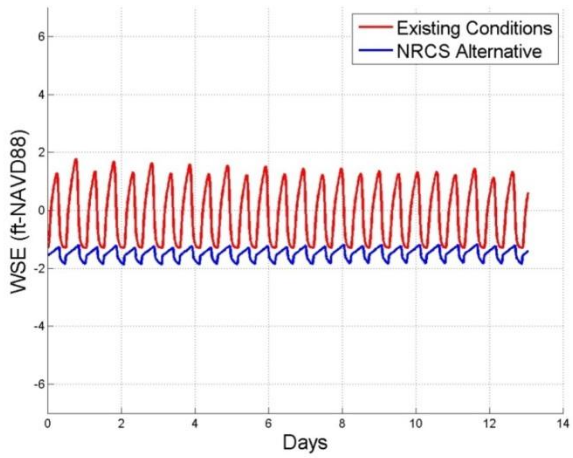


Figure 5-4. Comparison of water surface elevation (WSE) time series at West Marsh 1 for existing conditions and the preliminary NRCS alternative; normal tides.

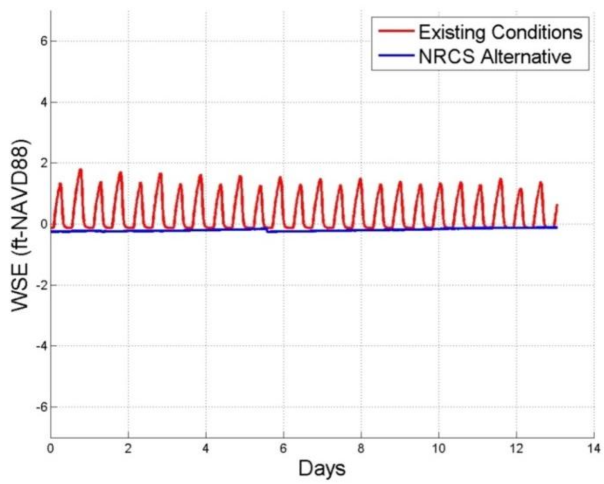


Figure 5-5. Comparison of water surface elevation (WSE) time series at Ditch 1 for existing conditions and the preliminary NRCS alternative; normal tides.

With the flap gate, the areas in the western branch of the Ballard Street marsh are no longer intertidal. Essentially water remains within the channel and ditches during normal tidal conditions, only allowing freshwater flow out of the system during low tides. The removal of the Ballard Street tide gate increases the tide range and high water in the eastern branch of the system by approximately 2 feet. This increase in tide range corresponds with an increase of 3.8 acres[5] of intertidal area (between monthly maximum and monthly minimum water levels during the simulated time period, which is similar to the area between Spring High Tides and Spring Low Tides) in the eastern branch. There is a slight loss of intertidal area in the west marsh due to the restriction of tidal flow. Again, these intertidal areas are used as a general proxy as the level of restoration that may be expected for each alternative. The exact distribution of wetland classification

[5] This is an over prediction of the restored area in the eastern marsh. At the time of this model simulation there was limited topography and no available tide data for model calibration in the eastern marsh. Additional data were collected in the eastern marsh and the model was recalibrated for this branch as presented in Section 6.

zones (e.g., high marsh, low marsh, mudflat, etc.) is not presented; however the intertidal areas are expected to correspond to primarily restored high and low marsh regions. Overall, the preliminary NRCS restoration option produces a net increase in intertidal area of approximately 3.1 acres compared to existing conditions, mostly low marsh in the eastern branch of the Ballard Street system. However, this preliminary alternative also successfully reduces flooding potential through providing extra flood storage in the western marsh.

Table 5-1. Tidal statistics for the preliminary NRCS alternative, normal tides simulation (elevations in ft-NAVD88).

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	4.2	-4.3	-0.1	8.5	-5.9	6.2
East Marsh 1	3.3	-2.5	0.04	5.8	-2.5	4.1
West Marsh 1	N/A	N/A	N/A	N/A	-1.9	-1.2
East Marsh 2	3.3	0.2	1.7	3.1	0.0	4.1
West Marsh 2	N/A	N/A	N/A	N/A	-1.6	-1.2
Ditch 1	N/A	N/A	N/A	N/A	-0.3	-1.2
Ditch 2	N/A	N/A	N/A	N/A	0.1	0.8

N/A indicates non-tidal areas.

Figure 5-6. Contours of maximum (red) and minimum (blue) water surface elevation during normal tides, preliminary NRCS alternative.

Table 5-2. Inundated marsh area and intertidal area for the preliminary NRCS alternative under normal tides.

Site	Maximum Inundated Area (acres)	Minimum Inundated Area (acres)	Intertidal Area (acres)	Change in intertidal area compared to existing conditions (acres)
East Marsh	8.2	3.5	4.7[6]	+3.8
West Marsh	4.5	4.4	N/A	-0.7

5.1.2 Tidal Flood Event

The tidal flood (storm surge) event was also simulated for the preliminary NRCS alternative configuration using the same boundary conditions applied for existing conditions. Water surface elevation results at the model output stations are shown in Figure 5-7, while comparisons of the water surface elevation to the existing conditions simulation at East Marsh 1 and West Marsh 1 locations are shown in Figures 5-8 and 5-9, respectively. The water surface elevation fluctuations in the west branch are insignificant, as the proposed I-95 flap gate prevents the surge from entering that portion of the marsh. In the east branch, the water level peaks at 4.6 ft-NAVD88, significantly less than the peak storm surge level in the Saugus River due to the restriction caused by the existing Ballard Street culvert. Even without the Ballard Street tide gate or the new I-95 structure, the Ballard Street culvert is restrictive enough prevent damaging water levels[7] in the marsh for a surge that does not overtop Ballard Street. Table 5-3 presents the maximum water levels throughout the Ballard Street system for the tidal flood event simulation.

Table 5-3. Maximum water levels for the preliminary NRCS alternative; tidal flood simulation.

Location	Maximum Water level (ft-NAVD88)
Saugus River	7.7
East Marsh 1	4.6
West Marsh 1	-1.1
East Marsh 2	4.6
West Marsh 2	-1.1
Ditch 1	0.1
Ditch 2	1.2

[6] This is an over prediction of the restored area in the eastern marsh. At the time of this model simulation there was limited topography and no available tide data for model calibration in the eastern marsh. Additional data were collected in the eastern marsh and the model was recalibrated for this branch as presented in Section 6.

[7] Damaging water levels are assumed to occur when water elevations exceed the elevation of the lowest critical infrastructure (house) elevation that was measured at 5.25 feet NAVD88.

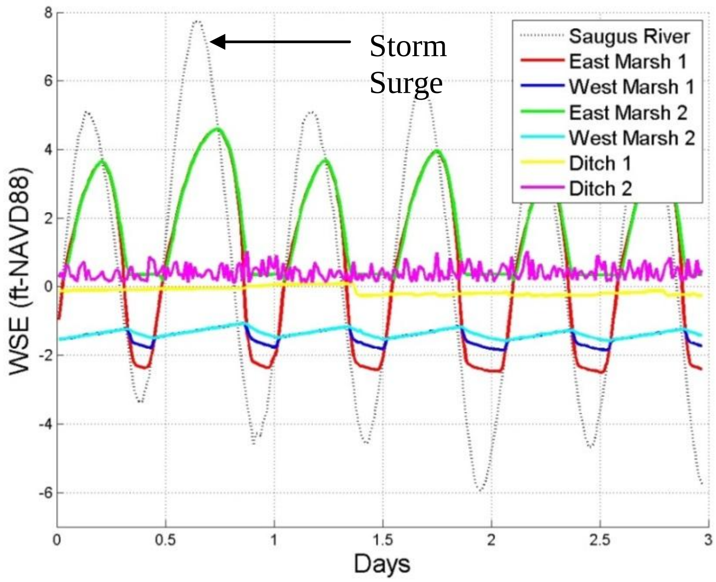


Figure 5-7. Water surface elevation (WSE) time series for the preliminary NRCS alternative under the tidal flood event simulation.

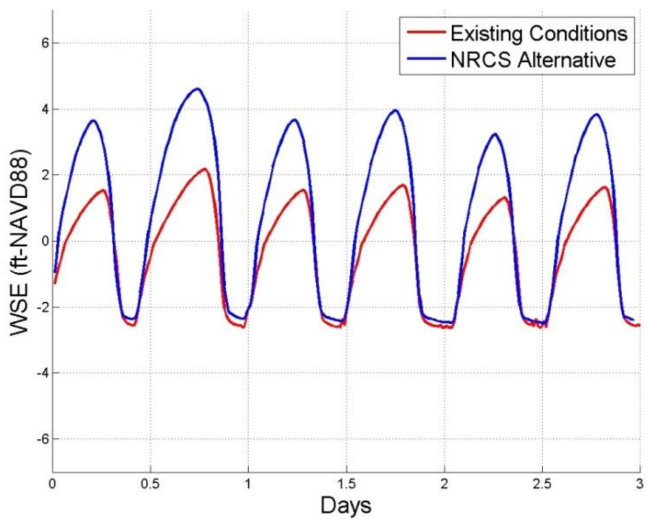


Figure 5-8. Comparison of water surface (WSE) elevation time series at East Marsh 1 for existing conditions and the preliminary NRCS alternative; tidal flood event.

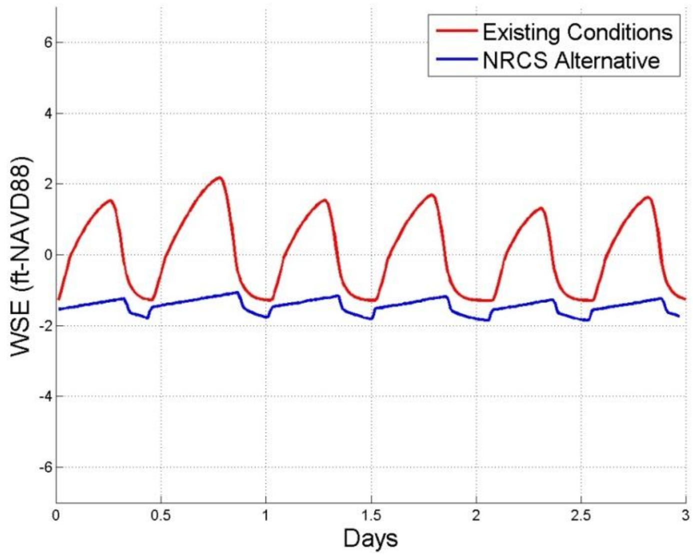


Figure 5-9. Comparison of water surface elevation (WSE) time series at West Marsh 1 for existing conditions and the preliminary NRCS alternative; tidal flood event.

5.1.3 100-Year Rainfall Event

The 100-year, 24-hour rainfall event was simulated for the preliminary NRCS alternative using the same boundary conditions (subsequently updated in section 6.0) used for existing conditions. Water surface elevation time series at the model output stations are shown in Figure 5-10. Comparisons of the water surface elevation to the existing conditions simulation at the East Marsh 1, West Marsh 1, and Ditch 2 locations are shown in Figures 5-11 through 5-13, respectively. Peak water surface elevations during the storm are shown in Table 5-4. The results indicated the preliminary NRCS alternative significantly reduces the peak water level in the west branch of the marsh system as the excavated area significantly increases flood storage capacity. The greatest peak water levels occur in the east portion of the marsh where a combined influence of spring high tides and runoff discharge cause an increase in the total water surface elevation. In this dynamic simulation, the west marsh and Eastern Avenue ditch do experience increases in water level due to the intermittent drainage delays caused by closure of the new I-95 tide gate during each high tide event. The time series show that it takes about 24 hours for the water levels to return to normal after the time of the peak discharge. Peak water levels are relatively consistent throughout the system ranging from 4.3 ft-NAVD88 in the ditch to 4.7 ft-NAVD88 in the east marsh. Overall the preliminary NRCS alternative is effective in maintaining water levels well below the critical 5.6 ft-NAVD88[8] during the 100-year, 24-hour rainfall event, indicating that the excavation proposed in the NRCS design is overly conservative and the total recommended excavation may not be needed to provide flood storage even during an extreme 100-year rainfall event.

[8] This was the lowest elevation measured by NRCS. Subsequent additional survey of the infrastructure west of the Ballard Street Marsh identified the lowest structural (house) elevation at 5.25 feet NAVD88 (see section 6.0).

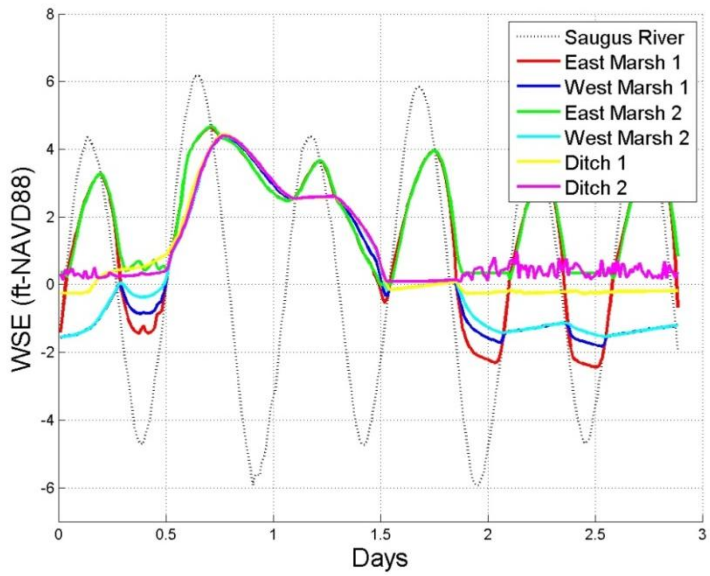


Figure 5-10. Water surface elevation WSE) time series for the preliminary NRCS alternative 100 year rainfall event simulation.

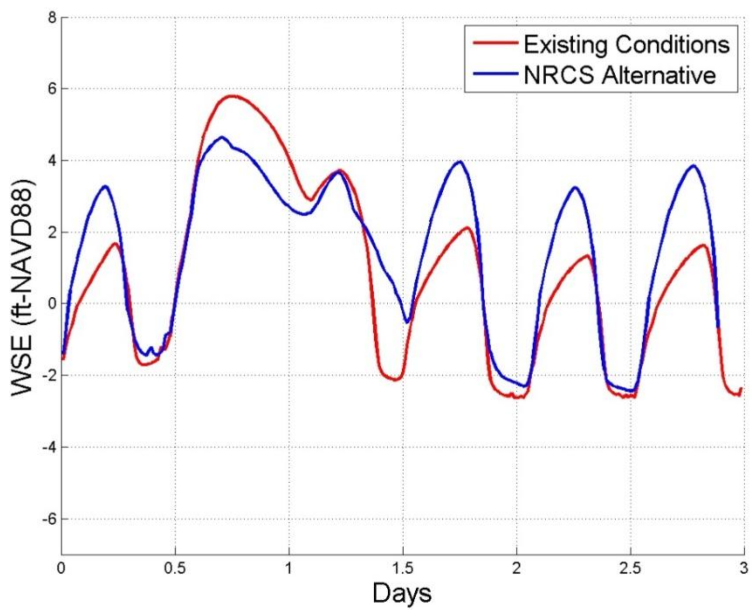


Figure 5-11. Comparison of water surface elevation (WSE) time series at East Marsh 1 for existing conditions and the preliminary NRCS alternative; 100 year rainfall event.

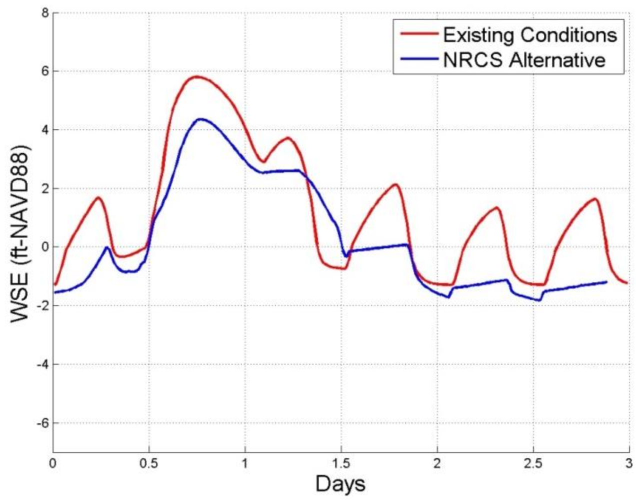


Figure 5-12. Comparison of water surface elevation WSE) time series at West Marsh 1 for existing conditions and the preliminary NRCS alternative; 100 year rainfall event.

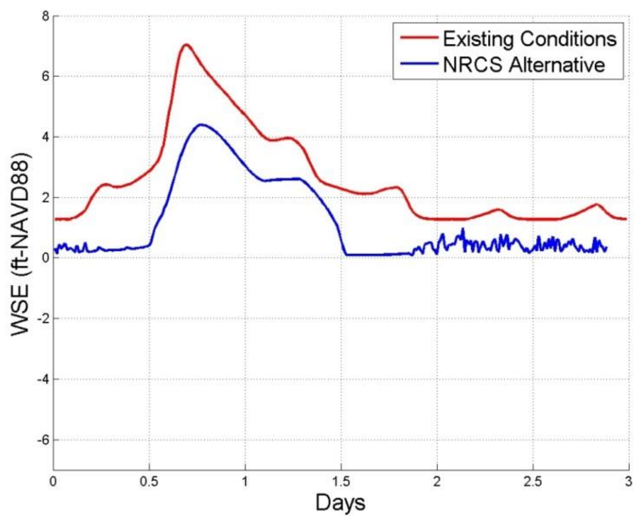


Figure 5-13. Comparison of water surface elevation (WSE) time series at ditch 2 for existing conditions and the preliminary NRCS alternative; 100-year rainfall event.

Table 5-4. Maximum water levels for NRCS alternative 100 year rainfall event simulation.

Location	Maximum Water level (ft-NAVD88)
East Marsh 1	4.6
West Marsh 1	4.4
East Marsh 2	4.7
West Marsh 2	4.4
Ditch 1	4.3
Ditch 2	4.4

5.1.4 Preliminary NRCS Design Summary

The preliminary NRCS design was simulated in the calibrated and validated Ballard Street marsh system hydrodynamic model. Normal tidal conditions, storm surge conditions and 100-year rainfall conditions were simulated. The results of the modeling indicate the following:

- The preliminary NRCS design recommended excavation of 60 acre-ft of material, equivalent to the 100-year runoff volume determined by NRCS (1999), to provide storm flood storage for a 100-year rainfall event. Therefore, the NRCS design assumed that the existing western marsh had little to no existing storage capacity. The hydrodynamic modeling for this storm event indicated that the proposed excavation was overly conservative, and potentially less material could be removed to provide adequate storage volume. The conservative NRCS proposed excavation is likely due to (1) the incorrect survey elevations used by NRCS, (2) the conservative NRCS assumption that the total runoff volume would need to be stored instantaneously not allowing for any temporal factor, and (3) that the existing system had little to no storage capacity. The 100-year rainfall event proposed also represents an extreme storm event and use of this level of storm a design level may be overly conservative, especially considering the marsh system would be significantly flooded during storm surge events that exceed a 10-year return period level in water surface elevation.

- While the preliminary NRCS design as presented in the NRCS study (1999), does not evaluate any restoration of the western portion of the Ballard Street marsh, it provided the potential to restore some acreage of salt marsh. The new tide gate structure was proposed to be implemented with a flap gate control system that only allowed water to flow out of the western marsh. As such, all tidal exchange and salt-laden water would not be allowed into this portion of the marsh. The approach was to attempt to enhance restoration of the eastern marsh, while limiting the potential increased flood risk within the western marsh, which is surrounded by infrastructure. However, the new proposed structure and excavation are overly conservative in this segregation of the western marsh and creates a potentially undesirable ponded area in the western marsh branch. NRCS and the project stakeholders were aware of the initial problem, and subsequently modified the proposed design to include a tide gate structure that would allow bi-directional, controlled flow (e.g., self-regulating tide gate).

- The preliminary NRCS design (1999) restores a relatively small portion of the eastern marsh (approximately 4 acres). The hydrodynamic model developed herein indicates that the existing Ballard Street culvert itself is the main constriction in the system. As such, removing the tide gate alone does not let enough tidal exchange into the system to result in a significant restoration of the eastern marsh. Consideration of re-opening the connection to the Pines marsh system may result in additional tidal exchange into the eastern portion of the system. In addition, it is likely that the elevations of the eastern marsh plain have been influenced by significant anthropogenic activities and are not at the same elevations as they were historically, making restoration more challenging.

- The preliminary NRCS design (1999) includes construction of a new culvert and tide gate at the entrance to the western branch of the system near the end of the I-95 embankment. This would add another anthropogenic feature to the Ballard Street marsh system with a significant financial cost (both initial and maintenance). This proposed restoration approach does not address the primary tidal constriction of the system (the Ballard Street culvert), and offers limited wetland restoration on the eastern side of the system. In addition, the Ballard Street culvert has a limited service life remaining, and may require maintenance in the relatively near future.

Due to some of the limitations in the preliminary NRCS design, some additional alternatives were considered to potentially enhance the restoration of the Ballard Street marsh system. These alternatives considered were completed at an initial screening level and were not a component of the contracted scope of work. Results of these alternatives were used to evaluate some potential alternatives and provide further refinement and recommendations for the potential restoration of the Ballard Street marsh system.

5.2 New Ballard Street Tide Gate

In order to gauge the relative level of restoration that could be obtained through the least obtrusive modification to the Ballard Street marsh system, an alternative was considered that removed the existing Ballard Street tide gate, or replaced it with a fully functional combination flap/sluice gate that could be adjusted as needed (e.g., closed during significant storm surge events). This new tide gate would be adjustable to allow for adaptive management of the system, and protection from storm events when required. However, under the scenarios considered here it is assumed this gate would be fully open for normal tidal conditions. The system would behave similar to the existing system, but with the steel plate removed from the Ballard Street culvert. This approach represents one of the simplest alternatives, essentially upgrading the existing tide gate on the Ballard Street culvert with the intent to have the tide gate open during normal operating conditions. Additional subsets of this alternative (e.g., replacing the Ballard Street culvert) may also be considered for more enhanced restoration. This alternative is not intended to represent a preferred approach to the restoration; rather, the alternative evaluates the simplest form of restoration at the site and establishes that this approach has minimal restoration potential.

5.2.1 Normal Tides

Normal tides were simulated with the new Ballard Street tide gate alternative using the same boundary conditions applied to the existing conditions model. Figure 5-14 shows water surface elevation time series at the model output stations. Comparisons to the water surface elevation time series for existing conditions at the East Marsh 1, West Marsh 1, and ditch 1 locations are shown in Figures 5-15 thru 5-17, respectively. Mean tidal water levels and the minimum and maximum water levels at the output locations are listed in Table 5-5, while Figure 5-18 shows the maximum and minimum inundation contours (between monthly maximum and monthly minimum water levels during the simulated time period, which is similar to the area between Spring High Tides and Spring Low Tides) for this alternative. Minimum and maximum areas of inundation are listed in Table 5-6.

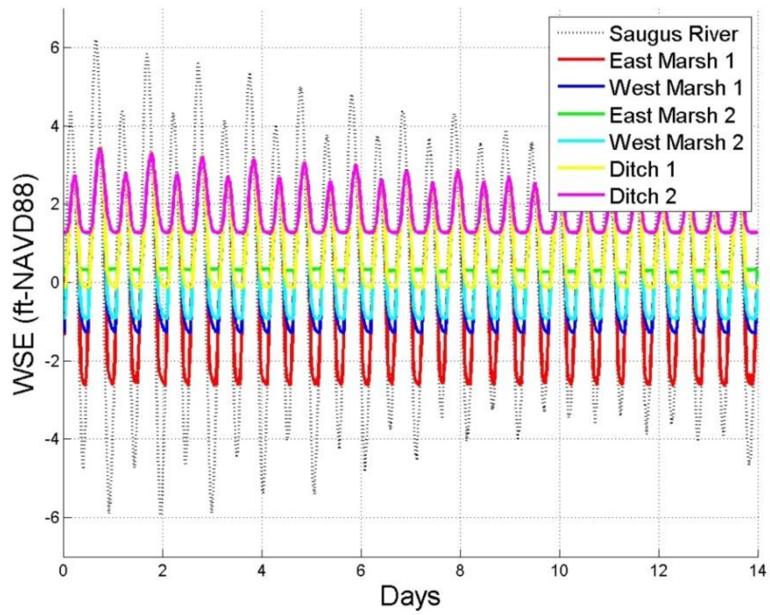


Figure 5-14. Water surface elevation (WSE) time series for the new Ballard Street tide gate alternative normal tides simulation.

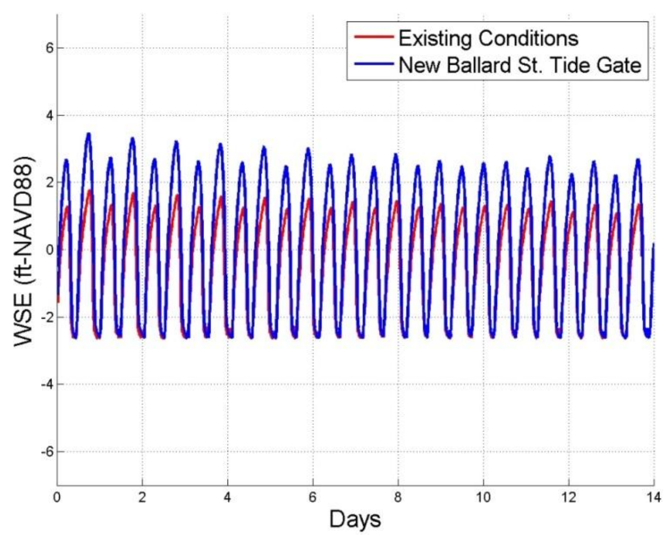


Figure 5-15. Comparison of water surface elevation (WSE) time series at East Marsh 1 for existing conditions and the new Ballard Street tide gate alternative; normal tides.

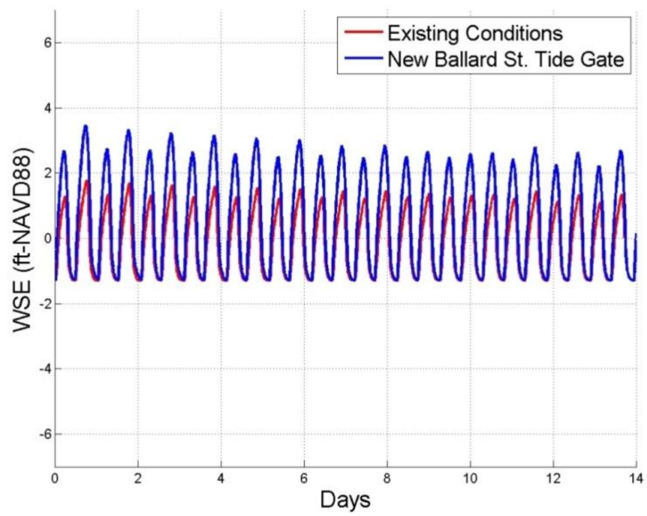


Figure 5-16. **Comparison of water surface elevation (WSE) time series at West Marsh 1 for existing conditions and the new Ballard Street tide gate alternative; normal tides.**

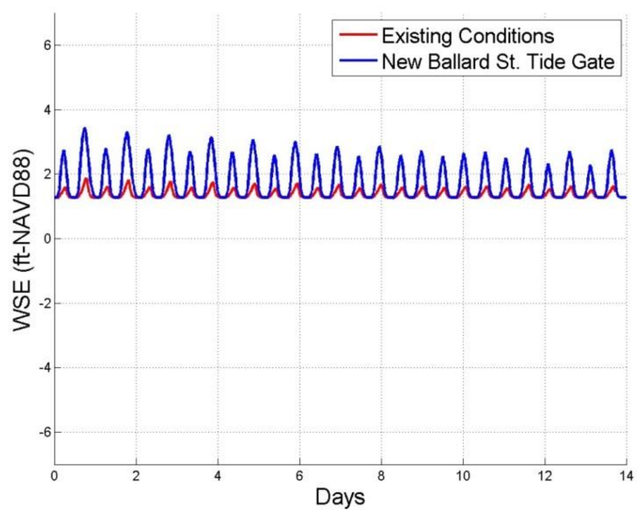


Figure 5-17. **Comparison of water surface elevation (WSE) time series at Ditch 2 for existing conditions and the new Ballard Street tide gate alternative; normal tides.**

Table 5-5. **Tidal statistics for the new Ballard Street tide gate alternative normal tides simulation (elevations in ft-NAVD88).**

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	4.2	-4.3	-0.1	8.5	-5.9	6.2
East Marsh 1	2.7	-2.6	0.1	5.3	-2.6	3.5
West Marsh 1	2.7	-1.3	0.7	2.0	-1.3	3.5
East Marsh 2	2.7	0.1	1.4	1.3	0.0	3.5
West Marsh 2	2.7	-0.9	0.9	3.6	-0.9	3.5
Ditch 1	2.7	-0.1	1.3	1.4	-0.1	3.5
Ditch 2	2.8	1.3	2.0	0.8	1.3	3.4

Figure 5-18. Contours of maximum (red) and minimum (blue) water surface elevation during normal tides, new Ballard Street tide gate alternative. Disconnects in the water surface elevation contours represent culverts and/or areas of shallow water.

Table 5-6. Inundated marsh area and intertidal area for the new Ballard Street tide gate alternative under normal tides.

	Maximum Inundated Area (acres)	Minimum Inundated Area (acres)	Normal Intertidal Area (acres)	Change in intertidal area compared to existing conditions (acres)
East Marsh	6.2	3.7	2.5[9]	+1.6
West Marsh	6.8	5.1	1.7	+1.0

When compared with existing conditions, the new Ballard Street tide gate alternative increases MHW throughout the system by approximately 1.3 feet, and also increases the tidal range by approximately the same amount. The intertidal area increases to 2.5 acres in the east marsh and 1.7 acres in the west marsh giving a total increase of 2.6 acre for the entire system, which is similar to the total gain provided by the preliminary NRCS alternative. The preliminary NRCS design alternative provides a slightly greater increase in intertidal area than the new Ballard Street tide gate alternative since it blocks the western branch from tidal exchange and allows more volume to be directed to the eastern branch. This raises the water level above the banks of the eastern channels to a point where it can inundate a significantly larger area. For both alternatives, the Ballard Street tide gate is open and the conveyance into the marsh system is the same. However, for the new Ballard Street tide gate alternative, the flooding tide can enter both the east and west portions of the marsh and must spread out over a larger sub-tidal area.

[9] This is an over prediction of the restored area in the eastern marsh. At the time of this model simulation there was limited topography and no available tide data for model calibration in the eastern marsh. Additional data were collected in the eastern marsh and the model was recalibrated for this branch as presented in Section 6.

This alternative also illustrates the constrictive nature of the existing Ballard Street culvert. The new Ballard Street tide gate alternative has potential for restoring a greater area but it would require increasing conveyance into the system by replacing the existing 4-foot diameter Ballard street culvert with something larger and/or opening the Bristow Street culvert at the southeastern corner of the system allowing tidal exchange with the Pines River to the south.

5.2.2 Tidal Flood Event

A tidal flood event (storm surge) was also simulated with new Ballard Street tide gate alternative using the same boundary conditions applied for the existing conditions simulation. Water surface elevation time series at the model output stations are shown in Figure 5-19, while Table 5-7 lists the maximum water surface elevations predicted in the system due to the tidal flood. At all locations, the flood peak is limited to less than 4.0 ft-NAVD88. This is significantly lower than the 5.6 ft-NAVD88 elevation at which NRCS assumed damage might occur, and less than the 5.25 ft-NAVD88 elevation measured by WHG (Section 6.0). The results suggest that the existing Ballard Street culvert, even with the tide gate removed, would be successful preventing damage from a tidal flood event that does not exceeded 7.7 ft-NAVD88 in the Saugus River. A surge above 7.7 ft-NAVD88 would overtop Ballard Street at which point the Ballard Street culvert would have little influence on controlling flooding in the marsh[10]. As discussed, the 10-percent annual chance tidal flood event has a peak water level of 8.0 ft-NAVD88 (NRCS, 1999).

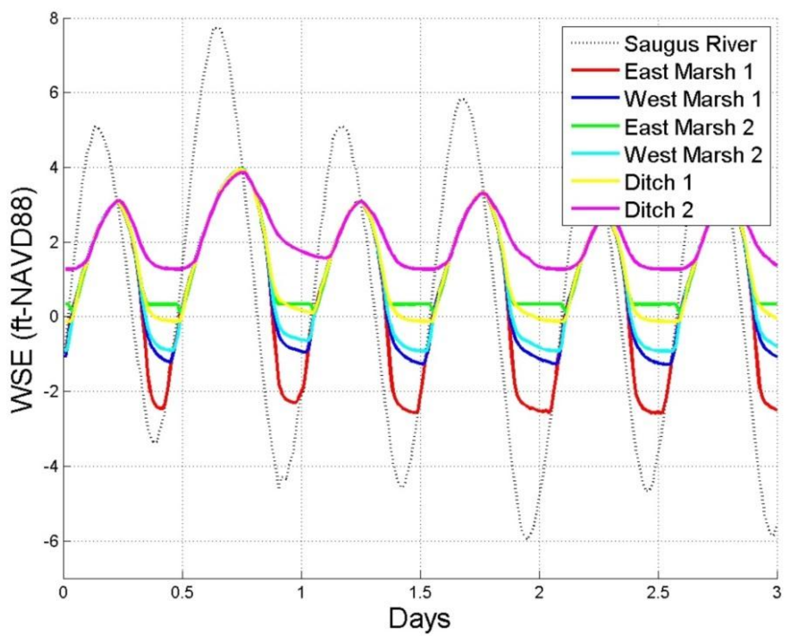


Figure 5-19. Water surface elevation (WSE) time series for the New Ballard Street tide gate alternative tidal flood event simulation.

[10] Subsequently, more detailed topography indicated that the low point in the road was actually 7.1 feet-NAVD88 (section 6.0)

Table 5-7. Maximum water levels for new Ballard Street tide gate alternative tidal surge simulation.

Location	Maximum Water level (ft-NAVD88)
Saugus River	7.7
East Marsh 1	4.0
West Marsh 1	4.0
East Marsh 2	4.0
West Marsh 2	4.0
Ditch 1	3.9
Ditch 2	3.9

5.2.3 100 Year Rainfall Event

A 100-year, 24-hour rainfall event was also simulated with the new Ballard Street tide gate alternative using the same boundary conditions applied for the existing conditions simulation. Water surface elevation time series at the model output stations are shown in Figure 5-20, while maximum water surface elevations reached during the storm event as presented in Table 5-8. The results are approximately the same as the existing conditions simulation. As expected, due to the limited existing flood storage in the western branch, this scenario would potentially cause flooding concerns as peak water elevations exceed critical infrastructure elevations in the area. Of course, existing conditions also would cause approximately the same level of flooding during this extreme event. As with the existing conditions simulation, and the preliminary NRCS design alternative simulation, the water levels return to normal tidal condition within about 24 hours after the peak runoff.

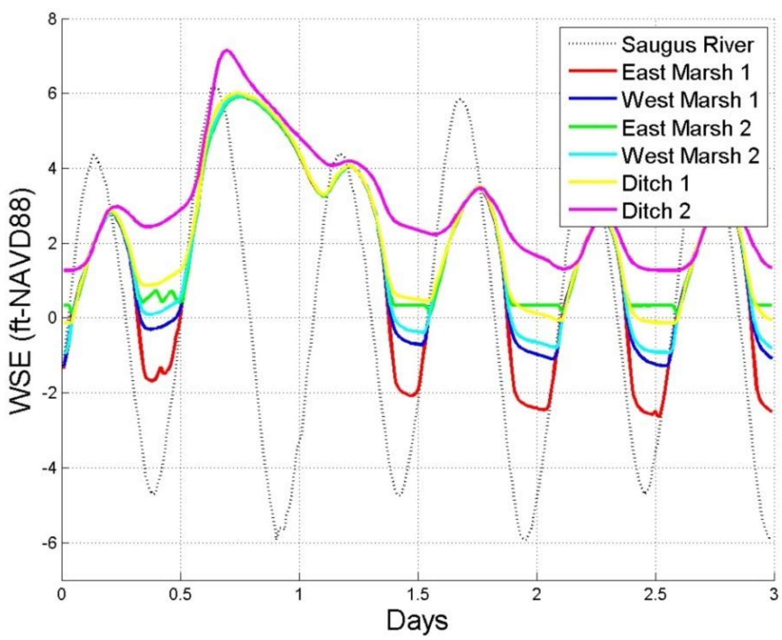


Figure 5-20. Water surface elevation (WSE) time series for the new Ballard Street tide gate alternative 100-year rainfall event simulation.

Table 5-8. Maximum water levels for new Ballard Street tide gate alternative 100-year rainfall event simulation.

Location	Maximum Water level (ft-NAVD88)
East Marsh 1	5.9
West Marsh 1	5.9
East Marsh 2	5.9
West Marsh 2	5.9
Ditch 1	6.0
Ditch 2	7.1

5.2.4 Storage Area Simulation

In order to further assess the potential removal of the existing Ballard Street tide gate, a storage area simulation, assuming the Ballard Street culvert tide gate was removed, was also conducted. This additional simulation used the 100-year, 24-hour rainfall event[11], but with a storage area added to west marsh for the new Ballard Street tide gate alternative. The simulation aligned the tide, such that the water surface elevation in the Ballard Street system corresponded to a spring high when the rainfall event occurred. Changes to the modeled system are similar to those made for the preliminary NRCS design alternative, however significantly less material was extracted from the west marsh. Based on an assumed critical threshold elevation of 5.6 ft-NAVD88 (NRCS, 1999)[12], calculations based on the observed topographic data (section 2) show that there is already approximately 44,000 yd^3 below 5.6 ft-NAVD88 available for storage in the west marsh under existing conditions. Therefore, using a conservative approach, 53,000 yd^3 would need to be excavated from the west marsh to provide the necessary storage. This alternative requires excavating approximately 41,000 yd^3 less than the NRCS alternative, but still is considered conservative due to the assumptions used for this storm event and its passage (marsh is filled to capacity and maximum discharge occur simultaneously). The resulting modified model grid is shown in Figure 5-21.

Figure 5-22 shows the water surface elevation time series at the output locations for the storage area simulation. Comparisons to the water surface elevation time series for existing conditions at the East Marsh 1, West Marsh 1, and Ditch 2 locations are shown in Figures 5-23 through 5-25, respectively. The peak water levels at the model output stations are listed Table 5-9. With the exception of the Ditch 2 location, the inclusion of the additional storage area in the west marsh reduces the peak water surface elevation in the system to acceptable levels. The peak water level at the Ditch 2 location primarily results from the high volume of water entering the system in that portion of the ditch and the restrictive culverts that connect that area to the rest of the marsh in the existing system. The peak water level at the Ditch 2 location could be reduced by adding an

[11] This is the precipitation event determined by NRCS, and not the updated case as presented in Chapter 6.
[12] This was the lowest elevation measured by NRCS. Subsequent additional survey of the infrastructure west of the Ballard Street Marsh identified the lowest structural (house) elevation at 5.25 feet NAVD88 (see section 6.0).

auxiliary culvert under Eastern Avenue as was done for the preliminary NRCS design alternative. The auxiliary culvert was not included in this alternative simulation.

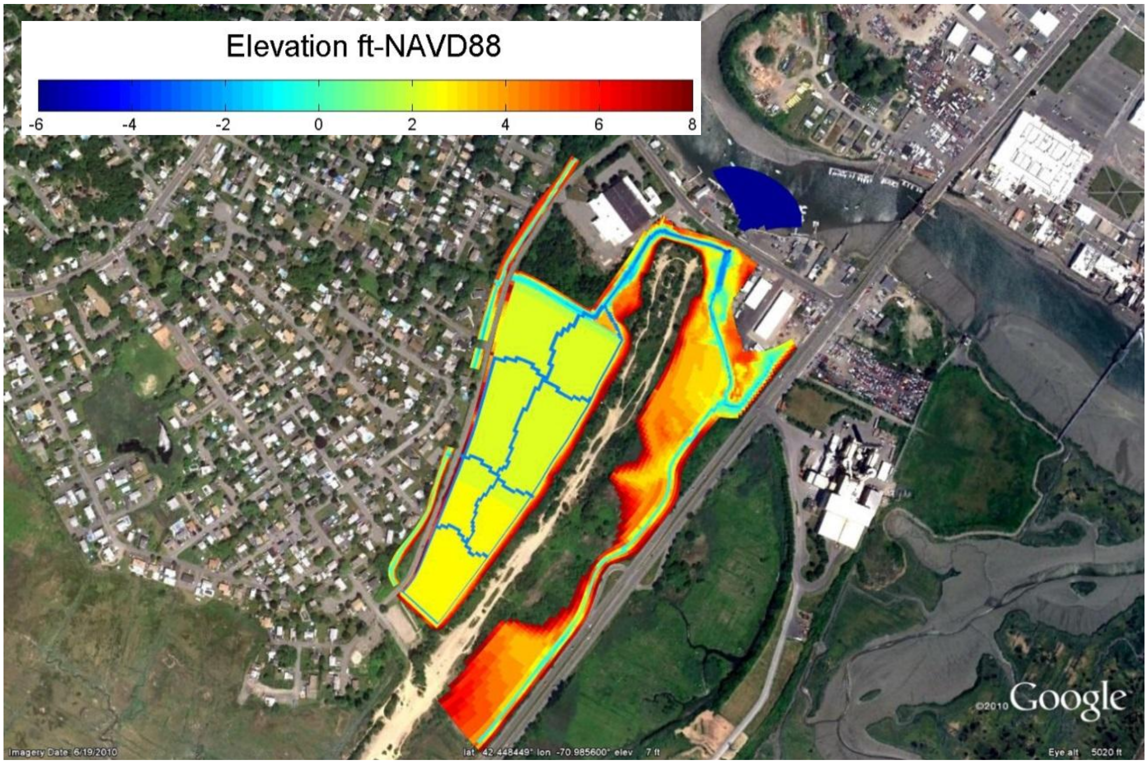


Figure 5-21. Modified Ballard Street marsh model grid for new Ballard Street tide gate alternative with additional storage area.

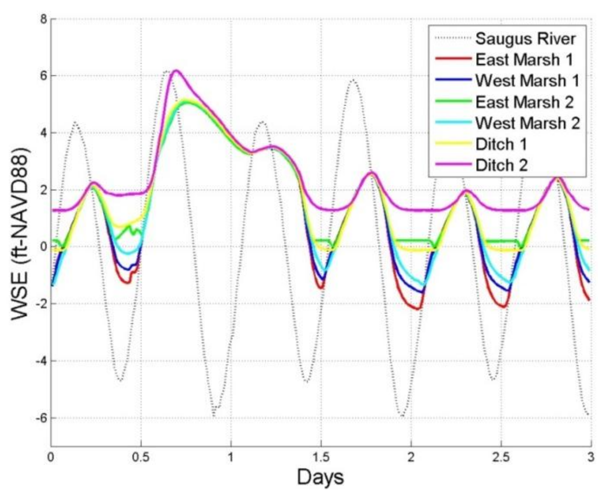


Figure 5-22. Water surface elevation (WSE) time series for the New Ballard Street tide gate alternative 100-year rainfall event simulation with additional storage area.

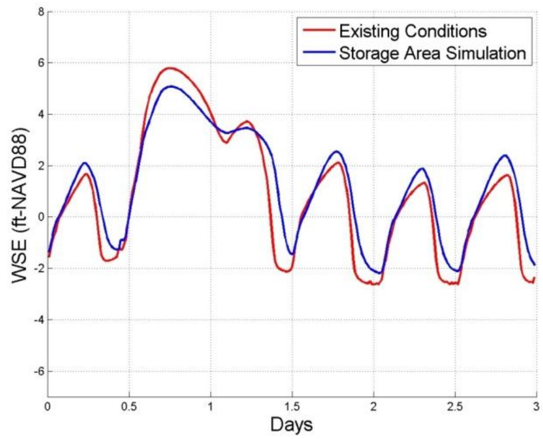


Figure 5-23. Comparison of water surface (WSE) elevation time series at East Marsh 1 for existing conditions and the new Ballard Street tide gate alternative with additional storage area; 100-year rainfall event.

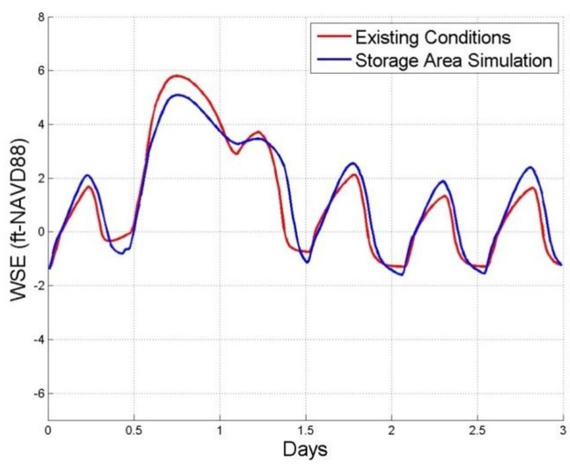


Figure 5-24. Comparison of water surface elevation (WSE) time series at West Marsh 1 for existing conditions and the new Ballard Street tide gate alternative with additional storage area; 100-year rainfall event.

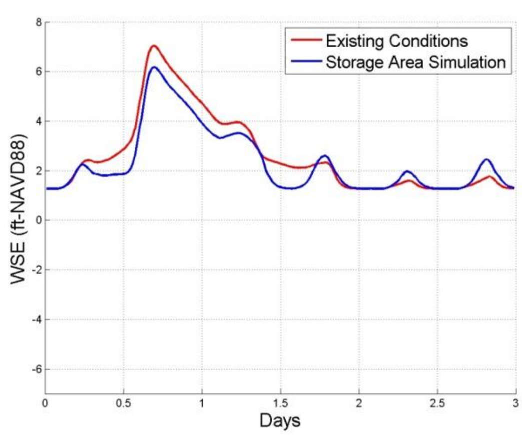


Figure 5-25. Comparison of water surface elevation (WSE) time series at ditch2 for existing conditions and the new Ballard Street tide gate alternative with additional storage area; 100-year rainfall event.

Table 5-9. Maximum water levels for new Ballard Street tide gate with additional storage area 100-year rainfall event simulation.

Location	Maximum Water level (ft-NAVD88)
East Marsh 1	5.1
West Marsh 1	5.1
East Marsh 2	5.0
West Marsh 2	5.1
Ditch 1	5.1
Ditch 2	6.2

5.3 MODIFIED NRCS ALTERNATIVE

After the preliminary NRCS design alternative was reviewed by stakeholders, a recommendation to modify the design further in order to enhance the restoration potential of the project while maintaining flood-control benefits was proposed. This alternative is based on recommended changes to the preliminary NRCS design that were implemented by NRCS in permitting documents following their report (e.g., the removal of the flap gate for a recommended self-regulating tide gate and opening of the blocked Bristow Street culvert). This modified NRCS alternative consists of the following components:

- the same excavation and re-grading plan (Geosyntec, 2007) to create additional storage for rainfall runoff in the portion of the marsh west of the I-95 fill
- the addition of an auxiliary 4 foot diameter culvert under Eastern Avenue
- Removal of the flap gate at the Ballard Street culvert
- Removal of the plywood and metal plate from the Bristow Street culvert at the southeast corner of the marsh area to allow tidal exchange between the Pines River and the portion of the marsh east of the abandoned I-95 embankment. The model simulated the open culvert with invert elevations based on observed conditions. As such, tides from the Pines River are allowed through the east marsh into the Ballard Street System for this scenario. This alternative was simulated prior to detailed data collection in the channel in the eastern marsh (which consisted of significant shoals and blockages as presented in Chapter 6).
- The two proposed 4'x4' culverts at I-95 berm would be installed, both with combination slide/flap gates. This modified alternative was simulated with both gates completely open to evaluate maximum tidal exchange[13]. However, they also could be modified to allow non-linear tidal exchange.

Implementation of these components in the Ballard Street marsh model required the addition of an open box culvert (currently partially clogged and blocked by an existing sheet of plywood) at Bristow Street and extension of the model domain approximately 100 feet seaward of the Bristow Street culvert to accommodate an additional water surface elevation boundary condition in the Pines channel. Water surface elevation time series applied at the Pines channel boundary are based on water levels observed at the

[13] A set of simulations was also conducted for this alternative with one gate closed (allowing only water out of the system), and one gate fully open (allowing tidal exchange). The results are not presented herein, but were used to help identify potential gate configurations for drainage capacity.

DER 2 location as described in section 2.3. The proposed culverts at the I-95 location were replaced with one culvert only allowing ebbing flow, the other allowing bi-directional flow. The culvert with bi-directional flow was also equipped with a device which allows for controlled restriction of the flooding tide (e.g., a self-regulated tide gate, combination sluice/flap gate), if needed. Because this effort aims to primarily assess the feasibility of the previously permitted modified NRCS alternative, this device is assumed to be fully open allowing unrestricted flow into the culvert for this simulation. As such, the configuration modeled simulates the maximum tidal restoration possible for the west branch and is conservative with respect to tidal flooding events. Determination of the device settings (e.g., sluice height) that may ultimately be required to meet the combined goals of restoration and flood protection were not determined in this alternative[14].

The components of this modified NRCS alternative are illustrated in Figure 5-26. Results of simulations for normal tides, a tidal flood event, and a 100 year rainfall event are presented in the following sections and compared with results from the existing conditions model.

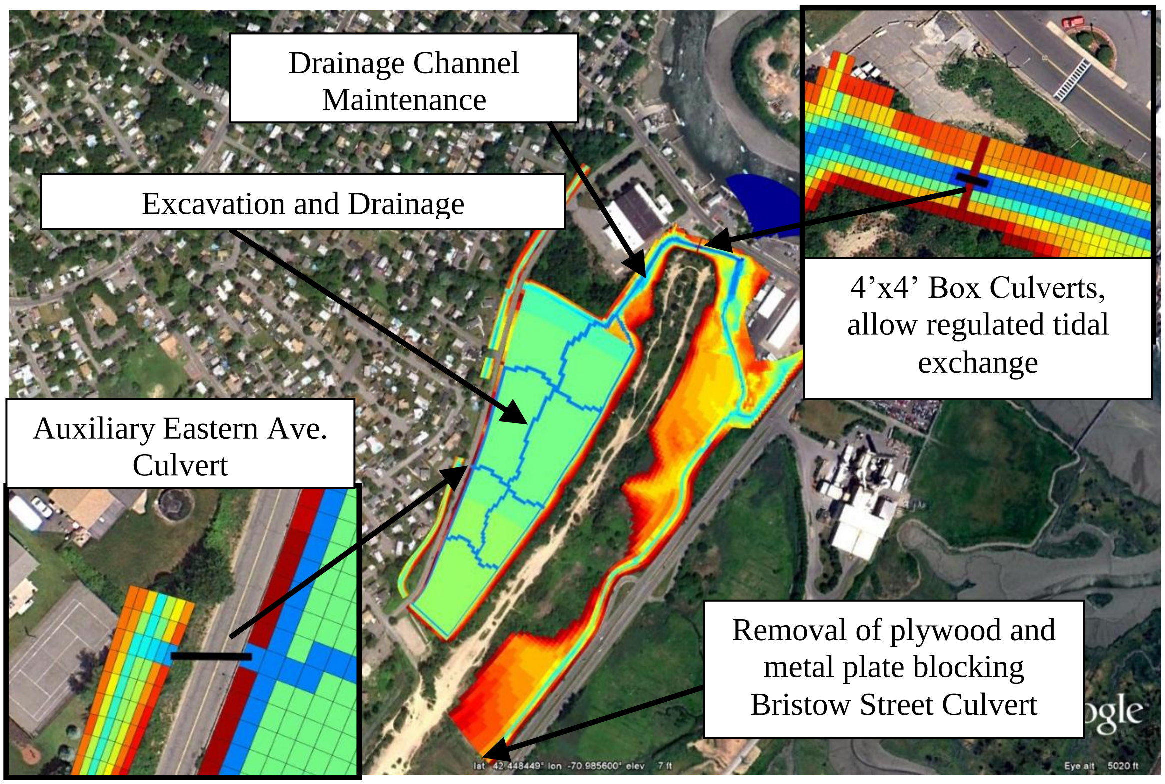


Figure 5-26. Components of the modified NRCS alternative.

5.3.1 Normal Tides

Boundary conditions for the normal tides simulation of the modified NRCS design alternative were based on observations of a fortnightly spring-neap cycle beginning on May 26th 2010. The same boundary condition used for the existing conditions model was

[14] Potential gate configurations and opening requirements, which were evaluated in a later scope of work are described in the preferred alternative sections (Section 6.0 and 7.0).

applied for the modified NRCS design alternative. An additional boundary condition for the Pines channel was added based water surface elevation observations made during the same time period in the Pines Channel.[15]

Modeled water surface elevation time series are shown in Figure 5-27 for the model output stations, and calculated tidal statistics are presented in Table 5-10. When compared to existing conditions, the removal of the Ballard Street tide gate and the opening of the Bristow Street culvert both contribute to an increase in the mean tide level throughout the system. This increase is evident at all model output stations. Removal of the tide gate at Ballard Street increases the mean tide level by allowing for greater tidal exchange from the Saugus River. Opening of the Bristow Street culvert allows tidal exchange with the Pines River, which is not present in the existing system. However, it is expected that the relatively high culvert invert and sedimentation of the Pines Channel limits this exchange to the upper portion of the tide cycle only (above approximately 2.5 feet NAVD88)[16]. This results in a significant increase in the mean tide level in the southeast portion of the marsh since once the water level in the system falls below the control elevation of approximately 2.5 feet-NAVD88, water exiting the system can only drain through the Ballard Street culvert.

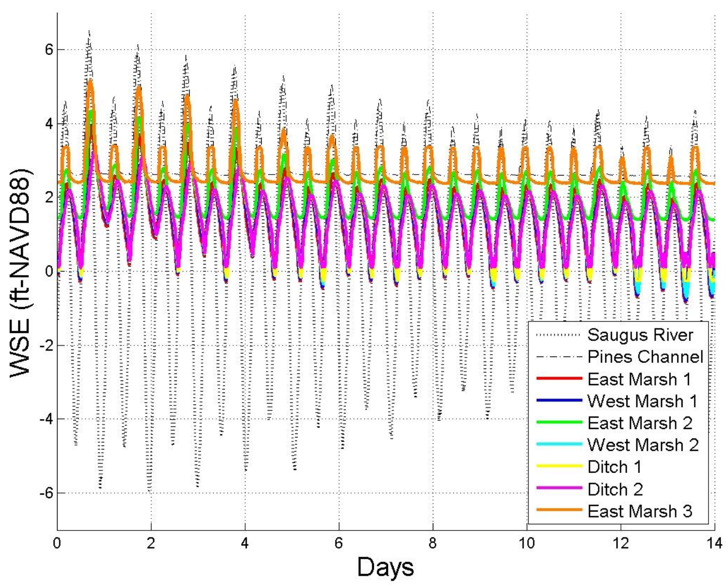


Figure 5-27. Water surface elevation time series for the modified NRCS alternative at model output stations; normal tides.

Figure 5-28 compares the water surface elevation time series at East Marsh 1 for the modified NRCS design alternative with the existing conditions simulation. The mean

[15] Additional tide observations and surveying resulted in further refinement of the model for the eastern branch of the Ballard Street marsh, as presented in Section 6.0.
[16] The existing condition of the Bristow Street culvert and the surrounding upstream and downstream channels were investigated further in an additional scope of work presented in section 6.0.

water level at East Marsh 1 increases significantly. Specifically, the modified NRCS alternative shows a large increase in the low tide level when compared with existing conditions. Mean low water at East Marsh 1, just upstream of the Ballard Street culvert, was calculated to be -0.1 feet-NAVD88 for the modified NRCS alternative. This elevation, which is 3.5 feet above the invert of the Ballard Street culvert, suggests that the Ballard Street culvert may flow full or nearly full at all times for the modified NRCS alternative. The higher mean water surface elevation in the Pines River which delivers additional water into the system. Opening the Bristow Street culvert allows this tide (ranging between approximately 2.5 to 6 feet NAVD88) into the Ballard Street system (Figure 5-27), which increases the mean water surface elevation. Figure 5-29 shows a comparison to the existing conditions water surface elevation time series at the East Marsh 3 location (near the Bristow Street culvert). At this location, the effect of opening the Bristow Street culvert results in a significant increase in tide range and the mean low water elevation. While this allows for the tidal inundation of a larger area the southeast portion of the marsh, it also indicates that drainage ability out through the Pines River may be limited due to channel elevations and sedimentation. Water will flow into the Ballard Street system from the Pines, but since the water surface elevation is always higher in the Pines than in the eastern side of Ballard Street, flow is not allowed to exit in this direction, which has a higher elevation head. Due to these results, additional investigations related to the East Channel and the influence of the Pines River tides on the restoration were conducted, as presented in Chapter 6, and the addendum to this report.

Table 5-10. Tidal statistics for the modified NRCS alternative; normal tides simulation (elevations in feet-NAVD88).

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	4.2	-4.3	-0.1	8.5	-5.9	6.2
Pines Channel	4.6	2.6	3.6	2.0	2.6	6.5
East Marsh 1	2.6	-0.1	1.3	2.7	-0.9	3.9
West Marsh 1	2.3	-0.1	1.1	2.4	-0.8	3.2
East Marsh 2	2.9	1.4	2.2	1.5	1.4	4.4
West Marsh 2	2.3	-0.1	1.1	2.4	-0.7	3.3
Ditch 1	2.3	0.0	1.2	2.3	-0.3	3.2
Ditch 2	2.3	0.2	1.3	2.1	0.1	3.3
East Marsh 3	3.6	2.4	3.0	1.2	2.4	5.2

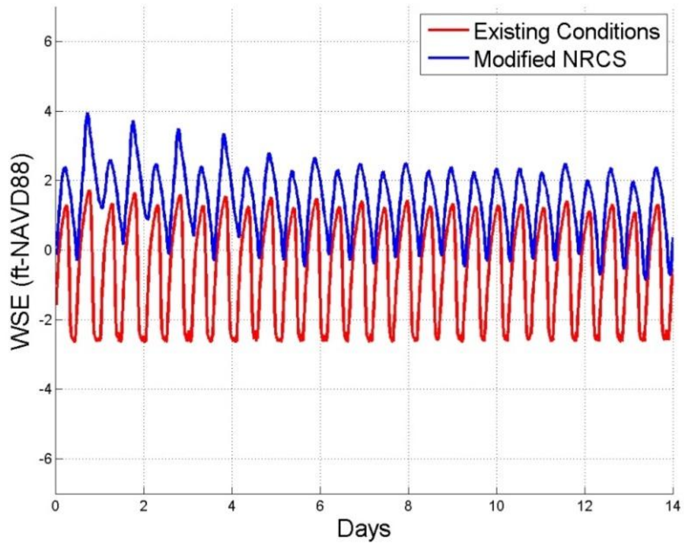


Figure 5-28. Comparison of water surface elevation (WSE) time series at East Marsh 1 for existing conditions and the modified NRCS alternative; normal tides.

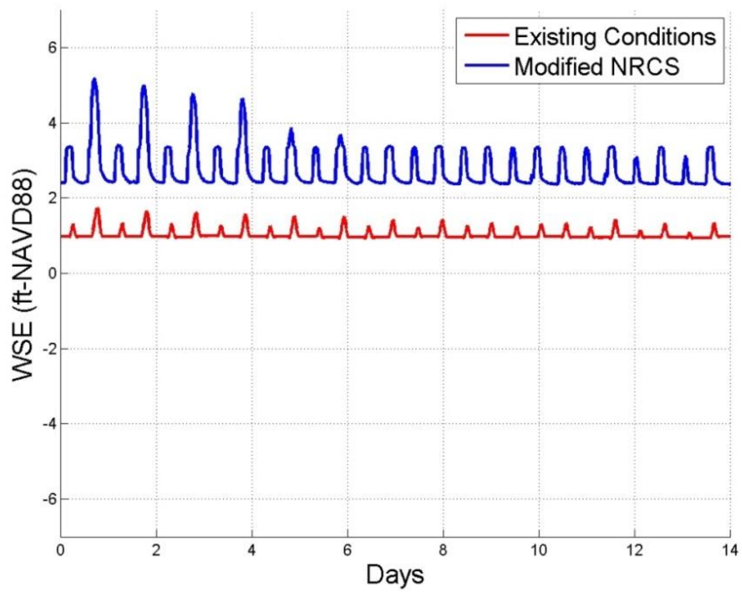


Figure 5-29. Comparison of water surface elevation (WSE) time series at East Marsh 3 for existing conditions and the modified NRCS alternative; normal tides

Water levels in the western branch are compared to existing conditions at the West Marsh 1 and Ditch 2 locations in Figures 5-30 and 5-31, respectively. These results indicate that the modified NRCS alternative allows uniform tidal exchange in the excavated western marsh system (minimal tidal attenuation). Both mean low water and mean tide levels increase. At the Ditch 2 location, the tide range increases and mean low water decreases resulting from the addition of the auxiliary culvert under Eastern Avenue and improved drainage channels. Figures 5-32 and 5-33 delineate the minimum and maximum extent of inundation in the marsh during the normal tides simulation (spring/neap cycle). Areas of inundation were computed separately for the portions of the marsh on the east and west sides of the abandoned I-95 fill. These areas were used to estimate the potential restored intertidal areas (between monthly maximum and monthly minimum water levels during the simulated time period, which is similar to the area between Spring High Tides and Spring Low Tides) and are presented in Table 5-11. Although the modified NRCS alternative reduces the tide range (larger area to fill at the higher elevation), both branches of the Ballard Street marsh system have significantly increased intertidal areas. In the western branch, the excavation and re-grading contribute to an increase in intertidal area of about 16 acres. In the eastern branch, there is 5[17] acre increase in intertidal area as the mean water level is elevated above the channel banks allowing tidal inundation of some of the higher elevation areas. These intertidal areas are used as a general proxy as the level of restoration that may be expected for each alternative. The exact distribution of wetland classification zones (e.g., high marsh, low marsh, mudflat, etc.) is not presented; however, the intertidal areas are expected to correspond to primarily restored high and low marsh regions. This represents a significant increase in restoration area.

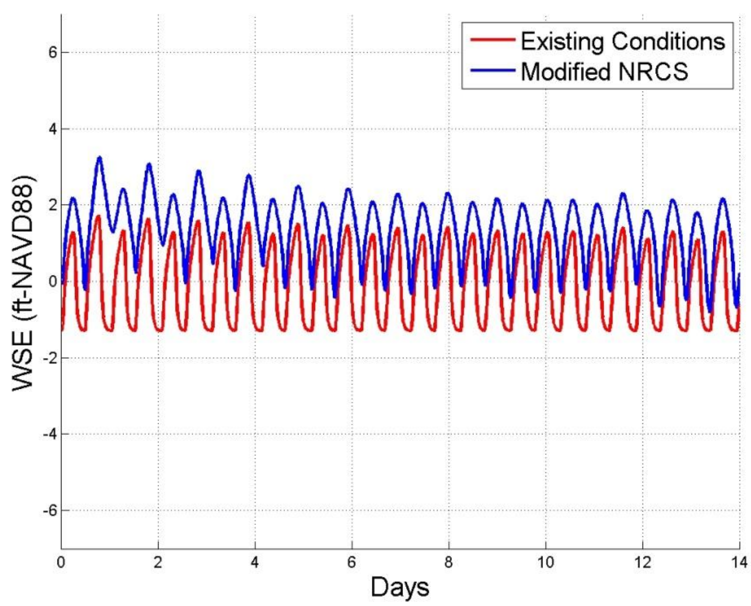


Figure 5-30. Comparison of water surface elevation (WSE) time series at West Marsh 1 for existing conditions and the modified NRCS alternative; normal tides.

[17] This is an over prediction of the restored area in the eastern marsh. At the time of this model simulation there was limited topography and no available tide data for model calibration in the eastern marsh. Additional data were collected in the eastern marsh and the model was recalibrated for this branch as presented in Section 6.

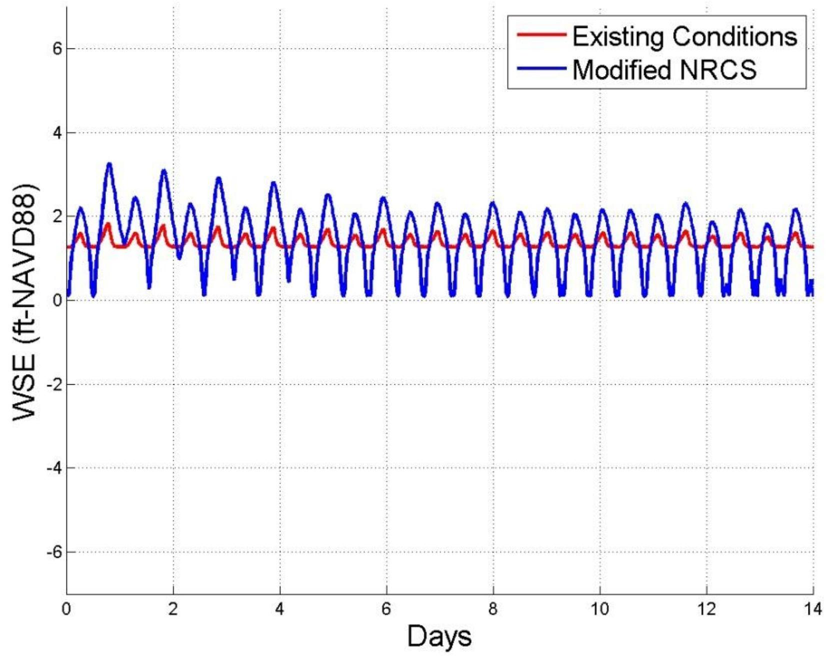


Figure 5-31. Comparison of water surface elevation (WSE) time series at Ditch 2 for existing conditions and the modified NRCS alternative; normal tides.

Figure 5-32. Minimum extent of inundation during normal tides (full spring to neap tidal cycle) for the modified NRCS alternative.

Figure 5-33. Maximum extent of inundation during normal tides (full spring to neap tidal cycle) for the modified NRCS alternative.

Table 5-11. Inundated area and estimated intertidal area for the modified NRCS alternative under normal tides.

	Maximum Inundated Area (acres)	Minimum Inundated Area (acres)	Intertidal Area (acres)	Change in intertidal area compared to existing conditions (acres)
East Marsh	9.5	3.6	5.9[18]	+5.0
West Marsh	19.8	3.5	16.3	+15.6

5.3.2 Tidal Flood Event

The tidal flood (storm surge) event was simulated for the modified NRCS alternative configuration using the same water surface elevation boundary condition applied for the existing conditions simulation. A similar water surface elevation boundary condition was generated for the Pines Channel and is shown in Figure 5-34, reaching the peak elevation of 7.7 ft-NAVD88. As such, it was assumed that the storm surge level would be the same in the Saugus River as it would be in the Pines Channel, which is likely a conservative assumption. For this simulation, it was assumed the tide control device (e.g. self-regulating tide gate, sluice/flap gate) on one of the proposed I-95 culverts would remain fully open as it was for the normal tides simulation. As such, the simulation presented here is conservative with respect to the volume of storm surge allowed into the western branch of the marsh. In practice, such a device would be used to limit or reduce storm surge in the western portion of the system if needed.

[18] This is an over prediction of the restored area in the eastern marsh. At the time of this model simulation there was limited topography and no available tide data for model calibration in the eastern marsh. Additional data were collected in the eastern marsh and the model was recalibrated for this branch as presented in Section 6.

Water surface elevation time series at the model output stations are shown in Figure 5-35. Peak tidal flood elevations at the model output stations are presented in Table 5-12. The results show a significant increase in the peak water levels throughout the system compared to existing conditions. However, for this moderate tidal flood event (i.e. just greater than a 10 percent annual chance of occurrence) peak water levels remain below the NRCS (1999) estimated point of damage of 5.6 ft-NAVD88 on the western marsh[19]. A peak level of 5.9 ft-NAVD88 occurs on the eastern marsh, but there is no critical infrastructure below that elevation in this region.

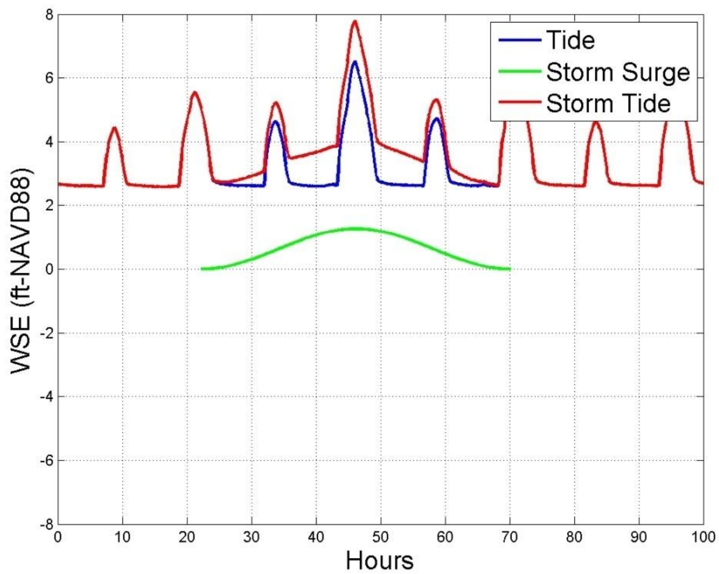


Figure 5-34. Tide, storm surge, and storm tide hydrograph for tidal flood event at the Pines Channel boundary.

[19] This was the lowest elevation measured by NRCS. Subsequent additional survey of the infrastructure west of the Ballard Street Marsh identified the lowest structural (house) elevation at 5.25 feet NAVD88 (see section 6.0). As such, the modified NRCS alternative would not keep water below the damage elevation for the 100-year precipitation event.

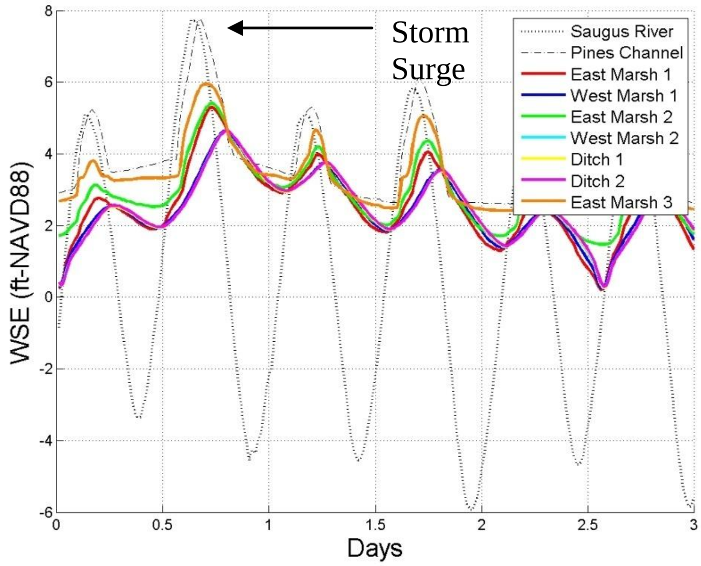


Figure 5-35. Water surface elevation time series for the modified NRCS alternative at model output stations for at tidal flood event.

Table 5-12. Maximum water levels for the modified NRCS alternative tidal surge simulation.

Location	Maximum Water level (ft-NAVD88)
Saugus River	7.7
East Marsh 1	5.3
West Marsh 1	4.7
East Marsh 2	5.4
West Marsh 2	4.7
Ditch 1	4.7
Ditch 2	4.7
East Marsh 3	5.9

5.3.3 100 Year Rainfall Event

A 100-year, 24-hour rainfall event was simulated for the modified NRCS alternative using the boundary conditions applied for the existing conditions simulation. However, this simulation also included a water surface elevation boundary for Pines Channel based on observations made at the DER 2 location. Water surface elevation time series at the model output stations are shown in Figure 5-36, while maximum water levels are presented in Table 5-13. The results show a significant reduction in the peak water level when compared to existing conditions due to the large excavation in the west branch of the Ballard Street marsh. The highest water levels occur in the southeast portion of the marsh near the Bristow Street culvert where there is the greatest influence from the spring high tide. Throughout the rest of the system the rise in water level due to the runoff is fairly consistent and remains below the NRCS (1999) estimated 5.6 feet-NAVD88 point of damage for the western portion of the system.[20]

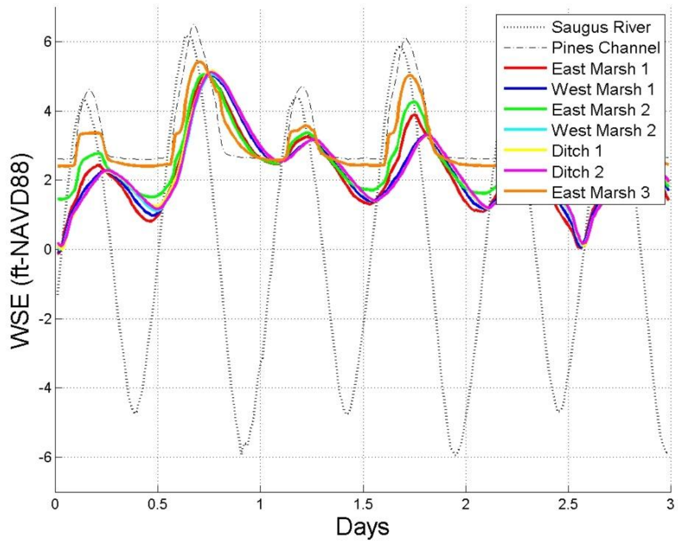


Figure 5-36. Water surface elevation time series for the modified NRCS alternative at model output stations for the 100-year rainfall event.

Table 5-13. Maximum water levels for the modified NRCS alternative; 100-year rainfall simulation.

Location	Maximum Water level (ft-NAVD88)
East Marsh 1	5.0
West Marsh 1	5.0
East Marsh 2	5.0
West Marsh 2	5.1
Ditch 1	5.2
Ditch 2	5.1
East Marsh 3	5.4

[20] This was the lowest elevation measured by NRCS. Subsequent additional survey of the infrastructure west of the Ballard Street Marsh identified the lowest structural (house) elevation at 5.25 feet NAVD88 (see section 6.0).

6.0 REFINED ALTERNATIVE SIMULATION

Following the completion of the modified NRCS alternative, additional data observations and analyses were collected to further refine and investigate potential restoration alternatives. New data and analysis included:

- Water surface elevation observations collected by DER in three locations within the eastern branch of the Ballard Street marsh system in March 2012.

- Additional survey cross-sections in the eastern branch of the Ballard Street marsh system collected by DER

- Survey of low lying infrastructure, local catch basins, and centerlines of roads in the vicinity of Ballard Street performed by WHG

- Review and recalculation of the extreme precipitation event determined by NRCS using revised climatology data developed by the Northeast Regional Climate Center at Cornell University

- A second validation of the existing conditions model using the new 2012 water surface elevation data collected by DER

As such, DER authorized an additional scope of work to continue to refine the preferred restoration effort at the Ballard Street marsh. This section provides the results of these additional technical tasks, including development of a refined restoration alternative. Specifically, this section presents (1) a review of the methodology used to determine the rainfall runoff storage requirements and hydrodynamic model inputs for extreme rainfall events as applied in the previous effort by the Natural Resources Conservation Service (NRCS, 1999), as well as revised calculations of return period precipitation events based on climatology data developed by the Northeast Regional Climate Center at Cornell University (NRCC); and (2) updates made to the Ballard Street Salt Marsh hydrodynamic model based on new survey cross-sections and water surface elevation data, validation of the updated model, and simulation results for updated alternatives.

This section details the intended preferred solution prior to the proposed DCR extraction of sediment from the abandoned I-95 berm that bisects the Ballard Street marsh. The modeling of this refined alternative was nearly completed when DER learned about the potential extraction of a portion of the berm for beneficial reuse at Winthrop Beach. As such, a new assessment and modeling effort was conducted and is presented in section 7. The sediment extraction is beneficial to the restoration effort, since flood storage capacity and excavation of material from the current marsh is needed for the restoration project. The proposed sand extraction by DCR provides a portion of the require flood storage and assists the restoration effort.

6.1 STORM PRECIPITATION AND EVENT REVIEW

Previous work conducted by NRCS (1999) utilized extreme rainfall data from the Weather Bureau Technical Paper 40 (Hershfield 1961), and soil types from the Essex County Soils Report to develop a hydrologic model (TR20) of the runoff in the Ballard Street Marsh watershed. Although the TR20 model does compute runoff hydrographs, it was assumed that only the total runoff volume computed by the TR20 model was relevant for the analysis and the hydrographs and peak discharge values from the TR20 model were not reported by NRCS. Therefore, flood storage requirements for the western portion of the Ballard Street marsh were based on this total runoff volume (60 acre-feet) and is was assumed that the total runoff volume occurred instantaneously. However, the hydrodynamic model developed by Woods Hole Group requires a time dependent runoff hydrograph for input. Because sufficient information was not provided in the NRCS report to reproduce the TR20 simulations (e.g. stream network details, curve numbers) Woods Hole Group took a simplified and conservative approach to generate a runoff hydrograph for the 100-year, 24 hour precipitation event. For this approach, it was assumed all rainfall would be available for direct runoff (i.e., curve number of 100) and a combination of the Snyder Method and SCS unit hydrograph method (Singh, 1992) were applied to generate the runoff hydrograph. A rainfall hyetograph was also developed for input to the model based on the rainfall amount and the rainfall distribution given in the Weather Bureau Technical Paper 40. This rainfall event was used in the existing conditions and alternative simulations presented in sections 6.5.3 and 7.3.3.

.However, the extreme precipitation data used in the previous work were based on climatology developed over 50 years ago (Hershfield 1961). As the climate continues to change, more recent analyses have been completed and indicated there are significant increases in the return frequency and magnitudes of extreme events. Therefore, more recent studies have included observations from the last half century and are readily available for New York and New England. These analyses provide newer estimates of the magnitude, distribution, and frequency of extreme rainfall events which are more appropriate for use in today's climate. Data from the North East Regional Climate Center at Cornell University (NRCC) were obtained from the website http://precip.eas.cornell.edu/. These data include rainfall amounts for storms of varying duration and recurrence intervals, as well as hyetographs and site specific distribution curves. Using the online web-map, 24-hour duration rainfall amounts for storms with recurrence intervals of 10-, 50-, and 100-years were obtained along with the associated precipitation distributions curves for a point centrally located in the Ballard Street Marsh System. These data were then used along with the simplified conservative methods described in the section 4.5.3 to generate runoff hydrographs and rainfall hyetographs for updated precipitation input to the updated hydrodynamic model. Table 6-1 presents the rainfall amounts and total runoff volume as determined from the NRCC data. Due to the increased frequency and magnitudes of extreme events, the 10-year event as determined from the NRCC analysis produces nearly as much total runoff as the 100-year event used in the old NRCS analysis. Figure 6-1 shows the rainfall hyetographs and runoff hydrographs associated with the 10-, 50-, and 100-year recurrence interval precipitation events. These new estimates of extreme precipitation events were used in the subsequent analyses of potential restoration alternatives. Specifically, the 50-year recurrence interval precipitation event was selected for simulation in the Ballard Street restoration model. This event is larger than the 100-year precipitation event assumed by NRCS and also corresponds to the expected service life of the proposed infrastructure (e.g., tide gates, new box culverts, etc.). The extreme precipitation event is also greater than the storm surge return period (approximately 10-year return period) that is expected to overtop Ballard Street.

Table 6-1. Total rainfall and runoff volume for 10, 50, and 100-year precipitation events from the NRCC analysis.

Recurrence Interval	Total Rainfall (inches)	Total Runoff Volume (acre-ft)
10-Years	4.91	59.0
50-Years	7.37	88.5
100-Years	8.79	105.5

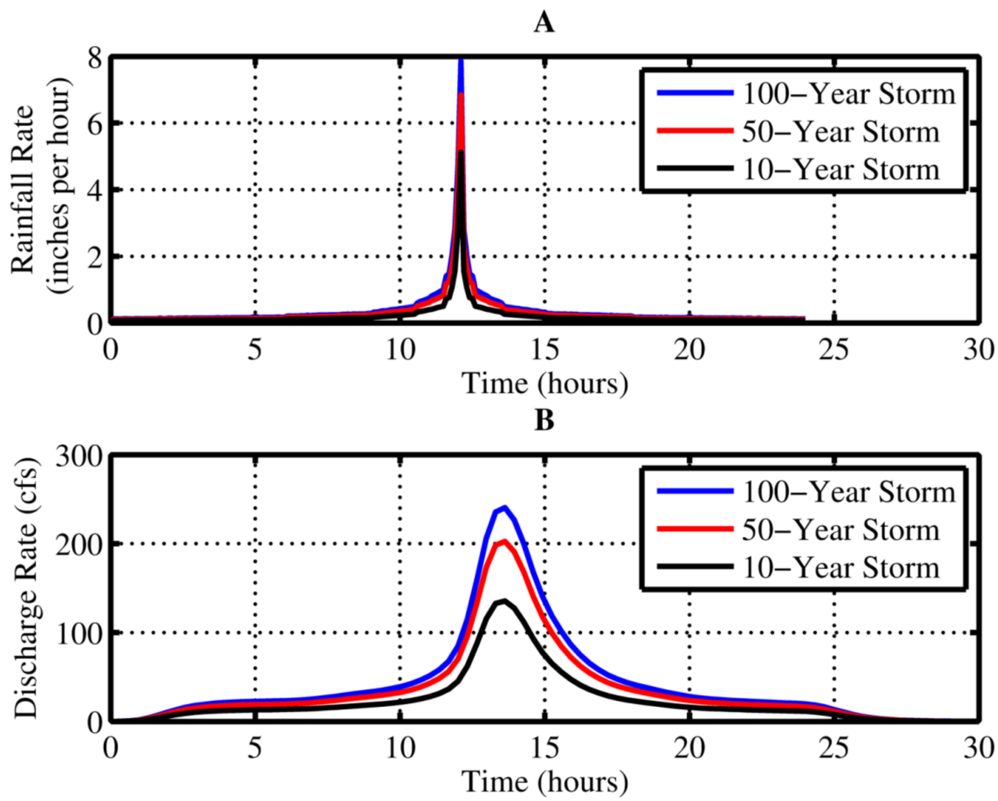


Figure 6-1. Rainfall hyetographs (A) and runoff hydrographs (B) for the 10-, 50-, and 100-year recurrence interval extreme rainfall events.

6.2 LOW LYING INFRASTRUCTURE SURVEY

A supplemental survey of low lying infrastructure was also completed in support of the Ballard Street marsh restoration project. Survey data points were collected using a Trimble® real-time kinematic global positioning system (RTK GPS) that provides centimeter-level geodetic positioning, and operates by receiving GPS corrections from the KeyNET base station network. The survey was conducted between June 18th and 20th, 2013 of the Ballard Street Marsh project area. The survey coordinate system was Massachusetts State Plane Mainland 2001 feet (horizontal datum) and NAVD88 feet (vertical datum). The RTK GPS was site calibrated to the local benchmarks that were set by Otte & Dwyer, Inc. (Appendix B). Table 6-2 presents a comparison of the Woods Hole Group measured benchmarks to the established benchmarks. There were only minor differences between the established elevations at the benchmarks (using traditional surveying equipment) and the RTK survey indicating confidence in the overall survey results. Overall, the Woods Hole Group measured benchmarks showed good agreement with those established by Otte & Dwyer. The discrepancies that do exist are likely due to GPS shadowing and multipath errors caused by interference from trees and tall structures.

Table 6-2. Comparison of benchmark elevations in the vicinity of Ballard Street marsh.

Benchmark ID	Otte &Dwyer Elevation (NAVD88, ft)	WHG Elevation (NAVD88, ft)	Difference (ft)
PK Nail 11	10.38	10.28	-0.10
PK Nail 15	9.20	9.20	0.00
MNAIL 1	9.39	9.41	0.02
MNAIL 2	6.98	6.93	-0.05
MNAIL 3	6.80	6.82	0.02
NRCS200	7.50	7.50	0.00
Stone Bound	7.58	7.50	-0.08

Following the site calibration of the RTK GPS, survey of critical infrastructure was conducted. The survey focused on the collection several different types of data types including, but not limited to:

- Structures, including houses, out buildings (sheds, etc.), and other potential low-lying structures (e.g., pools, tennis courts) in the areas surrounding Ballard Marsh
- Low points in yards
- Streets and roads, including centerlines, transects on Ballard Street in the vicinity of the outlet, and low points in road elevations
- Catch basins elevations

Permission (written or verbal) was obtained from each land owner prior to collecting data from their property, but permission could not be gained for all properties. Structures that were surveyed included residential homes and other structures such as sheds, pools, etc. An attempt was made to capture each corner or, at the very least, the lowest corner of the structure. In addition, survey points were collected in the low points within the yards at each property.

The centerline of the streets in the vicinity of Ballard and Eastern Avenue were surveyed. Catch basins on these streets were also surveyed to help determine potential draining/flooding characteristics. Cross-street transects were collected at Ballard Street in the vicinity of where the culvert connects Rumney Marsh to the Saugus River to determine the low points in the road. In addition, several survey points were taken using a total station and rod in several locations where a GPS fix could not be maintained. The total station was setup on a temporary benchmark that was established using the RTK GPS, and the rod was setup on the target. Two locations surveyed by these means included the invert elevation of the culvert underneath Ekstrand Road and the stream bed downstream of the culvert in the backyard of 54 Gates Road. Table 6-3 presents the key results from the low lying property survey.

Table 6-3. Elevations of key local infrastructure in the vicinity of Ballard Street marsh.

Survey Data Point Type	**Lowest Elevation (NAVD88 Feet)**
Ballard Street	7.10
Lowest Structure (houses)	5.25
Yard	4.65
Lowest Non-house infrastructure (shed)	4.93

6.3 UPDATED SURVEY INFORMATION FOR EASTERN MARSH

New elevation data were incorporated into the model grid based on 2012 Real-Time-Kinematic (RTK) survey performed by DER. These data are illustrated in Figure 6-2. In addition to providing additional channel cross sections and spot elevations along the channel center line in the eastern branch of the marsh, the DER survey also identified specific obstructions in the eastern marsh. A description and corresponding photographs of these obstructions and their locations are shown in Figure 6-3. These obstructions have a major role in the flow dynamics within the eastern marsh, therefore extra care was taken to ensure they were accurately represented in an updated model domain.

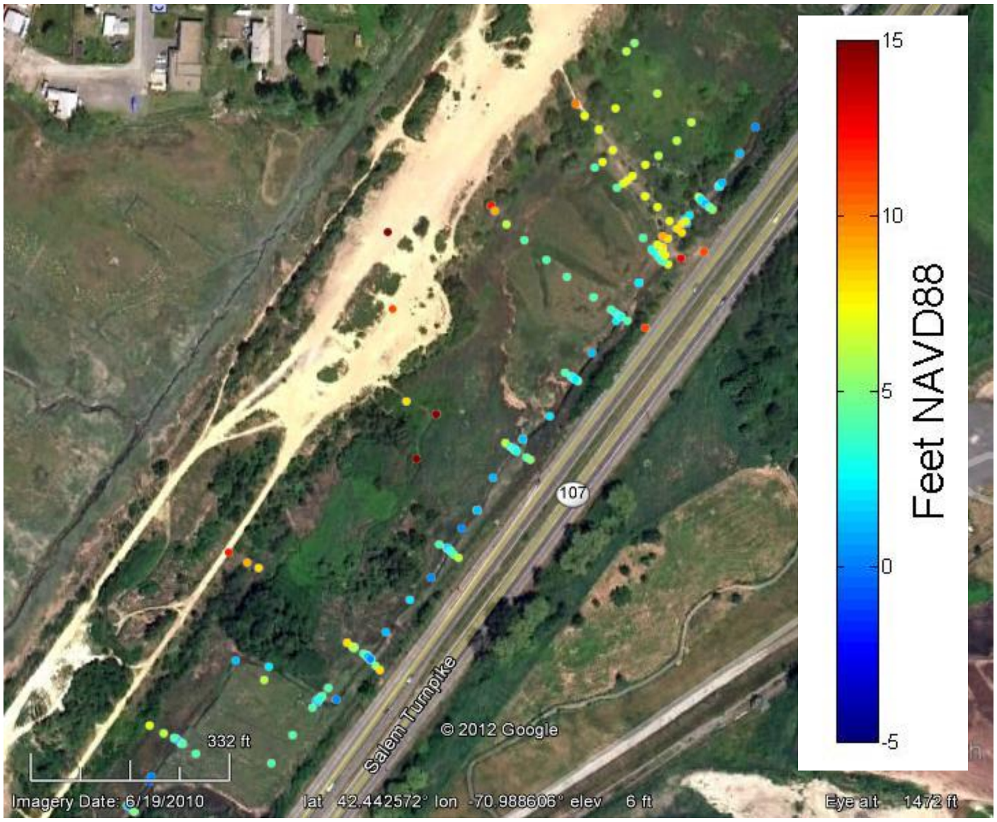


Figure 6-2. 2012 RTK survey data from DER.

Figure 6-3. Obstructions in the east marsh channel (photographs provided by DER).

The survey also provided updated dimensions and measurements of the Bristow Street culvert. Photographs of the downstream side (looking north) and upstream side (looking south) with the plywood barrier removed are shown in Figures 6-4 and 6-5, respectively. This information was utilized to update the previously developed Ballard Street marsh hydrodynamic model and refine the Bristow Street culvert included in the model.

6.4 ADDITIONAL TIDE DATA AND MODEL VALIDATION

Additional water surface elevation was collected by DER in 2012 to (1) provide more detailed information on the flow dynamics through the eastern branch of the Ballard Street marsh and to (2) provide another set of data for model validation. As such, an additional validation of the Ballard Street hydrodynamic model was performed using water level data collected by DER in March 2012. These data were used to provide water surface elevation boundary conditions in the Pines channel, as well as in the Saugus River. Figure 6-6 shows the locations where water surface elevation data were collected between March 16th and March 30th, 2012 and Figure 6-7 shows a time series of the observed data at the four locations.

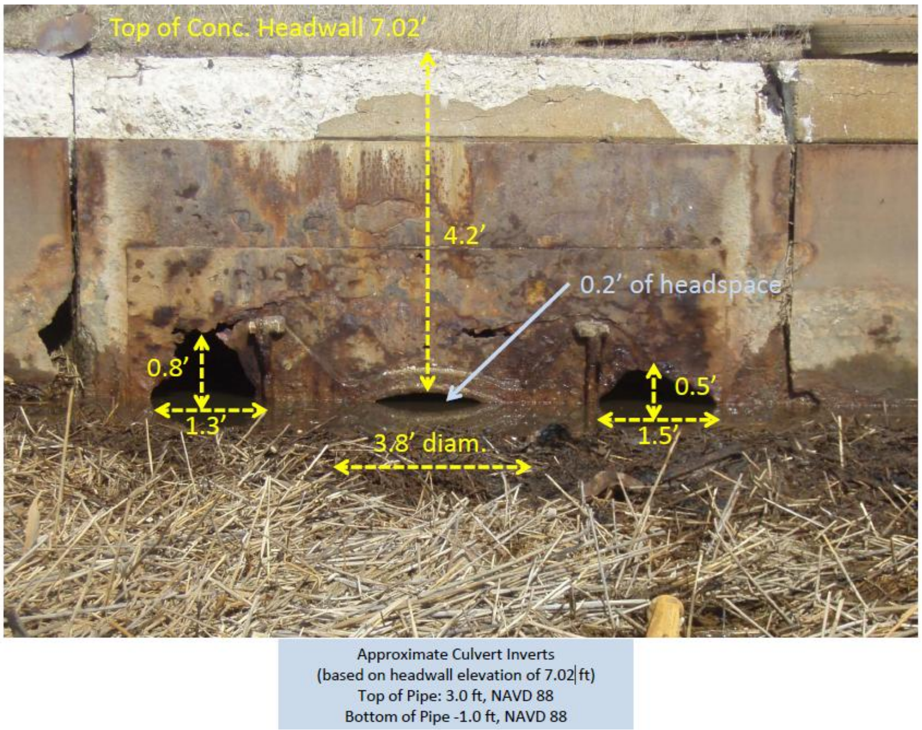


Figure 6-4. Photograph of the south side of the Bristow Street Culvert (looking north) (photograph and dimensions provided by DER).

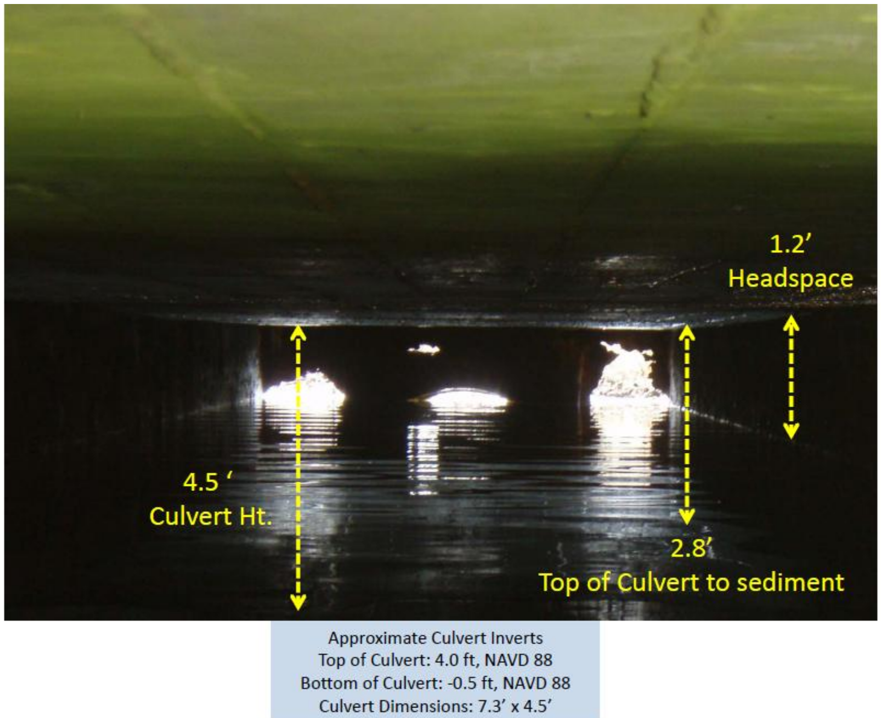


Figure 6-5. Photograph of the south side of the Bristow Street Culvert (looking south) (photograph and dimensions provided by DER).

The hydrodynamic model was validated a second time by comparing simulated water surface elevations to observed water surface elevations at the Bristow Up and Ballard Up measurement stations (Figure 6-6) by simulating the model for the March 16th and March 30th, 2012 time period. Absolute error (RMSE and Bias) was quantified using the same methodology applied in the initial model validation (Section 4). Overall the absolute error in water surface elevation is less than 3.5 inches and relative error, computed as a percentage of the observed range, is less than 10% at both locations. The model error statistics are summarized in Table 6-4.

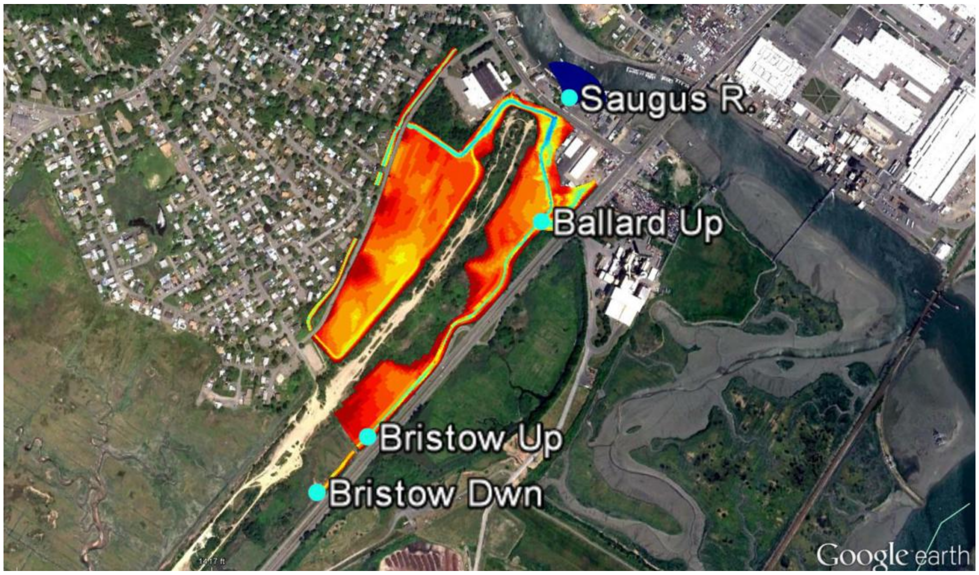


Figure 6-6. Updated model domain and water surface elevation locations for DER March 2012 observations.

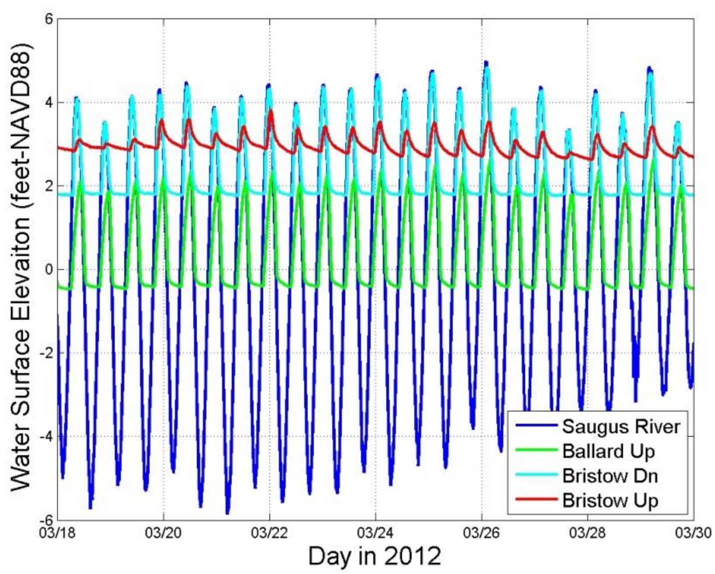


Figure 6-7. Observed water surface elevation time series from data collected by DER in the eastern branch of the Ballard Street salt marsh in March, 2012.

Table 6-4. Water surface elevation error statistics for secondary model validation.

Gauge ID	Absolute Error (ft)		Observed Range (ft)	Relative Error (%)	
	RMSE	BIAS		RMSE	Bias
Ballard Up	0.26	0.06	3.38	7.7	1.8
Bristow Up	0.16	0.07	1.80	8.9	3.9

6.5 REFINED RESTORATION ALTERNATIVE SIMULATIONS

Following the updated model refinement and secondary validation, additional modifications were made to the updated model domain to include refined components of the modified NRCS alternative. These components included:

- The same NRCS excavation and re-grading plan (Geosyntec, 2007) to create additional storage for rainfall storm water in the western branch of the Ballard Street marsh system and also allow for restoration of the marsh plains
- The addition of an auxiliary 4 foot diameter culvert under Eastern Avenue in the vicinity of the Carr Road extension
- Removal of the flap gate at the Ballard Street culvert
- Removal of the plywood and metal plate from the Bristow Street culvert[21] at the southeast corner of the marsh area to allow tidal exchange between the Pines River and the portion of the marsh east of the abandoned I-95 embankment
- The two proposed 4'x4' culverts at I-95 berm would be installed, both to be fitted with combination slide/flap gates. In the model simulation, one combination gate was set to be completely closed and only let flow out of the system, while the second gate was set to be fully open.[22]

6.5.1 Normal Tides

The same boundary condition used for the existing conditions model and the previous alternatives presented in section 5 were applied for the refined alternative. Modeled water surface elevation time series are shown in Figure 6-8 for the model output stations, and calculated tidal statistics are presented in Table 6-5. These results indicate:

- Improved drainage from the southern portion of the Eastern Avenue ditch (Ditch 2 model station) due to the additional auxiliary culvert under Eastern Avenue.
- Significant changes in the tidal regime directly adjacent to the opened Bristow Street culvert (East Marsh 3); however on minor changes in the eastern marsh as a whole for this refined model that includes more detailed east marsh topography and channel restrictions. For example, the cross-sectional data indicated channel inverts that act as natural weirs within the channel limiting exchange from the Pines marsh to the Ballard Street marsh.

[21] For this particular culvert, the removal of the plywood and metal plate did not consist of modeling the full capacity of the as built culvert since the existing culvert system has experienced significant sedimentation (see figures 6-4 and 6-5). The culvert opening simulated in the model was based on the actual current physical opening available at this location and was then calibrated to the water surface elevation observations on both sides of the culvert.

[22] Note that this is a different configuration than the modified NRCS alternative presented in section 5; however, simulations with both tide gates completely open were also conducted for this alternative.

- Increased tidal range in the western marsh and significant restoration gains due to lowered marsh elevations, which now reside in the intertidal range of the tides allowed into the system.

- A significant increase in the volume of water entering the western marsh. Although MHW levels remain approximately the same, the excavation of the marsh area results in significantly more volume to fill.

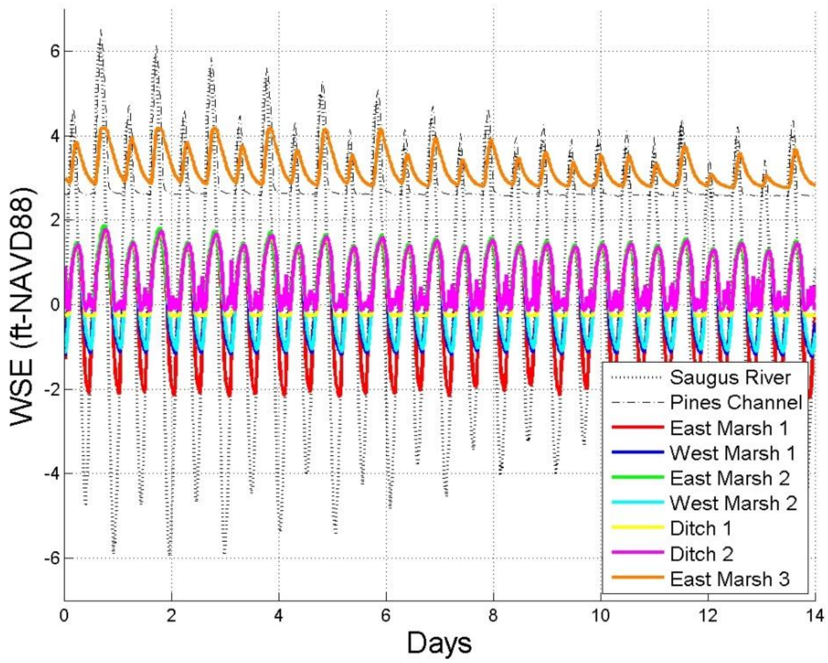


Figure 6-8. Water surface elevation time series for the updated, refined alternative normal tides simulation.

Table 6-5. Tidal statistics for the updated, refined alternative simulation (elevations in feet-NAVD88)

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	4.2	-4.3	-0.1	8.5	-5.9	6.2
Pines Channel	4.6	2.6	3.6	2.0	2.5	6.5
East Marsh 1	1.5	-2.1	-0.3	3.6	-2.2	1.8
West Marsh 1	1.4	-1.2	0.1	2.6	-1.2	1.8
East Marsh 2	1.5	0.0	0.8	5	0.0	1.9
West Marsh 2	1.4	-1.1	0.2	2.5	-1.2	1.7
Ditch 1	1.4	-0.3	0.6	1.7	-0.3	1.7
Ditch 2	1.4	-0.1	0.7	1.5	0.1	1.8
East Marsh 3	3.8	2.8	3.3	1.0	2.8	4.2

The increased intertidal area is shown in Figures 6-9 and 6-10, which delineate the minimum and maximum extent of inundation in the marsh during the normal tides simulation for the refined alternative. Areas of inundation were computed separately for the portions of the marsh on the east and west sides of the abandoned I-95 fill. These areas were used to estimate the potential restored intertidal areas and are presented in Table 6-6. Although the refined alternative has a similar tidal range (slightly larger), there is larger area to fill at the higher elevations and due to the excavation. As such, the western marsh has significantly increased intertidal areas. In the western branch, the excavation and re-grading contribute to an increase in intertidal area of about 15.8 acres. In the eastern branch, there is smaller 0.7 acre increase in intertidal area as the refined model better represents the topography in this region. Overall, the refined alternative produces an increase of approximately 15.8 acres in intertidal area. These intertidal areas are used as a general proxy as the level of restoration that may be expected for each alternative. The exact distribution of wetland classification zones (e.g., high marsh, low marsh, mudflat, etc.) is not presented; however, the intertidal areas are expected to correspond to primarily restored high and low marsh regions.

Figure 6-9. MLW contour for updated, refined restoration alternative.

Figure 6-10. **Maximum water surface contour (approximately equivalent to the monthly high spring tide) for the updated refined alternative.**

Table 6-6. **Inundated area and estimated intertidal area for the refined alternative under normal tides.**

	Maximum Inundated Area (acres)	Minimum Inundated Area (acres)	Intertidal Area (acres)	Change in intertidal area compared to existing conditions (acres)
East Marsh	5.1	3.5	1.6	+0.7
West Marsh	19.6	3.8	15.8	+15.1

6.5.2 Tidal Flood Event

The tidal flood (storm surge) event was simulated for the refined NRCS alternative configuration using the same water surface elevation boundary condition applied for the previous alternatives. For this simulation, it was assumed the combination slide/flap gates at the proposed I-95 culverts would remain in the same state as for the normal tides simulation (one closed and one open). As such, the simulation presented here is conservative with respect to the volume of storm surge allowed into the western branch of the marsh. In practice, such a device could be used to limit or reduce storm surge in the western portion of the system if needed.

Water surface elevation time series at the model output stations are shown in Figure 6-11. Peak tidal flood elevations at the model output stations are presented in Table 6-7. The results show an increase in the peak water levels throughout the system compared to existing conditions. However, due to the reconfigured tidal control (one gate open, one gate closed only allowing flow out of the system) at the new I-95 culvert location, the peak water surface elevations are much lower than in alternatives that had both culverts open. This illustrates the ability of the combination slide/flap gates to provide control of the water levels within the western marsh. In all simulation cases (even with both tide gates open), the moderate storm event does not exceed the critical infrastructure elevation of 5.25 feet NAVD88. The storm level at East Marsh 3 is significantly higher than East Marsh 1 and 2 due to the drainage impairment caused by the topographic features (Figure 6-3). This is also shown in the data observations (Figure 6-7) and the model results (Figure 6-8) and causes the northern portion of the channel to have a lower water surface elevation at low tide.

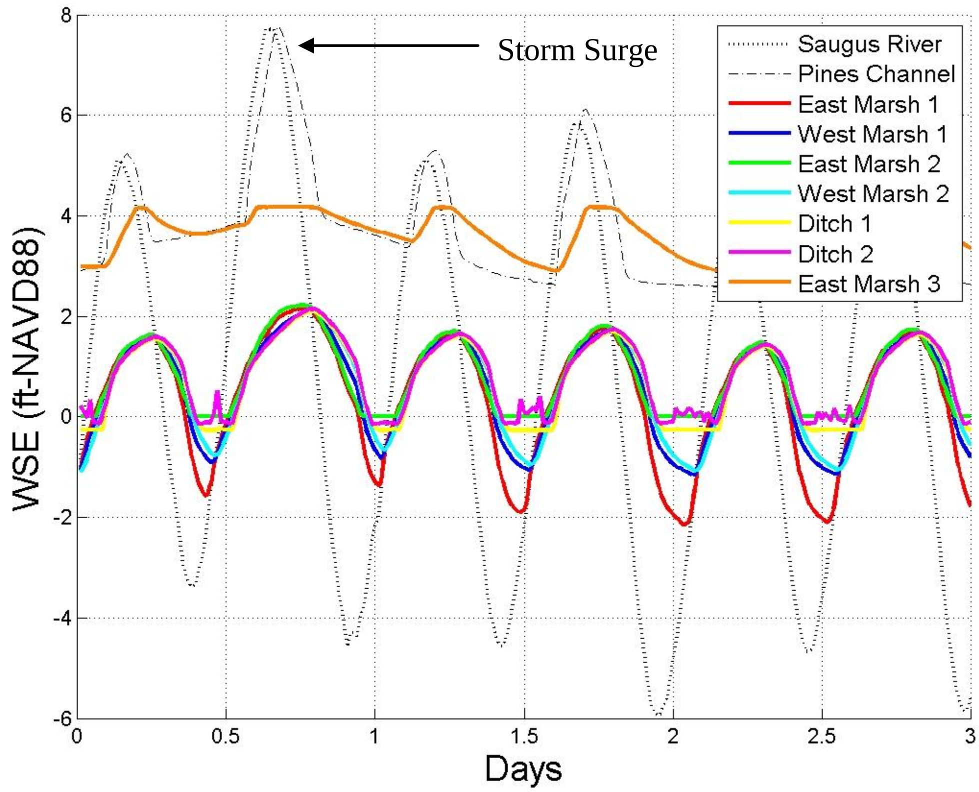


Figure 6-11. Water surface elevation time series for the updated, refined alternative at model output stations for at tidal flood event.

6.5.3 Extreme Precipitation Event

Using more recent rainfall event data as presented in section 6.1, the updated 50-year, 24-hour precipitation event was simulated for the refined restoration alternative. The updated 50-year event produces a larger volume of total storm water over the 24 hours than the NRCS 100-year event. Water surface elevation time series at the model output stations are shown in Figure 6-12, while maximum water levels are presented in Table 6-8. The results show a significant reduction in the peak water level when compared to existing conditions due to the excavation in the west branch of the Ballard Street marsh. In addition, drainage is enhanced from the Eastern Avenue ditch due to the auxiliary culvert installed to help improve the drainage ability from the watershed feeding the ditch. The maximum water elevations are approximately 4.0 ft NAVD88 throughout the system, which is well below the critical elevation of 5.25 (Table 6-3). As such, this refined alternative provides adequate flood storage, enhances drainage to the storage area, and also provides proper elevations for salt marsh establishment.

Table 6-7. Maximum water levels for the updated, refined alternative tidal surge simulation.

Location	Maximum Water level (ft-NAVD88)
Saugus River	7.7
Pines Channel	7.7
East Marsh 1	2.2
West Marsh 1	2.1
East Marsh 2	2.2
West Marsh 2	2.1
Ditch 1	2.1
Ditch 2	2.1
East Marsh 3	4.2

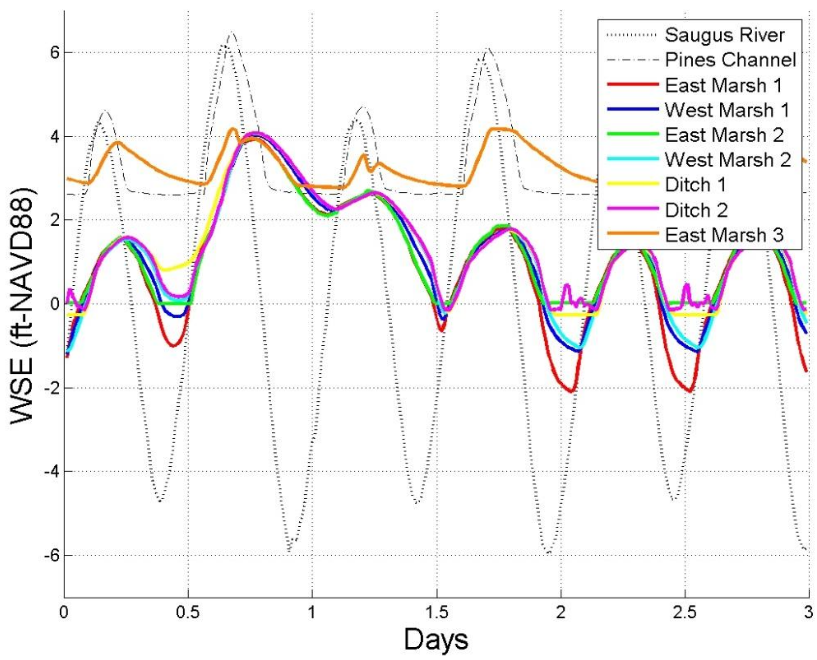


Figure 6-12. Water surface elevation time series for the refined alternative at model output stations for the updated 50-year rainfall event.

Table 6-8. Maximum water levels for the refined restoration alternative; updated 50-year rainfall simulation.

Location	Maximum Water level (ft-NAVD88)
East Marsh 1	3.9
West Marsh 1	4.0
East Marsh 2	3.9
West Marsh 2	4.1
Ditch 1	4.1
Ditch 2	4.1
East Marsh 3	4.2

7.0 DCR EXTRACTION AND PREFERRED ALTERNATIVE

During the final stages of the development of the restoration project, MA DCR advanced a proposed project to beneficially re-use material from the abandoned I-95 embankment that bifurcates the Ballard Street salt marsh system. DCR has proposed extracting beach-compatible material from a portion of the embankment for beneficial reuse (beach nourishment) at Winthrop Beach. Since the restoration project at Ballard Street marsh required added flood storage capacity, as well as re-grading of the marsh elevations, this was also beneficial for the restoration of the salt marsh to more natural conditions. Therefore, the hydrodynamic model was utilized to evaluate the potential extraction, and develop a new restoration approach that incorporated the proposed extraction. This required a modification of the modeling domain to include the portion of the I-95 embankment that is proposed to be extracted, as well as development and simulation of a new restoration alternative.

7.1 MODEL GRID MODIFICATION

To model the Ballard Street marsh system for the proposed DCR extraction scenario, the model domain developed for the original NRCS restoration proposal had to be modified. Specifically, the model domain had to be updated to include the I-95 embankment region. The redevelopment of the model domain was accomplished in two specific steps. In the first step, the model domain was expanded to include the east side of the I-95 berm that is proposed to be extracted. Figure 7-1 shows the extent of the original model domain in blue and the expanded domain, encompassing a majority of the I-95 embankment in red.

Figure 7-1. Original model domain (blue) with expanded domain area (red) for DCR extraction alternatives.

The proposed DCR extraction is intended to advance in two distinct phases. In the first phase, the western side of the embankment will be extracted to an elevation of approximately 5 feet NAVD88. The second phase will extract approximately the same area down to an elevation of -1 feet NAVD88. As such, the second step in the model modification was to incorporate the proposed excavation elevations for both excavation phases into the model domain. Data from the DCR extraction plan was digitized, converted to NAVD88 feet (vertical datum) and Massachusetts Mainland State Plane coordinates (horizontal datum). The newly added cells were then tagged for interpolation and the digitized data was interpolated to these cells. The new model domain with the interpolated elevations are shown in Figure 7-2 and Figure 7-3 for the intermediate and final excavation levels proposed by DCR, respectively. These model domains are essentially the existing topography with the proposed embankment extraction(s) included. For Figure 7-2, the extraction lowers the area (shown in green) to an elevation of approximately -1 feet NAVD88. The color bar in Figure 7-2 indicates the elevation (in NAVD88 feet) and all elevations above 5 feet NAVD88 are shown as red in order to show the detail within the existing marsh system. For Figure 7-3, the extraction lowers the area (shown in orange) to an elevation of approximately 5 feet NAVD88. The color bar in Figure 7-3 indicates the elevation (in NAVD88 feet) and all elevations above 6 feet NAVD88 are shown as red in order to show the detail within the existing marsh system. Therefore, the scale in Figure 7-3 is different than the scale in Figure 7-2.

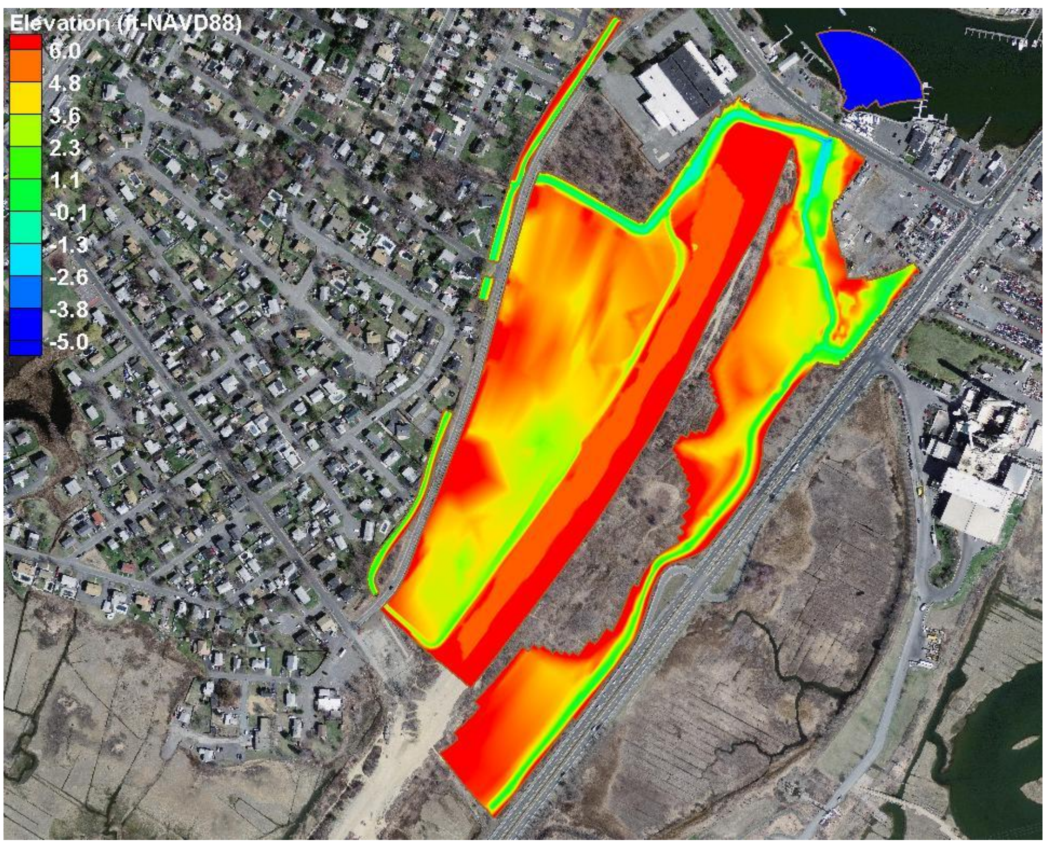


Figure 7-2. Model domain with elevation contours after the intermediate proposed DCR extraction.

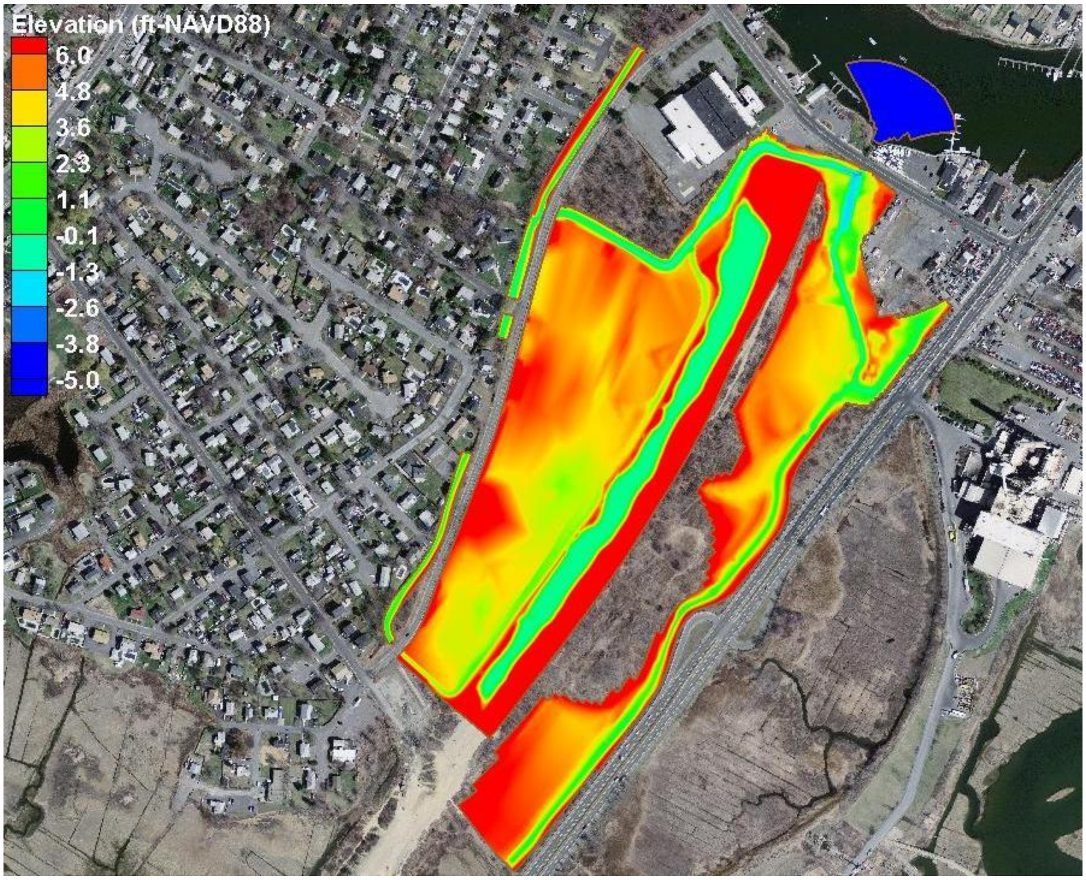


Figure 7-3. Model domain with elevation contours after the full proposed DCR extraction.

7.2 PREFERRED ALTERNATIVE DESIGN PROCESS

Integrating the proposed DCR extraction into the restoration project allowed for a reassessment of the restoration project, specifically the required re-grading required for marsh creation and flood storage. The proposed DCR excavation was beneficial to the restoration project since it (1) expanded the total area for restoration, (2) improved flood storage capacity in the western branch of the Ballard Street marsh, and (3) created a cavity in the system that could be filled with material required to obtain appropriate marsh elevations within the western marsh. The hydrodynamic model was used to develop a new restoration design concept with the goals of maximizing the salt marsh restoration area, providing adequate flood storage for storm events, and minimizing cost of the restoration project. The development of the preferred restoration design incorporated components from the previous alternatives (e.g., auxiliary culvert under Eastern Avenue to help drain the ditch regions), integrated lessons learned from previous alternative simulations, and added some additional components that aid in the establishment of a diverse salt marsh.

The restoration of the western marsh depends on numerous variables. Figure 7-4 presents a conceptual multi-variant diagram that illustrates the marsh grading design process. The figure indicates that as excavation increases (blue line); the flood storage also increases (green line). Due to the muted tidal signal caused by the anthropogenic restrictions to the system, as well as the slightly elevated marsh plain from deposited material from the placement of the I-95 embankment, increased excavation also increased the restoration area (a black line). However, as the excavation increases, the Mean High Water (MHW) elevation decreases due to the larger volume of the marsh area (i.e., the volume of water must fill a larger area and thus the elevation [height] of the water is reduced). Restoration level, which is a function of both excavation (marsh grade) and water surface elevation (MHW), changes as these variables also change, making it more difficult to optimize restoration. In addition, as the excavation level increases, there is a point where no additional restoration can be achieved and the intertidal area starts to become subtidal area. Eventually, excessive excavation would lead to the creation of an impounded marsh system that cannot adequately drain due to the limited capacity of the Ballard Street culvert. Ultimately, the ideal marsh configuration will maximize restoration area while minimizing excavation and also provide adequate flood storage and drainage ability. This can be attained by creating a marsh surface that corresponds to the yellow dot on Figure 7-4. Therefore, the development of the preferred restoration grading in the western marsh was a lengthy iterative process consisting of more than 50 simulations of different marsh configurations to arrive at the preferred alternative design.

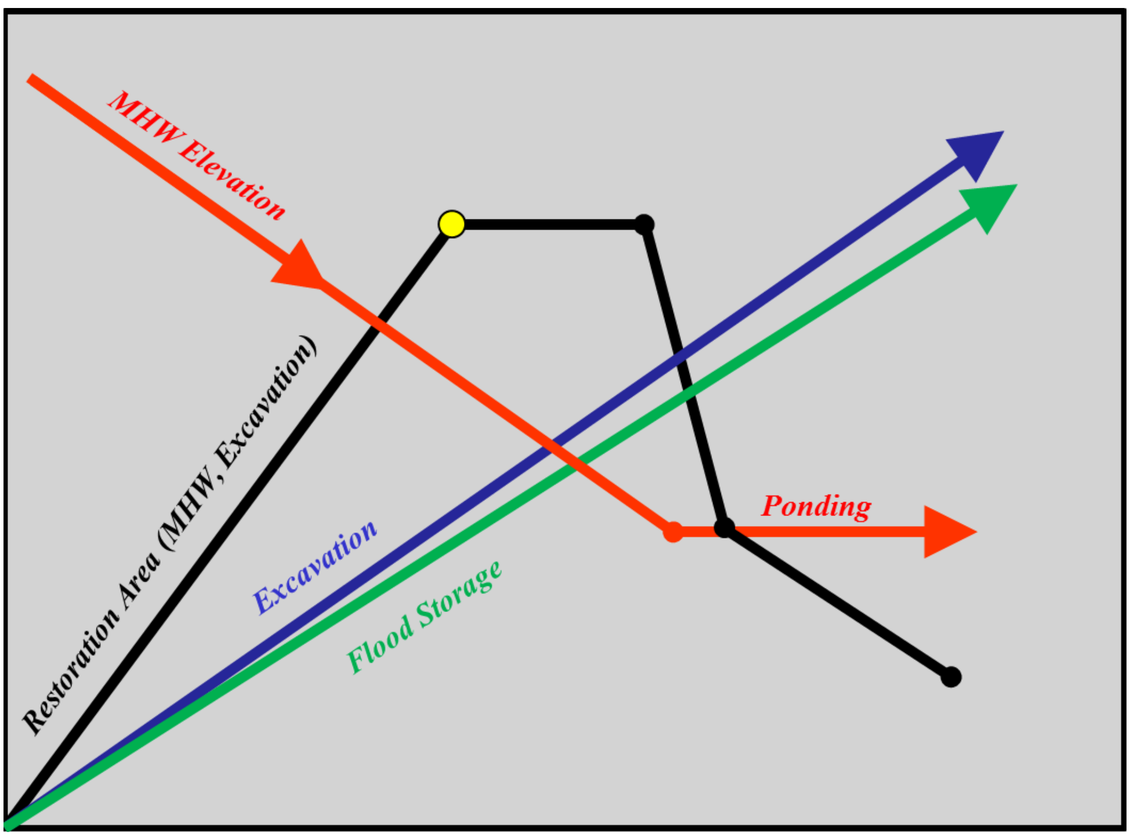


Figure 7-4. Conceptual multi-variant diagram showing the variables associated with design of the elevations within the western marsh.

In order to arrive at the preferred restoration design, a basic template was used where the recommend channel locations were defined and variations were made to the elevation profiles extending from the channels through the marsh. This iterative approach was used to identify the optimal balance between:

- Maximizing marsh restoration (specifically low marsh habitat at the higher elevations to accommodate projected sea level rise)
- Minimizing excavation (to reduce project cost)
- Provide adequate flood storage to prevent flooding during storms

While maximizing any one variable is relatively straightforward, achieving all three simultaneously is much more difficult. Figure 7-5 presents the marsh restoration template that was used to define the optimized restoration marsh grading. The black areas show the recommended primary creek channels, the green areas show low marsh regions, and the blue areas show high marsh areas. The red regions represent areas that would remain at the same elevation as existing conditions (unmodified).

Figure 7-5. Aerial photo showing the template used for all potential restoration alternatives following DCR extraction.

The vertical component of the template always slopes up from the channel to the high marsh. The elevations for the base of the channel, extent of low marsh and the upper limit of the high marsh were varied through numerous simulations. Varying these elevations changes the amount of low marsh, flood storage capacity, and excavation volumes. After numerous iterations, the optimized marsh grading was developed for the expected tidal benchmarks in the system. Figure 7-6 presents the final preferred alternative for restoration of the western marsh. The elevations are presented in

NAVD88 feet, and all elevations above 5 feet NAVD88 are shown as red in order to show the detail within the proposed restoration area.

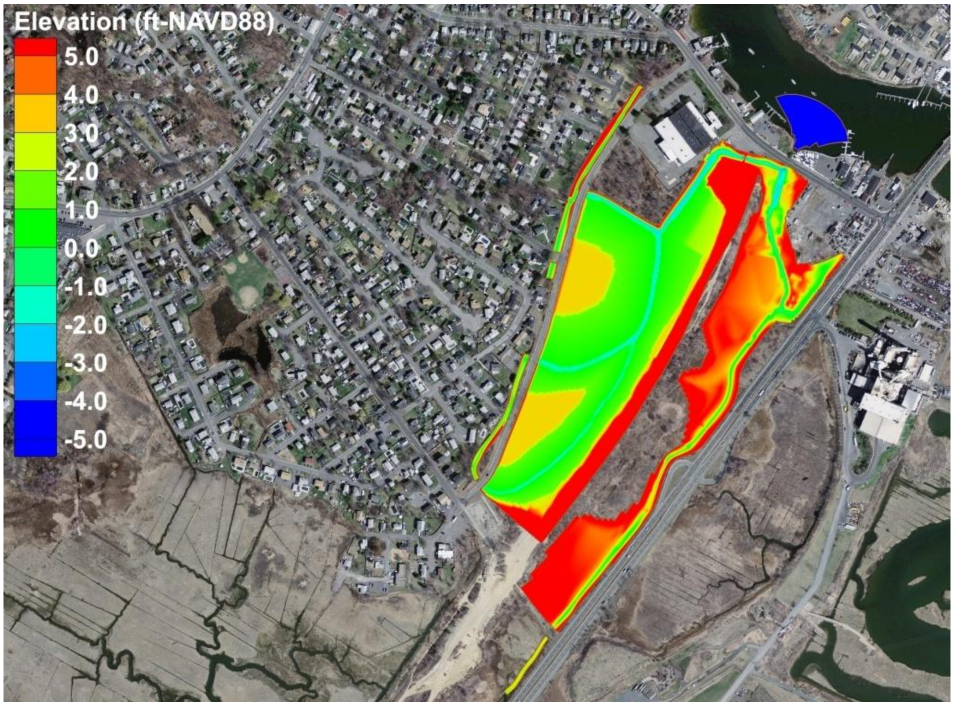


Figure 7-6. Aerial photo showing the final preferred alternative elevations following the DCR extraction.

In order to determine the marsh zones within the preferred alternative, and as a guide for the design of the system, basic vegetative classifications as a function of tidal benchmarks were evaluated. Figure 7-7 provides a schematic showing the basic zonation within a typical salt marsh system. The zonation depicted represents the commonly accepted distribution of the various vegetative zones as a function of tidal benchmark water levels. Specifically, the area between Mean Low Water (MLW) and Mean Tide Level (MTL) is defined as mudflats; the area between MTL and Mean High Water (MHW) is defined as Low Marsh; the area between MHW and Mean High Water Spring (MHWS) is defined as High Marsh; and areas below MLW are defined as open water or sub-tidal. Although this distribution is not precisely correct for every site-specific marsh system due to various other factors (e.g., the amount of freshwater discharge entering the system, etc.), this distribution is commonly accepted for northeastern United States salt marsh systems. Site-specific variations on these zones could be made. For the Ballard Street system, this zonation could also be adjusted

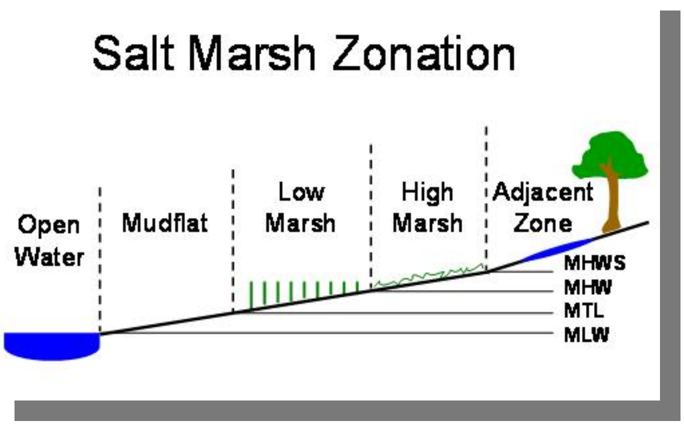


Figure 7-7. Schematic showing representative vegetation zones within a typical salt marsh system as a function of tidal benchmarks.

slightly based on the site-specific bio benchmarks (if available). However, for the purposes of this assessment, this zonation, which in generally accepted by the scientific community, provides a reasonable estimate of the extent of the existing and projected marsh coverage types. Table 7-1 provides a summary of the elevation ranges that correspond to the approximate marsh classifications based on the tidal benchmark results for the preferred alternative. Minimal mudflat area was included in the initial design layout; however, it is expected that is the marsh restoration naturally progresses; some limited mudflat regions will develop between the tidal creeks and the low marsh areas.

The modeling effort focused on optimizing the excavation as much as possible given the stated goals of the project. Substantial effort was placed on reducing the permitted NRCS excavation (97,000 cubic yards) to optimize costs. In order to provide full flood storage capacity for the 50-year precipitation event (Chapter 6), while still maximizing restoration within the system, a total of 43,500 cubic yards of material would require offsite disposal, a significant reduction from the NRCS value. Determining the excavation requirements that met these criteria was not a straightforward exercise, as described in Figure 7-4. The excavation associated with the preferred alternative is significant and results in a substantial expense. Additionally, there is some uncertainty associated with the amount of the required excavation due to various uncertainties (e.g., precipitation analysis, sea level rise, model uncertainty associated with flow over the re-graded marsh plains, etc.). This excavation uncertainty is further evaluated in the attached Addendum to this report. Ultimately, the excavation levels were geared towards maximizing the restoration and meeting the worst-case scenario associated with the 50-year rainfall event. If the full flood storage capacity is not required in the western marsh, or the restoration is reduced, then less excavation may be required. Modification of these assumptions results in greater changes than would be related to uncertainties in the analysis. It is also important to consider the practical aspects of the excavation requirements. For example, although a model uncertainty may reveal an error of approximately an inch (0.1 feet), it is likely unrealistic to expect a contractor to modify cut quantities based on the grading of a marsh elevation to those small levels.

Table 7-1. Summary of the elevation ranges corresponding to approximate marsh zones for the preferred alternative.

Marsh zone	Marsh Elevation Range (ft, NAVD88)	Approximate Acres in Preferred Alternative
Tidal Creeks	-2.4 to 1.4	Minimal
Low Marsh	1.4 to 1.8	18.8
High Marsh	1.8 to 2.2	4.9

7.3 PREFERRED ALTERNATIVE

This final preferred alternative, which is proposed to be constructed following the DCR extraction phases, includes the following components:

1. Structures and Flow control measures:

- Removal of the current flap gate from the existing Ballard Street culvert.

- An auxiliary culvert installed under Eastern Ave. (near the Carr Road extension to align with the proposed creek channel in the western marsh [see Figure 5-26]). The proposed culvert is a 4' diameter culvert with an upstream (ditch side) invert elevation of -1.6 feet NAVD88 and a downstream (marsh side) invert elevation of -2.2 feet NAVD88. The culvert will significantly enhance drainage from the southern portion of the ditch that parallels Eastern Avenue (as well as the entire ditch), which has historically experience poor drainage. This poor drainage capacity was also shown in the model simulations. Potential installation of flap gate(s) or duckbill system(s) could be considered at the marsh side (to be owned by DCR) of this culvert and the other existing culverts to limit tidal exchange from the ditch region, only allow freshwater drainage, and potentially reduce flooding potential within the ditch areas. However, if tidal control measures are installed at these locations and coupled with a reduced excavation approach (e.g., the west marsh is not used for flood storage), assessment needs to ensure that the duckbills/gates do not cause unintended flooding in the ditch region. For example, during a storm surge event with heavy precipitation, the western marsh may fill to capacity with storm surge ocean water, while watershed based storm water would be filling the ditches. If the duckbills or gates cannot open due to high waters in the marsh system, there is potential for backing up water in the ditch system. No simulations with duckbills of flap gates on these systems were conducted.

- While 4'x4' box culverts are already purchased and on-site from the NRCS design, the preferred alternative recommends installation of twin 4' wide x 6' high box culverts at the northern end of the I-95 embankment (at the same location as NRCS design). The increased vertical dimension of the culvert adds adequate air space in the culvert for all normal tidal conditions to address potential public safety concerns, especially considering the system is proposed to be fitted with tidal control structures. The invert elevation of these would be -2.4 feet NAVD88 and a 4'x6' culvert provides adequate head space under all normal tidal conditions (non-storm related conditions). We recommend that each culvert be fitted with a combination slide/flap gate on the downstream side (closer to the Saugus River) to allow for increased and adaptable control of the water levels in the western marsh. The combination gates will allow for adaptive management of the restoration process, increased control over water levels, the ability to provide an unbounded non-linear exchange of water, and are easily adjusted for unknown conditions that may arise (e.g., accelerated sea level rise projections, future modifications to other flow control structures such as the Ballard Street culvert, changes to marsh grade, model uncertainty in predictions, etc.). As an initial starting point for the restoration, one gate should be completely closed (acting as a flap gate), while the other gate should be set to completely open.

- Removal of the plywood and steel plate at the Bristow street extension culvert. This will allow some enhanced tidal exchange in this region. Some additional channel maintenance in this area may be required (section 6.0) for some of the natural constrictions that have developed in the eastern branch. However, WHG recommends that the response of the Ballard Street marsh system as a whole be monitored following the initial restoration (e.g., re-grading, Ballard St. flap gate removal, etc.) before opening the Bristow culvert or removing any of these features in the channels on the eastern branch of the system. The higher water surface elevation in the Pines River has the potential to increase the mean water surface elevation in the Ballard system if all restrictions are removed. This source of additional tide waters may be warranted to be handled through an adaptive management approach.

2. New marsh creeks:

- Creation of two primary new channels/creeks in the western marsh system (as illustrated in Figure 7-6). The channels will be approximately 8-10' wide and have an initial constructed bottom elevation of approximately -2.4 feet NAVD88 at the downstream end of each new channel. It is likely that the channel width and depth will vary throughout the system, with widths expected to taper to narrower dimensions further upstream in the system, and depths expected to become shallower further upstream. The 8-10' width provides a general guidance for channel width near the downstream end of the channel, and this may vary to match the existing width of the current channels. It is expected that these initial channels will naturally adjust to an equilibrium level for the system and will adequately convey tidal exchange.

- The banks of the creek should be set at an elevation of 1.4 feet NAVD88. The slope of the creek banks can be designed as required based on the material stability. It is not expected that the cross-sectional creek slopes would be steeper than 2H:1V.

- In addition to the main channels/creeks, potential addition of some smaller ditches (similar to the ones typically created by mosquito control) may be required to help distribute water in the restored system. For example, as the marsh re-adjusted to tidal exchange, potential ponded areas may form that require additional drainage pathways to feed the main channels. The restored marsh has been designed such that the marsh plains are all sloped to the main channels; however, it is likely that this marsh surface may evolve through the restoration process. These channels, if required, would not be a component of the initial restoration design, but may be considered as part of the permitting to allow for amendment of the site.

3. Marsh grading:

- Areas classified as low marsh (approximately between Mean Tide Level and Mean High Water) will extend from the creek banks (elevation 1.4 feet NAVD88) to EL. 1.8 feet NAVD88. The approximate area of low marsh for the preferred alternative in the western marsh is 15 acres.

- Areas classified as high marsh (approximately between Mean High Water and Mean High Water Spring) will extend from elevation 1.8 feet NAVD88 to Elevation 2.2 feet NAVD88. The approximate area of high marsh for the preferred alternative in the western marsh is 4.1 acres.

4. Regrading and Excavation:

- A total excavation amount of 65,000 cubic yards in the preferred alternative. The amount of material that will likely need to be taken off-site or stored is approximately 43,500 cubic yards after re-grading of the marsh (21,500 cubic yards can be beneficially re-used in the excavated depression remaining after the DCR extraction). A significant portion of this removed material is to ensure that the proper hydroperiods are attained in the marsh to allow for salt marsh restoration. This volume also provides more than adequate flood storage (Section 7.3.3).

Results for this preferred alternative for normal tidal conditions, a storm surge event that doesn't overtop Ballard Street, an extreme precipitation event, and 50-years of sea level rise are presented in the following sub-sections.

7.3.1 Normal Tides

The same boundary condition used for the existing conditions model and the previous alternatives was applied for the final preferred alternative. Modeled water surface elevation time series are shown in Figure 7-8 for the model output stations, and calculated tidal statistics are presented in Table 7-2. These results indicate:

- Improved drainage from the southern portion of the Eastern Avenue ditch (Ditch 2 model station) due to the additional auxiliary culvert under Eastern Avenue.

- Significant changes in the tidal regime directly adjacent to the opened Bristow Street culvert (East Marsh 3); however minor changes in the eastern marsh as a whole for this refined model that includes more detailed east marsh topography and channel restrictions. For example, the cross-sectional data indicated channel inverts that act as natural weirs within the channel, thereby limiting exchange from the Pines marsh to the Ballard Street marsh.

- Significant increases in tidal range in the western marsh and significant restoration gains due to lowered marsh elevations, which now reside in the intertidal range of the tides allowed into the system.

- Increased MHW levels due to the optimized grading of the marsh. This is a significant difference from the refined NRCS alternative that was the preferred alternative prior to DCR's excavation plan. The improvement is related to the reduced excavation amounts and optimized marsh levels with appropriate hydroperiods for sustaining marsh habitat, which was estimated to be a minimum of 4 hours. (Seneca, R.P, et al., 1985).

- Improved spring high water levels (as represented by the maximum water level). This will increase biodiversity within the restored marsh system by providing the full range of marsh classifications (mudflats, low marsh, high marsh).

The delineation of the mean low water and mean high water[23] extent of inundation in the marsh during the normal tides simulation for the preferred alternative is presented in Figure 7-9. Areas of inundation were computed separately for the portions of the marsh on the east and west sides of the abandoned I-95 fill. Additionally, the minimum and maximum water levels were also determined and used to estimate the potential restored intertidal areas and are presented in Table 7-3. In the western branch, the excavation and re-grading contribute to an increase in intertidal area of about 19.7 acres with an optimized grading and expansion of the marsh into the former embankment region. In the eastern branch, there is a 4.0 acre increase. Overall, the preferred alternative produces an increase of over 23 acres in intertidal area, which maximizes the restoration area. These intertidal areas are used as a general proxy as the level of restoration that may be expected for each alternative. The exact distribution of wetland classification zones (e.g., high marsh, low marsh, mudflat, etc.) is not presented; however, the intertidal areas are expected to correspond to primarily restored high and low marsh regions.

Figure 7-10 also provides a graphical summary of normal tidal conditions for the preferred alternative. The figure shows the extent of water within the marsh system during a typical Mean Low Water elevation and a Mean High Water elevation. A Spring High Water elevation would inundate the rest of the west marsh, and a portion of the east marsh system along the channel. Culverts within the system are color coded (shown in the key) as existing and open (green), new and gated (yellow), or new and open (purple) and the subpanel in the left hand corner shows the tide range in the Saugus River and in the Ballard street marsh for the preferred alternative. Figure 7-10 also identifies one of the key topographic restrictions surveyed in the eastern channel. The influence of these features is further discussed in relationship to the tidal flow from the Pine River system in the addendum to this report.

[23] This figure differs slightly from the previously presented intertidal area figures, which presented a minimum and maximum water surface elevation during the tidal simulation. The calculated intertidal areas for this alternative use the minimum and maximum water levels such that the area calculations are directly comparable.

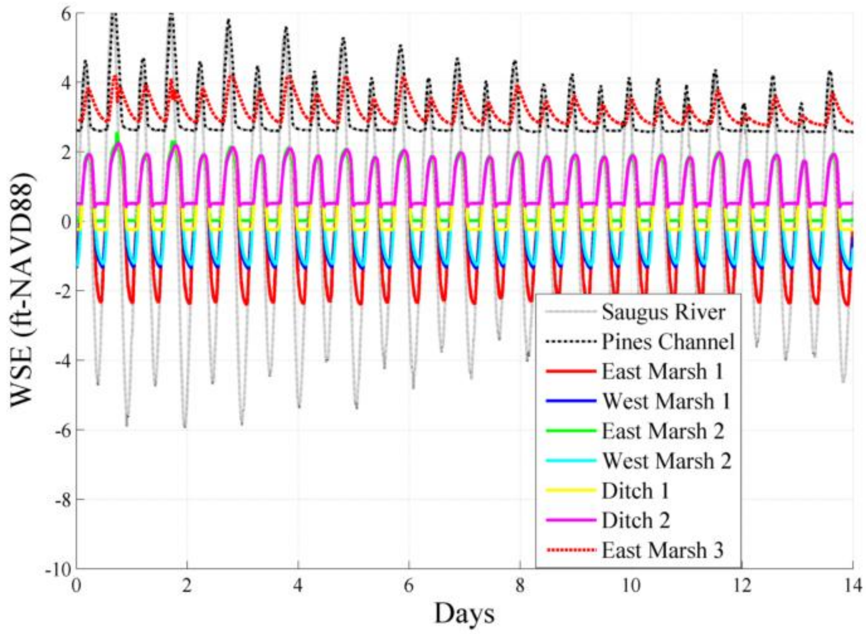


Figure 7-8. **Water surface elevation (WSE) time series for the preferred alternative, normal tides simulation.**

Table 7-2. **Tidal statistics for the preferred alternative, normal tides (spring neap tidal cycle) simulation (elevations in ft-NAVD88).**

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	4.2	-4.3	-0.1	8.5	-5.9	6.2
Pines Channel	4.6	2.6	3.6	2.0	2.6	6.5
East Marsh 1	1.9	-2.3	-0.2	4.2	-2.4	2.4
West Marsh 1	1.9	-1.3	0.3	3.2	-1.4	2.2
East Marsh 2	2.0	0.0	1.0	2.0	0.0	2.6
West Marsh 2	1.9	-1.2	0.3	3.1	-1.3	2.2
Ditch 1	1.9	-0.2	0.8	2.1	-0.2	2.2
Ditch 2	1.9	0.4	1.2	2.3	0.4	2.2
East Marsh 3	3.7	2.8	3.3	1.1	2.8	4.2

Figure 7-9. Contours of mean high water (red) and mean low water (blue) water surface elevation during normal tides, preferred alternative.

Table 7-3. Inundated marsh area and intertidal area for the preferred alternative under normal (a full spring to neap tidal cycle) tides.

Site	Maximum Inundated Area (acres)	Minimum Inundated Area (acres)	Intertidal Area (acres)	Change in intertidal area compared to existing conditions (acres)
East Marsh	6.3	1.4	4.9	4.0
West Marsh	23.4	3.0	20.4	19.7

7.3.2 Tidal Flood Event

The tidal flood (storm surge) event was simulated for the preferred alternative configuration using a storm surge peak of 7.1 feet NAVD88[24]. For this simulation, it was assumed the combination slide/flap gates at the proposed I-95 culverts would remain in the same state as for the normal tides simulation (one box culvert open, and one only allowing flow out of the system with a flap gate. As such, the simulation presented here is conservative with respect to the volume of storm surge allowed into the western branch of the marsh. In practice, such a device could be used to further limit or reduce storm surge in the western portion of the system if needed.

[24] This is a reduction from the 7.7 feet surge used in the previous simulations due to the new elevation information obtained during the most recent surveys. As such, these results may not be directly comparable to previous alternative storm simulations.

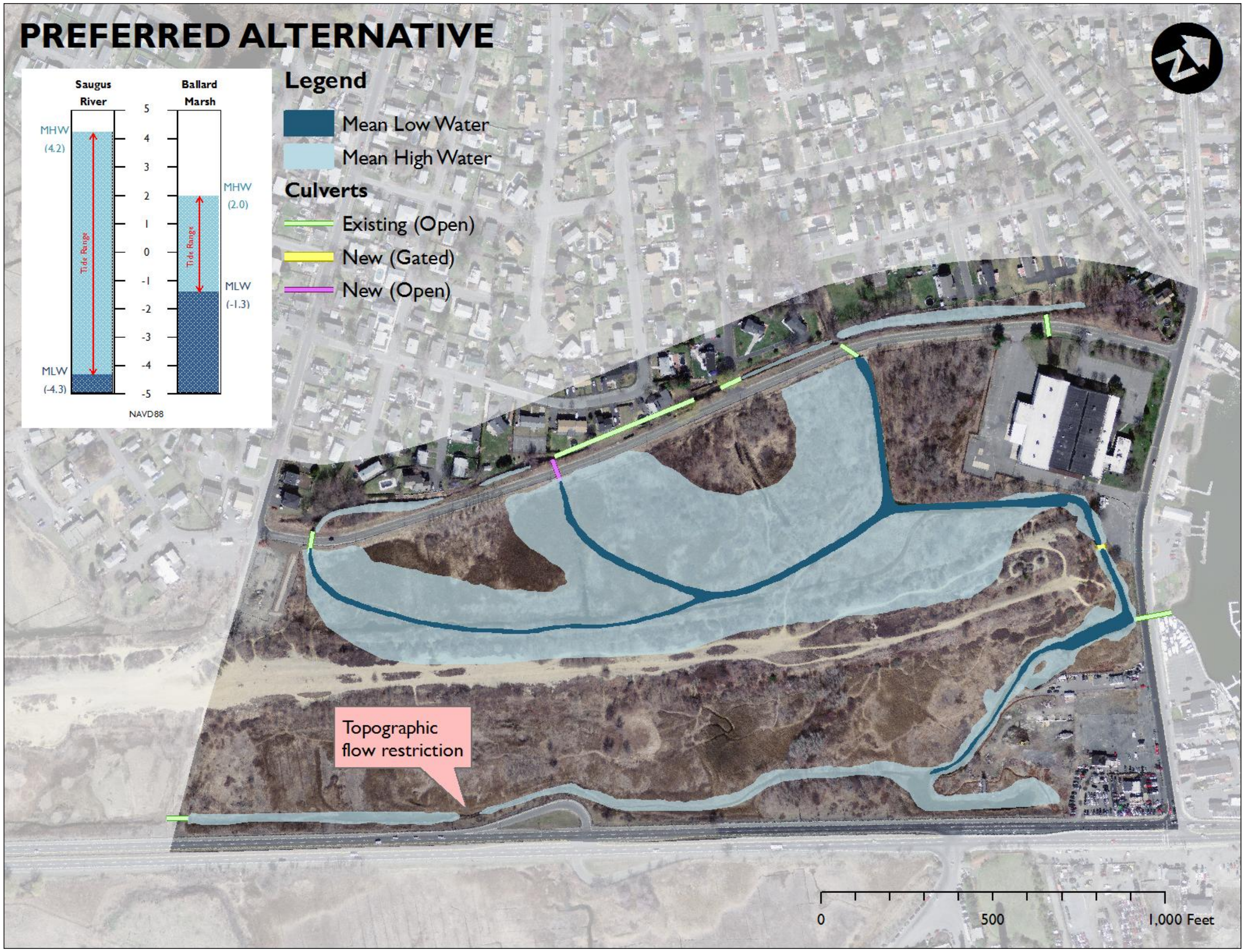


Figure 7-10. **Graphical representation of MHW and MLW water levels within the Ballard Street marsh system for normal tidal conditions (results from model simulation) with the preferred alternative in place.**

Water surface elevation time series at the model output stations are shown in Figure 7-11. Peak tidal flood elevations at the model output stations are presented in Table 7-4. The results show an increase in the peak water levels throughout the system compared to existing conditions. In all simulation cases (even with both tide gates open), the moderate storm event does not exceed the critical infrastructure elevation of 5.25 feet NAVD88.

Figure 7-12 provides a graphical summary of a storm surge condition at Ballard Street marsh for the preferred alternative. While the Ballard Street marsh system and surrounding area is certainly vulnerable to flooding due to a storm surge event (primarily due to the low surrounding topography at Ballard Street), significant flooding will likely only occur when Ballard Street is overtopped based on the results of the storm surge modeling for the preferred alternative. The storm surge reaches a higher level on the east side of the system due to the reduce storage capacity in the east, as well as the influence from the Pines River system.

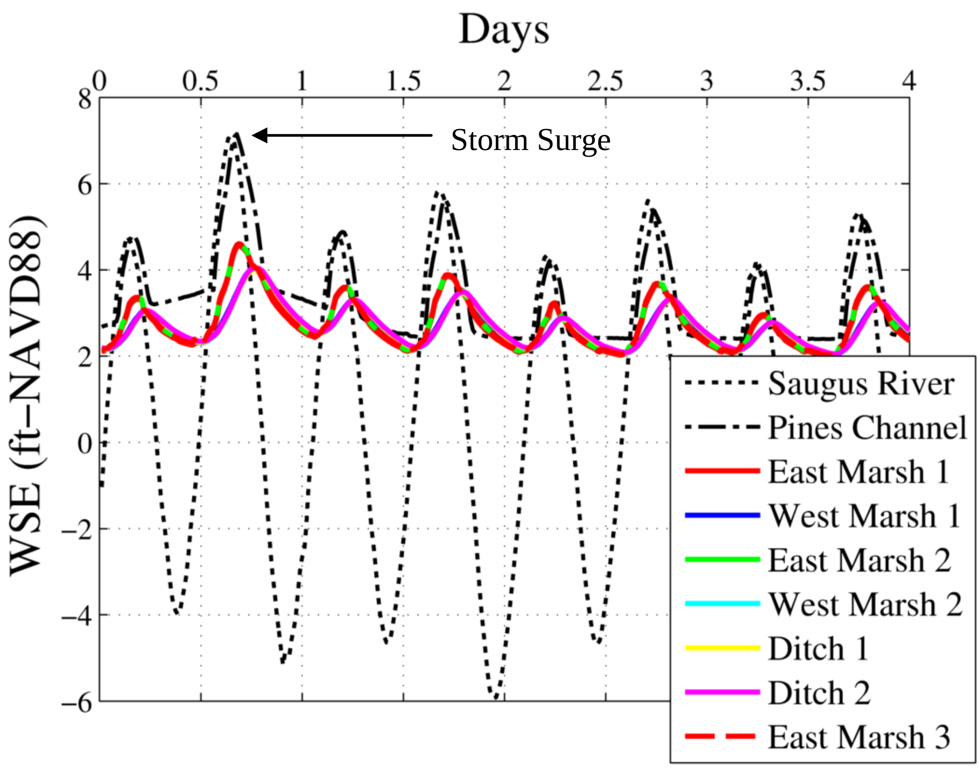


Figure 7-11. Water surface elevation (WSE) time series for the preferred alternative (one flap gate opened, one flap gate closed) tidal flood event simulation.

Figure 7-12. **Graphical representation of water levels within the Ballard Street marsh system for storm surge conditions (results from model simulation) with the preferred alternative in place.**

Table 7-4. Maximum water levels for preferred alternative tidal flood simulation.

Location	Maximum Water level (ft-NAVD88)
Saugus River	7.1
East Marsh 1	4.6
West Marsh 1	4.0
East Marsh 2	4.6
West Marsh 2	4.0
Ditch 1	4.0
Ditch 2	4.0
East Marsh 3	4.6
Pines Channel	7.3

7.3.3 Extreme Precipitation Event

Using more recent rainfall event data as presented in section 6.1, the updated 50-year, 24-hour precipitation event was simulated for the preferred restoration alternative. The peak of the watershed discharge was aligned to coincide with the peak of a spring high tide. The updated 50-year event produces a larger volume of total storm water over the 24 hours than the NRCS 100-year event, so in that sense this is a fairly conservative estimate of flooding potential (i.e., a significantly rare event). Water surface elevation time series at the model output stations are shown in Figure 7-13, while maximum water levels are presented in Table 7-5. The results show a significant reduction in the peak water level when compared to existing conditions due to the excavation in the west branch of the Ballard Street marsh. In addition, drainage is enhanced from the Eastern Avenue ditch due to the auxiliary culvert installed to help improve the drainage ability from the watershed feeding the ditch. The maximum water elevations are approximately 4.0 feet NAVD88 throughout the system, which is well below the critical elevation of 5.25 (Table 6-3). As such, the preferred alternative provides adequate flood storage, enhances drainage to the storage area, and also provides proper elevations for salt marsh establishment.

Figure 7-14 provides a graphical summary of an extreme precipitation condition (updated 50-year return period event) at Ballard Street marsh for the preferred alternative. It should be noted that the shaded areas represent areas where water would reside; however this is only for within the modeling domain (Figure 4-3) and does not provide graphical representation of the areas outside of the modeling domain that would be flooded under this scenario. The key indicates the elevation of storm water that occurs throughout the system. Compared to existing conditions (Figure 4-26), there is a significant reduction in water surface elevation due to the flood storage capacity and better drainage ability from the ditch system.

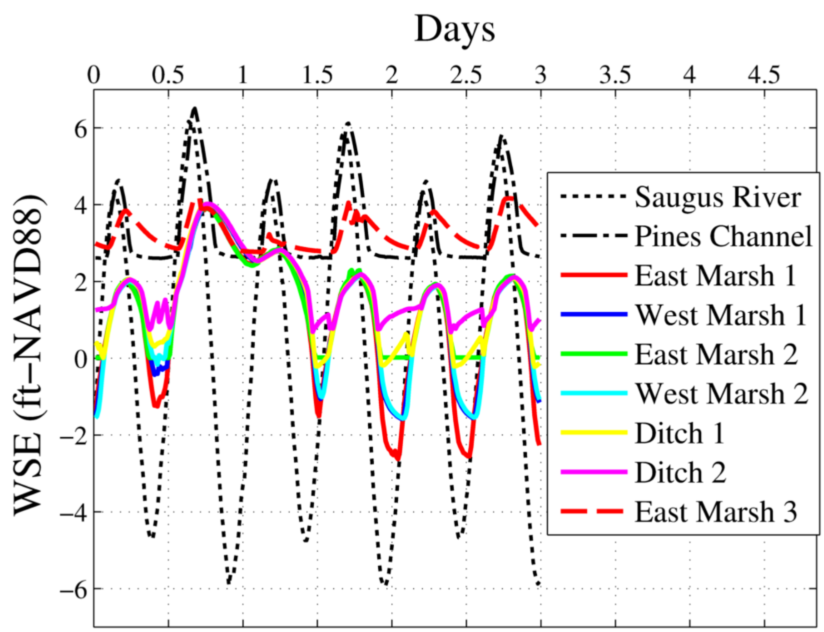


Figure 7-13. Water surface elevation WSE) time series for the preferred alternative 50-year precipitation event simulation.

7.3.4 Sea Level Rise

Sea level rise simulations were conducted corresponding to the low and intermediate scenarios for 50 years into the future (as presented in Table 4-8). The high scenario was not simulated because an increase in more than 1.6 feet in relative sea level would cause overtopping of Ballard Street and Bristow Street on the spring high tide. Tidal statistics for the intermediate projected SLR are presented in Table 7-6. The results show a uniform increase in the MHW and maximum water levels within the marsh with minor increases in MLW or the minimum water levels. MHW increases by 0.5 feet compared to existing conditions, which is a combined factor of increase tidal exchange and the increase in sea level rise. There are also increases to the mean tide level in the system.

Table 7-5. Maximum water levels for preferred alternative 50-year precipitation event simulation.

Location	Maximum Water level (ft-NAVD88)
Saugus River	6.2
East Marsh 1	3.9
West Marsh 1	4.0
East Marsh 2	3.9
West Marsh 2	4.0
Ditch 1	4.0
Ditch 2	4.0
East Marsh 3	4.2
Pines Channel	6.5

Table 7-6. Tidal statistics for the intermediate SLR scenario (elevations in ft-NAVD88).

Location	MHW	MLW	MTL	Mean Range	Minimum	Maximum
Saugus River	5.9	-2.7	1.6	8.6	-4.3	7.8
Pines Channel	6.2	4.2	5.2	2.0	4.2	8.0
East Marsh 1	2.1	-2.2	0.0	4.3	-2.4	2.4
West Marsh 1	2.1	-1.3	0.3	3.4	-1.4	2.3
East Marsh 2	2.1	0.0	1.1	2.1	0.0	2.6
West Marsh 2	2.1	-1.2	0.3	3.3	-1.3	2.3
Ditch 1	2.1	-0.2	0.9	2.3	-0.2	2.4
Ditch 2	2.1	0.7	1.4	1.4	0.6	2.4
East Marsh 3	4.1	3.4	3.8	0.7	3.4	4.2

The new I-95 culvert system is recommended to be installed with a tide gate control system (combined slide/flap gates). As such, future sea level rise projects could be mitigated by adjustment of the gates. The gates will also allow for adaptive management of the marsh restoration project, the ability to for non-linear flow capacity (e.g., allowing more water out of the system than into the system), and preparedness for unforeseen projected sea level rise or storm conditions.

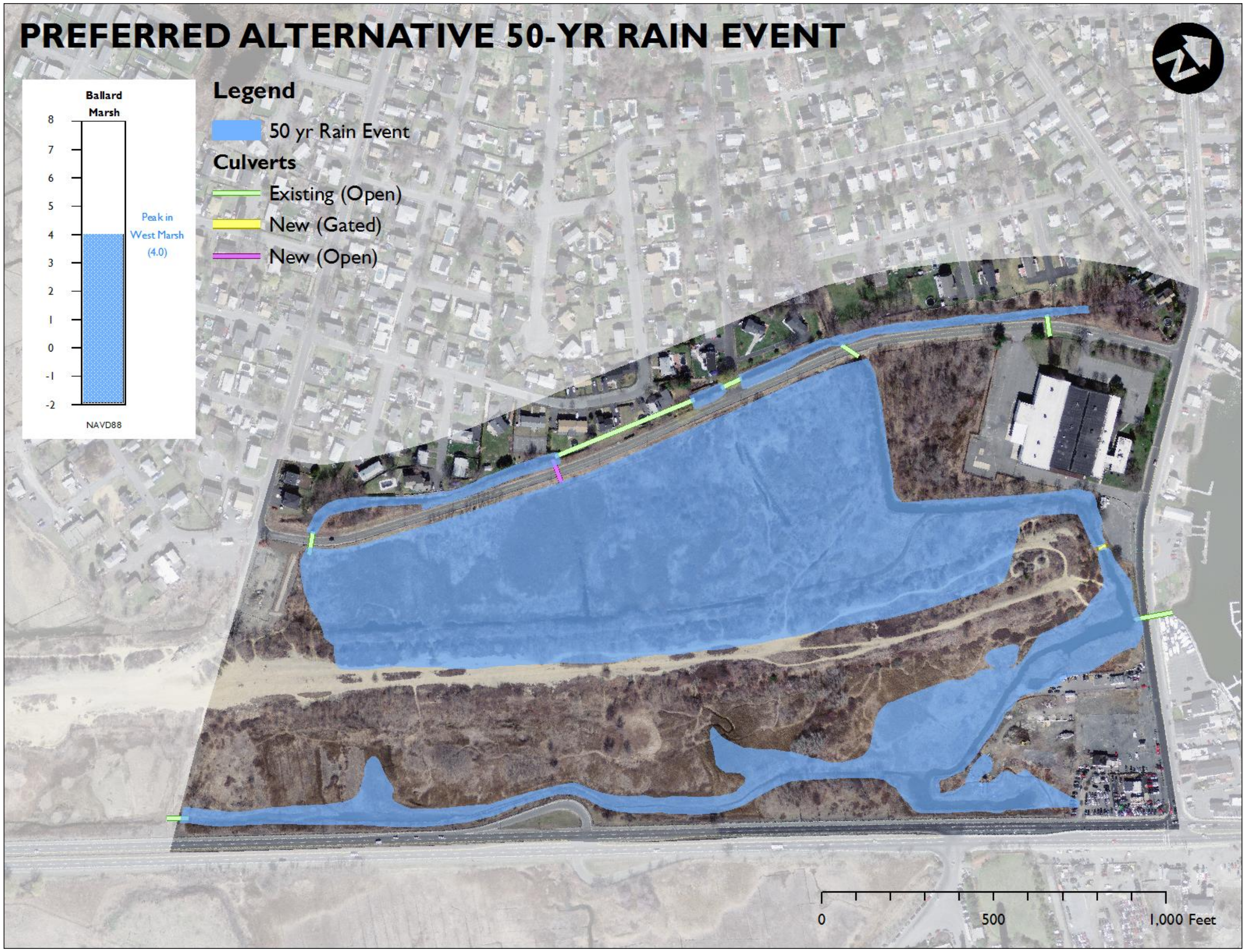


Figure 7-14. **Graphical representation of water levels within the Ballard Street marsh system for an extreme rainfall scenario (results from model simulation) with the preferred alternative in place.**

8.0 SUMMARY

This report presented the development of a hydrodynamic model for the Ballard Street marsh system. The report details: the field data collection, the modeling approach, the development of the model, including model calibration and validation, simulation of the proposed documented NRCS alternative, and subsequent modification, initial screening of some supplemental alternatives, a refined NRCS alternative, that was an offshoot of the NRCS initial design, a modified restoration alternative that integrated components of the NRCS recommendation with new methods, data, and boundary conditions, and finally, presents the preferred restoration alternative that could be implemented after the proposed DCR extraction of sediment from the abandoned I-95 embankment is completed. Detailed elevations used in the model development for the elevations in the western marsh were provided to DER for future use in the development of engineering plans. It is expected that subsequent engineering analyses and drawings will be conducted to finalize and detail the conceptual approach presented herein.

Based on the results of the data collection and modeling effort, Woods Hole Group offers the following key synopses:

- The water surface elevation data indicates the Ballard Street marsh system is significantly restricted. The tidal range in the Saugus River is damped by over 70% by the Ballard Street culvert and tide gate. Only the highest spring tides are able to reach the upper portions of the system.

- Opening of the existing tide gate will allow more tidal exchange to occur; however, the tide is still damped by over 40% due to the undersized culvert at Ballard Street.

- Under the existing setting, the restoration potential in the Ballard Street marsh system is limited by the Ballard Street culvert, which is undersized. The tidal range in the system is significantly inhibited by the existing culvert at Ballard Street and the elevations within the degraded salt marsh have been significantly altered through anthropogenic activities.

- A comprehensive 2-D hydrodynamic model was developed for the Ballard Street marsh system. The model was calibrated and validated to observations within the system and was simulated for normal tidal conditions, storm surge conditions, an extreme precipitation event, and projected sea level rise.

- The storm surge event that was simulated for a storm with a peak water surface elevation that would not exceed the elevation of Ballard Street. A storm tide above this elevation would overtop Ballard Street rendering the Ballard Street culvert inconsequential since water would be flowing directly over Ballard Street. This storm event corresponds to approximately a 10-year storm surge event.

- A 100-year, 24-hour extreme rainfall event was also considered based on previous work completed by NRCS (1999). This level of storm represents a relatively rare occurrence (annual 1% chance of occurrence). NRCS (1999) determined that this rainfall event would produce a runoff volume of 60 acre-ft. This storm event was subsequently modified by using more recent precipitation data, and a 50-year, 24-hour storm was used to simulate the preferred alternative. The new 50-year return period event has a greater total runoff volume (88.5 acre-ft) than the NRCS (1999) 100-year, 24-hour event.

- Sea level rise (SLR) was incorporated into the modeling effort using three distinct projections of the rate of SLR (USACE, 2009). The scenario representing the high rate of SLR (2.1 foot increase in 50 years) indicated that water would potentially be close to overtopping Ballard Street in 50 years during the highest spring tides. Therefore, the projected intermediate sea level rise scenario was used for simulating projected sea level rise in the expected service life time frame for the infrastructure.

- Removal of the Ballard Street tide gate allows for some limited restoration potential; however, the Ballard Street culvert itself is undersized and restricts the tidal exchange to the system.

- The removal of the temporary wood barrier and steel plate at the Bristow St culvert also has the potential to improve the salt marsh ecology, fish and wildlife of the East Branch of the Ballard Street marsh. However, due to the elevated mean water surface elevation on the Pines River side of the Bristow Street culvert, removal of the temporary blockage may need to be conducted in a phased approach, adaptively managing the culvert opening and the channel maintenance in this region.

- The extreme precipitation event was updated using newer estimates of the magnitude, distribution, and frequency of extreme rainfall events which are more appropriate for use in today’s climate. Data from the North East Regional Climate Center at Cornell University (NRCC) were used to generate a modern extreme precipitation event for use in the flood storage calculations. The new 50-year, 24-hour recurrence interval precipitation event was selected for simulation in the Ballard Street restoration model. This event is larger than the 100-year precipitation event assumed by NRCS and also is corresponds to the expected service life of the proposed infrastructure (e.g., tide gates, new box culverts, etc.).

- During the final stages of the development of the restoration project, MA DCR advanced a proposed project to beneficially re-use material from the abandoned I-95 embankment that bifurcates the Ballard Street salt marsh system. DCR has proposed extracting beach-compatible material from a portion of the embankment for beneficial reuse (beach nourishment) at Winthrop Beach. Since the restoration project at Ballard Street marsh required added flood storage capacity, as well as regarding of the marsh elevations, this was also a beneficial for the restoration of the salt marsh to more natural conditions. Therefore, the hydrodynamic model was utilized to evaluate the potential extraction, and develop a new restoration approach that incorporated the proposed extraction.

- From the primary alternatives considered, Table 8-1 presents the change in intertidal areas for the east and west portions of the marsh system, and can be used as a general proxy for wetlands area restored.

Table 8-1. Change in estimated intertidal area for the alternatives under normal tides and required excavation amounts.

	NRCS Alternative (acres)	New Ballard Tide Gate (acres)	Modified NRCS Alternative (acres)	Refined Alternative (acres)	Preferred Alternative (acres)
East Marsh	+3.8	+1.6	+5.0[25]	+0.7	+4.0
West Marsh	-0.7	+1.0	+15.6	+15.1	+19.7
Total Change	+3.1	+2.6	+20.6	+15.8	+23.7

- Table 8-2 indicates the required excavation amount for each scenario. This excavation is required to regrade the marsh to optimize marsh restoration as well as provide adequate flood storage capacity.

Table 8-2. Required excavation volumes for various restoration alternatives.

	NRCS Alternative	Modified NRCS Alternative	Refined Alternative	Preferred Alternative
Excavation (cubic yards)	94,000	94,000	94,000	65,000

- Table 8-3 indicates the acre-feet of flood storage capacity for each scenario with a marsh water surface elevation at Mean Low Water (MLW) and Mean High Water (MHW). Flood storage values are presented for both the East and West marsh systems.

Table 8-3. Flood storage capacity in the Ballard Street marsh below 5.25 feet NAVD88 (volume in acre-feet).

		Storage available at MLW	Storage available at MHW
Existing Conditions	East Marsh	23.7	21.1
	West Marsh	50.9	30.2
Remove Tide gate at Ballard Street	East Marsh	23.3	17.3
	West Marsh	50.9	27.2
Modified NRCS Alternative	East Marsh	21.8	14.5
	West Marsh	103.0	60.7
Refined Alternative	East Marsh	23.1	19.6
	West Marsh	106.3	73.7
Preferred Alternative	East Marsh	23.4	10.2
	West Marsh	73.6	57.0

[25] This is an over prediction of the restored area in the eastern marsh. At the time of this model simulation there was limited topography and no available tide data for model calibration in the eastern marsh. Additional data were collected in the eastern marsh and the model was recalibrated for this branch as presented in Section 6.

Preferred Alternative Components:
The final preferred alternative, which may be constructed following the DCR extraction phases, is recommended to include the following components:

1. *Structures and Flow control measures:*

- Removal of the current flap gate from the existing Ballard Street culvert.

- An auxiliary culvert installed under Eastern Ave. (near the Carr Road extension to align with the proposed creek channel in the western marsh [see Figure 5-26]). The proposed culvert is a 4' diameter culvert with an upstream (ditch side) invert elevation of -1.6 feet NAVD88 and a downstream (marsh side) invert elevation of -2.2 feet NAVD88. The culvert will significantly enhance drainage from the southern portion of the ditch that parallels Eastern Avenue (as well as the entire ditch), which has historically experience poor drainage. This poor drainage capacity was also shown in the model simulations. Potential installation of flap gate(s) or duckbill system(s) could be considered at the marsh side (to be owned by DCR) of this culvert and the other existing culverts to limit tidal exchange from the ditch region, only allow freshwater drainage, and potentially reduce flooding potential within the ditch areas. However, if tidal control measures are installed at these locations and coupled with a reduced excavation approach (e.g., the west marsh is not used for flood storage), assessment needs to ensure that the duckbills/gates do not cause unintended flooding in the ditch region. For example, during a storm surge event with heavy precipitation, the western marsh may fill to capacity with storm surge ocean water, while watershed based storm water would be filling the ditches. If the duckbills or gates cannot open due to high waters in the marsh system, there is potential for backing up water in the ditch system. No simulations with duckbills of flap gates on these systems were conducted.

- While 4'x4' box culverts are already purchased and on-site from the NRCS design, the preferred alternative recommends installation of twin 4' wide x 6' high box culverts at the northern end of the I-95 embankment (at the same location as NRCS design). The increased vertical dimension of the culvert adds adequate air space in the culvert for all normal tidal conditions to address potential public safety concerns, especially considering the system is proposed to be fitted with tidal control structures. The invert elevation of these would be -2.4 feet NAVD88 and a 4'x6' culvert provides adequate head space under all normal tidal conditions (non-storm related conditions). We recommend that each culvert be fitted with a combination slide/flap gate on the downstream side (closer to the Saugus River) to allow for increased and adaptable control of the water levels in the western marsh. The combination gates will allow for adaptive management of the restoration process, increased control over water levels, the ability to provide an unbounded non-linear exchange of water, and are easily adjusted for unknown conditions that may arise (e.g., accelerated sea level rise projections, future modifications to other flow control structures such as the Ballard Street culvert, changes to marsh grade, model uncertainty in predictions, etc.). As an initial starting point for the restoration, one gate should be completely closed (acting as a flap gate), while the other gate should be set to completely open. In the future, the opening can be increased, decreased, and/or modified as the Bristow Street culvert is opened.

- Removal of the plywood and steel plate at the Bristow street extension culvert. This will allow some enhanced tidal exchange in this region. Some additional channel maintenance in this area may be required (section 6.0) for some of the natural constrictions that have developed in the eastern branch. However, WHG recommends that the response of the Ballard Street marsh system as a whole be monitored following the initial restoration (e.g., re-grading, Ballard St. flap gate removal, etc.) before opening the Bristow culvert or removing any of these features in the channels on the eastern branch of the system. The higher water surface elevation in the Pines River has the potential to increase the mean water surface elevation in the Ballard system if all restrictions are removed. This source of additional tide waters may be warranted to be handled through an adaptive management approach.

2. New marsh creeks:

- Creation of two primary new channels/creeks in the western marsh system (as illustrated in Figure 7-6). The channels will be approximately 8-10’ wide and have an initial constructed bottom elevation of approximately -2.4 feet NAVD88 at the downstream end of each new channel. It is likely that the channel width and depth will vary throughout the system, with widths expected to taper to narrower dimensions further upstream in the system, and depths expected to become shallower further upstream. The 8-10’ width provides a general guidance for channel width near the downstream end of the channel, and this may vary to match the existing width of the current channels. It is expected that these initial channels will naturally adjust to an equilibrium level for the system and will adequately convey tidal exchange.

- The banks of the creek should be set at an elevation of 1.4 feet NAVD88. The slope of the creek banks can be designed as required based on the material stability. It is not expected that the cross-sectional creek slopes would be steeper than 2H:1V.

- In addition to the main channels/creeks, potential addition of some smaller ditches (similar to the ones typically created by mosquito control) may be required to help distribute water in the restored system. For example, as the marsh re-adjusted to tidal exchange, potential ponded areas may form that require additional drainage pathways to feed the main channels. The restored marsh has been designed such that the marsh plains are all sloped to the main channels; however, it is likely that this marsh surface may evolve through the restoration process. These channels, if required, would not be a component of the initial restoration design, but may be considered as part of the permitting to allow for amendment of the site.

3. Marsh grading:

- Areas classified as low marsh (approximately between Mean Tide Level and Mean High Water) will extend from the creek banks (elevation 1.4 feet NAVD88) to EL. 1.8 feet NAVD88. The approximate area of low marsh for the preferred alternative in the western marsh is 15 acres.

- Areas classified as high marsh (approximately between Mean High Water and Mean High Water Spring) will extend from elevation 1.8 feet NAVD88 to Elevation 2.2 feet NAVD88. The approximate area of high marsh for the preferred alternative in the western marsh is 4.1 acres.

4. Regrading and Excavation:

- A total excavation amount of 65,000 cubic yards in the preferred alternative. The amount of material that will likely need to be taken off-site or stored is approximately 43,500 cubic yards after re-grading of the marsh (21,500 cubic yards can be beneficially re-used in the excavated depression remaining after the DCR extraction). A significant portion of this removed material is to ensure that the proper hydroperiods are attained in the marsh to allow for salt marsh restoration. This volume also provides more than adequate flood storage (Section 7.3.3).

- The modeling effort focused on optimizing the excavation as much as possible given the stated goals of the project. Substantial effort was placed on reducing the permitted NRCS excavation (97,000 cubic yards) to optimize costs. In order to provide full flood storage capacity for the 50-year precipitation event (Chapter 6), while still maximizing restoration within the system, a total of 43,500 cubic yards of material would require offsite disposal, a significant reduction from the NRCS value. Determining the excavation requirements that met these criteria was not a straightforward exercise, as described in Figure 7-4. The excavation associated with the preferred alternative is significant and results in a substantial expense. Additionally, there is some uncertainty associated with the amount of the required excavation due to various uncertainties (e.g., precipitation analysis, sea level rise, model uncertainty associated with flow over the re-graded marsh plains, etc.). This excavation uncertainty is further evaluated in the attached Addendum to this report. Ultimately, the excavation levels were geared towards maximizing the restoration and meeting the worst-case scenario associated with the 50-year rainfall event. If the full flood storage capacity is not required in the western marsh, or the restoration is reduced, then less excavation may be required. Modification of these assumptions results in greater changes than would be related to uncertainties in the analysis. It is also important to consider the practical aspects of the excavation requirements. For example, although a model uncertainty may reveal an error of approximately an inch (0.1 feet), it is likely unrealistic to expect a contractor to modify cut quantities based on the grading of a marsh elevation to those small levels.

The primary goals of the restoration project include restoration of former and currently degraded salt marsh areas in the system and improved flood protection for the communities surrounding the Ballard Street marsh, especially those areas just west of Atlantic Avenue. Specifically, the goal of the restoration, as specified by DER, was to maximize the restoration of the system while providing comprehensive flood storage for an extreme precipitation event for adjacent communities. Less flood storage (excavation) could be considered if storage for a small storm event was considered, or if the goal of the project was solely to improve flooding compared to existing conditions. The preferred alternative maximizes restoration, provides improved flood storage capacity, improves drainage from the Eastern Avenue ditch, enhances the biodiversity of the proposed salt marsh, minimizes the amount of excavation that is required, provides tidal control ability for the western marsh in case of unforeseen conditions, and creates improved drainage pathways from the western marsh.

9.0 REFERENCES

Akcelik, V., B. Jaramaz, and O. Ghattas. 2001. Nearly Orthogonal Two-Dimensional Grid Generation with Aspect Ratio Control. J. Comp. Phys. 171, 805-821.

Chow, V. T. 1959. Open-Channel Hydraulics. The McGraw-Hill Book Company, Inc.

Fofonoff, P. and Millard, R.C. Jr Unesco. 1983. Algorithms for computation of fundamental properties of seawater, 1983. Unesco Tech. Pap. in Mar. Sci._, No. 44, 53

Geosyntec. 2007. Ballard Street Marsh Saugus, Massachusetts Salt Marsh Restoration Project Conceptual Construction Sequence Drawings. Prepared for the Massachusetts Office of Coastal Zone Management. Prepared by Geosyntec Consultants, June 2007.

Hamrick, J. M. 1992. A Three-Dimensional Environmental Fluid Dynamics Computer Code: Theoretical and Computational Aspects. The College of William and Mary, Virginia Institute of Marine Science. Special Report 317, 63 pp.

Hamrick, J. M. 1994. Linking hydrodynamic and biogeochemical transport models for estuarine and coastal waters. Estuarine and Coastal Modeling, Proceedings of the 3rd International Conference, M. L. Spaulding et al, Eds., American Society of Civil Engineers, New York, 591-608.

Hamrick, J. M. 1996. A User's Manual for the Environmental Fluid Dynamics Computer Code. The College of William and Mary, Virginia Institute of Marine Science. Special Report 331, 185 pp.

Hershfield, D. M. 1961. United States Department of Commerce Weather Bureau Technical Paper No. 40 Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. Prepared for the Engineering Division, Soil Conservation Service U.S. Department of Agriculture.

IPCC. 2007. Climate Change 2007: The Physical Science Basis, Contributions of Working Group I to the Fourth assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averty, M. Tignor and H.L. Miller (eds.). Cambridge University Press. Cambridge, United Kingdom, and New York, NY, USA 996 pp.

NRC. 1987. National Research Council Responding to Changes in Sea level: Engineering Implications. National Academy Press, Washington, D.C.

NRCS. 1999. Hydrologic and Hydraulic Analysis Wetlands Restoration Investigation Ballard Street Salt Marsh Saugus, Massachusetts, Prepared for Town of Saugus in cooperation with Exxes Conservatino District, prepared by United States Department of Agriculture Natural Resources Conservation Service Amherst, Massachusetts.

Reiner, Ed. 2010. Personal Communication.

Seneca, R.P, S.W. Broome, and W.W. Woodhouse, 1985. The influence of duration of inundation on development of an initiated *spartina alterniflora* marsh in North Carolina. Journal of Exploratory Marine Biology and Ecology. 94:259-268.

Singh, V. P. 1992. Elementary Hydrology. Prentice-Hall Inc., Upper Saddle River, NJ.

USACE. 1988. Tidal Flood Profiles, New England Coastline. Hydraulics and Water Quality Section, New England Division U.S. Army Corps of Engineers.

USACE. 2009. Water Resource Policies and Authorities Incorporating Sea-level Change Considerations in Civil Works Programs. Department of the Army, U.S. Army Corps of Engineers, Washington DC 20314-1000. Engineering Circular No. 1165-2-211.

U.S. Environmental Protection Agency. 1990. Technical Guidance Manual for Performing Waste Load Allocations, Book III Estuaries, Part 2, Application of Estuarine Waste Load Allocation Models. EPA 823-R-92-003.

Woods Hole Group. 2008. Herring River Hydrodynamic Modeling Model Development Draft Report. Prepared for the Town of Wellfleet, prepared by Woods Hole Group Inc., December 2008.

APPENDIX A. NRCS DESIGN RECINDMENT

APPENDIX B. OTTE AND DWYER SURVEY

APPENDIX C. TECHNICAL MODEL APPENDIX

C.1 THE ENVIRONMENTAL FLUID DYNAMICS CODE

The EFDC model solves the three-dimensional, vertically hydrostatic, free surface, turbulent-averaged equations of motions for a variable-density fluid. The model includes dynamically coupled transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature. In addition, the EFDC model can simulate cohesive and non-cohesive sediment transport, eutrophication processes, both near field and far field dilution of discharges, and the transport and fate of toxic contaminants. The model is capable of simulating multiple size classes of cohesive and non-cohesive sediments along with the associated deposition and resuspension processes and bed geomechanics. The model allows for the wetting and drying of shallow areas using a mass conservative scheme. EFDC also includes measures for simulating flow control structures and highly vegetated areas.

To represent the geometry of a water body, the EFDC model uses Cartesian or curvilinear-orthogonal horizontal coordinates and, when applied in three dimensions, terrain-following vertical coordinates. A finite difference numerical scheme is employed within EFDC with two time levels and a procedure that splits the internal-external modes. The free-surface gravity wave or barotropic external mode is solved explicitly along with the simultaneous computation of a two-dimensional surface elevation field using an iterative conjugate gradient solver. Calculating the depth-integrated barotropic velocities using the newly computed surface elevation completes the external solution. Horizontal boundary condition options for the external mode solution include specifying the water surface elevation, the characteristic of an incoming wave, free radiation of an outgoing wave, or the normal volumetric flux on arbitrary portions of the boundary.

The EFDC model implements a mass conservation solution scheme for the Eulerian transport equations, which is at the same time step or twice the time step of the momentum equation solution. The advective step of the transport solution uses either a central difference scheme or a hierarchy of positive definite upwind difference schemes. The horizontal diffusion step is explicit in time, while the vertical diffusion step is implicit. Horizontal boundary conditions include material or constituent inflow concentrations, which can be specified as being depth-dependant and both constant and time-variable. The EFDC model can be used to drive a number of external water quality models using internal linkage processing procedures described in Hamrick (1994).

C.2 MODEL CONFIGURATION

C.2.1 Grid Generation

The first step in building the model is constructing the model grid. The grid is a digital abstraction of the prototype's (Ballard Street marsh system) geometry that provides the spatial discritization on which the model equations are solved. Different numerical methods require different types of grids, each having unique geometrical requirements. The grid building process involves using geo-referenced digital maps or aerial photos to define the model domain, then the grid is generated within this domain providing the desired degree of spatial resolution, and topographic data are incorporated by interpolation of elevation values to grid nodes or cells within the domain.

For EFDC, the computational grid defines the spatial domain on which EFDC performs its finite difference calculations. EFDC requires a structured grid, either Cartesian or curvilinear orthogonal, comprised of a number of rectangular grid cells on which model the variables are computed. The accuracy of the model is highly dependent on accurate representation of the form of the real system expressed through the model grid. While a curvilinear orthogonal grid is more difficult to implement than a strict Cartesian grid, the curvilinear option was chosen because of its increased flexibility, allowing grid boundaries to better follow natural irregular boundaries. The curvilinear orthogonal grid also allows gradual variation in horizontal resolutions, such that higher resolution can be applied in areas where greater detail is required. To create the grid, a method for 'nearly-orthogonal' grid generation (Akcelik et al., 2001) was implemented and is described in detail within this section.

Topographic data collected by Woods Hole Group, Inc. were combined with topographic data collected by Otte and Dwyer, Inc. and used in constructing the Ballard Street model grid. In addition, Woods Hole Group collected topographic and geometric information required to accurately define all the systems culverts. The combined topographic data are shown in Figure C-1.

A curvilinear-orthogonal grid is generated by determining the physical domain coordinates (x,y) in the interior of the domain that correspond to the computational domain coordinates (ξ,η) given a known distribution of physical domain coordinates along the boundary. The method for nearly orthogonal grid generation with aspect ratio control as described by Akcelik et. al., (2001) was employed to generate the grid for the Ballard Street marsh system EFDC model. This method is an improvement upon previous methods for curvilinear orthogonal grid generation that allows for control of the grid's aspect ratio resulting in high quality computational grids. Despite its name, this method is capable of producing grids with a high degree of orthogonality in some cases better than grids produced with other methods, particularly for domains with complex boundaries where perfect orthogonality is not possible.

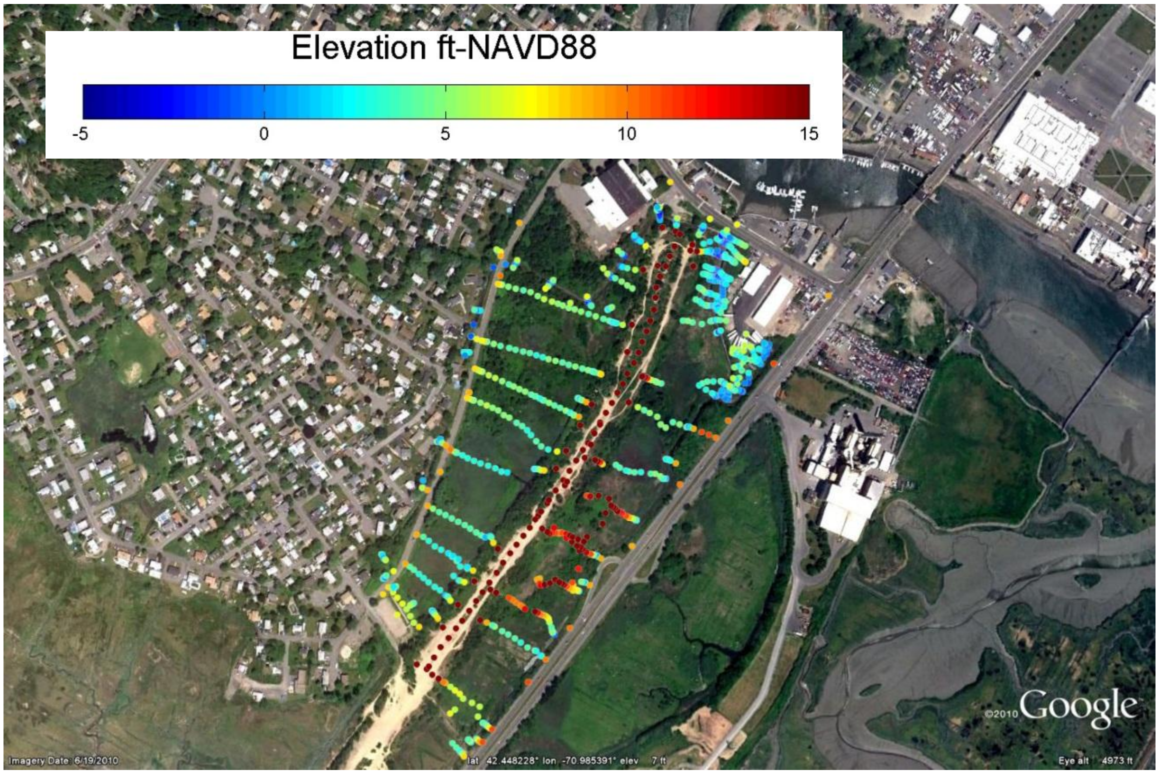


Figure C-1. Combined topographic data used to construct EFDC model grid.

The grid generation system is based on the fact that physical Cartesian coordinates (x,y) are linear functions of position in the computational domain, their gradients are constant valued vector fields, and therefore their 2nd order spatial derivatives must be zero.

$$\frac{\partial}{\partial \xi}\left(f \frac{\partial x}{\partial \xi} \right) + \frac{\partial}{\partial \eta}\left(\frac{1}{f} \frac{\partial x}{\partial \eta} \right) = 0 \qquad (1a)$$

$$\frac{\partial}{\partial \xi}\left(f \frac{\partial y}{\partial \xi} \right) + \frac{\partial}{\partial \eta}\left(\frac{1}{f} \frac{\partial y}{\partial \eta} \right) = 0 \qquad (1b)$$

where

$$f = \frac{h_\eta}{h_\xi} \qquad (2)$$

is the scale factor ratio, and the scale factors are

$$h_\xi = \sqrt{\left(\frac{\partial x}{\partial \xi} \right)^2 + \left(\frac{\partial y}{\partial \xi} \right)^2} \qquad (3a)$$

$$h_\eta = \sqrt{\left(\frac{\partial x}{\partial \mu}\right)^2 + \left(\frac{\partial y}{\partial \eta}\right)^2} \tag{3b}$$

The scale factors as defined by equation (3) enforce orthogonality. Equations (1)-(3) describe the traditional curvilinear-orthogonal grid generation system. To allow for control of the aspect ratio inhomogeneous source terms are added to Equation (1).

$$\frac{\partial}{\partial \xi}\left(f \frac{\partial x}{\partial \xi}\right) + \frac{\partial}{\partial \eta}\left(\frac{1}{f} \frac{\partial x}{\partial \eta}\right) + P_X(h_\xi) + Q_x(h_\eta) = 0 \tag{4a}$$

$$\frac{\partial}{\partial \xi}\left(f \frac{\partial y}{\partial \xi}\right) + \frac{\partial}{\partial \eta}\left(\frac{1}{f} \frac{\partial y}{\partial \eta}\right) + P_y(h_\xi) + Q_y(h_\eta) = 0 \tag{4b}$$

where

$$P(h_\xi) = c\left(h_\xi - \frac{\overline{h}_\xi^2}{h_\xi}\right) \tag{5a}$$

$$Q(h_\eta) = c\left(h_\eta - \frac{\overline{h}_\eta^2}{h_\eta}\right) \tag{5b}$$

$P(h_\xi)$ and $Q(h_\eta)$ favorably control the value of the scale factors and thus improve the aspect ratio of the resulting grid. They act as distributed forces repelling or attracting neighboring grid points, preventing grid lines from collapsing, when the local scale factor deviates from the mean scale factors $\overline{h_\xi}$ and $\overline{h_\eta}$ (computed on grid lines of constant η and constant ξ, respectively). The aspect ratio forcing constant, *c*, controls the strength of the forcing functions and can be varied throughout the domain. Also to improve grid quality, grid boundary points are allowed to "slide" along the boundary from their initial positions during the iterative grid generation process resulting in boundary point distribution that allows for better orthogonality of the generated grid.

To generate the grid, the boundaries of the domain are first defined by drawing lines over a geo-referenced aerial photograph of the site and initial boundary points are defined by distributing points evenly along those lines. Next, all interior grid points are placed at the center of the domain, the scale factors are set to unity, and equation (1), discritized by finite differences, is solved by a number of successive over-relaxation iterations to determine an initial approximation of the interior grid points. Next, a number of iterations are made in which:

1) the scale factors are calculated from equation (3);
2) equation (4), discritized by finite differences, is solved by a few successive over-relaxation iterations;
3) Boundary point locations are adjusted for points that are allowed to slide;
4) Orthogonality is checked by computing angles at the corners of the grid cells.

Steps 1-4 are repeated until mean and maximum deviation from orthogonality of the resulting grid is minimized.

Due to the complex shape of the Ballard Street marsh system and the need for higher grid resolution in certain areas, it was convenient to generate a number of separate grids for different portions of the system and then combine them to create the final model grid. Figure C-2 shows the domain boundaries for the four portions of the system that were gridded separately. Areas of overlap were deleted or merged carefully to preserve orthogonality of the final grid. The final grid is shown in Figure C-3 and a close up of the grid which shows individual grid cells more clearly is shown in Figure C-4. The final grid has a total of 10,387 computational cells ranging in size from approximately 4 feet to approximately 60 feet.

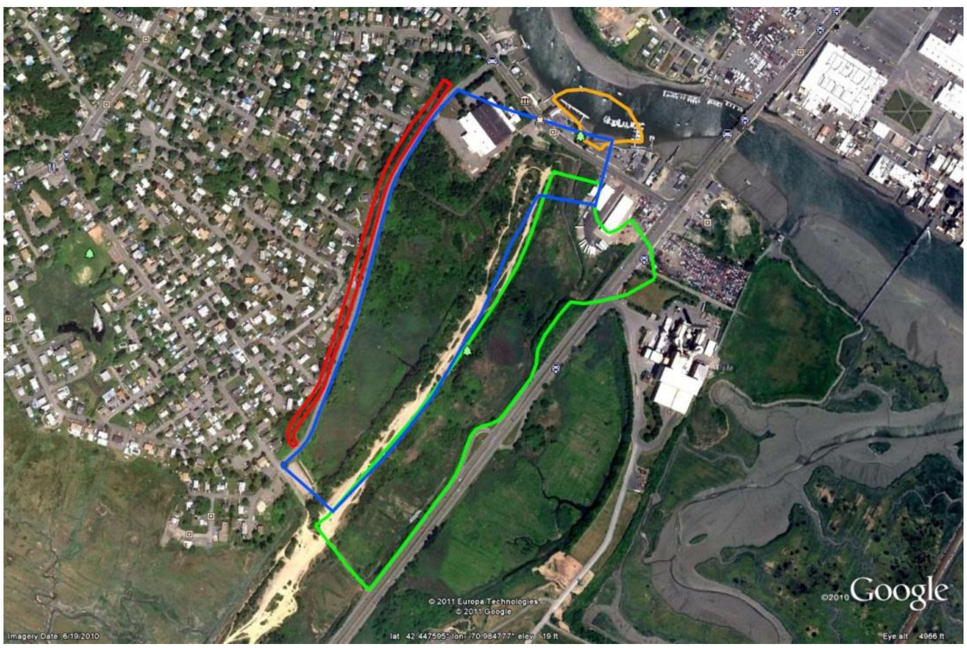


Figure C-2. Domain boundaries for generation of grid portions.

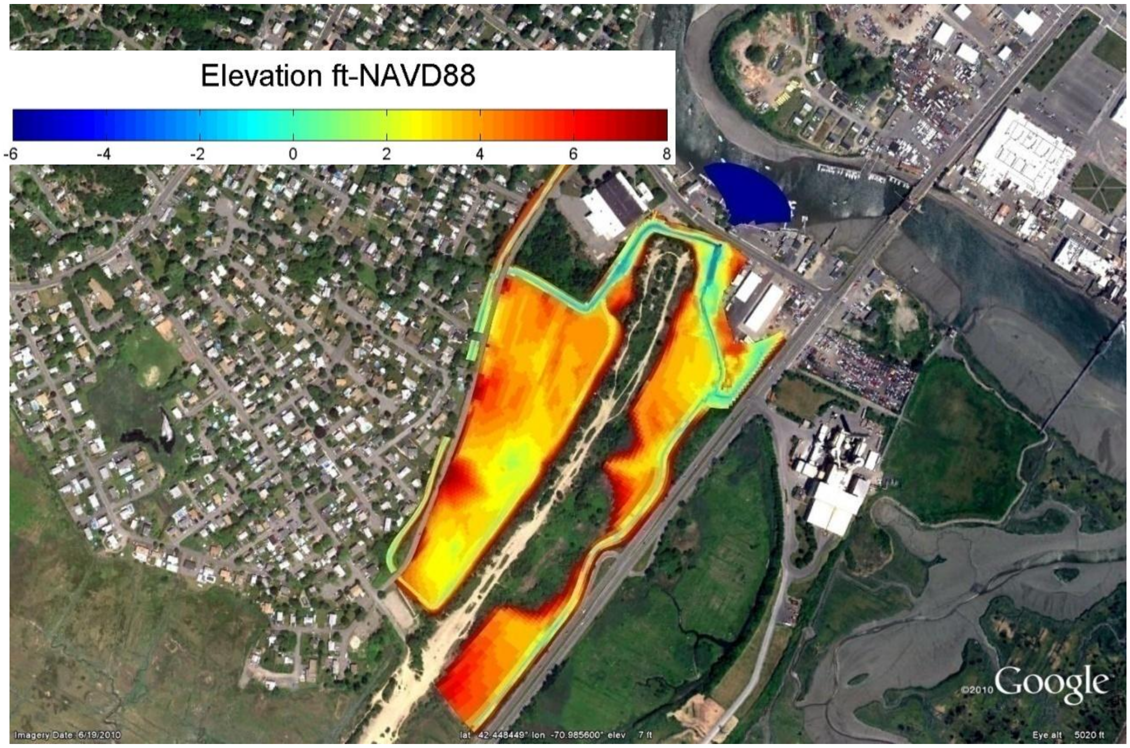


Figure C-3. Ballard Street marsh EFDC model grid.

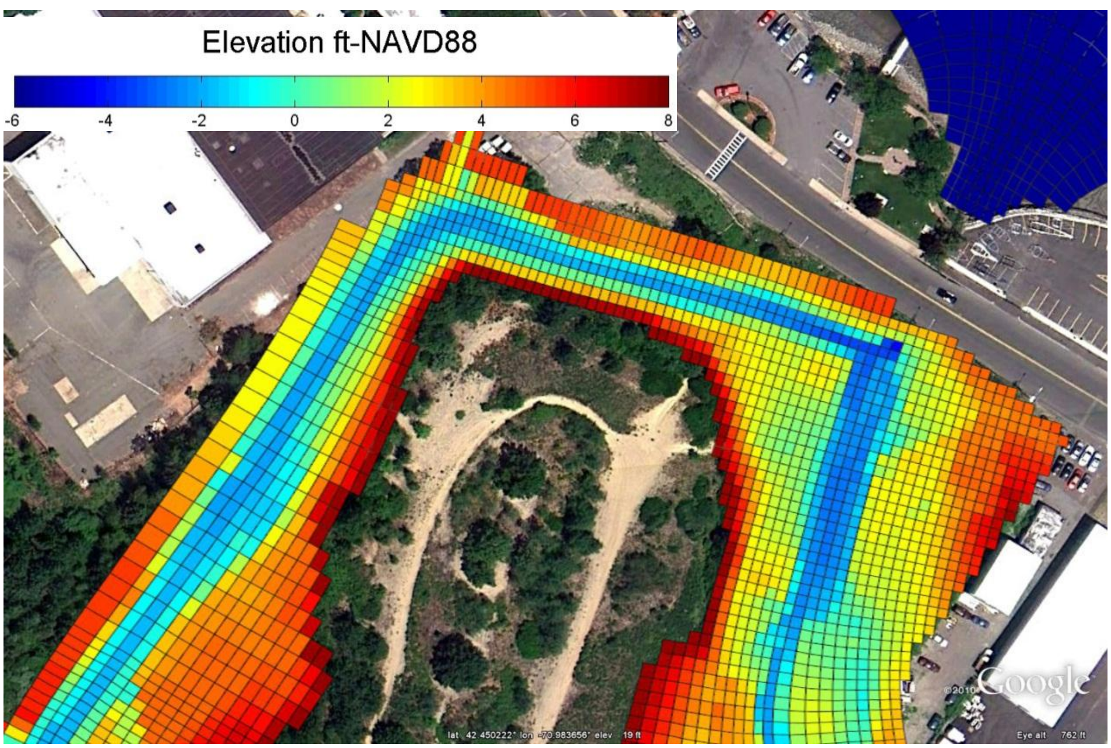


Figure C-4. Close up of Ballard Street marsh EFDC model grid.

C.2.2 Boundary Conditions

The assignment of model specific boundary conditions allows EFDC to compute a unique solution for a given model scenario. Most of the Ballard Street marsh system is bounded by roadways or high ground. The minimum elevation at which water can flow over Ballard Street and into the marsh is approximately 7.7 feet NAVD88, according to the previous study (NRCS, 1999). In addition, a lower elevation of 7.3 feet NAVD88 was reported by NRCS between Bristow Street and the Ballard Street System. Without overtopping Bristow or Ballard Street, tidal flow may currently only enter and exit the marsh system through the Ballard Street culvert and tide gate. The Ballard Street marsh hydrodynamic model was designed to simulate water levels in the marsh below 7.7 ft-NAVD88 elevation (the highest elevation before the culvert becomes inconsequential). Therefore, the roadways and high ground bounding the marsh system were defined as land boundaries. Along land boundaries water is constrained to flow parallel to the boundary and there is no restriction on the water surface elevation.

Tidal forcing for the model is applied on an open boundary in the Saugus River. Figure C-5 shows the location of the open boundary in the Saugus River. Along the open boundary there is no restriction on the current velocity, however both water surface elevation and salinity must be specified. Data collected in the Saugus River at the WHG3 location (see Figure 2-1) were used to specify the water surface elevation and salinity for model calibration and validation.

Freshwater input to the model can be specified as a uniform input over the entire domain representing rainfall, as well as volume sources at individual model grid cells. Rainfall input used for model calibration and validation is based on rainfall observations made at Logan Airport as shown in Figure 2-17. Although no stream flow data are available to quantify actual freshwater flow into the Ballard Street marsh System, a relatively small base flow of approximately 1 cfs was distributed between three cells in the ditch along Eastern Ave. This base flow volume is relatively insignificant when compared with the tidal flux in the system. Also the observation of primarily brackish water in the ditch along Eastern Ave. suggests that minimal freshwater input occurs except during and immediately after rainfall events. The locations of these freshwater input cells are shown in Figure C-6.

EFDC uses a log law roughness length to parameterize bottom drag forces. Each grid cell may have a different value for roughness length. Physically, bottom drag forces depend on a number of phenomena which are difficult to characterize including bottom material type, growth of biota, and the amount of channel meander, which all contribute to the overall energy loss that is accounted for by the roughness length. Because the bottom friction parameterization in the model accounts for the effect of a number of different factors, it is difficult to determine a priori what values will provide the best results and thus it is typically used as the primary parameter for "tuning" the model to reproduce the observations during the model calibration process. For the Ballard Street marsh system model, three different roughness values were assigned based on depth, observations of ground cover, and prior experience applying the EFDC model to estuarine environments. In the Saugus River, a value of 1cm was assigned. Within the marsh two separate values were used. For most of the higher marsh area a value of 10 cm was assigned to represent relatively large friction that might result from vegetation. However, this specification is somewhat inconsequential because under existing conditions much of this are remains dry and does not influence the tidal hydraulics within the system. For marsh channels, the roughness value was adjusted during model calibration to determine roughness lengths that give the best model performance. Figure C-7 provides the bottom roughness throughout the model domain.

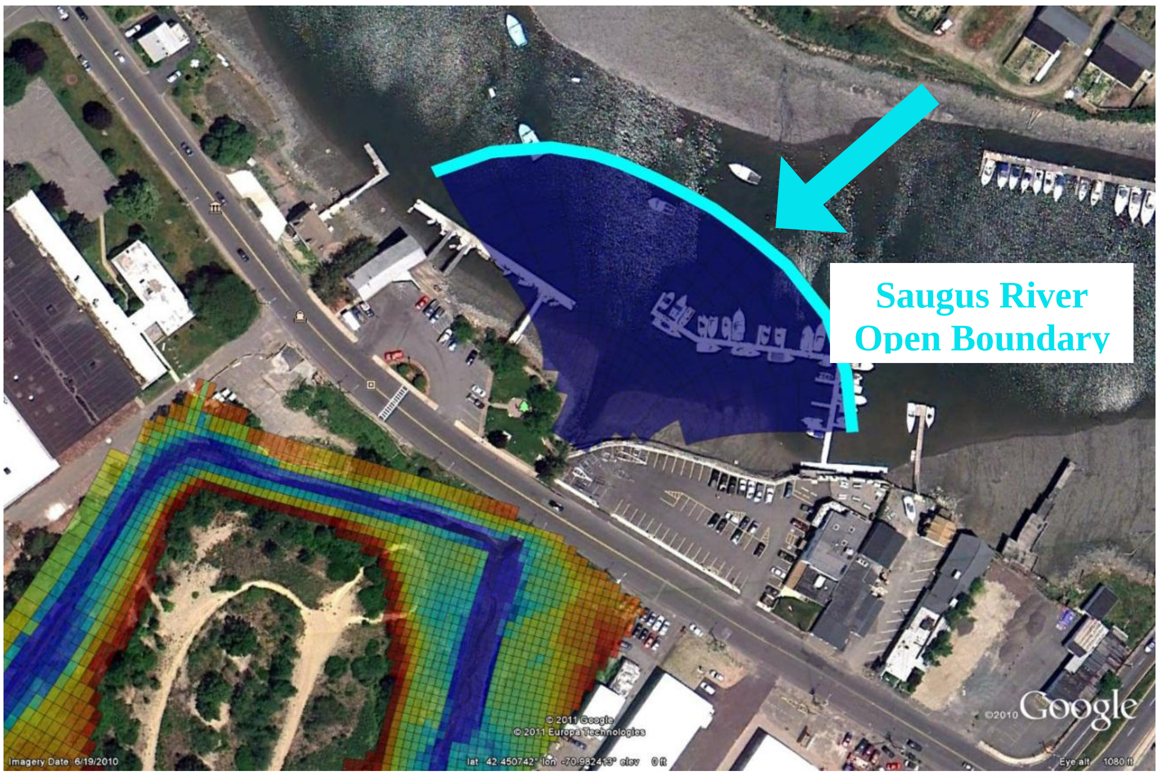


Figure C-5. Location of the open boundary in the Saugus River.

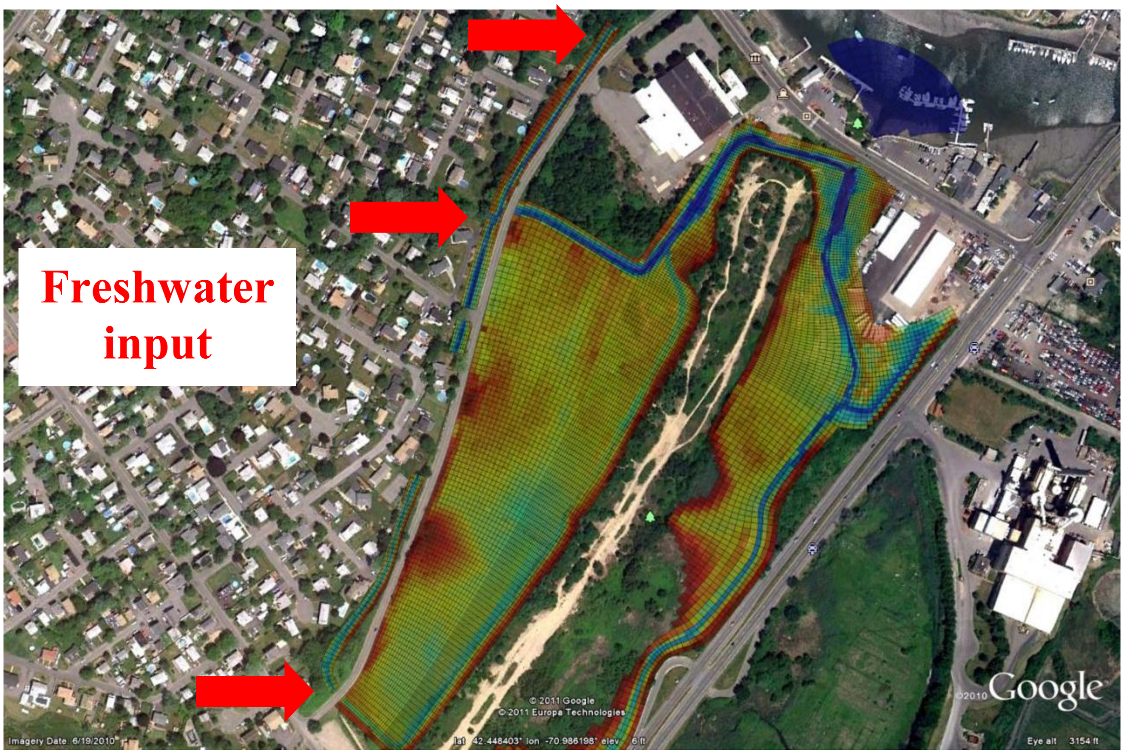


Figure C-6. Location of freshwater input cells in the ditch along Eastern Avenue.

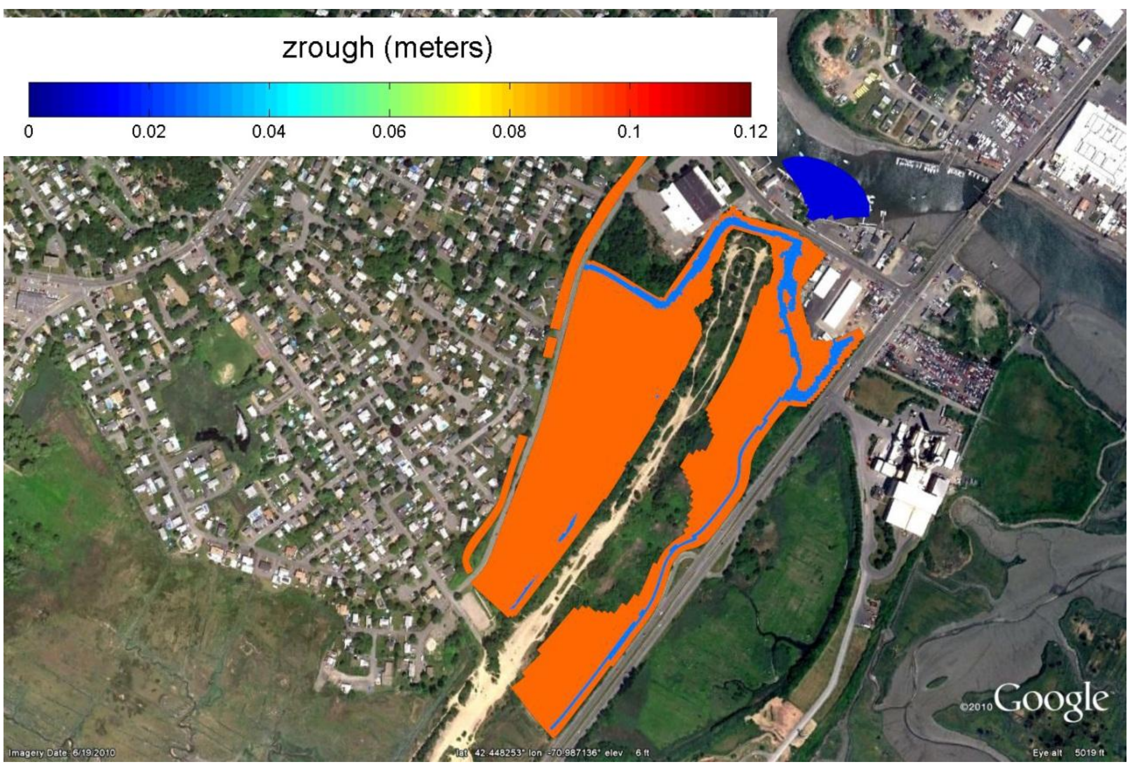


Figure C-7. Bottom roughness values for the Ballard Street marsh system hydrodynamic model.

C.2.3 Flow Control Structures

A total of seven culverts have been identified within the Ballard Street marsh system. The location of these culverts was shown in Figure 2-5. Of the seven culverts in the system, six have been included in the Ballard Street marsh hydrodynamic model. The small culvert under Eastern Avenue at the northern end of the Eastern Avenue ditch (culvert F) is also not include because it drains only a relatively small swale on the east side of Eastern Avenue and does not contribute significantly to the hydraulics in the larger marsh system. The stock version of EFDC permits the modeling of hydraulic control structures by allowing the model to contain pairs of cells between which fluid volume can be transferred at discharge rates based on a predetermined rating curve. While this is useful for the modeling of many types of hydraulic control structures, effective use of this method requires accurate knowledge of how the discharge depends on the energy loss across the structure. This relationship can be determined empirically if observed data are available, but this was not possible here. Also it should be considered that the discharge through a hydraulic control structure may not be completely described by a single head-discharge relationship. For example, with a given head difference across a culvert the discharge will be different if the culvert if fully submerged than if it is only flowing half full. To reconcile these problems the EFDC code was modified to dynamically compute discharge though the culverts included in the model using well established methods for culvert hydraulic analysis (Chow, 1959). A flow chart showing the logic used by the program to determine the flow regime within a culvert is shown in Figure C-8. Once the flow regime is determined the discharge is computed using Manning's equation.

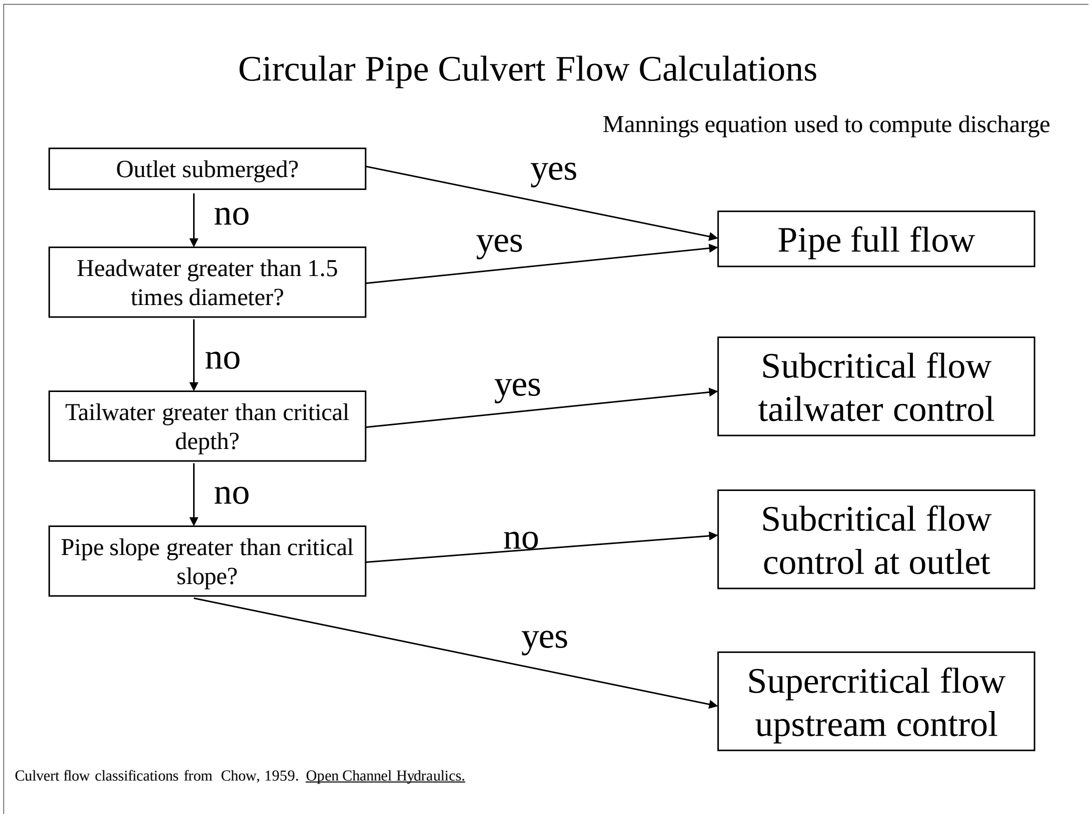


Figure C-8. Flow chart for culvert flow regime determination.

REPORT ADDENDUM

Following completion of the modeling and reporting effort, project stakeholders had specific questions and concerns related to the proposed restoration approach. As such, target additional modeling and analyses were performed to help provide expanded information related to the hydrodynamic processes and conceptual design development. The requested additional modeling, analysis, and evaluation of the proposed restoration project focused on three specific elements:

1. Increased information regarding the interrelationship between various parameters, as illustrated in Figure 7-4, used to optimize the excavation needs. A number of iterative simulations were conducted to minimize the excavation amounts, while maximize the restoration levels, all while ensuring that adequate flood storage was available for a 50-year return period precipitation event. This addendum presents additional details on the optimization model simulations that were conducted to further illustrate the relative sensitivity of the model to various parameter changes and determine if changes to the conceptual design may be warranted.

2. Evaluation of the impacts to the system if the natural, topographic constrictions residing in the channel of the eastern marsh were removed (either through natural processes or anthropogenic actions). In the current development of the conceptual restoration design, these features were not modified as part of the proposed project. In this addendum, model simulations were conducted that evaluated the hydrodynamics of the preferred alternative for Ballard Street Marsh with clearing of the east branch of the channel. Two specific scenarios were evaluated changing the forcing information at the Pines River boundary to the model. Subsequently water surface elevation results were evaluated throughout the system to determine potential impacts and evaluate the need for modifications to the preferred alternative.

3. A more in-depth evaluation of velocities and water depths in the vicinity of the existing Ballard Street culvert. Model results were extracted at the Ballard Street culvert for existing conditions and for the preferred alternative scenario to facilitate evaluation of potential changes to the relative safety of the system.

AD.1 OPTIMIZATION OF EXCAVATION

Figure AD-1 presents results from a subset of the iterative model runs simulated to optimize the restoration and excavation components of the preferred design. The figure illustrates the general process conducted to arrive at the conceptual design for the marsh grading and restoration. Figure AD-1 presents three variables that were the key interrelated parameters that were keys in the optimization process: (1) Mean High Water (MHW) level in the western marsh (function of excavation and grading), (2) excavation volume (trying to minimize while still providing adequate storage for precipitation event, and (3) restored area (divided into high marsh and low marsh and a function of both water levels and excavation). The horizontal axis presents simulation case (selected from a subset of the iterative runs conducted). The black diamonds represent the amount of excavation (cubic yards) corresponding to the right-hand vertical axis. The blue bars in the upper panel show the elevation of Mean High Water in NAVD88 feet achieved for each case corresponding with the left-hand vertical axis. The green bars in the lower panel show the total restored area and restored low marsh area (acres) for each case.

Given the primary goals of the restoration project (i.e., maximize restoration, while minimizing the excavation that still provides flood storage for a 50-year return period precipitation event), the focus was not solely on minimizing cost or excavation levels alone. In addition, the object of the marsh grading was to maximize the low marsh area, while also maintaining a reasonable hydroperiod. For cases that seemed promising (high restoration value), we then tested those cases with the 50-year precipitation event to ensure adequate flood storage and the critical elevation of 5.25 feet NAVD88 was not exceeded. The iterative model approach started with the large NRCS excavation (97,000 cubic yards), and reduced excavation amounts while also varying marsh gradation.

The figure indicates that reduced excavations increase MHW (a smaller basing to fill) and also initially increase restoration area since the higher tides create more intertidal area. However, with continued excavation, and MHW increases, the restoration levels starts to decrease, high marsh become more prevalent, and flood storage capacity is lost. Too much excavation and intertidal areas turn to subtidal areas, reducing excavation. This was illustrated in Figure 7-4. Based on the DER restoration goals, Figure AD-1 indicates the optimal marsh occur with excavation amounts between 60,000 and 65,000 cubic yards from the west marsh given the forcing tides from Ballard Street and the Pines River. With this excavation range, there is a significant increase in restoration area and low marsh is also maximized. These cases were also tested with the 50-year precipitation event, and the 65,000 cubic yard case was determined to provide full flood storage capacity under worst case conditions (marsh at mean high water spring conditions aligned with peak of storm water discharge). The results shown in Figure AD-1 indicate that it may be feasible to reduce excavation slightly, from 65,000 to 60,000 cubic yards and still maximize restoration, while only having a slight increase in flood risk; however smaller excavations (less than 60,000 cubic yards) indicate a sharp loss in restoration area, while also losing flood storage capacity.

The preferred alternative was focused on maximizing restoration as the primary objective, while ensuring we provided adequate flood storage for the 50-year precipitation event. In this approach, excavation cost is not optimized since the focus was on gaining the most possible restoration acreage (i.e., whatever excavation was required to maximize restoration and solve the flood storage issue was the excavation recommended). However, if goals were reconstituted (e.g., improve flooding capacity compared to existing conditions, but not necessarily provide maximum flood storage), then perhaps a reduced excavation approach could be considered. For example, a conceptual marsh design could be focused on reducing excavation costs while providing improved flood storage capacity and the level of restoration left non-optimized.

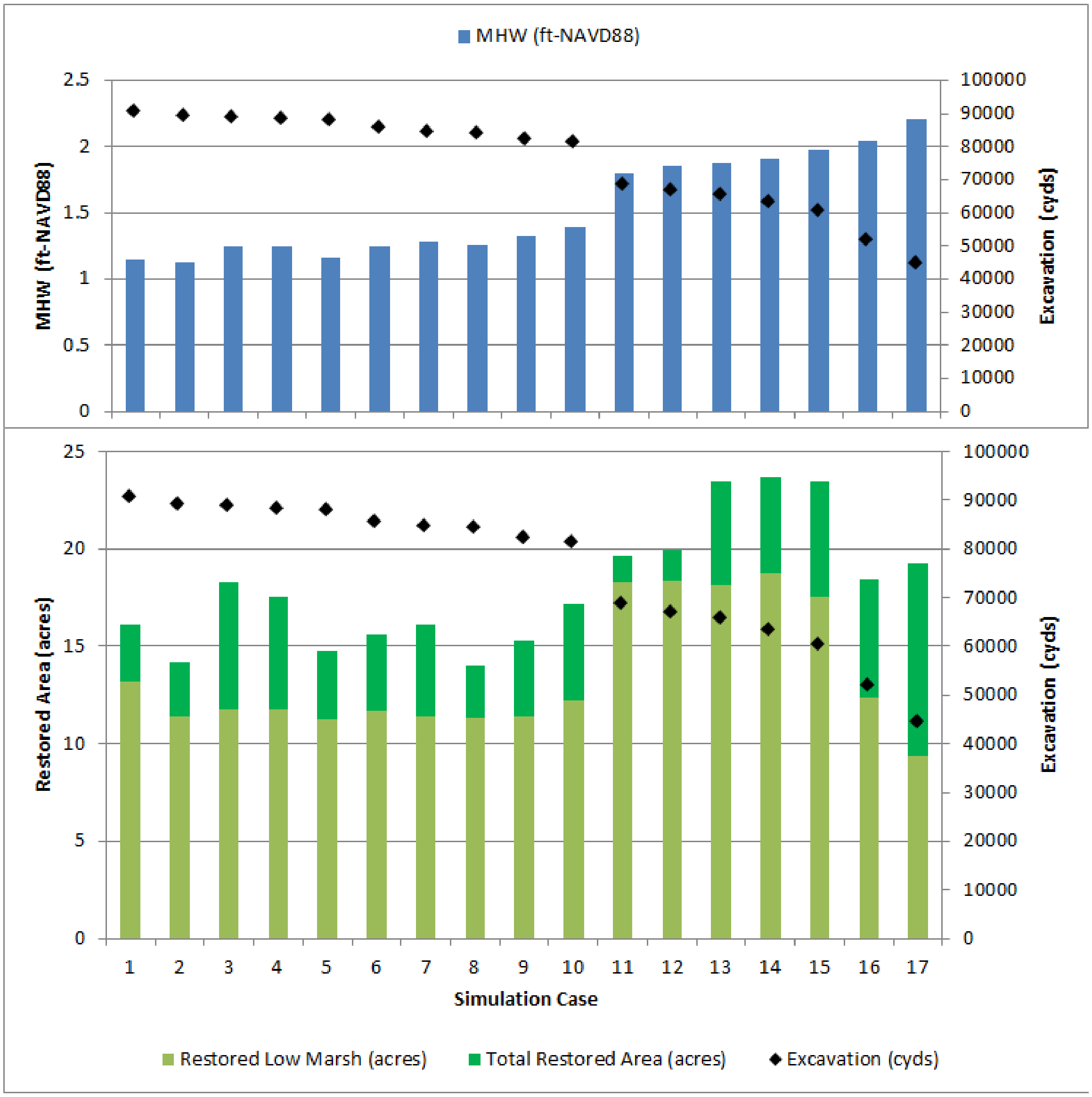


Figure AD-1. Results of multiple excavation and marsh restoration area cases used to assist in determining the preferred alternative marsh grading design.

AD.2 POTENTIAL REMOVAL OF EAST CHANNEL FLOW OBSTRUCTIONS

In the preferred alternative model simulations, existing natural flow obstructions in the east marsh channel (see Chapter 6) were assumed to remain in place. This inhibited the tidal flow from the Pines River system into the Ballard Street marsh to a certain extent. Considering the water levels in the Pines are almost always higher than those in Ballard Street marsh (see Figure 6-7), the potential removal of the obstructions may have a significant impact on the hydraulics in the restored marsh system. Therefore, hypothetical scenarios with the east marsh channel completely cleaned and the Bristow Street culvert fully operation were simulated to determine the impacts on the system as a whole. Figure AD-2 shows the observational locations where data were extracted from the model in order to assess the changes in water levels within the system. Two scenarios were considered to assess this hypothetical situation where the obstructions were removed.

Figure AD-2. Model observations locations for testing potential removal of east channel flow obstructions scenarios.

- Scenario A - This scenario includes full opening of the Bristow Street culvert, and clearing of the east branch of the Ballard street channel. However, since the Pines channel data observations indicate the Pines channel dries at low tide, the channel invert at an individual cell between East Marsh 2 and East Marsh 3 model observations point was set to 1.9 feet NAVD88 to replicate the drying of the boundary condition at the Pines channel. This limits the flow during mid-to-low tide from the Pines to the East branch since there is no source of water in the Pines channel at those times (All other components are the same as the preferred alternative [i.e., excavation, removing Ballard St. flap, additional culvert under Eastern Ave., etc.]).

- Scenario B - This scenario also includes full opening of the Bristow Street culvert and clearing of the east branch of the Ballard street channel. However, this sets the east branch channel invert at -1.6 NAVD88 feet for the entire length of the channel. This effectively assumes that there is an infinite amount of water arriving from the Pines Channel with a depth of over 3 feet even at low tide. (All other components are the same as the preferred alternative [i.e., excavation, removing Ballard St. flap, additional culvert under Eastern Ave., etc.]). This alternative may be unrealistically in terms of the water that can arrive from the Pines channel (infinite water source). Scenario B is an unrealistic situation.

Normal tidal simulation water surface elevation results from scenario A and B at the various model observation points are presented in Figure AD-3 and AD-4, respectively. Under scenario A, the mean water surface elevation is increased approximately 0.5 to 0.9 feet (depending on location) compared to the preferred alternative results due to the removal of the obstructions. The removal of the obstructions also slightly increases the MHW levels in the west marsh, while more significantly increasing MHW in the east marsh. Under scenario B, mean water levels are increased by more than a foot and the tide range becomes reduced in the western marsh. However, the water level in the western marsh can also be controlled by the tide gates installed at the new I-95 culvert.

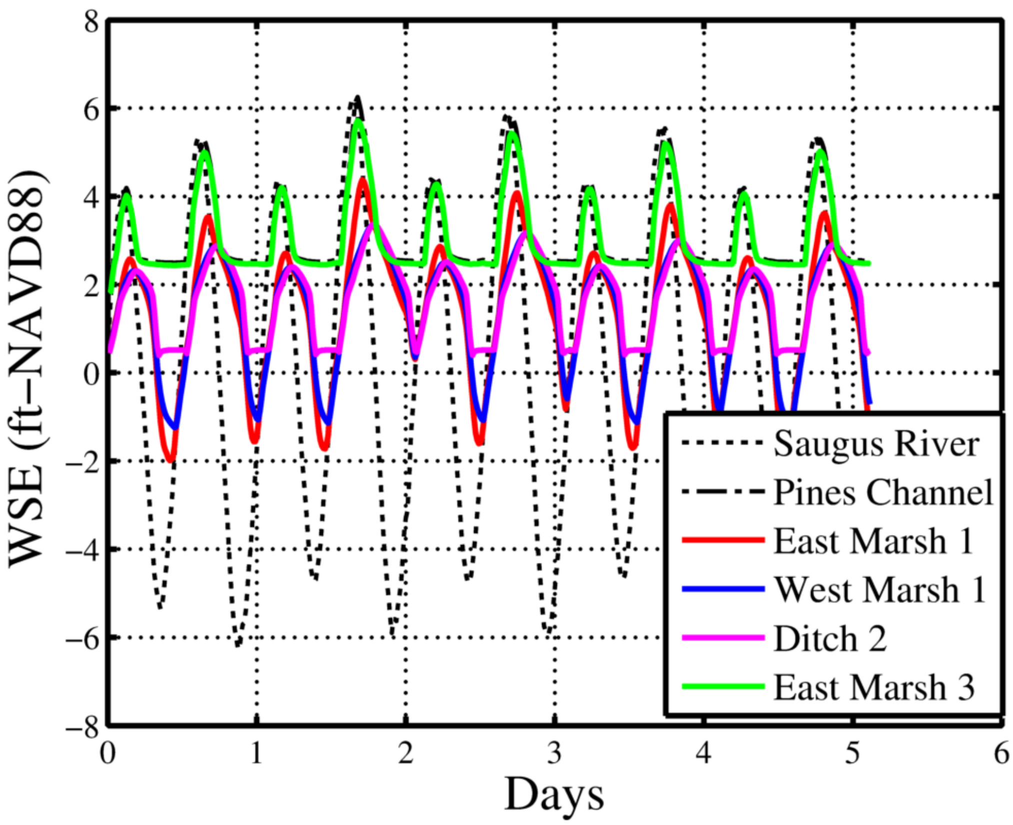


Figure AD-3. Water surface elevation results for Scenario A under normal tidal conditions.

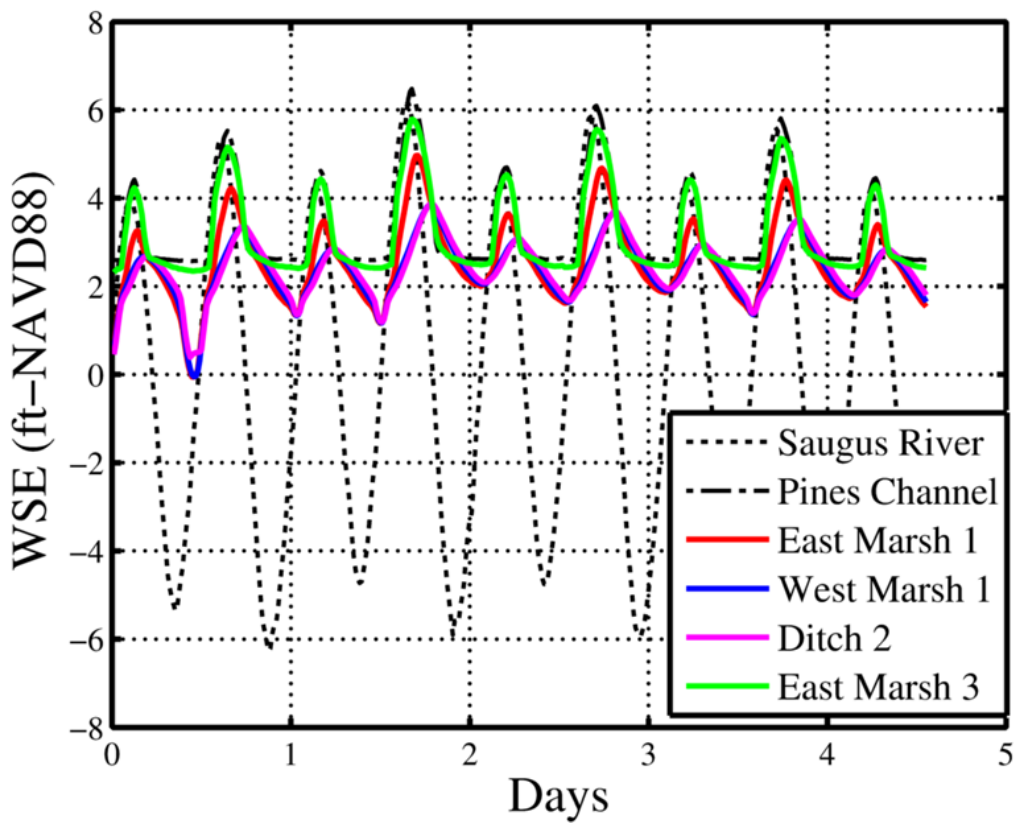


Figure AD-4. Water surface elevation results for Scenario A under normal tidal conditions.

The arrival of additional water from the Pines River system also may impact the flood storage capacity of the preferred design. As such, the 50-year precipitation event was also simulated with scenario A and B to determine the maximum water surface elevation that results from the storm event. For these cases, the peak storm water discharge was coincident to the high water level in the western marsh. Table AD-1 compares the results for the maximum observed water level at the various observation stations for the preferred alternative (as simulated in Chapter 7), Scenario A, Scenario B, and existing conditions. The results indicate that for Scenario A, the peak water levels all remain under the critical elevation of 5.25 feet NAVD88 in the west marsh and ditch, and well under the peak water levels that occur for existing conditions. Scenario B shows peak water elevations over 5.25 feet; however, this scenario is unrealistic and could ultimately be controlled by the tidal gates.

The removal of obstructions from the east marsh channel and fully open Bristow Street culvert does allow a consistent flow of water into the Ballard Street system from the Pines River. However, if the obstructions are removed (naturally or anthropogenically), water levels propagating to the west marsh can still be controlled by the tide gates at the new I-95 culvert. With or without the obstructions in the east marsh channel, the preferred alternative can still performs as expected. Nonetheless, consideration should be given to an adaptive management approach coupled with field monitoring for the potential opening of the Bristow Street culvert.

Table AD-1. Comparison of maximum water levels for 50-yr precipitation event.

Location	Maximum Water elevation (ft-NAVD88) Preferred Alt.	Maximum Water elevation (ft-NAVD88) Pines Scenario A	Maximum Water elevation (ft-NAVD88) Pines Scenario B	Maximum Water elevation (ft-NAVD88) Existing Conditions*
Saugus River	6.2	6.2	6.2	6.2
East Marsh 1	3.9	5.0	5.5	5.8
West Marsh 1	4.0	4.9	5.3	5.8
East Marsh 2	3.9	5.1	5.6	5.8
West Marsh 2	4.0	4.9	5.3	5.8
Ditch 1	4.0	5.0	5.4	5.9
Ditch 2	4.0	4.9	5.4	7.0
East Marsh 3	4.2	5.8	5.9	N/A
Pines Channel	6.5	6.5	6.5	N/A

AD.3 VELOCITIES AND WATER DEPTHS AT THE EXISTING BALLARD ST. CULVERT

A more in-depth evaluation of velocities and water depths in the vicinity of the existing Ballard Street culvert was conducted. Since the Ballard Street culvert was not intended to by modified under the preferred alternative, it was not explicitly evaluated from a velocity and flow perspective (it was being left in its current state). However, due to the potential development of this area into a recreational park, a closer evaluation of the existing culvert was warranted. Model results were extracted at the Ballard Street culvert for existing conditions and for the preferred alternative scenario to evaluate potential changes to velocities and elevations.

Table AD-2 presents the results for the peak velocities and depth in the culvert at the corresponding peak velocity, while Figure AD-5 shows time series results of velocities in the Ballard Street culvert and the water elevations on the upstream side of the culvert. A majority of the time there is head space in the culvert and velocities are less than 3.0 feet per second in all cases. However, during high tides and peak ebb flow, the culvert is fully flowing and velocities exceed 4.0 feet per second for existing conditions, 6.0 feet per second for existing conditions with the flap removed, and 7.0 feet per second for the preferred alternative.

Table AD-2. Velocities and water levels in existing Ballard Street culvert.

Tidal Phase	Existing Conditions		Existing Conditions, No Flap		Preferred Alternative	
	Velocity in culvert	Depth in culvert	Velocity in culvert	Depth in culvert	Velocity in culvert	Depth in culvert
Peak Flood	1.0	3.9	3.1	4.0	3.2	4.0
Peak Ebb	4.2	3.7	6.3	3.7	7.3	3.7
Slack Low	1.5	1.1	2.0	1.1	2.0	1.2
Slack High	0.0	4.0	0.0	4.0	0.0	4.0

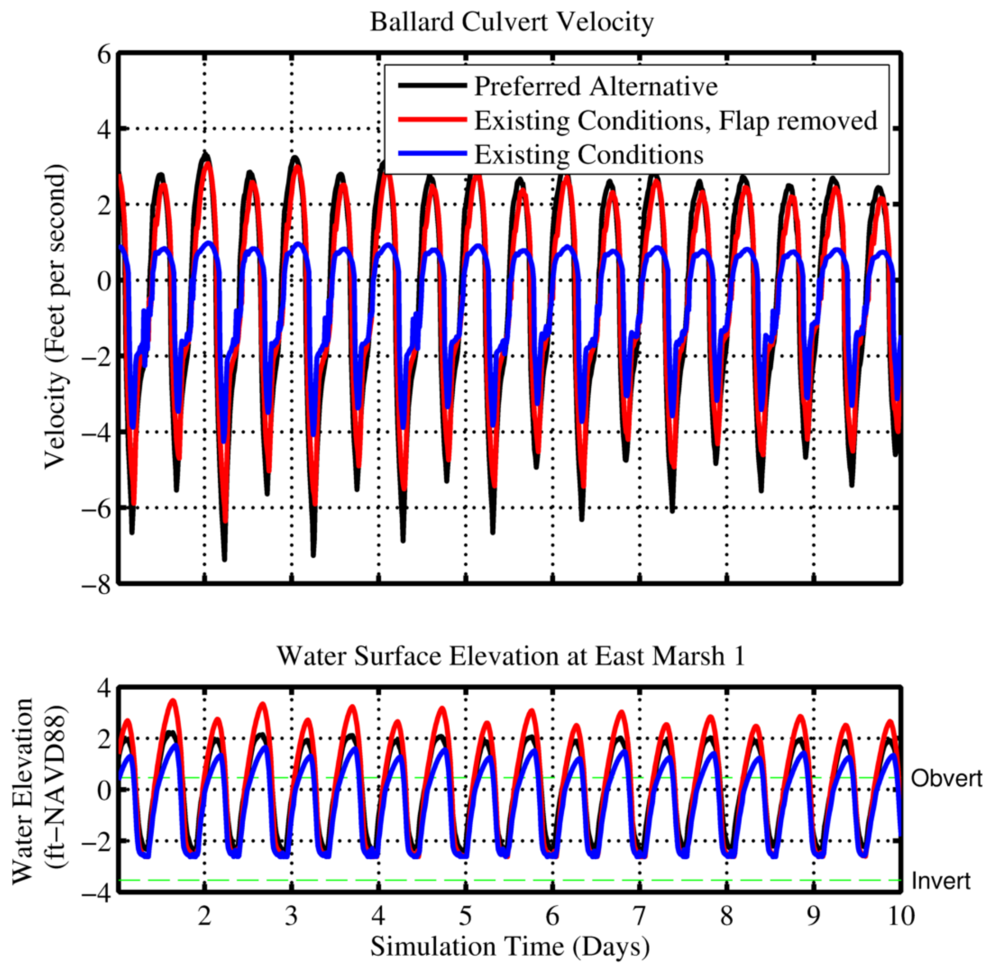


Figure AD-5. Velocities in the Ballard Street culvert for existing conditions (with and without flap) and preferred alternative under normal tidal conditions (upper panel). Water surface elevation at the upstream end of the culvert, indicating culvert is fully flowing for both existing conditions and preferred alternative during high tides (lower panel).

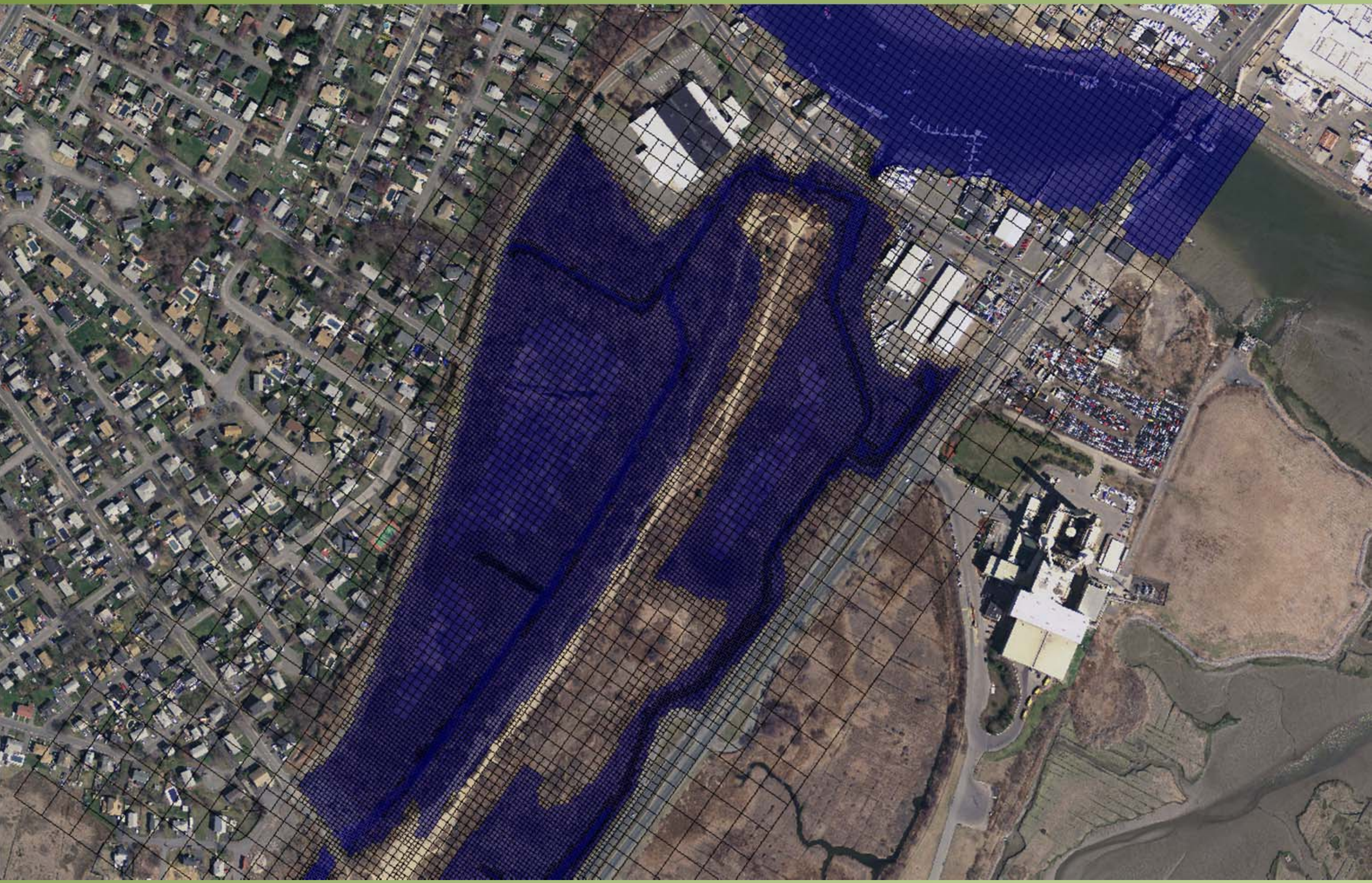
Appendix 2

Saugus Marsh Hydrodynamic Study Analysis of Existing Conditions and Restoration Alternatives

Applied Coastal Research and Engineering, Inc.
March 2015

Saugus Marsh Hydrodynamic Study

Analysis of Existing Conditions and Restoration Alternatives



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Final Report - March 2015

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1. INTRODUCTION

The Ballard Street salt marsh is a tidally restricted part of the larger Rumney Marsh ACEC located within the Town of Saugus, Massachusetts. The approximate 57-acre project area is bounded by Eastern Avenue on the west, Ballard Street on the north, Route 107 on the east, and the abandoned Bristow Street right-of-the-way to the south (Figure 1). The marsh system is heavily influenced by anthropogenic modifications to the historic salt marsh system, including the bifurcation of the natural marsh by a large linear berm of sand and gravel fill which is a remnant from the planned extension of Route I-95 (abandoned in 1972). The marsh system is connected to the Saugus River at Ballard Street by a four foot inner-diameter pipe fitted with a deteriorated steel plate "tide gate" chained to the culvert entrance at the seaward end. This hydraulic connection significantly inhibits tidal exchange to and from the Ballard Street salt marsh system.

A hydrodynamic model of Ballard Street Marsh was developed in order to determine the relative merits and performance of the different proposed restoration alternatives. The model was parameterized using existing topographic datasets and available tide data. The hydrodynamic model that is integral to the Coastal Modeling System (CMS) of the U.S. Army Corps of Engineers (USACE) was implemented for this analysis. This model solves hydrodynamic equations using a finite volume method on a non-uniform Cartesian grid, where the specific model gridding routines allow for more efficient refinements of the grid in locations of interest within the model domain without forcing small cell sizes in areas where it is not required or desired. This methodology represents the most robust approach for evaluating tidal hydrodynamics in regions that include significant wetting and drying, as well as simulations where culverts and/or marsh channels govern tidal exchange.

Figure 1. Aerial photograph illustrating main features surrounding the Ballard Street restoration site (*source: Modified from Woods Hole Group, Inc.*).

After the calibration of the model to existing conditions, the model was modified to incorporate various new hydraulic components (i.e., culverts and earth dikes) to evaluate several different conceptual restoration alternatives. These restoration alternatives were developed based on the results of a screening analysis, where various exclusionary and discretionary criteria were utilized to guide development of the engineering alternatives.

In general, alternative marsh restoration scenarios sought to maximize the areal extent of salt marsh restoration and minimize excavation requirements, while mitigating both upland flooding and public safety concerns associated with the existing marsh system. Results from the hydrodynamic model were used to compute overall restoration area achieved by each alternative, variations in both tidal currents and water elevations throughout the marsh system, and potential flood levels for selected alternatives. Along with existing tidal conditions, the existing conditions model and preferred alternative were evaluated for the 50-year extreme rainfall event based on data from the Northeast Regional Climate Center (NRCC), to ensure that proposed conditions would not exacerbate upland flooding.

2. EVALUATED RESTORATION ALTERNATIVES

As described above, the targeted alternatives sought to maximize salt marsh restoration area, while balancing other interests associated with the Ballard Street project area. As a baseline, existing conditions were evaluated to determine the extent of existing marsh resources relative to the various restoration options. In addition, other parameters associated with tidal water elevations, current velocities, required excavation volume, and potential safety concerns could be evaluated within the context of the hydrodynamic modeling effort. The following is a brief description of the five alternatives evaluated with numerical hydrodynamic models as part of the alternatives analysis.

Alternative 1 – Existing Conditions (i.e. No-Build Scenario)

The No-Build alternative would maintain the existing flap gate and culvert conditions at Ballard Street and Bristow Street. As described above, the marsh system is connected to the Saugus River by a four foot inner-diameter pipe fitted with a deteriorated steel plate “tide-gate” chained to the culvert entrance at the seaward end. The current make-shift gate was historically implemented as stop-gap measure, intended to allow only one-way drainage of the system seaward to the Saugus River. In its current leaky condition, this hydraulic connection significantly inhibits tidal exchange to and from the Ballard Street salt marsh system and preferentially allows substantially higher tidal velocities during ebbing conditions. Figure 2 shows tides by the Division of Ecological Restoration (DER) within the Saugus River and in Ballard Street salt marsh illustrating the substantial tidal attenuation created by the restricted culvert. In addition, this figure illustrates the steeper slope of the tide curve within the marsh occurs during the ebbing portion of the tide cycle (i.e. the water drops in elevation faster than it fills the marsh), indicating that the leakage through the flap gate on the incoming tide is slower than the release of marsh waters on the ebbing tide. Therefore, the flooding currents through the culvert have a lower velocity than the ebbing currents, indicative of a marsh system that exports sediment and may have difficulty keeping up with sea level rise (Friedrichs and Perry, 2001).

This scenario provides no flood protection during coastal storm events beyond the approximate 7.0 feet (North American Vertical Datum of 1988, NAVD88) elevation of Ballard Street. It is assumed that the plate covering the Bristow Street West culvert would remain in place. In addition, the excavation of the I-95 embankment for use as beach nourishment under the permitted Winthrop Shores Project would not proceed below elevation 5.0 feet NAVD88, allowing no salt marsh restoration under the embankment footprint and no corresponding additional flood storage volume. For purposes of modeling this alternative, it presumes that there is no further deterioration of the existing flap gate at Ballard Street which would result in additional tidal intrusion. In addition, there are no flow control structures limiting tidal flow into the drainage ditch running along the western side of Eastern Avenue. Schematically, this alternative is depicted in Figure 3.

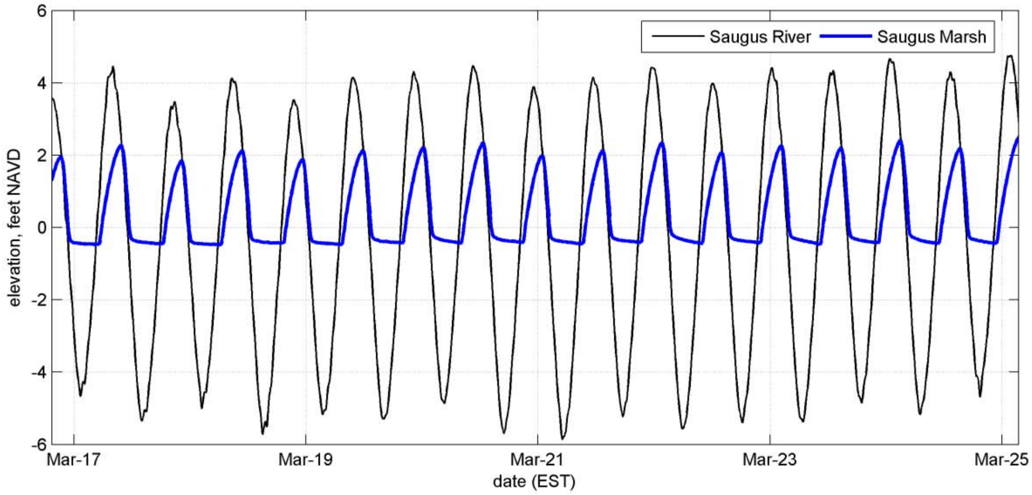

Figure 2. Measured tides from DER March 2012 deployment for the time period used for calibration of the existing conditions model. This plot demonstrates the ebb-dominant nature of the restricted Ballard Street salt marsh.

Alternative 2 – Modified NRCS Design with Self-Regulating Tide Gate (SRT) near Ballard Street

This alternative includes leaving the existing Ballard Street culvert in place, constructing a dike with two SRTs in the creek channel west of the existing 48-inch diameter culvert at Ballard Street and lowering the western marsh elevation by 2-to-3 feet. It also includes removing the obstructions on the existing Bristow Street East culvert. However channel obstructions within the channel to the north of the Bristow Street East culvert would remain; therefore, unblocking the culvert would functionally only re-introduce tidal exchange into the area immediately north of the culvert. Based on the WHG modeling results, this alternative would not create conditions for fully open tidal exchange throughout the eastern marsh.

This alternative is a modification of the original NRCS design from 2002 and includes the operation of tide gates servicing the western marsh as depicted by Woods Hole Group (2013, Section 7.0). This alternative requires contribution of tidal flow from both the Ballard Street culvert and the Bristow Street East culvert to provide the tidal connection to the western marsh and much of the eastern marsh. To achieve the proposed 60 acre-feet of flood storage within the western marsh, significant excavation of the western marsh is required to compensate for the low invert associated with the existing Ballard Street culvert. Due to the complex tide gate operation needed to artificially maintain water elevations in the western marsh 2-to-3 feet below high tide in the Saugus River, ebbing tide flows and associated tidal velocities exiting the western marsh are substantially higher than incoming tidal flow velocities. As depicted, this alternative requires that at least one of the two proposed tide gates be closed for a portion of the tide cycle.

Additionally, this alternative was not evaluated for conditions where tidal flow restoration was complete for the eastern marsh (i.e. removal of shoals and/or blockages in the eastern marsh channel); therefore, it remains unclear whether the proposed tide gates controlling flow between the eastern and western marshes could be operated as depicted in the Woods Hole Group report (2013).

This alternative was evaluated extensively as part of the previous hydrodynamic modeling effort (see Wood Hole Group, 2013); therefore, the updated model did not include a reconstruction of this analysis. Rather, results already provided from this previous analysis were incorporated into this updated alternatives analysis. Schematically, this alternative is depicted in Figure 4.

Alternative 3 – Install a new SRT Gate at Bristow-West and Close Ballard Street Culvert

Initial evaluation of Alternative 2 indicated that the tidal control created by the existing Ballard Street culvert limited options regarding the extent of marsh restoration, as well as the long-term sustainability of the marsh restoration due to the low marsh elevations required and the ebb-dominance of the created system that would prevent the marsh from accreting. To address these concerns, the engineering analysis first assessed the possibility of raising and increasing the cross-section of the existing Ballard Street culvert. Following a detailed analysis of existing utilities under Ballard Street, it was determined that it would not be possible to raise the existing culvert due to conflicts with existing utility mains, nor would it be possible to add culverts that would improve tidal exchange without creating public safety concerns.

Understanding that Alternative 2 requires substantial costly excavation of the western marsh and it may be difficult to develop an operation plan for the proposed SRTs that would effectively support both the combined goals of marsh restoration and upland flood protection, a new set of alternatives were developed that included a hydraulic connection from the western marsh to the Pines River Marsh to the south. The primary advantage of this connection over Alternative 2 is that flow control into the marsh restoration site is not limited by the low elevation and restrictive flow conditions associated with the Ballard Street culvert.

Alternative 3 involves installation of a new open-topped culvert and SRT gate at Bristow-West in order to provide tidal exchange with the Pines River to the south. The existing Bristow-East culvert would have the obstructions to the face of the culvert removed and the channel connecting to the northern part of the eastern marsh would be cleared. The low-elevation Ballard Street culvert would be closed.

In addition, tide propagation into the Eastern Avenue drainage ditch would be prevented by “duck bill” valves placed on the culverts exiting the Saugus neighborhood, where this alternative also includes installation of a new auxiliary culvert under Eastern Ave to improve drainage from the residential neighborhood. As described above, the auxiliary culvert would also be fitted with a one-way duck-bill valve to prevent tidal flow into the Eastern Ave ditch, similar to the existing Eastern Avenue culvert. Required excavation of the western marsh would be minimized, as a larger tide range could be allowed, as the relatively high elevation dike created by Eastern Avenue would prevent tidal flooding of areas west of Eastern Avenue.

This change allows for full tidal exchange within both the eastern and western marsh; however, the primary hydraulic connection for both culverts (Bristow east and Bristow west) is with the Pines River to the south. Since tidal flow is not dependent on the excessively low Ballard Street culvert, the western marsh only requires about 1-to-2 feet of excavation. A schematic representation of this alternative is shown in Figure 5.

Figure 3. Schematic representation of Alternative 1, Existing Conditions, where the only hydraulic connection for the Ballard Street salt marsh system is the existing 4-ft diameter culvert with the flap gate connecting to the Saugus River. The area outlined in red represents the hydrodynamic model domain and is not intended to represent tidal inundation area.

Figure 4. Schematic representation of Alternative 2, Modified NRCS Design, where the hydraulic connection for the Ballard Street salt marsh system is primarily through the existing 4-ft diameter culvert with the flap gate removed and an additional connection is provided by removing obstructions at the Bristow-East culvert. Substantial lowering of the west marsh and installation of SRTs to further attenuate the tide signal is required to achieve design goals. The area outlined in red represents the hydrodynamic model domain and is not intended to represent tidal inundation area.

Alternative 4 – Install New SRT at Bristow-West, Install Dike in Channel near Ballard Street with 1-ft Culvert in Dike

Since Alternative 3 required closure of the Ballard Street culvert in order to mitigate safety issues related to removing the Ballard Street culvert flap gate while also supporting the more natural tidal flow patterns sought for restoration of the western marsh, an additional alternative also was evaluated that provided similar tidal flow regimes and retained a hydraulic connection to the Saugus River. Alternative 4 involves installation of a new SRT at Bristow Street West (identical to Alternative 3) and leaving the existing Ballard Street culvert in place with the flap gate removed as described in Alternative 2.

Construction of a dike that hydraulically separates the eastern and western marshes is required to minimize excavation of the western marsh to approximately 1-to-2 feet, where the excavated 'footprint' includes the approximate 5-acre area associated with the DCR berm removal that was utilized to nourish Winthrop Beach.

Under this alternative, the berm or dike would be installed across the channel in approximately the location of the SRT near Ballard Street proposed in Alternative 2, above. Since the Ballard Street and Bristow-East culverts provide tidal flow only to the eastern marsh, restoration of this area is maximized as tidal attenuation is minimized. Similar to Alternative 3, this alternative also includes the new auxiliary culvert under Eastern Ave and the duckbills on all of the Eastern Ave culverts. This alternative is illustrated schematically in Figure 6.

A 1-ft culvert is placed within the proposed dike in the creek near Ballard Street to allow for a tidal connection and associated fish passage from the Saugus River to both the eastern and western marshes.

Figure 5. Schematic representation of Alternative 3, Install New SRT at Bristow-West and Close Ballard Street Culvert, where the hydraulic connection to the marsh system is through the Bristow-East and Bristow-West culverts. Only moderate lowering of the western marsh is required to achieve restoration design goals. The area outlined in red represents the hydrodynamic model domain and is not intended to represent tidal inundation area.

Figure 6. Schematic representation of Alternative 4, Install New SRT at Bristow-West and Install Dike in Channel near Ballard Street with 1-ft Culvert through Dike, where the hydraulic connection to the western marsh is primarily through the Bristow-West culvert and the hydraulic connections to the eastern marsh is via both the Ballard Street and Bristow East culverts. Only moderate lowering of the western marsh is required to achieve restoration design goals. The area outlined in red represents the hydrodynamic model domain and is not intended to represent tidal inundation area.

3. TIDE DATA COLLECTION

Tide data were collected at three locations in the Pines River between May 15 and May 29, 2014. These data were collected to supplement the tide data previously recorded at sites around the Saugus restoration area. The data were needed in order to determine the available tide range in the upper Pines River (west of Route 107), and to collect concurrent tide data in the two channels that potentially would be used to connect the Pines River to the eastern and western areas of Saugus Marsh. The data are also used as boundary conditions with the hydrodynamic model used to simulate the proposed restoration alternatives for Saugus Marsh. Figure 7 shows the location of the gauging stations used for the 2014 deployment.

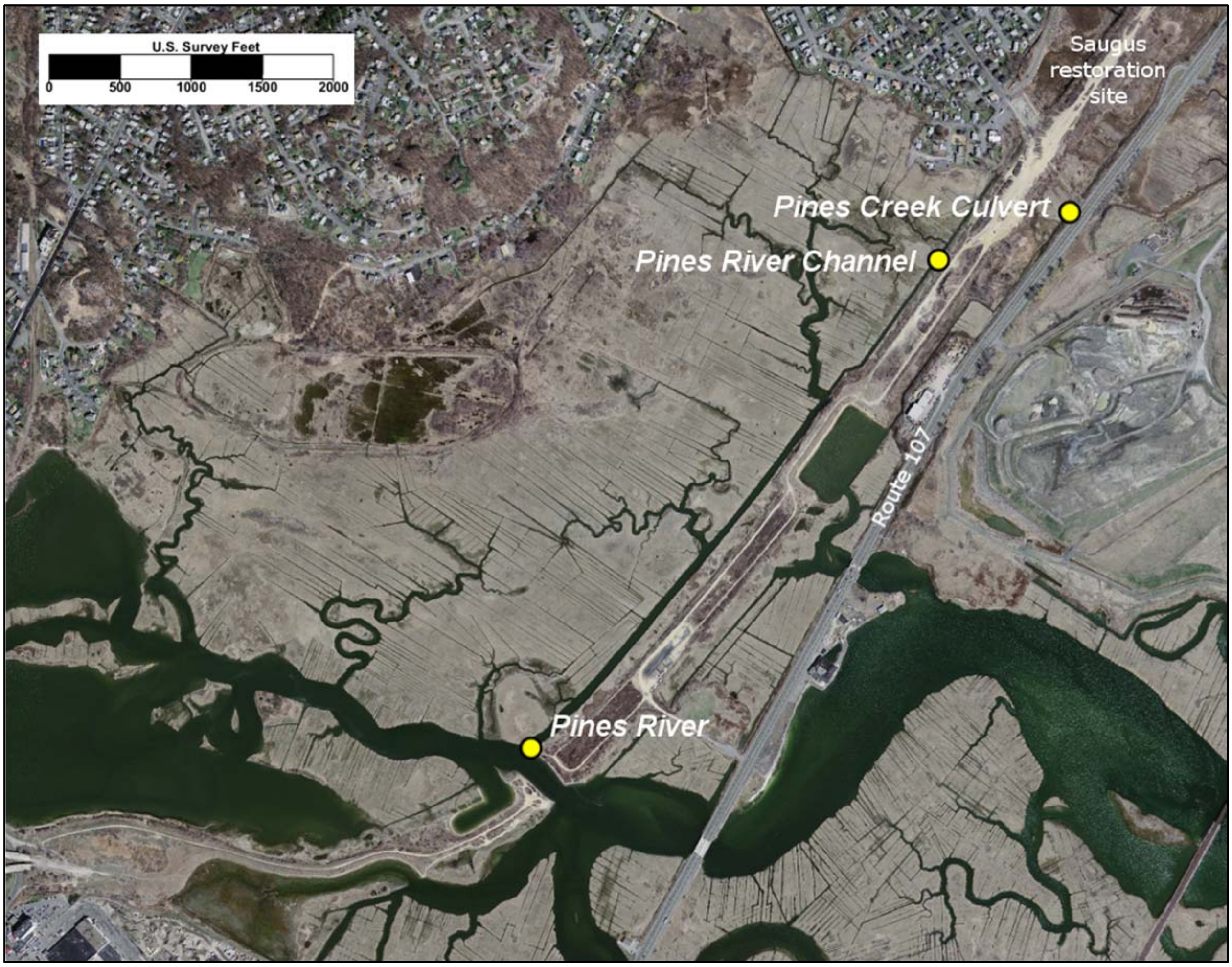

Figure 7. Map of the tide gauge locations used for the May 2014 deployment in the Pines River.

Plots of the tide data from the three gauges are shown in Figure 8 for the 15-day deployment. The spring-to-neap variation in tide range is visible in these plots. The data record begins during a period of spring tides. A week later there is a period of neap tides, which occurs around the time of the last quarter-moon of May 21. Following this spring tide is a return to a period of spring tides around the time of the new moon on May 28. The minimum neap tide range in the Pines River record is 9.8 feet (May23), while the maximum spring tide range is 11.7 feet (May 17).

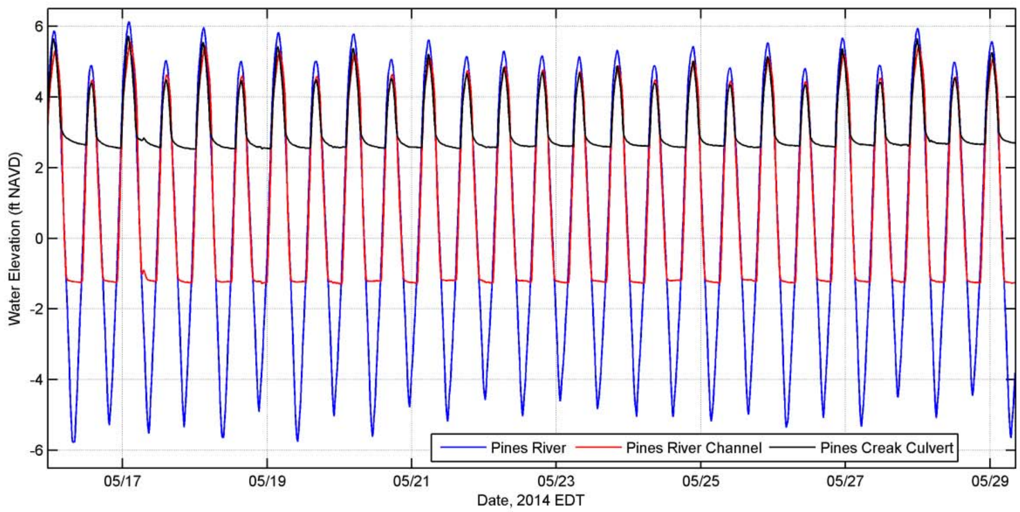

Figure 8. Tide data from the May 2014 deployment in the Pines River.

Tables 1 and 2 present the standard tide datums and computed tidal harmonics determined for the three gauge records. The tide datums and harmonic constituents of the measured tide records were calculated in order to better quantify the changes to the tide between the Pines River and inside the marsh. The standard tide datums were computed from the full length of the available tide records. These datums are presented in Table 1. For most NOAA tide stations, these datums are computed using 19 years of tide data, the definition of a tidal epoch. For this study, a significantly shorter time span of data were available; however, these datums still provide a useful comparison of tidal dynamics within the system. The Mean Higher High (MHH) and Mean Lower Low (MLL) levels represent the mean of the daily highest and lowest water levels. The Mean High Water (MHW) and Mean Low Water (MLW) levels represent the mean of all the high and low tides of a record, respectively. The Mean Tide Level (MTL) is simply the mean of MHW and MLW.

The tide datums presented in Table 1 show how the marsh channels attenuate the tide range. The mean tide range in the Pines River is 10.4 feet, though in the Pines River channel, the range is reduced by nearly one half. The reduction of the tide range is caused by the minimum elevation of the channel. Greater attenuation of the tide occurs in the creek at the Bristow Avenue Culvert, which has a mean range that only slightly greater than 2 feet.

The results of the tidal harmonic analysis presented in Table 2 show the expected transference of energy from the principle lunar semi-diurnal constituent (M_2) to its overtides (M_4 and M_6). Frictional damping of the tide by marsh channels causes the M_2 tide to diminish and the M_4 and M_6 tides to grow in amplitude. The constituent amplitudes listed in Table 2 are half of the total water level fluctuation due to each constituent. The K_1 constituent is the principle solar diurnal harmonic. The harmonic analysis shows that during the gauge deployment period the total astronomical tide signal was 95.2 percent of the measured water level fluctuations in the Pines River. The remaining 4.8 percent of the tide signal was due to atmospheric effects (e.g., barometric pressure and winds).

Table 1. Tide datums computed from 30-day records collected Pines River marsh system in May 2014. Datum elevations are relative to the NAVD vertical datum.

Tide Datum	Pines River	Pines River Channel	Pines Creek culvert
Maximum Tide	6.1	6.3	5.7
MHHW	5.7	5.9	5.3
MHW	5.3	5.6	4.9
MTL	0.1	2.6	3.7
MLW	-5.1	-0.4	2.6
MLLW	-5.3	-0.5	2.6
Minimum Tide	-5.8	-0.5	2.5
Mean Range	10.4	6.0	2.3

Table 2. Tidal Constituents computed for tide stations in Pines River and connected channels during the May 2014 deployment.

	Amplitude (feet)			
Constituent	M_2	M_4	M_6	K_1
Period (hours)	12.42	6.21	4.14	23.93
Pines River	4.78	0.17	0.18	0.45
Pines River Channel	3.17	0.79	0.24	0.35
Pines Creek Culvert	0.87	0.51	0.21	0.20

4. CMS-FLOW HYDRODYNAMIC MODEL

The CMS numerical modeling package utilized for this study was developed by the USACE Coastal Hydraulic Laboratory (Sanchez, *et al*., 2012). It includes separate CMS-Wave and CMS-Flow models that can be run independently or together to simulate sediment transport and morphology change that results from the combination of waves and hydrodynamic currents. CMS is an integral part of the Surface Water Modeling System (SMS) software application (graphic user interface). SMS is used to create model grids and specify all required model inputs and run-time parameters. Post-processing and visualization of model output is also done using SMS.

Model versions since 2012 (Sanchez, *et al.*, 2012) integrate both CMS-Wave and CMS-Flow into the same executable file. Before this version of the program was available, simulations that included both waves and hydrodynamics relied on a steering module within SMS to coordinate the running of the separate modules. Now with the new “in-line” version of the Flow and Wave models, the CMS executable handles the coordination between the two models internally. This simplifies the process required to set up a simulation, and has some useful secondary benefits, like the ability to pause a simulation. This makes it easier to view intermediate results during the course of a simulation run.

Simulations of hydrodynamics and sediment transport in the CMS system are computed using CMS-Flow. The latest releases of CMS and SMS allow a particular type of irregular Cartesian grid, called a “telescoping mesh”, to make more efficient refinements of the grid in locations of interest within the model domain without forcing small cell sizes in areas where it is not required or desired. Each level of mesh refinement is achieved by dividing a cell edge into two equal segments that become the edges of two new cells with a quarter of the area of the larger cell. As a result, no grid cell edges in a mesh are ever connected to more than two adjacent cells. This allows a very rapid change in mesh cell size over short distances.

Hydrodynamic features included in CMS-Flow include stable wetting and drying, with the possibility of ponding, wind forcing, spatially varying bottom friction, inclusion of culverts and tide gates and multiple methods for designating hydrodynamic boundary conditions. CMS-Flow also can model salinity transport. Boundary conditions can be specified by using a time series of water level elevations from a source such as a NOAA tide gauge or some other source of tide data. Alternately, boundary conditions can be can be extracted from a larger hydrodynamic simulation that the CMS domain is nested within.

Both explicit and implicit numerical formulations are available within the CMS-Flow code. The implicit formulation has been made available in the most recent public distributions of CMS. The key advantage of the implicit scheme is that simulations are much less restrained by issues related to time step size. Explicit formulations can require very small model time steps (of the order of 1 second) in order to ensure that no instabilities develop during the course of the model run. Small time steps are generally required with model meshes that have a high degree of refinement (small grid size) in areas with large depths that experience strong tidal currents. Common examples of this situation would be model meshes that include navigation channels or naturally deep inlet channels. With the implicit formulation that is now included in CMS-Flow, model time steps can be much larger (of the order of 10 minutes) because its stability is much less sensitive to the selected time step. The main benefit of being able to use large time steps is to reduce model total run times considerably. Simulations that take several days to run using the explicit formulation may be completed in a matter of several hours using the implicit version.

5. BALLARD STREET SALT MARSH MODEL DEVELOPMENT

The development of the model of present conditions for the Ballard Street Marsh proceeded first with the creation of the model grid. The grid specifies the special extent of the model domain, and includes the model topography/bathymetry and is used to designate other spatially varying model parameters, such as friction coefficients.

5.1 CMS-Flow Model Grid

The spatial extent of the model mesh was determined using recent (2013) aerial orthophotographs of the study area available from MassGIS and also recent topographic surveys of the marsh and adjoining upland areas. Survey data available for this analysis include the 2011 Otte and Dwyer survey of transects across the marsh plain and a 2014 plan of the region from Parsons Brinckerhoff with upland spot elevations. Additional bathymetry data in the Saugus River were available from the NOAA Geophysical Data Center. The combined data from these three sources is shown in Figure 9.

The model grid mesh of present conditions is shown in Figure 10. It includes all marsh areas below 8 ft NAVD in both the eastern and the western marshes, as well as a portion of the Saugus River. The mesh is made up of 18,620 total cells, with 15,053 active computational cells. Cell dimensions range between 32 and 2 meters for the entire mesh, including non-active upland areas, and between 8 and 2 meters within the designated active areas of the mesh, including the Saugus River.

After building the CMS-Flow mesh, the combined topography dataset constructed from the separate available sources it was imported into the model. The interpolated topography is presented in Figure 11. Additionally, spatially varying values of the Manning's *n* friction coefficient were specified for all active cells. For areas where marsh grass is present the value of 0.07 was specified. For marsh channels and the River, a value of 0.02 was specified.

The existing Ballard Street culvert is included in the model run file by following the procedure outlined in the USACE technical note CHETN-IV-95 (Li, *et al.*, 2013). Control cards are specified in the model run file specifying attributes such as the culvert diameter, length and presence of a flap gate. The culvert is a 4-foot diameter pipe with a length of approximately 70 feet. There is a flap gate on the Saugus River outlet of the culvert that is intended to permit the marsh to drain while preventing water from the Saugus River from entering the Marsh. The present state of disrepair of the gate does not completely block flow into the marsh, to the point where a two-foot tide range is allowed in the marsh.

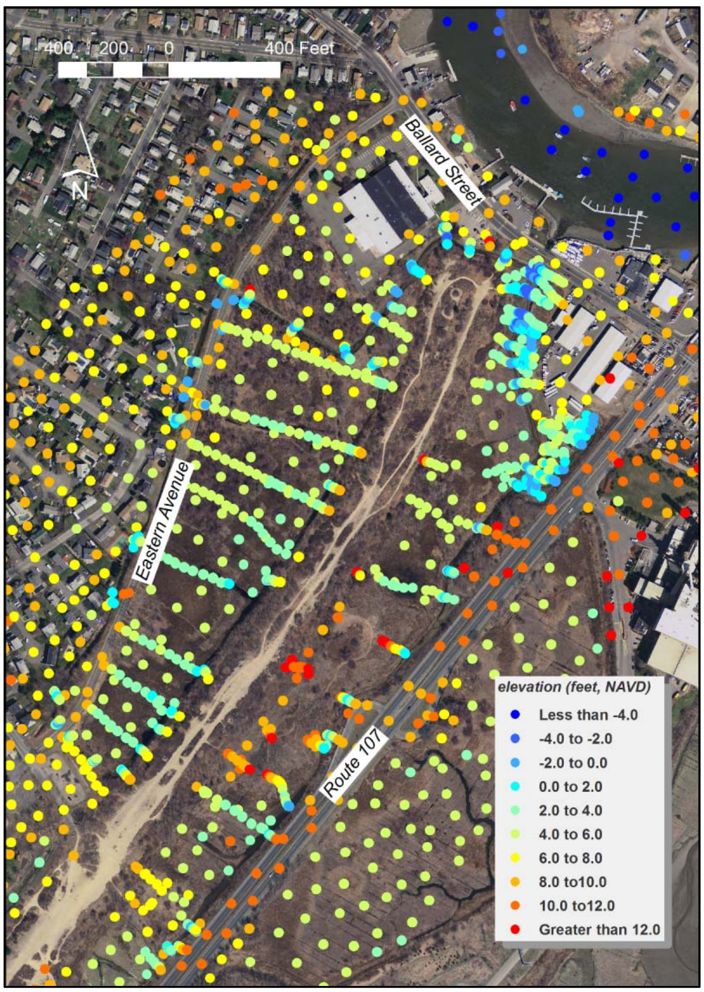

Figure 9. Mapped topography from plans (Otte and Dwyer, 2011 and Parsons Brinckerhoff, 2014) and bathymetry from NOAA (GEODAS archive). Survey points are overlain on the 2013 MassGIS aerial orthophoto of the study area.

Figure 10. CMS telescoping mesh developed for existing conditions at Saugus Marsh. Blue shaded area indicates active computational cells, while unshaded cells are inactive during runs of the model.

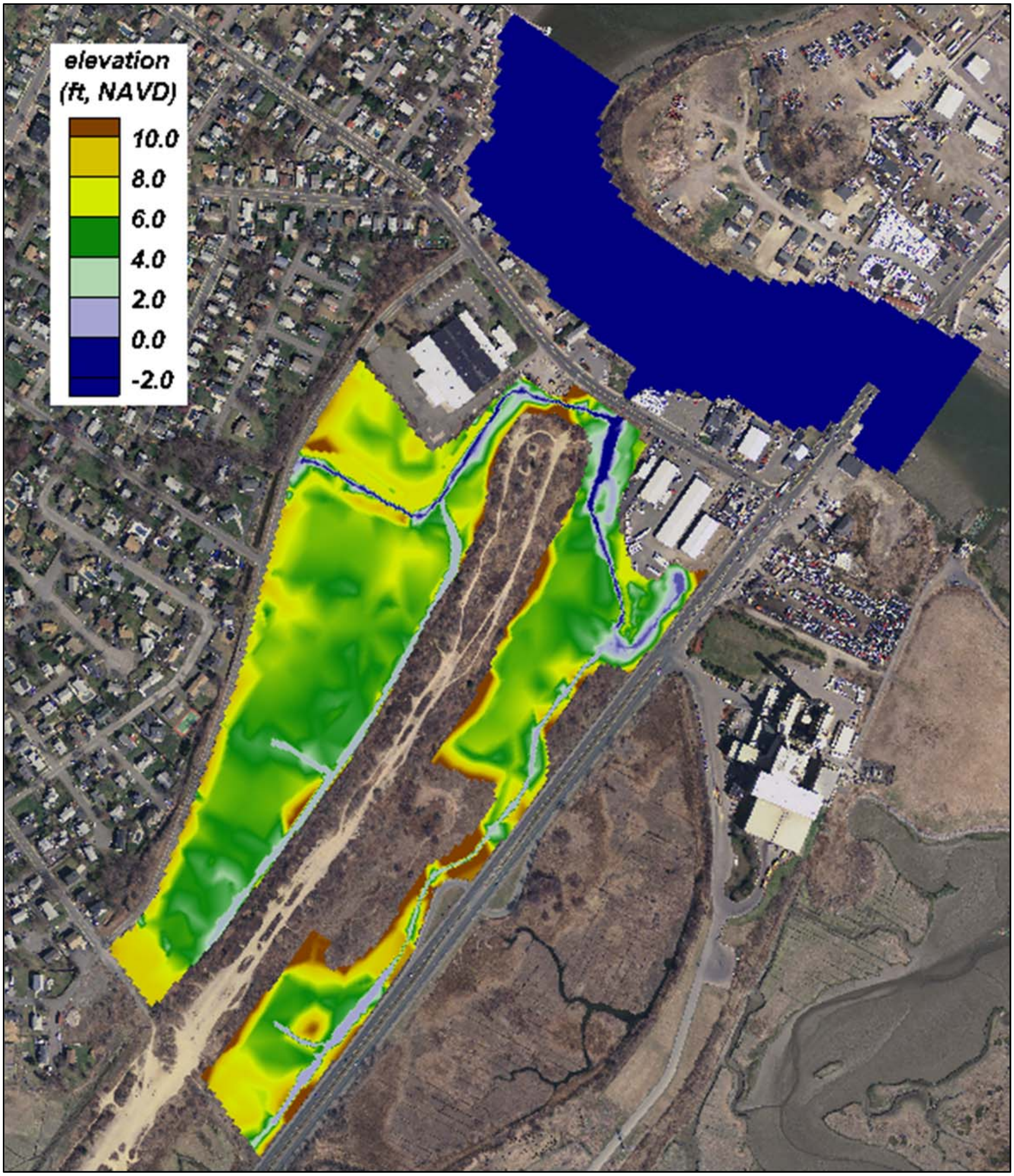

Figure 11. Final CMS grid of existing conditions with interpolated marsh topography.

5.2 Model Calibration

With the development of the model grid, the model of present conditions was calibrated using tide data made available from DER from a March 2012 deployment with gauges in the Saugus River and upstream of the culvert, in the marsh. The calibration time period is the 200-hour span of time starting at 1930 hours EST on March 16, 2012. Measured tides for that period in the river and in the marsh are plotted in Figure 13. The maximum tide range in the river during this period is about 10 feet, while it is only about 2 feet upstream of the culvert, in the marsh.

Figure 12 shows measured tides within the Saugus River and in Saugus Marsh illustrating the substantial tidal attenuation created by the under-sized culvert. In addition, this figure illustrates the steeper slope of the tide curve within the marsh occurs during the ebbing portion of the tide cycle (i.e. the water drops in elevation faster than it fills the marsh), indicating that the leakage through the flap gate on the incoming tide is slower than the release of marsh waters on the ebbing tide. Therefore, the flooding currents through the culvert have a lower velocity than the ebbing currents, indicative of a marsh system that exports sediment and may have difficulty keeping up with sea level rise. Since the planned alterations to the system will substantially alter the hydrodynamics of the system (i.e. more than doubling the tide range and increasing the tidally inundated area by as much as 12-fold), the efficacy of the calibration is of somewhat limited value and detailed model validation is not warranted. For a numerical comparison, the CMS modeling presented yields a slightly lower RMS error than the Woods Hole Group (WHG) modeling (Figures 13 and 14), with virtually no bias.

The system feature that has the greatest influence on the tide in the marsh is the deteriorated tide gate attached to the culvert. Therefore, the calibration proceeded by adjusting the performance of the culvert so that the tide upstream of the culvert in the model matched the measured tide. Ebbing tidal flow from the marsh is allowed to flow unobstructed through the 4 ft diameter culvert. When the tide reverses on flooding tides, the malfunctioning flap is simulated by restricting the area available for flow through the culvert. This flood tide flow area was adjusted until the model tide elevations in the marsh matched the measured data.

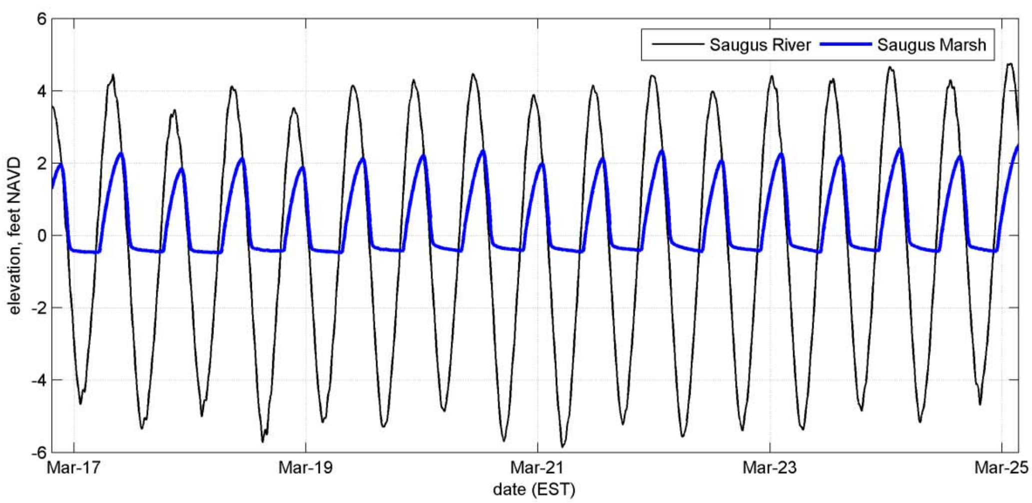

Figure 12. Measured tides from DER March 2012 deployment for the time period used for calibration of the existing conditions model.

The model was run using a 60-second time step, with model output saved at a six-minute interval, which is the same time step of the 2012 DER tide gauge data. The comparison of measured and modeled tides is presented in Figures 13 and 14 for the river and marsh gauges, respectively. In the river gauge comparison in Figure 13, it is impossible to distinguish the measured and modeled lines, which confirms that the model is properly responding to the boundary condition. For the marsh gauge comparison in Figure 14, the difference is perceptible visually, but still shows that the model is in good agreement with the measured tide.

A harmonic analysis also can be performed on the time series to assess the accuracy of the model calibration. Harmonic analysis is a mathematical procedure that fits sinusoidal functions of known frequency to the measured signal. The observed astronomical tide is therefore the sum of several individual tidal constituents, with a particular amplitude and frequency. For demonstration purposes a graphical example of how these constituents add together is shown in Figure 15. The amplitudes and phase of numerous tidal constituents result from this procedure. For this analysis, Table 3 presents the amplitudes of four tidal constituents in the Ballard Street Marsh system. In addition, the phase (in degrees) for each constituent is also shown, where the complete sinusoid consists of 360 degrees.

A more quantitative assessment of model error was performed by comparing tidal harmonic constituents computed for the model output and measured tide time series. Table 3 shows the comparison of four tide constituents computed using the measured data and the model output. By this comparison, the model is shown to perfectly reproduce the boundary condition, as should be expected, and also simulates the tide in the marsh with great skill, considering the substantial damping of the tide range across the Ballard Street culvert, and the dilapidated nature of the tide gate in place on the river side opening. The phasing of the M_2 (Principle lunar semi-diurnal constituent) and M_4 (first overtide of the M_2) tide constituents is nearly perfectly replicated for both gauge stations in the model, with a phase error that is a small fraction of the time step of the original data.

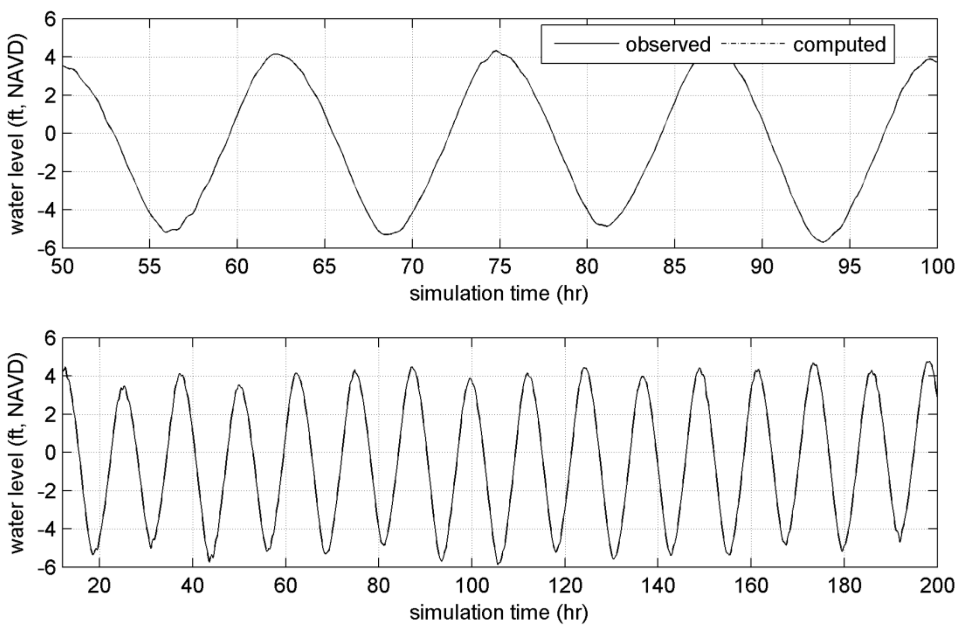

Figure 13. Comparison of model output and measured tides for the TDR (temperature-depth recorder) station in the Saugus River for the final calibration model run (starting March 16, 2012 at 1930 EST). The top plot is a 50-hour sub-section of the longer segment of the total modeled time period shown in the bottom plot. R^2 correlation is 1.00 and RMS error is 0.0 feet.

The M_2, or the familiar twice-a-day lunar semi-diurnal tide, is the strongest contributor to the signal with an amplitude of 4.5 ft in the Saugus River. The total range of the M_2 tide is twice the amplitude, or 9.0 ft. The M_4 and M_6 tides are higher frequency harmonics of the M_2 lunar tide (exactly half the period of the M_2 for the M_4, and one third of the M_2 period for the M_6), results from frictional attenuation of the M_2 tide in shallow water. The M_4 has an amplitude of 0.1 feet in the Saugus River, and increases to 0.5 feet inside the marsh. The M_6 has similar amplitude in the River, but does not increase inside the marsh. The largest change in amplitude across the culvert occurs with the M_2 constituent, which decreases from 4.5 feet to 1.2 feet in the marsh. This attenuation of the M2 is caused by the flow restriction created by the Ballard Street culvert.

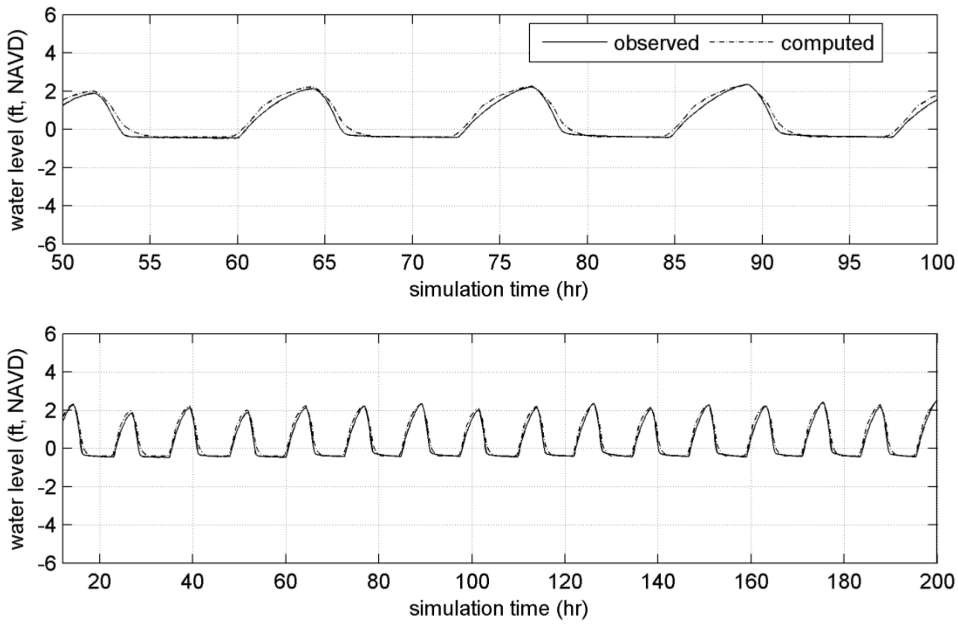

Figure 14. Comparison of model output and measured tides for the TDR station in the upstream of the Ballard Street culvert in the marsh for the final calibration model run (starting March 16, 2012 at 1930 EST). The top plot is a 50-hour sub-section of the longer segment of the total modeled time period shown in the bottom plot. R^2 correlation is 0.96 and RMS error is 0.2 feet.

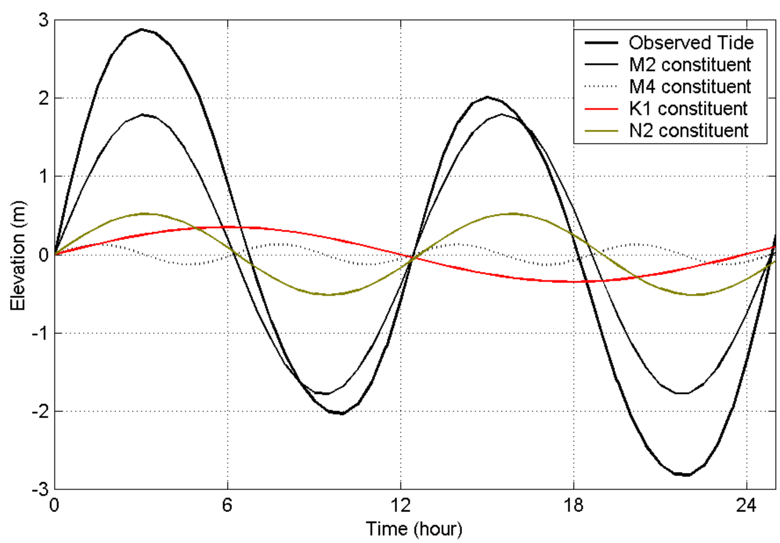

Figure 15. Example of an observed astronomical tide as the sum of its primary constituents.

Table 3. Tidal constituents for measured water level data and calibrated model output, with model error amplitudes, for the gauges located in the Saugus River and upstream of the Ballard Street culvert in the marsh, during modeled calibration time period.

Model calibration run						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Saugus River	4.54	0.10	0.11	0.13	28.1	-163.9
Saugus Marsh	1.31	0.40	0.11	0.04	56.2	117.9
Measured tide during calibration period						
Location	Constituent Amplitude (ft)				Phase (deg)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Saugus River	4.54	0.10	0.11	0.13	28.1	164.2
Saugus Marsh	1.20	0.50	0.14	0.04	56.6	117.4
Error						
Location	Error Amplitude (ft)				Phase error (min)	
	M_2	M_4	M_6	K_1	ϕM_2	ϕM_4
Saugus River	0.00	0.00	0.00	0.00	-0.01	-0.25
Saugus Marsh	0.11	-0.09	-0.03	0.00	0.75	-0.55

6. MODELING OF SCENARIOS

The existing conditions CMS-Flow model was modified in order to simulate two new scenarios: Alternatives 3 and 4 (described above). These three new alternative configurations are in addition to the one derived from the WHG analysis (Alternative 2). For the new model scenarios, the marsh plain of the western marsh was excavated to construct a sloped surface between +3.5 feet and +4.5 feet NAVD, as shown in Figure 16. For the initial alternatives modeling, the limits of the western marsh matched the existing marsh. This was performed as an initial screening analysis to determine the general response of the marsh to the various excavation elevations and flow control culverts and or tide gates. Additionally for Alternative 4, the completed berm excavation was included for the western marsh (also shown in Figure 16). In this scenario, the area is excavated to an elevation of +4.0 feet NAVD. The excavation of the berm adds approximately 5 acres of tidally inundated area to the western marsh.

Tide plots for the three modeled options are presented in Figures 17 and 18 for Alternatives 3 and 4 respectively. For Alternative 3, with the Ballard Street culvert wide open, the existing culvert under the Bristow Street extension open to the eastern marsh and the addition of a culvert between the western marsh and the Pines River (also under the Bristow Street extension). In Alternative 4, an earth dike is added to separate the eastern and western marshes and a 1-foot diameter culvert placed through the dike to provide a passage for fish between the Saugus River and the western marsh.

A comparison of wetted area and tide elevation for the alternatives is provided in Table 4. Maximum spring high tide elevation and maximum wetted surface area are provided for the eastern and western marshes separately. When the two marshes are not isolated, the tide height is the same across the marsh. With the addition of the dike, the eastern marsh floods to a higher elevation, and more land area is inundated by the tide.

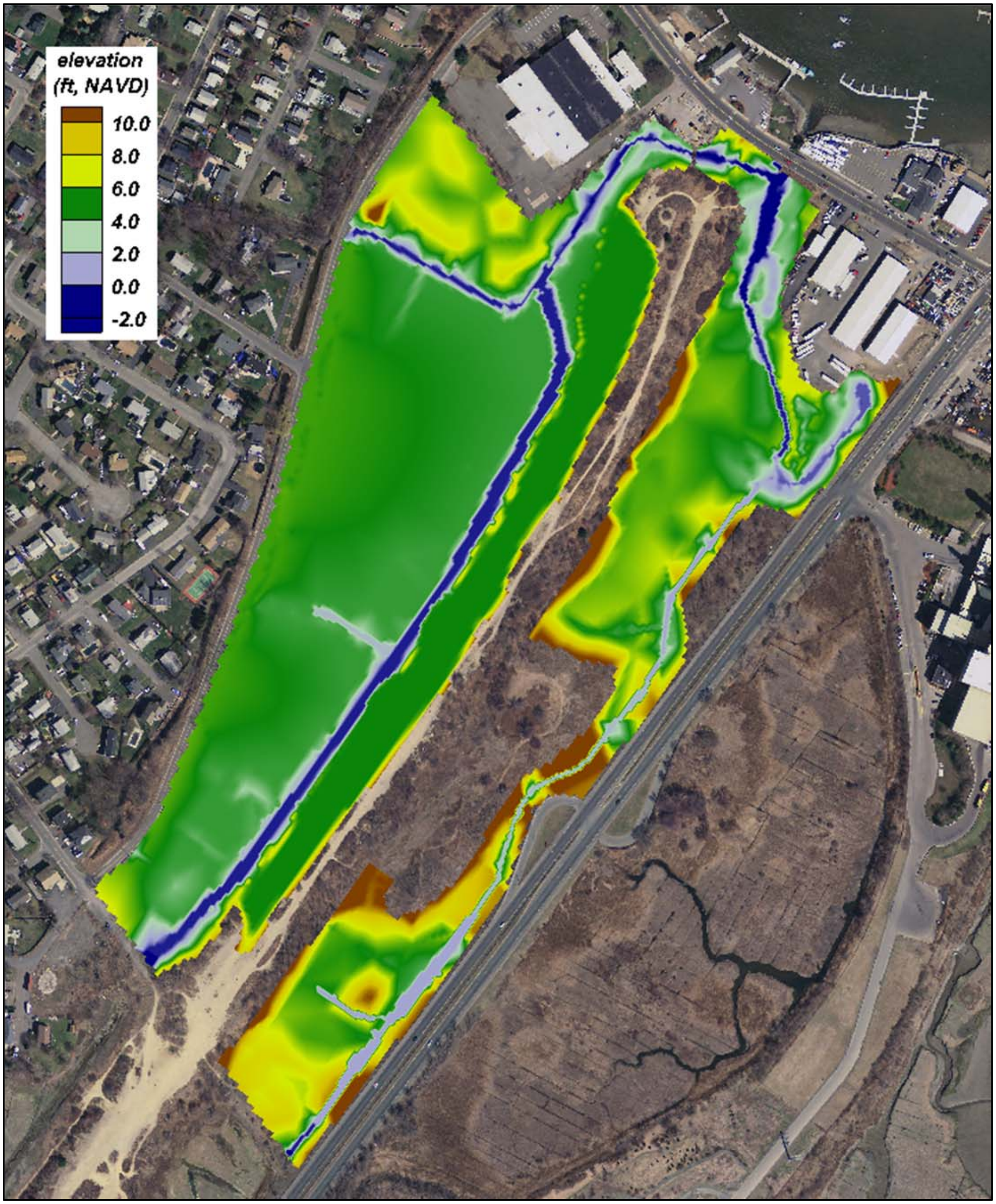

Figure 16. Contour plot of modified marsh plain topography used in the simulation of alternatives. Elevations in the excavated western marsh are constructed to slope between +3.5 and +4.5 feet NAVD. The area excavated from the existing berm between the eastern and western marshes, is included in only the final preferred alternative, Option 4.

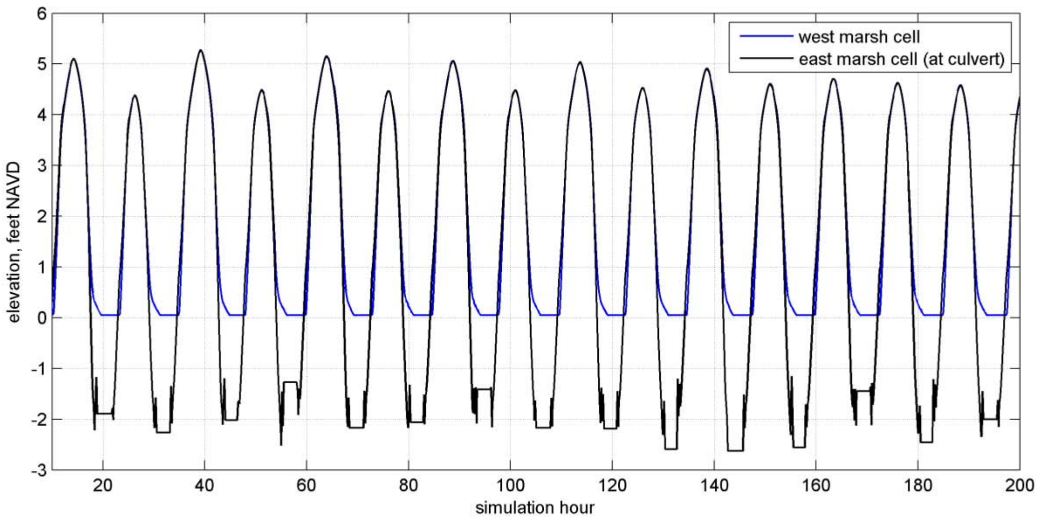

Figure 17. Alternative 3 modeled tides in the western and eastern marshes.

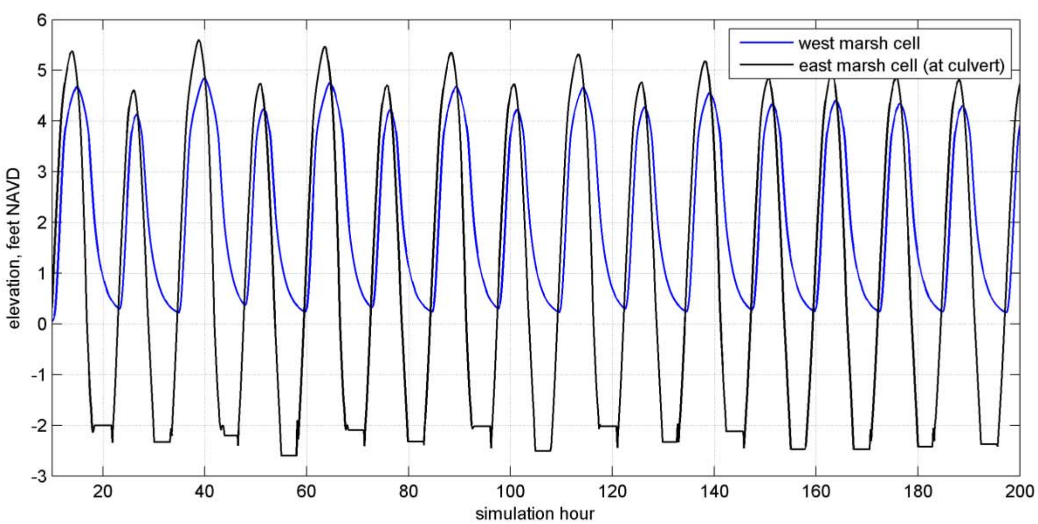

Figure 18. Alternative 4 modeled tides in the western and eastern marshes.

Table 4. Results of modeled restoration options. Maximum wetted areas and maximum tide elevations are provided for spring tide conditions.

alternative	Maximum wetted area (acre)			Maximum tide elevation (feet, NAVD)	
	Eastern Marsh	Western Marsh	Total	Eastern Marsh	Western Marsh
Alternative 1	1.6	1.4	3.0	2.4	2.4
Alternative 2	5.1	19.6	24.7	1.9	1.8
Alternative 3	9.2	20.7	29.8	5.3	5.3
Alternative 4	10.5	26.4	36.9	5.6	4.8

7. 50-YEAR RAINFALL EVENT

The 50-year rainfall event was simulated for both existing conditions and the preferred alternative (Option 4). These model runs were made in order to evaluate how the water level response in the marsh would change during an extreme rainfall event.

7.1 Development of Model Input Conditions

Model inputs used to simulate the fifty-year return period rainfall event for the marsh and its upland watersheds were developed using extreme precipitation data available from the Northeast Regional Climate Center (NRCC) via a website hosted by Cornell University (http://precip.eas.cornell.edu). The available data include total extreme rainfall amounts for a variety of events with different return periods and durations. Also available are distribution curves of rainfall rates as a function of time for selected return periods (e.g., 10-, 25-, 50- and 100-year return periods). The data available from this NRCC project is meant as an update to the regional rainfall climatology that had not been changed since published by the United States Department of Agriculture Soil Conservation Service (USDA SCS) in Technical Paper 40 (TP-40) in 1961 (Hershfield, 1961). Generally, the new NRCC data increase the intensity of rainfall for all return periods, compared to the older TP-40 climatology.

The 50-year event was selected for this analysis as the combined runoff and direct rainfall volume that must be managed using the updated climatology is roughly equivalent to the 100-year event used in the original NRCS (1999) analysis of the marsh, which is based on the older climatology. The plot of rainfall intensity as a function of time developed using the data from the NRCC website for the Saugus Marsh area is presented in Figure 19. The total rainfall amount for this event is 7.38 inches.

The NRCS analysis of Ballard Street Marsh delineated two upland watersheds that discharge to the marsh and split the marsh plain itself into two additional watersheds. This delineation is shown in Figure 20, as it was presented in the NRCS report. The areas of these watersheds are presented in Table 5, as reported by NRCS.

Runoff discharges from the upland watersheds (2 and 4) were determined using the Soil Conservation Service (SCS) dimensionless unit hydrograph procedure (SCS, 1972). The dimensionless hydrograph (Figure 21) provided by SCS is used to determine the time-depended distribution of runoff from a watershed. The time-to-peak (t_p) and peak discharge rate (q_p) determined for each watershed are needed to create the dimensional hydrograph input of the CMS model.

The peak discharge rate (q_p) is calculated using the relationship

$$q_p = \frac{484AQ}{\frac{D}{2} + T_{lag}}$$

where A is the watershed area, Q is the total rainfall for the event (7.38 inches, from NRCC), D is the unit duration and T_{lag} is the lag time. The unit duration D is in turn determined as

$$D = 0.133T_c$$

where T_c is the time of concentration defined as

$$T_c = T_{lag}/0.6$$

and T_{lag} calculated using

$$T_{lag} = \frac{L^{0.8}(S+1)^{0.7}}{1900(\%Slope)^{0.5}}$$

where L is the length of the longest drainage path in the watershed, S is the potential maximum retention after runoff begins and %Slope is the average watershed slope. The value of L used for both upland watersheds is 0.6 miles. S is calculated as

$$S = \left(\frac{1000}{CN}\right) - 10$$

where CN is the curve number for the watershed. For both upland watersheds, a value of 90 was used for CN, which is appropriate for developed residential areas with poor draining soils. The time-to-peak (t_p) needed to fix the time base of the unit hydrograph is determined using the equation

$$t_p = \frac{D}{2} + T_{lag}$$

with D and T_{lag} as described above. The final determined values of t_p and q_p for watersheds 2 and 4 are presented in Table 6.

Table 5. Ballard Street Marsh watershed areas as reported in NCRS (1999). Watersheds are shown in Figure 21.

Watershed ID	Area (acres)
Watershed 2	88
Watershed 4	56
Watershed 6	37
Watershed 8	36

Table 6. Time-to-peak (T_p) and peak discharge (Q_p) values determined from the SCS unit hydrograph procedure, for the two Ballard Street Marsh upland watersheds for the 50-year rainfall event.		
watershed	T_p, hours	Q_p, cfs
Watershed 2	1.3	370
Watershed 4	1.3	235

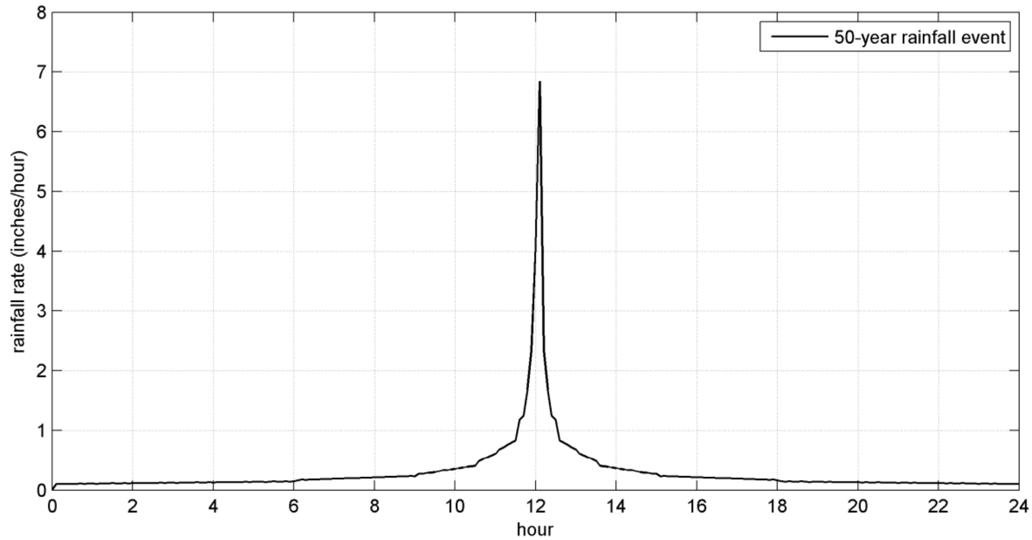

Figure 19. Rainfall intensity distribution from NRCC for the 50-year event at Ballard Street Marsh.

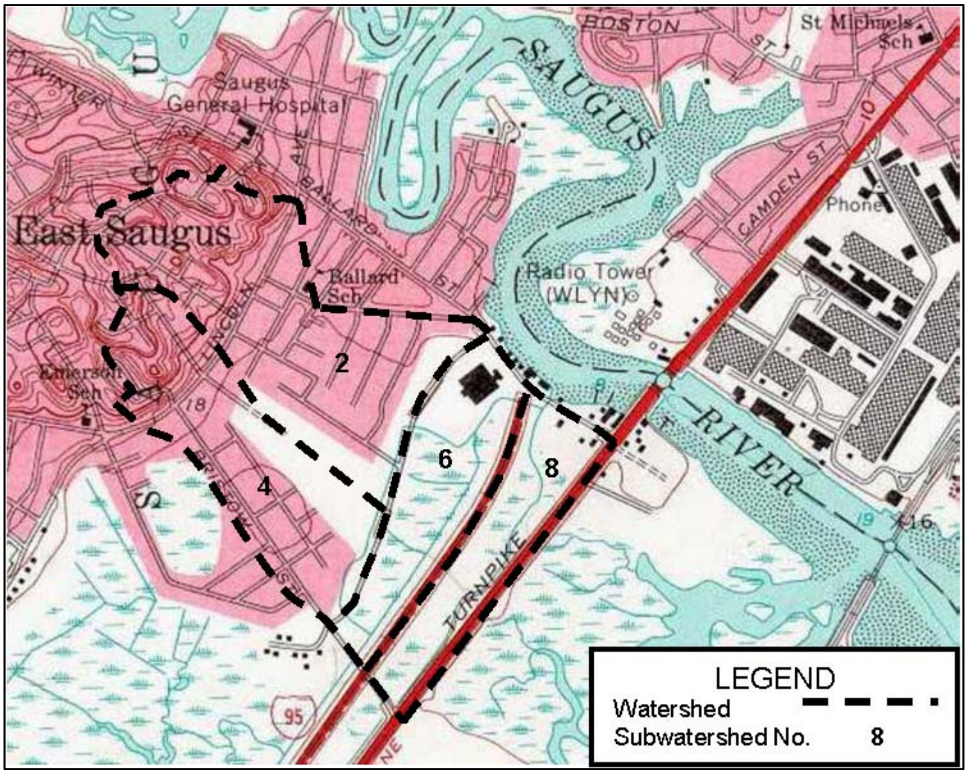

Figure 20. Watershed delineation from the 1999 NRCS Ballard Street Marsh analysis.

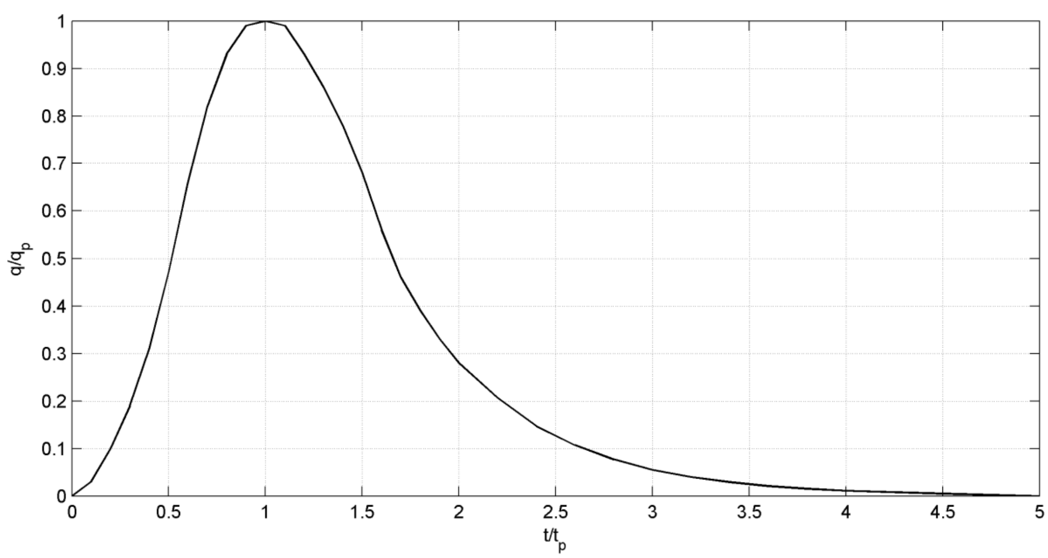

Figure 21. Soil Conservation Service (SCS) dimensionless unit hydrograph used to develop the runoff hydrographs of upland watersheds 2 and 4 (delineated in Figure 22).

The total rain volume applied to the Ballard Street Marsh model in the simulation of the 50-year event is the combination of the hydrographs determined for watersheds 2 and 4, along with the rainfall intensity time series of Figure 21 applied to the area of watersheds 6 and 8 separately. The total combined rain input to the model from all four watersheds is presented in

Figure 22. The first small peak in this plot the direct rainfall on the marsh plain, while the second larger peak (delayed 1.3 hours from the peak rainfall intensity) results from the runoff from the two upland watersheds. The time base of the discharge shown in Figure 21 is shifted in order that the peak discharge coincides with the peak spring high tide elevation in the Saugus River for the model runs of the 50-year rainfall event.

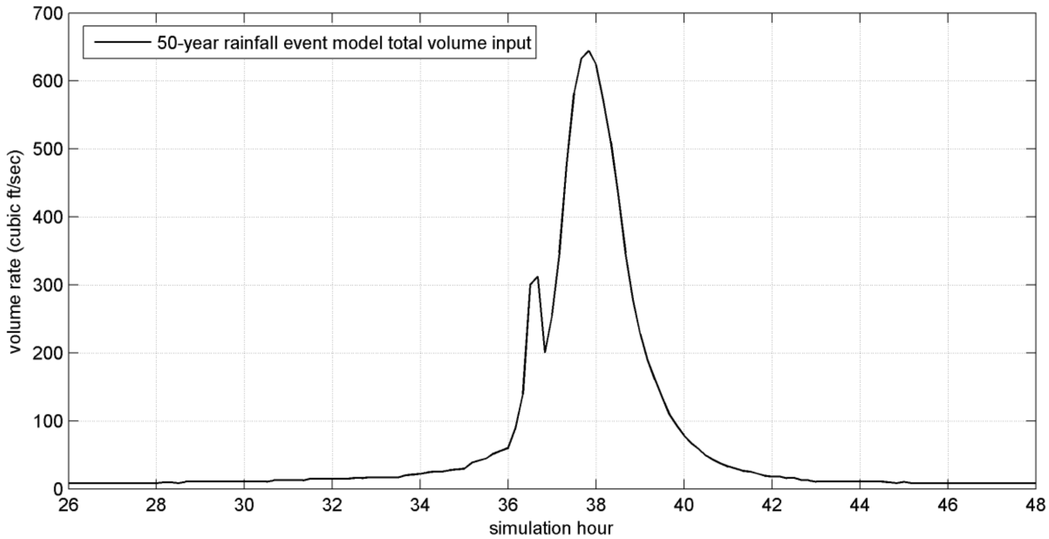

Figure 22. Resulting total water volume input rate applied to the Ballard Street Marsh hydrodynamic model for the modeled 50-year rainfall event. The curve is a combination of direct rainfall on the marsh plain and runoff from the two upland watersheds designated by the NRCS.

7.2 Model Results

A comparison of results from the present and preferred conditions model runs of the 50-year rainfall event are presented in Figure 23. It is seen from this plot that the preferred option offers a slight improvement (i.e., reduction) in the maximum water level, and also a shorter period of time when the waters are elevated. For existing conditions, the maximum water level in the western marsh is 7.5 feet NAVD, and water levels are above 5.0 feet for 11.1 hours. For the preferred option, the maximum water level is 6.7 feet NAVD, while the duration of flooding above 5.0 feet is 6.1 hours.

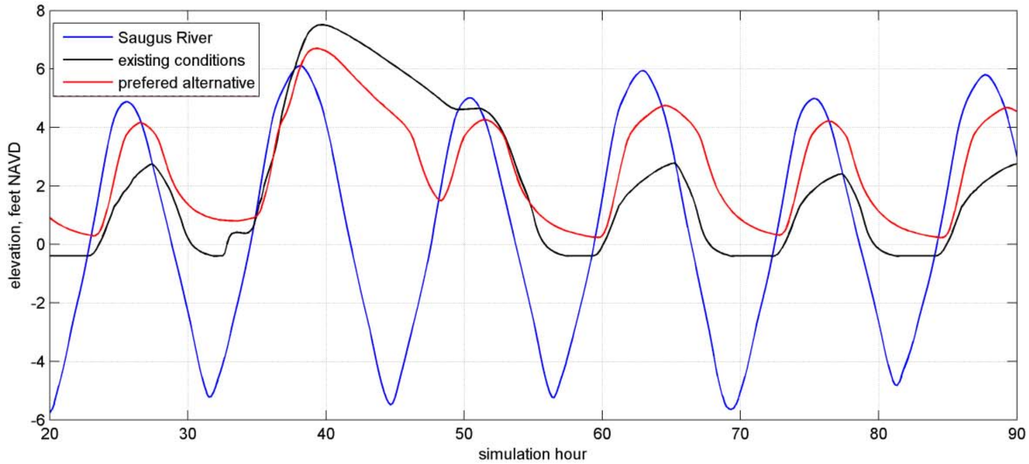

Figure 23. Comparison of modeled tides in the western marsh for existing conditions and the preferred alternative (Alternative 4) during the simulation of the 50-year rainfall event.

7.3 50-Year Rainfall Event Coincident with Low Tide

The 50-year rain event was also run so that the time of maximum discharge from the upland watersheds coincided with the time of low tide. Both the existing conditions and preferred alternative models were run with this scenario. The time of maximum discharge was shifted 6.5 hours in order to investigate how the timing of the tide could influence maximum water levels in the western marsh during an event of this magnitude. The results of this scenario and the previous scenario with maximum discharge occurring at spring high tide provide the range of maximum water levels that would occur during the 50-year rain event, for all tide conditions that occur at the marsh.

As shown in Figure 24, maximum water levels reach 6.8 feet NAVD in the simulation of existing conditions, and 6.0 feet for the preferred alternative. The duration of flooding above 5.0 feet NAVD is 9.7 hours in the existing conditions model, and 4.3 hours for the preferred alternative. These results show that when the maximum watershed discharge coincides with low tide both the maximum water level in the marsh and the duration of flooding are reduced compared to the same event timed to coincide with spring high tide.

Therefore, the range of maximum water level in the marsh for the 50-year event is between 6.8 and 7.5 feet NAVD for existing conditions, for all tide conditions. For the preferred alternative, the maximum water level range for the same event is between 6.0 and 6.7 feet NAVD, depending on the timing of the tide (i.e., phase of the daily tide and phase of the bi-monthly spring-to-neap cycle). Maximum water levels in the western marsh for these four scenarios are also presented in Table 7.

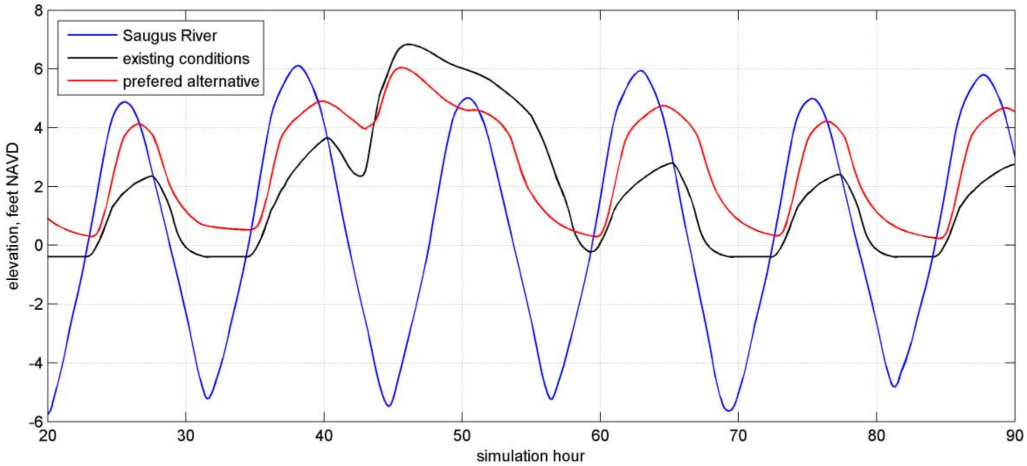

Figure 24. Comparison of modeled tides in the western marsh for existing conditions and the preferred alternative (Alternative 4) during the simulation of the 50-year rainfall event, with maximum discharge from upland watershed timed to coincide with low tide.

Table 7. Maximum water elevations in the western marsh, during the 50-year rainfall event, for existing conditions and the preferred alternative, with maximum upland runoff discharge coinciding with astronomical spring high tide and low tide in the marsh.	
Scenario	Max water elevation (feet, NAVD)
Existing Conditions, spring high tide	7.5
Existing Conditions, low tide	6.8
Prefered Alternative, spring high tide	6.7
Preferred Alternative, low tide	6.0

8. REFERENCES

Friedrichs, C.T. and J.E. Perry (2001). Tidal salt marsh morphodynamics: A synthesis". Journal of Coastal Research, special issue 27. West Palm Beach, FL. pp 7-37.

Hershfield, D.M. (1961). Rainfall Frequency Atlas of the United States. Technical Paper No. 40, prepared for Engineering Division, Soil Conservation Service, US Department of Agriculture, Washington, DC.

Li, H., A. Sanchez, W. Wu and C. Reed (2013). Implementation of Structures in the CMS: Part III, Culverts. Technical Note ERDC/CHL CHETN-IV-95. USACE Engineering Research and Development Center, Vicksburg, MS.

Otte and Dwyer (2012). Existing Conditions Plan of Land Transect Lines and Crossings, Ballard Street, Route 107 and Eastern Avenue, Saugus, Mass. 01906. Survey plan dated April 2011.

Parsons Brinckerhoff (2014). CAD survey plan of Saugus Marsh.

Sanchez, A., L. Lihwa, Z. Demirbilek, T. Beck, M. Brown, H. Li, J. Rosati, W. Wu, C. Reed, (2012). Coastal Modeling System, Draft User Manual. Coastal and Hydraulics Laboratory, USACE Engineer Research and Development Center 3909 Halls Ferry Road, Vicksburg, MS, pp. 315.

Woods Hole Group, Inc. (2013). Ballard Street Restoration Project Saugus, Massachusetts. Technical Report. Prepared for Commonwealth of Massachusetts Division of Ecological Restoration. *Technical Report*, Prepared for the Commonwealth of Massachusetts Division of Ecological Restoration, Boston, MA.

USDA Natural Resources Conservation Service (1999). Hydrologic And Hydraulic Analysis Wetlands Restoration Investigation Ballard Street Salt Marsh Saugus, Massachusetts. *Technical Report*, Prepared for the Town of Saugus, MA.

USDA Soil Conservation Service (1972). SCS National Engineering Handbook. Section 4, Hydrology. Washington, DC.

Appendix 3 Sample Operation and Maintenance Plan

STRAITS POND
TIDE GATE OPERATION AND MAINTENANCE PLAN

TOWN OF HULL, MASSACHUSETTS
DEPARTMENT OF PUBLIC WORKS

WEST CORNER CULVERT
ROUTE 228 OVER STRAITS CHANNEL
HULL, COHASSET, AND HINGHAM, MASSACHUSETTS

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December 5, 2007

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ATTACHMENTS

INTRODUCTION

This Tide Gate Operation and Maintenance (O&M) Plan, prepared for the West Corner Culvert Replacement/Straits Pond Habitat Restoration Project, addresses the procedures, protocols and evaluation methods that will be applied to the inspection, operation and override of the tide gates that control tidal exchange and the water level within Straits Pond. This O&M Plan should be periodically reviewed and modified to reflect operational and environmental changes related to the project. This manual was prepared by The Louis Berger Group, Inc. as a provision of the 401 Water Quality Certification, MA CZM Federal Consistency Concurrence, and the US Army Corps of Engineers permit and approval for the Massachusetts Highway Department reconstruction of the West Corner Culvert Replacement Bridge No. C-17-004 Route 228 Over Straits Channel Hull-Cohasset-Hingham and will serve as an enforceable mechanism for the operation of the associated tide gates. The Town of Hull Department of Public Works (DPW) is the responsible party overseeing construction and future operation of the West Corner tide gates. By adhering to the procedures set forth in this plan, involved parties can ensure the application of a consistent approach to tide gate operation and maintenance.

BACKGROUND

The Bridge Replacement of Route 228 (Nantasket Avenue) over Straits Channel is located in the Towns of Hull, Cohasset, and Hingham. See Locus Map. The West Corner Bridge is at the junction of these three Towns. Straits Channel connects to Straits Pond, which is a shallow coastal pond over 90 acres in size, located in the southeasterly area of Hull and northwestern area of Cohasset. Straits Pond forms the boundary between Hull and Cohasset. The Bridge is approximately 250 feet north of the Route 228/Rockland Street/Jerusalem Road intersection.

The existing West Corner Bridge (Route 228) consists of a 12-foot span, 8-1/2 foot rise culvert with stone masonry walls. The upstream or east side of the structure includes twin manually operated slide gates (one of which is 4x4 feet and the other is 5x5 feet). The combined structure provides flood protection to low-lying properties along Straits Pond. However, the current structure is too small to provide effective tidal exchange within the Pond, which has resulted in water quality impairments, major infestations of midges, explosive growth of widgeon grass, periodic algae blooms, and the spread of invasive plants.

Under current conditions, the opening of the gates can raise or lower the pond about 1 foot during a tide cycle.[1] Until relatively recently Straits Pond was typically maintained at a level of 3.3 feet, NGVD 1929 with only occasional operation of the gates in an attempt to allow some exchange or increased flood storage prior to storm events. More recently, tide gate operators have been responsible for regulating flushing and water levels in Straits Pond by manually opening and

[1] Army Corps of Engineers, 2004. Straits Pond Tidal Flushing Study- Hull, Cohasset and Hingham, Massachusetts. New England District, Concord, MA. 32 pp.

closing the tide gates using a protocol developed by ENSR,[2] although management has deviated from this protocol due to various management goals.[3]

[2] ENSR Inc., 2002. Weir River Estuary Flow Study: Hull, Hingham, and Cohasset Massachusetts. Prepared for Massachusetts Department of Environmental Management. Document No. 04481-009.

[3] Army Corps of Engineers, 2004. Straits Pond Tidal Flushing Study- Hull, Cohasset and Hingham, Massachusetts. New England District, Concord, MA. 32 pp.

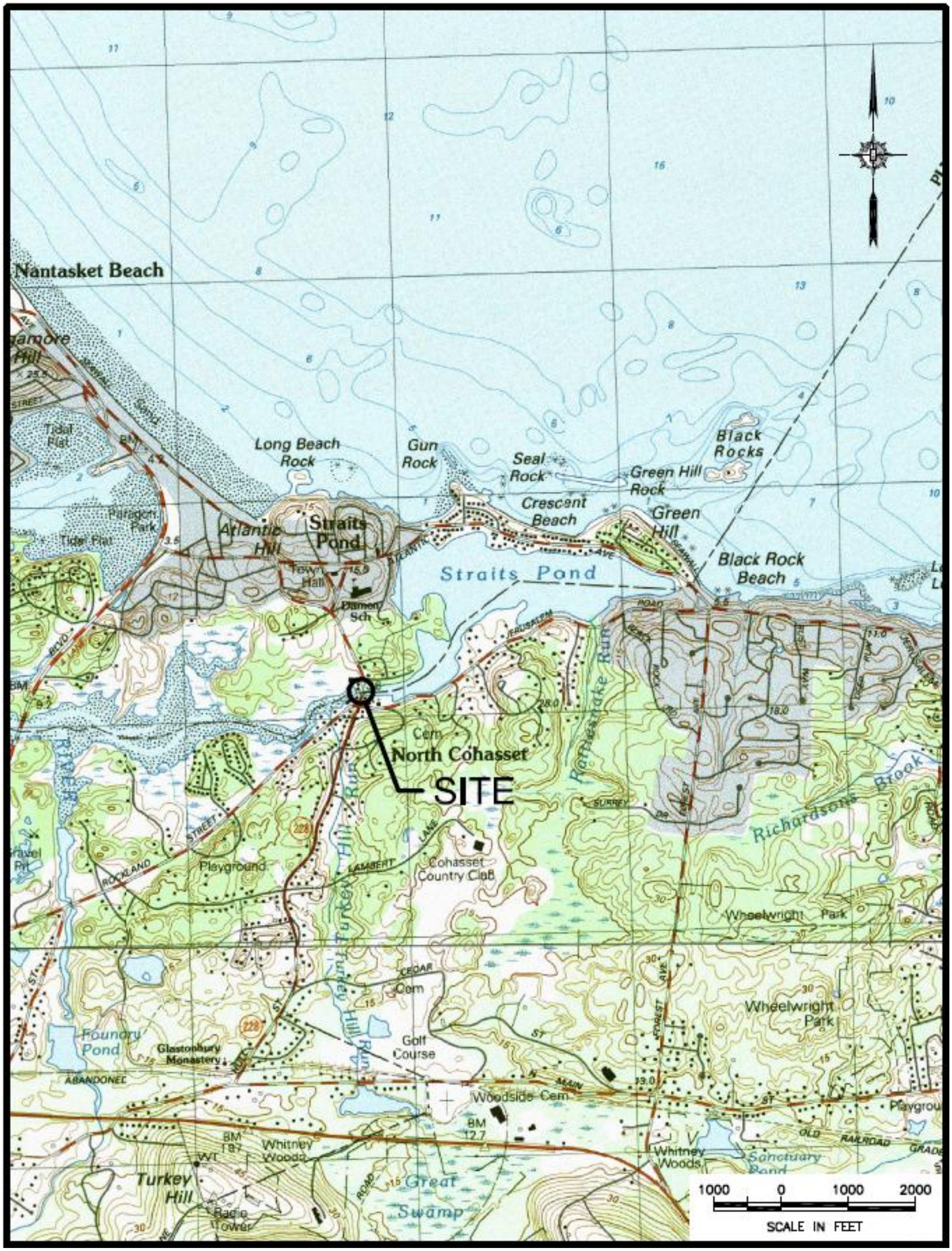

Figure 1: USGS Locus Map.

Twin 7-foot wide by 5-foot rise box culverts outfitted with automatically actuated sluice gates are proposed to replace the failing infrastructure and increase tidal circulation within Straits Pond. The Hull DPW will be the Responsible Party for undertaking water level management and routine actions, inspection, maintenance, repairs, and corrective actions as prescribed by the Straits Pond Advisory Committee.

PURPOSE AND INTENT

In addition to replacing the failing infrastructure, the current project seeks to restore degraded coastal wetland habitat upgradient of the West Corner Bridge by increasing tidal exchange and improving water quality and habitat value within Straits Pond, and improving ecological connectivity to the Weir River Estuary while controlling the risk of preventable flooding from the Weir River and overwash along Atlantic Avenue. The attached Inspection and Preventative Maintenance Checklist (Attachment A) provides a standardized method of keeping records for regular inspections. The attached Tide Gate Adjustment Log (Attachment B), in addition to the automated water level data logging equipment installed at the culvert, insures adequate record keeping of water level management. Record keeping will create the ability to make informed management decisions regarding future modifications to the gate management protocol. Further protocols may need to be developed between these parties. This document will provide basic guidelines to assist Department of Public Works officials to:

- Manage Straits Pond with oversight by the Straits Pond Advisory Committee.
- Perform and document the inspections and other relevant information regarding the status of surrounding resources (Attachment A).
- Document adjustments made to tide gate operations and manual override actions (Attachment B).
- To insure that emergency contact information is available.

The culvert at West Corner is a tidal restriction site listed in the Atlas of Tidal Restrictions on the South Shore of Massachusetts (MAPC/MA Wetlands Restoration Program, 2001) as a high priority site for restoration based on the size of affected area (>50 Acres), the presence of an anadromous fishway, it's status as an Area of Critical Environmental Concern (ACEC), and for potential upstream benefits.

In 2002, an investigation into management alternatives to control nuisance infestations of Chronomid midges and excessive primary production was conducted by Environmental Science Services, Inc. (ESS)[4]. This study evaluated chemical, in-pond, and watershed management alternatives. One watershed management alternative identified in the report was flow improvements through such means as modifications to the tide gates at the Route 228 Bridge. This study articulated benefits of increased tidal exchange between the estuary and pond as "such improvements are expected to improve benthic and fisheries habitat and passage by increasing tidal exchange, flushing nutrients, increasing DO and salinity, and reducing water temperatures".

[4] ESS 2002. Midge Management Recommendations for Straits Pond, Towns of Hull and Cohasset, Massachusetts. Prepared for Town of Hull 253 Atlantic Avenue Hull, Massachusetts 02045 Project No.: H114-000

In an effort to inform management and environmental issues the Straits Pond Watershed Association, in cooperation with local, state, and federal partners developed and presented a comprehensive public informational forum series that was recorded and presented on local cable access for those not able to make the forums in person (powerpoint presentations also available on the Hull Conservation Commission web page at http://www.town.hull.ma.us/Public_Documents/HullMA_conservation/spforum). At the conclusion of the informational forum series a facilitated public meeting was held during which the most salient environmental issues and management options were identified and prioritized. Increased tidal exchange through an expanded and enlarged culvert was universally identified as the top priority.

The goals for the management of Straits Pond through monitoring and adjustments to the proposed tide gates include:

- Increase in tidal prism
- No increase in flooding-related property damage
- Increase and stabilization of pond salinity levels
- Increase in pore water salinity levels
- Decrease in pond temperature
- Increase and stabilization of pond dissolved oxygen levels, and
- Increase in estuarine nekton species assemblage
- Increase in frequency of tidal exchange

PRE-REPLACEMENT CONDITION

Straits Pond is a large coastal pond that is located in the southeast side of Hull and northwest side of Cohasset. The pond reportedly supported tidal marshes prior to being dammed in order to provide hydropower for a mill near the existing bridge. The grist mill remained until it was destroyed by fire in 1800. In as early as 1900, the state Board of Health investigated complaints of nuisance plant growth and nuisance odors.

The existing West Corner Bridge (Route 228) consists of a 12-foot span, 8-1/2 foot rise culvert with stone masonry walls, and a reinforced concrete slab roof. This structure was last reconstructed in approximately 1908.

Tide gates were added during the 1940s in response to recommendations to improve water quality within Straits Pond. The current tide gates are manually operated slide gates (one of which is 4x4 feet and the other is 5x5 feet). During the 1950's, funds were appropriated for the construction of sewers within Hull and various chemical treatments began in an attempt to control both nuisance vegetation and midges (a nonbiting insect which hatch in prolific numbers creating a major nuisance for abutters to the Pond). Some species of midges are direct indicators of poor water quality and excess nutrients. During peak emergence, residential areas are inundated with midges, leading to inhalation and respiratory problems that result in quality-of-life issues for Pond abutters. The Town of Hull has applied insecticides under an Emergency Declaration issued by the Board of Health since the 1950's. However, the chemical control of midges generally has limited and short-term success and was discontinued in 2004.

A 1980 study cited continued eutrophication problems due to failing septic systems, direct discharge of sewage and storm water runoff. In subsequent years, additional sewer and stormwater management improvements have been implemented in Hull and Cohasset to reduce pollutant levels entering Straits Pond. Midge larvae numbers have been regularly monitored by professionally guided local volunteers and high school students. In the past, the Pond was typically managed to maintain a constant water level and the tide gates were manually operated to lower water levels in response to a predicted storm event to increase available water storage capacity. More recently, a protocol for more regular tidal flushing has been implemented to increase salinity levels and numbers of predatory fishes during spring months as a more effective midge control measure. A study of midges in Straits Pond revealed that midges taken from the Pond ceased to pupate and often died at salinities greater than 18-22 ppt. Additional studies of Straits Pond have shown that fish such as mummichogs and striped killifish fed extensively on midges, although ceased to feed or died at high water temperatures and low oxygen conditions.

The lack of effective tidal exchange within the Pond continues to cause water quality impairments, major infestations of midges, explosive growth of widgeon grass, periodic algae blooms and infestations of midges, and the spread of invasive plants. Figure 1 graphically represents tide data collected in May, 2003 and demonstrates the limited water level fluctuation within Straits Pond with both existing gates in an open position. Under moderate tides, the Pond can only experience water level fluctuations of approximately 1 foot between high and low tides.

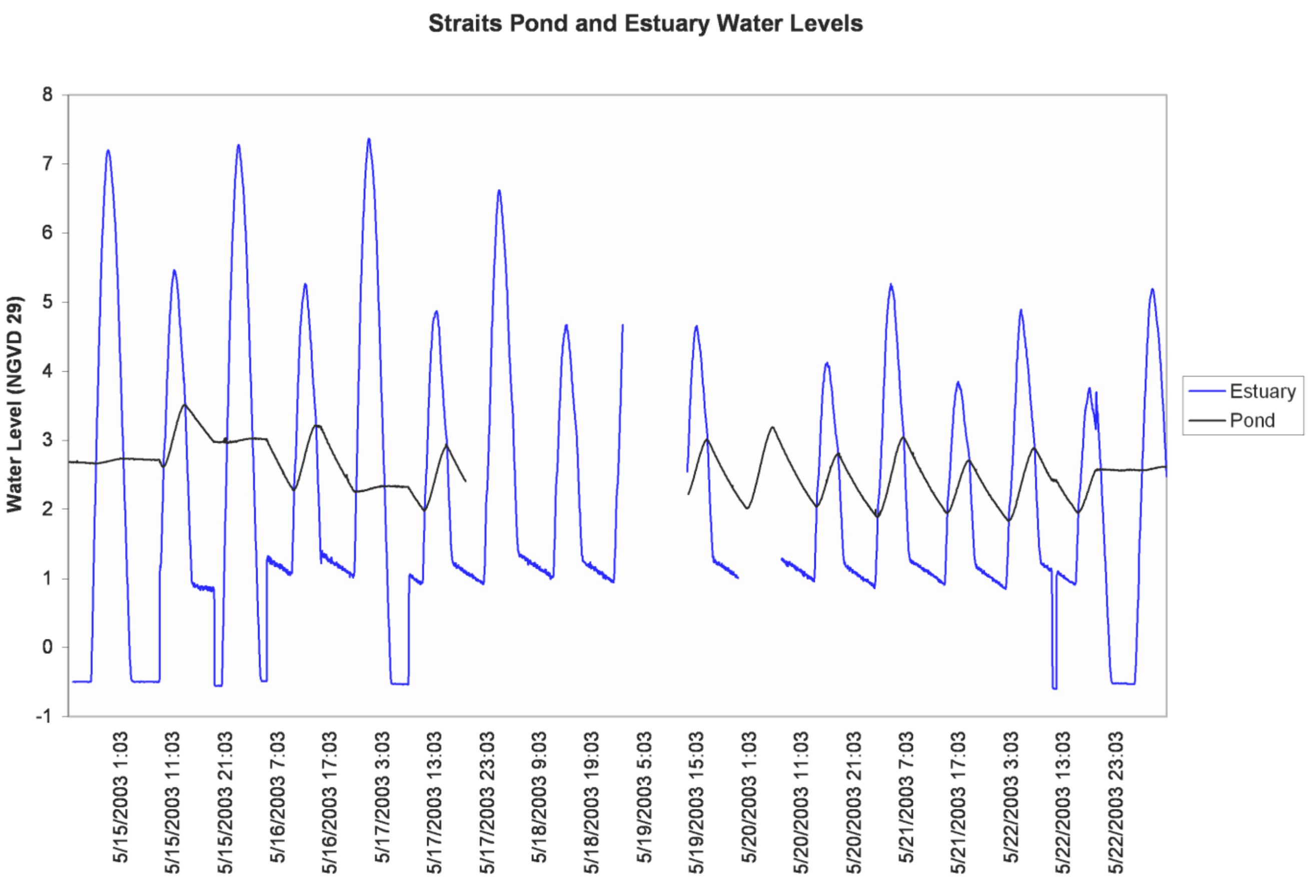

Figure 2: March 2003 Tide Data for Straits Pond and Weir River Estuary.

Stands of the invasive common reed or *Phragmites* reduce habitat value and are a considerable fire hazard. Low-lying properties surrounding the pond are susceptible to flooding impacts as flow becomes impounded above the road crossing. All of these symptoms present significant quality-of-life issues for residents surrounding the pond.

Historically, Straits Pond was maintained at a constant level of 3.3 feet, NGVD 29. More recently, a resident has been responsible for regulating flushing and water levels in Straits Pond by manually opening and closing the tide gates using a protocol developed by ENSR[5] in an attempt to increase tidal flushing and salinities and reduce residential time within the pond. These operations are the subject of an Existing Order of Conditions with the Hull and Cohasset Conservation Commissions. However, for several seasons the tide gates have not been operated per the ENSR protocol. Most recently the tide gates have been operated under an OOC that was based on the investigation of several management scenarios evaluated using automated level data loggers and in-situ salinity measurements that provided improvements over the ENSR protocol. This spring the revised operational scenario was altered as the existing ENSR tidal exchange protocol was insufficient to maintain high salinity values in the Pond during wet weather and high spring flow/groundwater conditions. Under the interim protocol the tide gates are operated in the open position as often as possible while attempting to maintain pond height in a range between approximately 2.4 and 3.4 feet NGVD 29. The gates have been open for approximately 1 week of the month during the highest high tides. During the two weeks of the month with roughly average tides, the gates have been closed for approximately 6 hours per day during one low tide cycle. During neap tides it is periodically necessary to close the gates for portions of both daily low tide cycles in order to achieve pond elevations above 3.0. Manual operations of the gates also occur in response to predicted major precipitation or coastal storm events in an effort to lower water levels and provide additional flood water storage capacity.

REPLACEMENT CONDITION

The project originated as a municipal project led by the Town of Hull with additional financial support from the Towns of Cohasset and Hingham, as well as the NOAA National Marine Fisheries Service and the Conservation Law Foundation in support of habitat restoration goals. The project recently received federal funding for construction through the Federal Highways Administration and as a result will be advertised as a MassHighway project. In addition, the project has received additional funding from the Massachusetts Transportation Improvement Program (TIP). The replacement design of twin 7-foot wide by 5-foot rise box culverts outfitted with automatically actuated sluice gates is based upon recommendations from a US Army Corps of Engineers study (include citation). This study conducted under the Flood Plain Management Services Program, determined that larger hydraulic openings than the recommended twin 7 X 5 foot culverts provided only minor additional flow to the Pond. The predicted range in pond surface elevation (during a relatively low high tide event of 5.2 feet, NGVD 1929), is anticipated to increase from 1.2 feet to 2.6 feet, with the new culvert/tide gate structure. While the predicted minimum pond surface elevation is controlled by an outcrop of bedrock, higher maximum pond surface elevations would be anticipated during higher tide events without resulting in flooding impacts to properties abutting the Pond which through pre-construction topographic surveys has been determined to be approximately 3.8 feet (NGVD 29). The automatic tide gates will also be outfitted with manual overrides for corrective actions and emergencies, including power failures.

[5] ENSR Inc., 2002. Weir River Estuary Flow Study: Hull, Hingham, and Cohasset Massachusetts. Prepared for Massachusetts Department of Environmental Management. Document No. 04481-009.

Studies of water quality conducted by the Office of Coastal Zone Management have found that with the existing tide gates left in an open position, salinity levels significantly increase throughout the Pond both spatially and at depth and water released on an outgoing tide is not the same water that returns on a subsequent incoming tide. It is anticipated that the predicted increase in tidal exchange with the new culverts will result in further water quality and habitat enhancements, will reduce habitat fragmentation, and increase ecological integrity.

The Town of Hull DPW will maintain signage on both sides of the culvert warning boaters and kayakers to stay out of area adjacent to the culvert.

STRAITS POND ADVISORY COMMITTEE

The Hull Department of Public Works is the Responsible Party for undertaking initial water level monitoring and water quality monitoring, adjusting gate operations, conducting necessary inspections, maintenance and repairs, and undertaking corrective actions as prescribed by the Straits Pond Advisory Committee. Restoration monitoring of water quality, vegetation, nekton, sediment, and benthic invertebrates is ongoing and being performed by the Straits Pond Watershed Association (SPWA) and the Cohasset Center for Student Coastal Research (CSCR) with technical and financial support from the CZM Wetland Restoration Program, the MassBays Program, and the Gulf of Maine Council on the Environment. The Straits Pond Advisory Committee is responsible for developing a management approach with regard to initial calibration, review of environmental conditions and prescribing modifications when necessary. Members of the Advisory Committee are identified below:

Director, Hull DPW
Attn: Marc Fournier
9 Nantasket Avenue
Hull, MA 02045
P: 781-925-0900
781-910-3973 (Emergency)
F: 781-925-0401
E: mfournier@town.hull.ma.us

CZM South Shore Regional Coordinator or
CZM Wetland Restoration Program
Attn: Jason Burtner
C/O: Stellwagen Bank National Marine Sanctuary
175 Edward Foster Road
Scituate, MA 02066
P: 781-545-8026 x209
F: 781-545-8036
E: jason.burtner@state.ma.us

MA DEP Restoration Coordinator
Attn: James Sprague
1 Winter Street
Boston, MA
P: 617-645-6601
E: James.Sprague@state.ma.us

MassBays Estuaries Program
Attn: Christian Krahforst
251 Causeway Street
Boston, MA 02041
P: 617-626-1216
F: 617-626-1240
E: Christian.Krahforst@state.ma.us

Areas of Critical Environmental Concern (ACEC) Program
Coastal Coordinator
Attn: Lisa G. Berry Engler
251 Causeway Street, Suite 700
Boston, MA 02114
T: (617) 626-1435
F: (617) 626-1349
Lisa.Engler@state.ma.us

Hingham Conservation Agent
Attn: Cliff Prentiss
210 Central Street
Hingham, MA 02043
P: 781-741-1445
E: **Error! Hyperlink reference not valid.**

Conservation Administrator
Hull Conservation Commission
Attn: Anne Herbst
253 Atlantic Avenue
Hull, MA 02045
P: 781-925-8102
F: 781-925-8509
E: conservationemail@town.hull.ma.us

Gulf of Maine Habitat Restoration Coordinator
Attn: Eric W. Hutchins
NOAA Restoration Center
1 Blackburn Drive, Gloucester, MA 01930
P: 978-281-9313
F: 978-281-9301
E: Eric.Hutchins@noaa.gov

Straits Pond Watershed Association
Attn: Lawry Reid
31 Richards Road
Hull, Ma 02045
P: 781-925-8659
E: viaspeech@comcast.net

Conservation Agent
Cohasset Conservation Commission
Attn: Paul Shea
41 Highland Avenue
Cohasset, MA 02025
P: 781-383-4119 or
508-240-6811
E: PaulShea@cape.com

Superintendent
Cohasset DPW
Attn: Carl Sestito
91 Cedar St.
Cohasset, MA 02025
P: 781 383 0273
F: 781 383 4125
E: cohassetdpw@yahoo.com

The initial testing and configuration of the automatic tide gate actuators will be scheduled with the contractor well in advance of installation. Configuration will require careful testing in order to achieve the targeted water elevation and water elevation change within Straits Pond. The Straits Pond Advisory Committee will provide oversight for initial testing and operation. It is anticipated that water quality habitat degradation, and ecological integrity problems will be improved with the increased tidal flushing allowed by the larger tide gates. An increase in tidal exchange will also provide fisheries benefits through increased opportunity for fish passage between the estuary and the pond, will reduce habitat fragmentation resulting from existing tide gate design/operation, and that the improved ecological “connectivity” between the pond and the estuary will enhance the pond’s ability to respond to environmental stressors such as nutrient loading and eutrophication. An increase in the degree and frequency of tidal exchange will serve to increase and stabilize salinity, lower and stabilize water temperature, and that with a reduction in eutrophic conditions water column dissolved oxygen is anticipated to improve and sediment oxygen demand is anticipated to be reduced thereby improving overall habitat value. However, the need for adaptive management remains a priority. Adverse environmental conditions are to be managed with advanced coordination and oversight by the Straits Pond Advisory Committee.

INITIAL TIDE GATE CALIBRATION AND OPERATION PROTOCOL

Maximum Water Level

Once the existing structure and tide gates are replaced, maximum water surface elevations would be controlled by the new automatically actuated sluice gates which would automatically close when the Pond reaches a predetermined water surface elevation and automatically open when elevations within the Estuary would fall below this elevation. The first action of the Hull DPW with input from the Straits Pond Advisory Committee will be the initial adjustments of the level switches to determine the appropriate Pond and Estuary water levels which will actuate the gates to prevent flooding from high water levels. The elevation of the pond water level will be automatically recorded by a GlobalWater WL16 unit that is mounted in the vicinity of the tide gates and will be configured to record water level at regular intervals so as to be comparable with the NOAA Boston recording facility. These adjustments will require careful monitoring of water levels to establish a maximum water level acceptable to local officials and Straits Pond abutters without causing avoidable adverse consequences to low-lying structures surrounding the Pond. The maximum water elevation is anticipated to be approximately 3.8 feet (NGVD 1926) or approximately 0.5 feet higher than typical high water conditions. During the initial configuration stage, tide gauges and salinity probes will be deployed within the Pond and Estuary to document water levels and salinity levels, water follow direction and velocity, water temperature, and dissolved oxygen in response to adjustments of the level switches. The automated actuators will initially be set to close the tide gates at a pond water level of approximately +3.5 feet (NGVD), or at the currently observed/recorded average high water level. Following the preliminary data collection phase for the initial setting, of approximately one month, the Straits Pond Advisory Committee will meet to review the available data and any reported concerns regarding pond water levels. The outcome of this meeting will be to establish the water level settings for the switches which will activate the gates under routine conditions. Based on the maximum water levels resulting from the initial actuator setting water level and closure settings will be incrementally adjusted to maximize pond water levels without flooding and with consideration of a reasonable safety factor. The intent is to incrementally adjust actuator settings once during each spring to facilitate better environmental response data collection.

Minimum Water Level

Establishing the maximum water level is only one tide gate O&M variable for restoration, relieving eutrophic conditions, addressing the midge infestations, etc and all of the associated quality-of-life issues that go along with the impairment of the Pond. Consideration of the minimum water level (i.e. tidal prism) and frequency of exchange are also critical considerations as they, collectively, will be what determine the degree and success of restoration and improvement of conditions for abutters. It is anticipated that the minimum water level in the pond will be a self-controlling function of culvert/tide gate design and pond channel/ledge bathymetry. The predicted range in pond surface elevation (during a relatively low high tide event of 5.2 feet, NGVD 1929), is anticipated to increase from 1.2 feet to 2.6 feet, with the new culvert/tide gate structure. This increase in the tide range is a result of expanded cross-sectional area of the culvert/tide gates and the associated hydrology of the system. The minimum potential water level in the pond is controlled by a ledge outcropping upgradient (pond-side) of the tide gates and the corresponding low water pond water elevation is approximately +1.0 feet (NGVD). At this minimum water level there is approximately 75% surface water coverage on the pond. This minimum level surface water coverage has been determined by detailed bathometric survey and photographic documentation when the Pond water level was in a drawn down condition. As +1.0 feet is a fixed minimum water level, and the average low water elevation during tidal exchange will primarily be higher than this level, it is anticipated that the large degree of surface water coverage during the transitional/short term low tide in the Pond will be sufficient to address abutter concerns regarding prolonged exposure of extensive inter-tidal flats as discussed during project public informational meetings. This lower water elevation is viewed as a longer-term goal of the restoration and the Advisory Committee. The initial actuator low water setting will seek to maintain a minimum water surface elevation of 2.0 feet (NGVD 29) with annual incremental adjustments of approximately 0.2 feet annually over a 5-6 year period. These adjustments will be determined by the Advisory Committee taking into consideration abutter concerns and adaptive management strategies that will be informed by ongoing restoration monitoring and in coordination with the appropriate permitting agencies. The Advisory Committee will need to consider the balance between maximized exchange and abutter concern with low water levels in the pond.

Protocol for drawing down the level of the pond to provide additional flood storage in anticipation of a significant storm event is discussed below.

Tidal Exchange Frequency
In order to maximize potential benefit for water quality, habitat, ecological integrity and quality-of-life considerations for residential abutters, tidal exchange between the estuary and the pond will be allowed to proceed unimpeded (except as discussed above and below) on a normal twice-daily regime in order to more closely mimic native hydrology and ecology of the tidal system.

The automatic tide gates will also be outfitted with manual overrides for corrective actions and emergencies, including power failures. This initial monitoring phase will also be useful to establish the time frames necessary to respond to a predicted major precipitation of a coastal storm flooding event where lowering pond levels is desirable for increased flood storage. In certain circumstances, more than a single ebb tide cycle may be necessary to lower the pond to elevation 1.0 feet (NGVD 1929). This is the maximum lowering possible due to bedrock outcrops within Straits Channel just upstream of West Corner Bridge. During this initial monitoring phase, the Straits Pond Advisory Committee will establish the minimum respond times (tides cycles) required for the manual operation of the gates for increased flood water capacity.

ROUTINE FIELD INSPECTIONS

Following the installation of the new culverts, routine annual field inspections will be conducted by the Hull Department of Public Works using the Inspection and Preventative Maintenance Checklist (Attachment A) and kept on record by the DPW. The routine inspections will evaluate performance, address maintenance needs and identify problems. Substantial corrective actions requiring the removal or placement of material via machinery will be reviewed and approved by the Advisory Committee. The Department of PublicWorks will be the primary contact to report observed problems with the functioning of the structure.

TIDE GATE ADJUSTMENTS AND MANUAL OVERRIDE EVENTS

All adjustments to the level switches which operate the tide gates will be coordinated with the Straits Pond Advisory Committee. The attached Tide Gate Adjustment Log (Attachment B) and the automated water level data loggers will insure adequate record keeping of water level management including all manual overrides of the gates. Record keeping will create the ability to make informed management decisions. Based on circumstances which may occur following installation, further protocols may become necessary. It is anticipated that the Advisory Committee will meet on an annual basis to review records and reports from the previous year and determine whether any adjustments to tide gate operations are warranted. Any modifications to operating procedures will be developed in cooperation with the Advisory Committee and clearly documented. Records of tide gate adjustments and operations will be distributed to municipal officials and resource agencies as directed by permit conditions.

ON-GOING TIDE GATE OPERATIONS

By December 15th of each year, the Straits Pond Advisory Committee will prepare a summary report. The report will document and justify any modifications or adjustments made to gate operations with supporting monitoring data. It is anticipated that this information will include data on water levels, salinity, temperature, and DO.,. The report will discuss observed trends in the data and the extent to which to project is achieving management goals. To the extent that additional date is collected, it will be provided in the annual report.

INSPECTION AND PREVENTATIVE MAINTENANCE CHECKLIST

Inspector's Name		Water Level Pond Side (ft. NGVD)	
Date (00/00/00) | Time (mil)		Water Level Estuary Side (ft. NGVD)	
Weather Condition		Next High Tide	
Temperature (F)		Next Low Tide	
Photographs attached (Y/N)		Ice, Vegetation, or Obstructions at Gates	

	NORTH GATE		SOUTH GATE	
Parts Inspected	**Condition**	**Action**	**Condition**	**Action**
Actuator- External Appearance				
Voltage Check				
Level Switches				
Controls Compartment				
Limit Switch Compartment				
Terminal Compartment				
Remove Motor Housing				
Position Indicator				
Actuator Lubricant				
Valve Stem				
Manual Override Components				
Visible Moving & Stationary Parts				
Gate				
Guide Frames				
Culvert				
Retaining Walls				
Shoreline and Scour Protection				

Glossary: Good = G, Fair = F, Poor = P, Needs Replacement = NR

Notes and Environmental Observations:________________________________

ADJUSTMENT LOG

Level Switch Adjustments*							
Operator Name	Manual Overide	Level Switch	Date	Time	Upstream	Downstream	Rationale /Comments

***Record as elevations in feet (NGVD 29)**

Appendix 4 Correspondences:

4.1 MEPA Record of Final Decision, EOEA #12889 December 30, 2002

4.2 MEPA Certificate on ENF, EOEA #13993 April 20, 2007

4.3 Letter from Massachusetts Historical Commission, October 4, 2002

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
251 Causeway Street, Suite 900
Boston, MA 02114-2119

JANE SWIFT
GOVERNOR

BOB DURAND
SECRETARY

Tel. (617) 626-1000
Fax (617) 626-1181
http://www.magnet.state.ma.us/envir

December 30, 2002

FINAL RECORD OF DECISION

PROJECT NAME	:	Ballard Street Salt Marsh and Flood Improvement Project
PROJECT MUNICIPALITY	:	Saugus
PROJECT WATERSHED	:	North Coastal
EOEA NUMBER	:	12889
PROJECT PROPONENT	:	Town of Saugus
DATE NOTICED IN MONITOR	:	November 23, 2002

Pursuant to the Massachusetts Environmental Policy Act (G. L. c. 30, ss. 61-62H) and Section 11.06 of the MEPA regulations (301 CMR 11.00), I have reviewed this project, and hereby **grant a Phase I Waiver** to allow Phase I of the project(as described in the Environmental Notification Form (ENF)) to proceed to the state permitting agencies prior to completion of the Environmental Impact Report (EIR). By a separate certificate, I have issued the scope for the EIR.

Project Description

As described in the ENF, the purpose of this project is to restore tidal flow and flushing within 22.5 acres of former and existing degraded salt marshes south of Ballard Street, within the Rumney Marshes Area of Critical Environmental Concern (ACEC). Also, the project will provide additional flood storage and storm damage prevention for an abutting low-lying East Saugus residential neighborhood. The Ballard Street salt marsh area has been degraded by numerous roads, development, inadequate culverts and non-functional tide gates, and the presence of the I-95 berm. The salt marsh is dominated by common reed (*Phragmites australis*).

Criteria for a Phase I Waiver

Section 11.11 of the MEPA Regulations provides that the Secretary may waive any provision or requirement of 301 CMR 11.00 not specifically required by MEPA, and may impose appropriate and relevant conditions or restrictions, provided that the Secretary finds that strict compliance with the provision or requirement would: a) result in an undue hardship for the proponent, unless based on delay in compliance by the proponent; and b) not serve to avoid or minimize Damage to the Environment.

In the case of a partial waiver of a mandatory EIR review threshold that would allow the proponent to proceed to phase one of the project prior to preparing an EIR, this finding shall be based on one or more of the following circumstances: 1) the potential environmental impacts of phase one, taken alone, are insignificant; 2) ample and unconstrained infrastructure facilities and services exist to support phase one; 3) the Project is severable, such that phase one does not require the implementation of any other future phase of the Project or restrict the means by which potential environmental impacts from any other phase of the Project may be avoided, minimized or mitigated; and 4)the Agency Action on phase one will contain terms such as a condition or restriction in a Permit, contract or other relevant document approving or allowing the Agency Action, or other evidence satisfactory to the Secretary, so as to ensure due compliance with MEPA and 301 CMR 11.00 prior to Commencement of any other phase of the Project.

Findings

Based upon the record before me, including the information submitted by the proponent, and after consultation with the relevant state agencies, I find that:

1) Delay in implementing Phase I would not serve to avoid or minimize Damage to the Environment.

2) The analysis of potential impacts for Phase I is adequate and demonstrates that the environmental impacts of phase one, taken alone, are insignificant. The proponent has demonstrated that any impacts will be addressed through proper mitigation.

Based on these findings, it is my judgment that the waiver request has merit and meets the tests established in Section 11.11. Therefore, I hereby grant the Phase I waiver for the Ballard Street Salt Marsh and Flood Improvement Project subject to the aforementioned findings and conditions.

December 30, 2002
Date

Bob Durand

Comments received on the ENF:

10/14/02	U.S. Environmental Protection Agency
10/28/02	Coastal Zone Management Office
10/29/02	Department of Environmental Management/ACEC Program
10/29/02	Department of Environmental Protection NERO
10/29/02	Division of Marine Fisheries
10/25/02	Massachusetts Highway Department
10/04/02	Massachusetts Historical Commission
10/17/02	The City of Revere, Ma/Department of Planning and Community Development
10/23/02	Massachusetts Audubon Society
10/29/02	Saugus River Watershed Council

Comments received on the DROD:

None

BAD/CDB/cdb

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
251 Causeway Street, Suite 900
Boston, MA 02114-2119

JANE SWIFT
GOVERNOR

BOB DURAND
SECRETARY

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November 8, 2002

CERTIFICATE OF THE SECRETARY OF ENVIRONMENTAL AFFAIRS ON THE ENVIRONMENTAL NOTIFICATION FORM

PROJECT NAME	: Ballard Street Salt Marsh and Flood Improvement Project
PROJECT MUNICIPALITY	: Saugus
PROJECT WATERSHED	: North Coastal
EOEA NUMBER	: 12889
PROJECT PROPONENT	: Town of Saugus
DATE NOTICED IN MONITOR	: October 9, 2002

Pursuant to the Massachusetts Environmental Policy Act (G. L. c. 30, ss. 61-62H) and Section 11.06 of the MEPA regulations (301 CMR 11.00), I have reviewed this project and find that it requires the preparation of an Environmental Impact Report (EIR). By a separate Draft Record of Decision (DROD), I will propose to grant a Phase I Waiver, as described in the ENF, allowing the first phase of the project to proceed to the state permitting agencies prior to completion of the Draft Environmental Impact Report (EIR).

The purpose of this project, and of salt marsh restoration projects in general, is to restore tidal flow and improve the ecological integrity of resources. This project is listed as a priority project in the *Rumney Marshes ACEC Salt Marsh Restoration Plan* prepared by the Massachusetts Wetlands Restoration Program (MWRP) and the Massachusetts Department of Environmental Management (DEM), and it has been designed to have a significant positive impact on environmental resources. This project emerged as a result of extensive multi agency and community cooperation. I have received supportive comments from the U.S. Environmental Protection Agency, Coastal Zone Management Office, DEM/Area of Critical Environmental Concern ACEC) Program, Department of Fisheries Wildlife and Environmental Law Enforcement, Division of Marine Fisheries, the City of Revere, Ma/Department of Planning and Community Development, the Massachusetts Audubon Society, and the Saugus River Watershed Council.

While this project is intended to improve the environmental resources of the Rumney Marshes and enjoys widespread support, it consists of a major alteration in a valuable wetland resource area. It will be important to ensure that the project is designed and constructed using best management practices appropriate to work in an ACEC.

Project Description

As described in the ENF, the purpose of this project is to restore tidal flow and flushing within 22.5 acres of former and existing degraded salt marshes south of Ballard Street, within the Rumney Marshes ACEC. Also, the project will provide additional flood storage and storm damage prevention for an abutting low-lying East Saugus residential neighborhood. The Ballard Street salt marsh area has been degraded by numerous roads, development, inadequate culverts and non-functional tide gates, and the presence of the I-95 berm. The salt marsh is dominated by common reed *Phragmites Australis)*.

The project is proposed in three phases. Phase 1 involves the installation of a Self Regulating Tide Gate (SRTG) and box culvert across an unnamed tidal creek upstream of the existing poorly functioning tide gate. Phase 2 consists of creation of a flood storage area between the abandoned I-95 berm and Eastern Avenue and construction of a new culvert under Eastern Avenue. Phase 3 consists of unblocking a culvert under Bristow Street, removing the leaky flap gate at Ballard Street and restoring tidal flow to Ballard Street Marshes, east and west of I-95. The proponent has requested a Phase I waiver to commence construction of the SRTG and culvert prior to preparation of the Environmental Impact Report.

Jurisdiction

The project will require a Section 401 Water Quality Certificate, a National Pollutant Discharge Elimination System (NPDES) General Construction Permit, a MA Surface Water

Discharge Permit and a Chapter 91 License from the Department of Environmental Protection (DEP), Coastal Zone consistency review, and an access and construction permit from the MDC. The project will also require an Order of Conditions from the Saugus Conservation Commission (and hence a Superseding Order from DEP if the Local Order is appealed). Because the project may involve state funding, MEPA jurisdiction extends to all aspects of the project that may have significant environmental impact.

The project is included for the preparation of a mandatory EIR pursuant to Section 11.03(3)(a)(1)(a) and 11.03(3)(a)(2) of the MEPA regulations because more than one acre of salt marsh and Bordering Vegetated Wetlands (BVW) will be altered and more than five thousand square feet of BVW will be altered requiring a variance in accordance with the Wetlands Protection Act(WPA).

SCOPE

The EIR should follow Section 11.07 of the MEPA regulations for outline and content, as modified by this scope. It should address the comments listed at the end of this Certificate to the extent that they are within this scope and it should include a copy of this Certificate.

Restoration of tidal flow and associated removal and repair of existing culverts do not require further MEPA review. The associated impacts of Phase 3 have been described adequately in the ENF and can be addressed through the local and state permitting process. The scope of the EIR will be limited to Phase 2, the creation of the flood storage area.

Alternatives Analysis

The proponent outlined the following five alternatives in the ENF:

- Alternative 1: No Action
- Alternative 2: Tide Gate Replacement at Ballard Street with a Standard Tide Gate
- Alternative 3: Tide Gate Replacements at Ballard Street with SRTG
- Alternative 4: Tide Gate Relocation North of I-95 Berm with Standard Tide Gate
- Alternative 5(Preferred Alternative): Tide Gate Relocation North of I-95 Berm with SRTG

The preferred alternative was selected because it is the only alternative that allows increased tidal flushing within the salt marshes without decreasing flood protection to the low-lying neighborhoods.

Sufficient information on alternatives was included in the ENF, including the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NCRS) *Hydrologic and Hydraulic Analysis: Wetlands Restoration Investigation, Ballard Street Salt Marsh* study to justify the selection of the Preferred Alternative. The scope of the EIR will be limited to a comparison of Alternative 1: No Action and Alternative 5, the Preferred Alternative

In addition, I am requesting the proponent provide information on one alternative that was not included in the ENF. I am aware that the Central Artery/Tunnel Project excavated the I-95 berms as part of its restoration of the Oak Island Salt Marsh area of the Rumney Marshes. The proponent should explain why this alternative was not considered for this project, address its potential for meeting the ecological goals of the proposed project, and describe any impacts this alternative would have on flooding in adjacent neighborhoods.

Wetlands

The proponent has indicated that it will file for limited project status under 310 CMR 10.55(4) because the purpose of this project is to improve the natural capacity of a resource to function. The proponent should clearly outline how it meets the criteria and performance standards for limited project status in the Wetlands Section of the EIR, including how wetland resources, their associated buffer zones, riverfront protection areas and 100-year flood plain areas will be protected and their ecological value improved by this project. It should detail any associated impacts to wetland areas that are unavoidable and illustrate that the impacts have been minimized, and that the project will be accomplished in a manner that is consistent with the Performance Standards of the Wetlands Regulations (310 CMR 10.00).

All resource area boundaries, riverfront areas, applicable buffer zones, and 100-year flood elevations should be clearly delineated on a plan. Bordering vegetated wetlands that have been delineated in the field should be surveyed, mapped, and located on the plans. Each wetland resource area and riverfront area should be characterized according to 310 CMR 10.00. The text should explain whether the local conservation commission has accepted the resource area boundaries and any disputed boundary should be identified.

The EIR should address the significance of the wetland resources on site, including public and private water supply; groundwater supply; riverfront areas; flood control; storm damage prevention; fisheries; shellfish; and wildlife habitat. It should identify the location of nearby public water wells.

The EIR should describe in detail any wetlands replication plans including: replication location(s) delineated on plans, elevations, typical cross sections, test pits or soil boring logs, groundwater elevations, the hydrology of areas to be altered and replicated, list of wetlands plant species of areas to be altered and the proposed wetland replication species, planned construction sequence, and a discussion of the required performance standards and monitoring.

The EIR should include a management and maintenance plan for the salt marsh area as a whole with particular emphasis on management of invasive species and mosquito control.

In addition, the EIR should include a plan for monitoring the effectiveness of the restoration project. This plan should report on the criteria and assumptions that have been a part of the *Rumney Marshes ACEC Salt Marsh Restoration Plan* and should be consistent with evaluations being conducted for other salt marsh restoration projects so that the information can be used to develop a quantified assessment of the cumulative benefits of these projects.

Drainage/Flooding:

The Preferred Alternative proposes restoration of full tidal flow in the existing degraded salt marsh east of the I-95 berm. To compensate for loss of flood storage on the eastern side of the berm where tidal flow will be restored, the area west of the berm will be excavated. The proponents have designed the project elements, including this flood storage area, consistent with the recommendations of the NCRS study in Appendix B. The storage area is designed to store water just below the elevation where surface flooding of residential properties begins (6.7 feet NGVD). The study concluded that the Preferred Alternative will generally reduce flood levels below present conditions. The Preferred Alternative will not reduce the risk of local or regional flood damage from catastrophic coastal storm events, such as the Blizzard of 1978.

The EIR should present drainage calculations and plans for the management of flooding and stormwater from the proposed project. It should identify the quantity and quality of flows for the 10, 25 and 100-year storm events.

The EIR should address the performance standards of DEP's Stormwater Management Policy. It should demonstrate that the project is consistent with this policy. The proponent should use the DEP Stormwater Management Handbook when addressing this issue. The EIR should discuss consistency of the project with the provisions of the National Pollution Discharge Elimination System (NPDES) general permit from the U.S. Environmental Protection Agency for stormwater discharges from construction sites. The EIR should include, in further detail, discussion of best management practices employed to meet the NPDES requirements, and it may be required to provide a draft Pollution Prevention Plan.

In addition, the EIR should include a maintenance plan to ensure long term effectiveness of the culverts. This maintenance program should outline maintenance activities and responsible parties.

Contaminated Soils/Hazardous Wastes:

The major element of Phase 2 is the excavation and disposal of 51 acre-feet (82,800 cubic yards) of sediment from the project site. Five soil augers have been advanced in the former salt marsh area to the approximate 3 foot depth of planned excavation for flood storage. These samples have indicated organic rich material with some fill identified at one location. To date, no environmental testing has been conducted on the soils but Appendix A did note that the site has been subject to illegal dumping. The ENF indicated that this sediment would be used to cap and re-vegetate the I-95 berm; however, the proponent's consultant had indicated that this approach would not be pursued because it could contribute to the spreading of common reed on top of the berm.

The proponent should provide more detail on the physical and/or chemical nature of the material to be disposed and describe alternatives for disposal. The results of a "due diligence" review to assess potential sources of contamination in the area and whether sampling data exists for material in/near the proposed excavation area should be included in the EIR.

Assuming that the proponent will pursue another alternative for stabilizing the I-95 embankment, the EIR should include information on the type of fill that will be used, the stability of such fill and whether erosion controls, capping, or other methods of stabilization will be required. The EIR should describe measures that will be taken to prevent fill material from washing back into the excavated area during large rain events.

The EIR should present a summary of the results of any hazardous waste studies and remediation efforts undertaken at the site.

Construction

The EIR should present a discussion on construction activities, including sequencing. The proponent should identify potential construction period impacts (including but not limited to noise, dust, wetlands, and traffic maintenance), analyze feasible measures that can avoid or eliminate these impacts and detail best management practices that will be adopted.

The proponent should consult the Division of Marine Fisheries before beginning work to determine if seasonal limitations on construction work apply to this project.

Public Access/Landscaping

The EIR should include a conceptual-level landscaping plan for the public access site. The EIR should clearly show where public access to the site will be located and how the area will be managed and maintained. It should identify connections to the public access sites across Ballard Street and include any plans for bicycle and car parking. The EIR should investigate all bicycle path connections and opportunities in the project area.

Wildlife and Protected Species

The Massachusetts Natural Heritage and Endangered Species Program was consulted and reported that no rare plants or animals or exemplary natural communities are known to be present in the vicinity of the Project Area. The proponent also included the Massachusetts Natural Heritage Atlas (2000-2001 Edition) maps (Figures 12 and 13) for this area showing that this area does not include any Priority Habitats of Rare Species and no Estimated Habitats of Rare Wildlife and Certified Vernal Pools.

Historic and Archaeological Resources

One ancient Native American site was identified in the Inventory of Historic and Archaeological Assets of the Commonwealth. Comments from the Massachusetts Historical Commission indicate that no further review is required because construction of the I-95 berm would have destroyed any intact resources.

Traffic

MHD has reviewed this project and indicated that traffic impacts will be minimal. MHD has requested that the proponent contact the District 4 Office to work out the details of the construction permit.

Mitigation

The EIR should include a separate chapter on mitigation measures. It should provide a clear commitment to implement these mitigation measures and should describe the timing of their implementation.

This chapter on mitigation should include proposed Section 61 Findings for all state permits. The proposed Section 61 Findings should contain a clear commitment to mitigation, an estimate of the individual costs of the proposed mitigation and the identification of the parties responsible for implementing the mitigation. A schedule for the implementation of mitigation should also be included.

Circulation

The EIR should be circulated in compliance with Section 11.16 of the MEPA regulations and copies should also be sent to the list of "comments received" below and to Saugus officials. A copy of the EIR should be made available for public review at the Saugus Public Library.

November 8, 2002

Date

Bob Durand

cc:

EOEA#12889 ENF Certificate 11/08/02

Comments received:

10/14/02	U.S. Environmental Protection Agency
10/28/02	Coastal Zone Management Office
10/29/02	Department of Environmental Management/ACEC Program
10/29/02	Department of Environmental Protection NERO
10/29/02	Division of Marine Fisheries
10/25/02	Massachusetts Highway Department
10/04/02	Massachusetts Historical Commission
10/17/02	The City of Revere, Ma/Department of Planning and Community Development
10/23/02	Massachusetts Audubon Society
10/29/02	Saugus River Watershed Council

BAD/CDB/cdb

The Commonwealth of Massachusetts
Executive Office of Energy and Environmental Affairs
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Deval L. Patrick
GOVERNOR

Timothy P. Murray
LIEUTENANT GOVERNOR

Ian A. Bowles
SECRETARY

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April 20, 2007

CERTIFICATE OF THE SECRETARY OF ENERGY AND ENVIRONMENTAL AFFAIRS
ON THE
ENVIRONMENTAL NOTIFICATION FORM

PROJECT NAME	: Ballard Street Marsh-Gateway Improvement Project
PROJECT MUNICIPALITIES	: Saugus
PROJECT WATERSHED	: North Coastal
EOEA NUMBER	: 13993
PROJECT PROPONENT	: Massachusetts Department of Conservation and Recreation (DCR)
DATE NOTICED IN MONITOR	: March 21, 2007

Pursuant to the Massachusetts Environmental Policy Act (G. L. c. 30, ss. 61-62H) and Section 11.06 of the MEPA regulations (301 CMR 11.00), I hereby determine that this project **does not require** the preparation of an Environmental Impact Report.

As described in the Environmental Notification Form (ENF), the Ballard Street Marsh-Gateway Improvement Project is the kick-off project for the Ballard Street Marsh improvement initiative (EOEA # 12889). The Gateway Improvement Project described in the ENF involves improvements to the existing parking lot. The proposed improvements include regrading the parking area to eliminate surface ponding and resurfacing the area with gravel. The existing parking lot is comprised of approximately 0.76 acres of compacted earth with a 1,700 square foot area of standard asphalt. Presently, the parking lot is being used as a dumping ground for construction debris which will be removed as part of this project. The proposed plans reduce the parking area to 0.45 acres which will be graded to ensure proper drainage to the eastern perimeter of the site towards a proposed storm water infiltration trench. The project area is bordered by Eastern Avenue on the west and the Rumney Marsh Area of Critical Environmental Concern (ACEC) on the north and east and the abandoned Bristow Street right-of-way to the south. All the lands within the project area are owned by the Department of Conservation and Recreation (DCR).

The project is undergoing review pursuant to Section 11.03 (11)(b) of the MEPA regulations because the project is located within a designated Area of Critical Environmental Concern (ACEC). Lands within the project area are owned by the Department of Conservation and Recreation (DCR). The project will require an Order of Conditions from the Saugus Conservation Commission (and hence a Superseding Order from MassDEP if the local Order is appealed). Because the project may involve state funding, MEPA jurisdiction extends to all aspects of the project that may have significant environmental impact.

The Gateway Improvement Project lies within the boundary of the Rumney Marshes Area of Critical Environmental Concern (ACEC), which is defined generally as the outer boundary of the 100-year flood elevation surrounding the Saugus and Pines Rivers and estuarine wetlands to the west of North Shore Road (Route 1A). The water bodies and wetlands of the Rumney Marshes ACEC are classified as Outstanding Resource Waters (ORW) in the Massachusetts Surface Water Quality Standards.

The overall Ballard Street Marsh improvement initiative (EOEA # 12889) involves the restoration of portions of the Rumney Marshes ACEC, a project which emerged as a result of extensive multi agency and community cooperation. The overall project is listed as a priority project in the Rumney Marshes ACEC Salt Marsh Restoration Plan prepared by the Massachusetts Wetlands Restoration Program (MWRP) and the former Massachusetts Department of Environmental Management (DEM), and it has been designed to have a significant positive impact on environmental resources. The site improvements for the Gateway Improvement Project are intended to create an aesthetically pleasing entrance for the local community to enjoy the surrounding Rumney Marsh ACEC as well as to provide enhanced stormwater management. I commend DCR for proposing to use Low Impact Development for stormwater management in order to meet compliance with the Stormwater Management Policy.

The review of the ENF has served to adequately disclose the potential impacts and mitigation associated with this project. Based on a review of the ENF, the comment letters, and consultation with the relevant public agencies, I find that the impacts of the project do not warrant further MEPA review

April 20, 2007
Date

Ian A. Bowles

Comments Received:

03/29/07 U.S. Environmental Protection Agency
04/10/07 Massachusetts Division of Marine Fisheries

IAB/ACC/acc

DB

The Commonwealth of Massachusetts

William Francis Galvin, Secretary of the Commonwealth
Massachusetts Historical Commission

RECEIVED
OCT 9 2002
MEPA

October 4, 2002

Secretary Bob Durand
Attn.: MEPA Office
Executive Office of Environmental Affairs
251 Causeway Street, 9th Floor
Boston, MA 02114-2150

12889

RE: Ballard Street Salt Marsh Restoration. Saugus, MA. MHC #RC.30733. EOEA # not yet

Dear Secretary Durand:

Staff of the Massachusetts Historical Commission have reviewed the Environmental Notification Form (ENF) for the proposed project referenced above and have the following comments.

Review of MHC's Inventory of the Historic and Archaeological Assets of the Commonwealth indicates that there is an ancient Native American archaeological site (MHC site #19-ES-258) within or adjacent to the project area. Because of previous disturbances to the project area during the aborted construction of I95 through the marshes, it is unlikely that intact archaeological deposits relating to this site remain within the project area. Therefore, MHC has determined that the proposed project is unlikely to affect significant historic or archaeological resources. No further MHC review is required for this project in compliance with Massachusetts General Laws, Chapter 9, Sections 26-27C as amended by Chapter 254 of the Acts of 1988 (950 CMR 71), and MEPA (301 CMR 11). If you have any questions, please feel free to contact Margo Muhl Davis, Archaeologist/Preservation Planner, at this office.

Sincerely,

Eric S. Johnson

Eric S. Johnson
Archaeologist/Preservation Planner
Massachusetts Historical Commission

xc: John J. Vasapolli, Saugus Town Manager's Office
Ann B. McMenemy, Environmental Sciences, Inc.
DEPNERO
Saugus Historical Commission

Appendix 5: Hydrologic Study of Pines River Channel (letter report) – Normandeau Associates, Inc. August 26, 2014.

August 26, 2014

Ms. Lisa Standley
Vanasse Hangen Brustlin, Inc.
101 Walnut Street
Watertown, MA 02472

Dear Ms. Standley,

Normandeau Associates Inc (Normandeau) has completed the hydrologic study for the Rumney Marsh mitigation sites in Saugus, MA. These sites are a coastal wetland restoration project to provide partial compensation for coastal wetland impacts associated with the Winthrop Beach Nourishment conducted by Massachusetts Port Authority. Normandeau was contracted by Vanasse Hangen Brustlin, Inc (VHB) to monitor tide stage and salinity in the vicinity of two newly constructed wetland sites on a tidal creek draining west to the Pine River (Figure 1). Site A was the more eastern project and therefore closer to the head of tide in this system versus Site B which was further west and slightly lower in elevation. Hydrologic monitoring commenced July 1, 2014 and continued for a complete lunar cycle ending August 1, 2014. Due to local site conditions and mechanical failure of one of the monitoring instruments the data record is incomplete. Missing are water level data and part of the salinity record from Site B as well as part of the salinity record from Site A. Site A was considered to be the more critical site for determining tidal fluctuations, therefore a decision was made by VHB to accept the dataset as is.

Methods

Tide data was recorded using two In-Situ Inc. Aqua Troll 200 data loggers which measure temperature, conductivity, and pressure. The loggers were set to record at 15 minute intervals and a single logger was installed at each site (Sites A and B in Figure 1). The site environment consisted of a large salt marsh complex with multiple deeply incised drainage channels. The loggers were deployed at low tide which at Site B featured several feet of water depth in the drainage channel and at Site A was characterized by a mostly dry channel (above mean low tide elevation) with a low volume of runoff in the channel thalweg. The data loggers were installed in a small length of slotted 1-inch PVC pipe which was attached to a 3-ft length of steel rebar and hammered into the channel substrate. At Site B the instrument sensor was below the mean low tide elevation but above the channel bottom while at Site A the sensor was installed flush with the channel bottom (which was above the mean low tide elevation) and within the wetted thalweg.

The instrument elevations were surveyed using a transit level and rod and referenced to constant elevation contours delineated for the wetland construction project (marked on site with stakes and flagging). The site was visited July 1, 2014 to deploy the instrumentation and survey the site then retrieved August 1, 2014. Instrument calibration checks showed the working sensors to be performing acceptably prior to, and at the time of deployment.

Aqua Troll 200 data loggers record absolute pressure while deployed, a value which includes the ambient atmospheric pressure and thus necessitates a correction to determine the pressure due to overlying water. For the correction we obtained meteorological data (every 6 hours) from Boston Logan Airport meteorological station for the study period and used a simple linear interpolation to derive a 15 minute data set to match our instrument logging intervals. Water pressure was then converted to stage using standard values based on our salinity and temperature data.

Figure 1. MassPort Rumney Marsh mitigation monitoring site map showing location of tide gaging stations

Results

The results from the study are presented in Figures 2 and 3 and Appendix A. Water surface elevation, salinity, and temperature are presented for Site A while temperature and salinity are presented for Site B. At the end of the study when the data logger was removed from Site A, several inches of sediment had accumulated at the lower end of the logger. The data record likewise indicated the instrument was periodically affected by siltation which likely compromised salinity data collected at that site and is therefore not reported as a complete record. Significant outlier values were flagged and removed from the final dataset and are not reported. While we note the salinity data was affected, the siltation did not appear to have an effect on pressure or temperature results, probably because the sensors are located higher in the instrument were better protected from direct effects of siltation. Those data are reported as a continuous record and are believed to be representative of surface water conditions. At Site B the pressure sensor on the data logger failed at the time of installation and yielded no usable pressure/tide stage data for that site. The instrument was also affected by fouling which affected salinity readings after the first eleven days of deployment; therefore, salinity data are not reported after July 13 at Site B. Temperature data were unaffected by instrument fouling and are reported as a continuous record.

Our data show a range of tidal fluctuations at Site A for the month-long deployment period varying from ~1.5 m above MSL at high tide to consistently below the channel bottom elevation of ~-0.7 m at low tide (Figure 2). Temperatures were inversely correlated with tide elevation and were generally lowest at high tide and highest at low tide while salinity was positively correlated with tide stage and reached a peak at or shortly after the high tide. Temperatures at Site A varied from ~16 to 28 °C and at Site B from ~15 to 27 °C (Figure 3). Temperature varied continuously with the tidal fluctuations and also exhibited some longer (multi-day) embedded trends due to other factors not identified. Salinity varied from ~21 to 30 Practical Salinity Units (PSU) at Site A and from ~13 to 30 PSU at Site B (Figures 2 & 3.) Salinity showed recurring daily variations and some longer scale trends including a general decrease in salinity over the study period. The complete quality controlled data record is provided in Appendix A.

Thank you for the opportunity to provide this study. I hope these data are sufficient for your needs. Do not hesitate to contact me (603-637-1158) or Joel Detty (603-637-1123) if you have questions.

Sincerely,

Sarah Allen

Sarah Allen
Principal Wetland Scientist

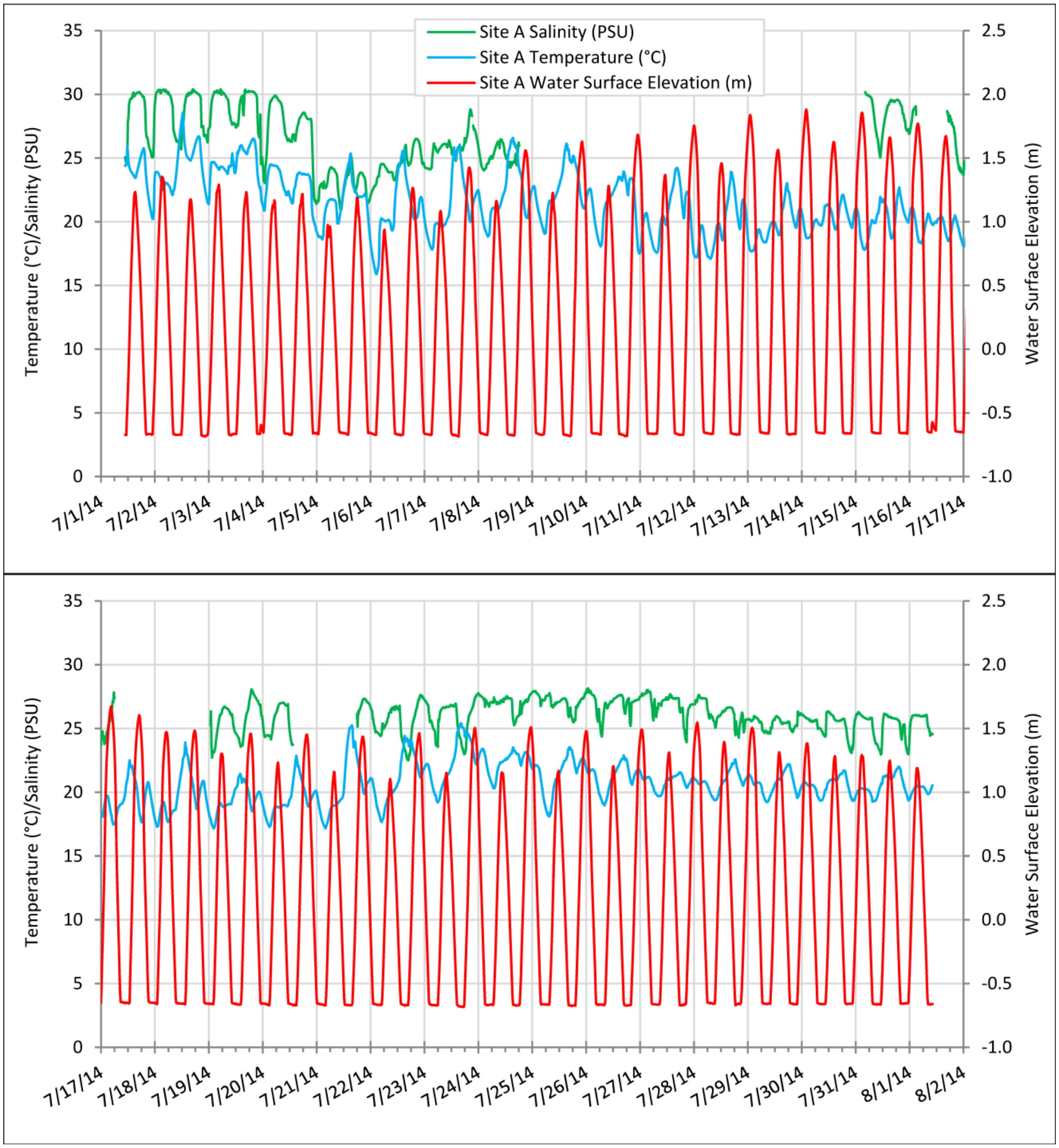

Figure 2. 15 minute temperature, salinity, and water surface elevation at Site A from July 1 to August 1, 2014.

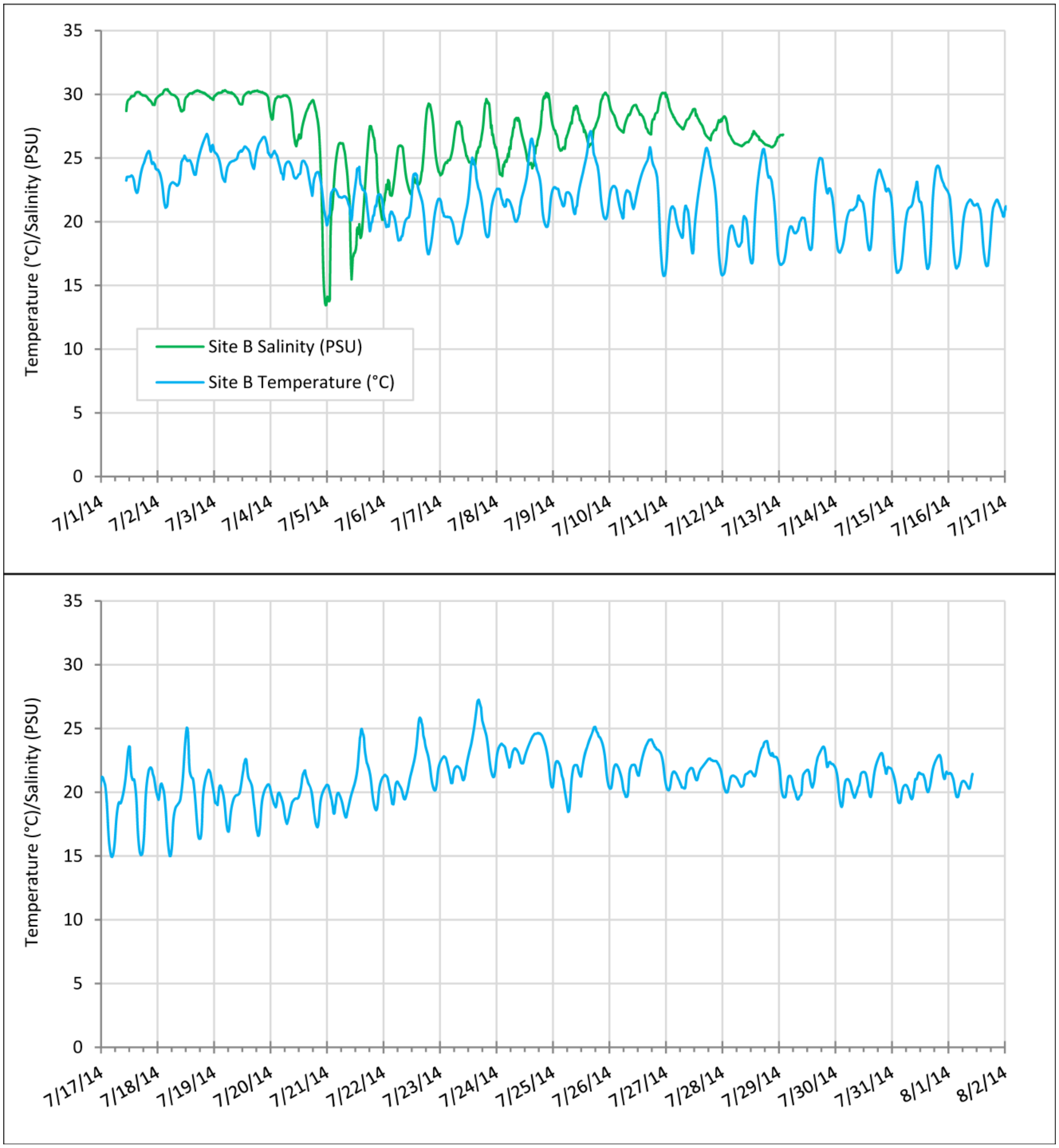

Figure 3. 15 minute temperature and salinity at Site B from July 1 to August 1, 2014.

Appendix A

Summary of Temperature, Salinity, and Water Surface Elevation data collected July 2014 for Mitigation Sites A and B – Rumney Marsh Wetland Mitigation Project

Source:

Normandeau Associates, Inc.

File attached:

Rumney Marsh Tide Monitoring 2014_NAI.xlsx

APPENDIX A. Summary of Temperature, Salinity, and Water Surface Elevation data collected					
July 2014 for Mitigation Sites A and B					
Rumney Marsh Wetland Mitigation					
	Mitigation Site A			Mitigation Site B	
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)
7/1/2014 10:45	24.399	25.065	-0.673	23.246	28.698
7/1/2014 11:00	24.437	24.812	-0.673	23.508	29.194
7/1/2014 11:15	24.461	24.627	-0.674	23.534	29.425
7/1/2014 11:30	24.784	24.741	-0.568	23.524	29.541
7/1/2014 11:45	25.969	25.171	-0.440	23.533	29.567
7/1/2014 12:00	25.372	27.788	-0.329	23.528	29.629
7/1/2014 12:15	24.711	28.237	-0.183	23.529	29.653
7/1/2014 12:30	24.388	29.267	-0.030	23.568	29.711
7/1/2014 12:45	24.26	29.424	0.117	23.597	29.823
7/1/2014 13:00	24.115	29.622	0.283	23.634	29.815
7/1/2014 13:15	24.008	29.643	0.453	23.604	29.877
7/1/2014 13:30	23.925	29.724	0.611	23.528	29.851
7/1/2014 13:45	23.844	29.660	0.755	23.424	29.868
7/1/2014 14:00	23.78	29.862	0.885	23.261	29.867
7/1/2014 14:15	23.712	30.104	1.014	22.972	29.919
7/1/2014 14:30	23.661	30.148	1.115	22.666	30.031
7/1/2014 14:45	23.6	29.847	1.183	22.455	30.126
7/1/2014 15:00	23.514	29.858	1.224	22.334	30.153
7/1/2014 15:15	23.444	29.983	1.235	22.276	30.166
7/1/2014 15:30	23.482	30.025	1.204	22.294	30.189
7/1/2014 15:45	23.702	30.078	1.145	22.471	30.182
7/1/2014 16:00	23.882	30.117	1.097	22.732	30.186
7/1/2014 16:15	24.027	30.145	1.029	22.98	30.165
7/1/2014 16:30	24.206	30.140	0.936	23.289	30.157
7/1/2014 16:45	24.381	30.165	0.844	23.568	30.051
7/1/2014 17:00	24.556	30.135	0.731	23.812	30.012
7/1/2014 17:15	24.753	30.187	0.636	24.013	29.991
7/1/2014 17:30	24.942		0.524	24.196	29.968
7/1/2014 17:45	25.108	30.055	0.396	24.369	29.92
7/1/2014 18:00	25.273	30.001	0.302	24.484	29.929
7/1/2014 18:15	25.423	29.965	0.198	24.606	29.93
7/1/2014 18:30	25.589	29.828	0.078	24.743	29.896
7/1/2014 18:45	25.707	29.842	-0.049	24.906	29.906
7/1/2014 19:00	25.779	29.784	-0.173	25.034	29.891
7/1/2014 19:15	25.701	29.650	-0.308	25.189	29.833
7/1/2014 19:30	25.362	29.414	-0.418	25.32	29.816
7/1/2014 19:45	24.819	28.717	-0.538	25.424	29.742
7/1/2014 20:00	23.931	27.185	-0.648	25.494	29.683

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/1/2014 20:15	23.143	26.700	-0.671	25.559	29.591	
7/1/2014 20:30	22.741	26.658	-0.668	25.535	29.599	
7/1/2014 20:45	22.44	26.535	-0.668	25.397	29.509	
7/1/2014 21:00	22.148	26.283	-0.666	25.2	29.504	
7/1/2014 21:15	21.878	26.029	-0.667	24.907	29.441	
7/1/2014 21:30	21.585	25.818	-0.665	24.659	29.377	
7/1/2014 21:45	21.305	25.706	-0.666	24.547	29.279	
7/1/2014 22:00	21.055	25.564	-0.667	24.647	29.178	
7/1/2014 22:15	20.82	25.418	-0.669	24.672	29.186	
7/1/2014 22:30	20.59	25.150	-0.671	24.562	29.187	
7/1/2014 22:45	20.392	25.069	-0.672	24.518	29.175	
7/1/2014 23:00	20.225	25.061	-0.667	24.378	29.376	
7/1/2014 23:15	20.222	25.086	-0.544	24.177	29.605	
7/1/2014 23:30	20.779	26.171	-0.440	24.135	29.658	
7/1/2014 23:45	22.9	28.479	-0.328	24.089	29.726	
7/2/2014 0:00	23.588	29.205	-0.203	24.112	29.768	
7/2/2014 0:15	23.884	29.631	-0.052	24.086	29.824	
7/2/2014 0:30	23.883	30.013	0.110	23.996	29.872	
7/2/2014 0:45	23.909	30.130	0.270	23.907	29.906	
7/2/2014 1:00	23.91	30.207	0.412	23.819	29.913	
7/2/2014 1:15	23.873	30.239	0.568	23.654	29.984	
7/2/2014 1:30	23.831	30.341	0.730	23.456	29.987	
7/2/2014 1:45	23.772	30.323	0.886	23.258	30.011	
7/2/2014 2:00	23.663	30.361	1.029	23.008	30.01	
7/2/2014 2:15	23.542	30.355	1.126	22.63	30.074	
7/2/2014 2:30	23.41	30.092	1.202	22.231	30.173	
7/2/2014 2:45	23.236	30.094	1.268	21.758	30.287	
7/2/2014 3:00	22.948	30.332	1.323	21.406	30.336	
7/2/2014 3:15	22.648	30.334	1.353	21.244	30.367	
7/2/2014 3:30	22.483	30.320	1.348	21.1	30.394	
7/2/2014 3:45	22.535	30.341	1.332	21.138	30.367	
7/2/2014 4:00	22.64	30.385	1.307	21.208	30.388	
7/2/2014 4:15	22.859	30.304	1.238	21.388	30.414	
7/2/2014 4:30	23.024	30.204	1.123	21.935	30.27	
7/2/2014 4:45	23.071	30.366	1.016	22.363	30.245	
7/2/2014 5:00	23.053	30.289	0.911	22.621	30.211	
7/2/2014 5:15	23.041	30.239	0.787	22.83	30.118	
7/2/2014 5:30	23.018	30.152	0.667	22.936	30.085	
7/2/2014 5:45	22.959	30.049	0.548	22.998	30.032	
7/2/2014 6:00	22.9	30.175	0.428	23.047	29.983	
7/2/2014 6:15	22.847	30.037	0.307	23.084	29.99	

Date and Time	Mitigation Site A			Mitigation Site B		
	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/2/2014 6:30	22.782	29.965	0.190	23.093	29.97	
7/2/2014 6:45	22.679	29.931	0.066	23.086	29.955	
7/2/2014 7:00	22.519	29.838	-0.069	23.055	29.948	
7/2/2014 7:15	22.346	29.673	-0.191	23.016	29.913	
7/2/2014 7:30	22.224	29.450	-0.317	22.973	29.891	
7/2/2014 7:45	22.126	29.236	-0.458	22.944	29.839	
7/2/2014 8:00	22.093	28.998	-0.596	22.901	29.794	
7/2/2014 8:15	22.404	27.234	-0.666	22.831	29.748	
7/2/2014 8:30	22.472	27.079	-0.669	22.831	29.666	
7/2/2014 8:45	22.673	26.873	-0.667	22.892	29.627	
7/2/2014 9:00	22.885	26.688	-0.670	22.957	29.371	
7/2/2014 9:15	23.393	26.564	-0.672	23.108	29.107	
7/2/2014 9:30	23.796	26.365	-0.674	23.349	29.033	
7/2/2014 9:45	24.223	26.277	-0.673	23.716	28.882	
7/2/2014 10:00	24.61	26.393	-0.674	24.367	28.713	
7/2/2014 10:15	25.046	26.344	-0.671	24.737	28.661	
7/2/2014 10:30	25.528	26.296	-0.672	24.77	28.679	
7/2/2014 10:45	25.991	26.118	-0.671	24.912	28.757	
7/2/2014 11:00	26.476	25.933	-0.671	24.931	28.75	
7/2/2014 11:15	26.953	25.910	-0.671	25.015	28.793	
7/2/2014 11:30	27.376	25.971	-0.671	25.188	29.235	
7/2/2014 11:45	27.837	25.691	-0.671	25.096	29.595	
7/2/2014 12:00	28.091	26.770	-0.622	25.004	29.714	
7/2/2014 12:15	28.385	27.294	-0.503	24.904	29.79	
7/2/2014 12:30	28.582	27.265	-0.386	24.857	29.814	
7/2/2014 12:45	27.515	27.826	-0.260	24.773	29.844	
7/2/2014 13:00	26.709	28.528	-0.119	24.771	29.933	
7/2/2014 13:15	26.114	29.144	0.027	24.804	29.982	
7/2/2014 13:30	25.76	29.390	0.175	24.818	30.044	
7/2/2014 13:45	25.494	29.670	0.324	24.827	30.076	
7/2/2014 14:00	25.279	29.850	0.483	24.76	30.072	
7/2/2014 14:15	25.168	29.939	0.636	24.644	30.074	
7/2/2014 14:30	25.087	30.028	0.770	24.51	30.077	
7/2/2014 14:45	25.043	29.885	0.900	24.359	30.057	
7/2/2014 15:00	24.949	30.109	1.008	24.145	30.134	
7/2/2014 15:15	24.914	30.102	1.092	23.964	30.16	
7/2/2014 15:30	24.861	30.135	1.155	23.79	30.161	
7/2/2014 15:45	24.817	30.000	1.171	23.689	30.228	
7/2/2014 16:00	24.812	30.132	1.175	23.695	30.234	
7/2/2014 16:15	24.909	30.175	1.154	23.711	30.24	
7/2/2014 16:30	25.035	30.119	1.086	23.97	30.282	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/2/2014 16:45	25.255	30.370	1.011	24.308	30.263	
7/2/2014 17:00	25.378	30.411	0.945	24.633	30.314	
7/2/2014 17:15	25.533	30.209	0.866	24.826	30.282	
7/2/2014 17:30	25.721	30.304	0.772	24.983	30.267	
7/2/2014 17:45	25.894	30.249	0.670	25.214	30.27	
7/2/2014 18:00	26.116	30.207	0.564	25.385	30.202	
7/2/2014 18:15	26.219	30.179	0.457	25.542	30.226	
7/2/2014 18:30	26.355	30.154	0.345	25.719	30.195	
7/2/2014 18:45	26.493	30.106	0.246	25.866	30.175	
7/2/2014 19:00	26.554	30.077	0.134	25.994	30.162	
7/2/2014 19:15	26.68	30.043	0.016	26.13	30.157	
7/2/2014 19:30	26.717	30.026	-0.105	26.26	30.099	
7/2/2014 19:45	26.681	29.950	-0.225	26.383	30.119	
7/2/2014 20:00	26.529	29.925	-0.347	26.499	30.106	
7/2/2014 20:15	26.141	29.824	-0.465	26.613	30.041	
7/2/2014 20:30	25.606	29.700	-0.588	26.718	30.042	
7/2/2014 20:45	24.702	27.429	-0.675	26.833	29.978	
7/2/2014 21:00	24.261	27.454	-0.679	26.895	29.95	
7/2/2014 21:15	23.925	27.523	-0.680	26.813	29.914	
7/2/2014 21:30	23.621	27.509	-0.680	26.662	29.875	
7/2/2014 21:45	23.263	26.831	-0.683	26.433	29.842	
7/2/2014 22:00	22.947	26.718	-0.681	26.097	29.82	
7/2/2014 22:15	22.692	26.786	-0.687	25.945	29.792	
7/2/2014 22:30	22.419	26.824	-0.683	25.597	29.706	
7/2/2014 22:45	22.133	26.738	-0.681	25.495	29.708	
7/2/2014 23:00	21.886	26.571	-0.679	25.767	29.679	
7/2/2014 23:15	21.676	26.400	-0.675	25.972	29.661	
7/2/2014 23:30	21.509	26.235	-0.673	26.035	29.59	
7/2/2014 23:45	21.443	27.163	-0.644	25.908	29.572	
7/3/2014 0:00	21.373	27.326	-0.556	25.565	29.821	
7/3/2014 0:15	21.756	27.352	-0.445	25.483	29.886	
7/3/2014 0:30	22.957	27.436	-0.336	25.427	29.882	
7/3/2014 0:45	23.875	28.185	-0.216	25.381	29.957	
7/3/2014 1:00	24.37	28.727	-0.079	25.342	29.969	
7/3/2014 1:15	24.677	29.263	0.052	25.277	30.049	
7/3/2014 1:30	24.672	29.628	0.193	25.182	30.06	
7/3/2014 1:45	24.641	29.817	0.350	25.097	30.092	
7/3/2014 2:00	24.689	29.941	0.495	24.986	30.131	
7/3/2014 2:15	24.646	30.061	0.656	24.802	30.121	
7/3/2014 2:30	24.686	30.212	0.802	24.606	30.116	
7/3/2014 2:45	24.597	30.195	0.936	24.429	30.13	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/3/2014 3:00	24.482	30.155	1.057	24.136	30.133	
7/3/2014 3:15	24.491	30.249	1.155	23.859	30.145	
7/3/2014 3:30	24.389	30.170	1.220	23.639	30.196	
7/3/2014 3:45	24.282	30.320	1.247	23.432	30.282	
7/3/2014 4:00	24.26	30.210	1.247	23.341	30.241	
7/3/2014 4:15	24.206	30.165	1.270	23.262	30.261	
7/3/2014 4:30	24.1	30.102	1.291	23.164	30.308	
7/3/2014 4:45	24.099	30.240	1.250	23.148	30.326	
7/3/2014 5:00	24.221	30.091	1.136	23.5	30.275	
7/3/2014 5:15	24.34	30.406	1.031	23.831	30.244	
7/3/2014 5:30	24.319	30.283	0.920	24.066	30.21	
7/3/2014 5:45	24.322	29.965	0.807	24.275	30.185	
7/3/2014 6:00	24.3	30.231	0.708	24.388	30.145	
7/3/2014 6:15	24.286	30.123	0.598	24.462	30.177	
7/3/2014 6:30	24.23	30.096	0.472	24.552	30.146	
7/3/2014 6:45	24.176	30.086	0.353	24.62	30.139	
7/3/2014 7:00	24.119	30.020	0.236	24.665	30.114	
7/3/2014 7:15	24.063	29.970	0.122	24.703	30.161	
7/3/2014 7:30	24.023	29.889	0.012	24.729	30.151	
7/3/2014 7:45	23.973	29.803	-0.104	24.747	30.069	
7/3/2014 8:00	23.899	29.740	-0.232	24.77	30.081	
7/3/2014 8:15	23.791	29.659	-0.358	24.772	30.04	
7/3/2014 8:30	23.759	29.596	-0.488	24.788	29.99	
7/3/2014 8:45	24.166	29.396	-0.617	24.816	29.958	
7/3/2014 9:00	24.372	28.985	-0.670	24.843	29.874	
7/3/2014 9:15	24.31	28.464	-0.669	24.868	29.839	
7/3/2014 9:30	24.287	28.354	-0.671	24.894	29.781	
7/3/2014 9:45	24.418	27.978	-0.677	24.942	29.721	
7/3/2014 10:00	24.402	27.868	-0.671	25.07	29.631	
7/3/2014 10:15	25.096	27.709	-0.673	25.274	29.494	
7/3/2014 10:30	25.374	27.621	-0.671	25.403	29.394	
7/3/2014 10:45	24.831	27.778	-0.667	25.454	29.285	
7/3/2014 11:00	24.737	27.747	-0.666	25.517	29.256	
7/3/2014 11:15	24.159	27.728	-0.665	25.554	29.223	
7/3/2014 11:30	23.815	27.718	-0.666	25.595	29.213	
7/3/2014 11:45	23.848	27.615	-0.666	25.512	29.219	
7/3/2014 12:00	24.011	27.450	-0.666	25.569	29.231	
7/3/2014 12:15	24.317	27.401	-0.667	25.647	29.46	
7/3/2014 12:30	24.96	27.597	-0.609	25.711	29.797	
7/3/2014 12:45	25.458	27.671	-0.501	25.809	29.874	
7/3/2014 13:00	25.358	27.555	-0.376	25.9	29.955	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/3/2014 13:15	25.594	27.975	-0.261	25.907	29.987	
7/3/2014 13:30	25.588	28.589	-0.143	25.87	30.053	
7/3/2014 13:45	25.794	29.106	-0.005	25.845	30.077	
7/3/2014 14:00	25.944	29.436	0.140	25.787	30.129	
7/3/2014 14:15	25.983	29.635	0.293	25.73	30.134	
7/3/2014 14:30	26.013	29.796	0.442	25.69	30.18	
7/3/2014 14:45	25.927	29.797	0.588	25.602	30.203	
7/3/2014 15:00	25.836	29.896	0.737	25.541	30.195	
7/3/2014 15:15	25.672	28.699	0.879	25.417	30.139	
7/3/2014 15:30	25.643	28.354	1.003	25.146	30.08	
7/3/2014 15:45	25.579	29.307	1.094	24.87	30.139	
7/3/2014 16:00	25.525	30.246	1.154	24.627	30.168	
7/3/2014 16:15	25.46	30.377	1.181	24.473	30.201	
7/3/2014 16:30	25.394	30.174	1.206	24.343	30.232	
7/3/2014 16:45	25.351	30.185	1.233	24.224	30.229	
7/3/2014 17:00	25.313	30.195	1.206	24.157	30.209	
7/3/2014 17:15	25.409	30.184	1.120	24.355	30.275	
7/3/2014 17:30	25.653	30.225	1.030	24.757	30.252	
7/3/2014 17:45	25.785	30.273	0.957	25.068	30.245	
7/3/2014 18:00	25.872	30.234	0.865	25.348	30.28	
7/3/2014 18:15	26.02	30.194	0.785	25.575	30.28	
7/3/2014 18:30	26.083	30.220	0.687	25.705	30.305	
7/3/2014 18:45	26.188	30.232	0.577	25.878	30.237	
7/3/2014 19:00	26.334	30.240	0.455	26.04	30.222	
7/3/2014 19:15	26.439	30.229	0.357	26.149	30.204	
7/3/2014 19:30	26.43	30.232	0.261	26.225	30.222	
7/3/2014 19:45	26.545	30.188	0.160	26.308	30.182	
7/3/2014 20:00	26.488	30.169	0.052	26.381	30.165	
7/3/2014 20:15	26.486	30.179	-0.064	26.456	30.157	
7/3/2014 20:30	26.325	30.127	-0.185	26.539	30.188	
7/3/2014 20:45	26.045	30.057	-0.305	26.608	30.136	
7/3/2014 21:00	25.657	29.984	-0.423	26.645	30.114	
7/3/2014 21:15	25.098	29.880	-0.543	26.667	30.099	
7/3/2014 21:30	24.381	29.724	-0.655	26.659	30.083	
7/3/2014 21:45	23.67	28.096	-0.666	26.592	30.015	
7/3/2014 22:00	23.4	27.013	-0.663	26.458	30.036	
7/3/2014 22:15	23.054	26.821	-0.665	26.264	29.969	
7/3/2014 22:30	22.813	26.613	-0.663	26.049	29.924	
7/3/2014 22:45	22.606	26.641	-0.666	25.794	29.873	
7/3/2014 23:00	22.721	28.420	-0.628	25.421	29.764	
7/3/2014 23:15	22.107	24.525	-0.595	25.4	29.503	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/3/2014 23:30	21.653	25.062	-0.613	25.271	29.057	
7/3/2014 23:45	21.494	25.045	-0.627	25.216	28.75	
7/4/2014 0:00	21.344	24.647	-0.637	25.13	28.527	
7/4/2014 0:15	21.17	23.926	-0.654	25.045	28.244	
7/4/2014 0:30	20.997	23.204	-0.641	25.123	28.13	
7/4/2014 0:45	20.866	23.156	-0.527	25.282	28.024	
7/4/2014 1:00	21.067	23.045	-0.416	25.301	28.084	
7/4/2014 1:15	21.855	24.271	-0.298	25.416	28.612	
7/4/2014 1:30	22.269	24.826	-0.192	25.526	29.055	
7/4/2014 1:45	22.512	25.186	-0.056	25.561	29.344	
7/4/2014 2:00	23.144	26.072	0.076	25.46	29.508	
7/4/2014 2:15	23.548	27.071	0.203	25.358	29.67	
7/4/2014 2:30	23.825	27.658	0.357	25.287	29.699	
7/4/2014 2:45	24.162	28.523	0.495	25.198	29.731	
7/4/2014 3:00	24.254	28.907	0.636	25.058	29.812	
7/4/2014 3:15	24.47	29.312	0.770	24.85	29.837	
7/4/2014 3:30	24.467	29.486	0.884	24.69	29.82	
7/4/2014 3:45	24.514	29.443	0.996	24.547	29.82	
7/4/2014 4:00	24.448	29.582	1.059	24.331	29.809	
7/4/2014 4:15	24.47	29.639	1.099	24.139	29.783	
7/4/2014 4:30	24.434	29.736	1.131	23.923	29.796	
7/4/2014 4:45	24.414	29.760	1.123	23.801	29.828	
7/4/2014 5:00	24.425	29.803	1.114	23.762	29.848	
7/4/2014 5:15	24.412	29.821	1.169	23.703	29.852	
7/4/2014 5:30	24.386	29.913	1.149	23.332	29.915	
7/4/2014 5:45	24.406	29.873	1.025	23.717	29.927	
7/4/2014 6:00	24.395	29.864	0.913	24.218	29.904	
7/4/2014 6:15	24.373	29.752	0.815	24.409	29.907	
7/4/2014 6:30	24.327	29.730	0.696	24.528	29.942	
7/4/2014 6:45	24.282	29.591	0.581	24.616	29.877	
7/4/2014 7:00	24.152	29.575	0.482	24.668	29.903	
7/4/2014 7:15	24.117	29.497	0.408	24.708	29.821	
7/4/2014 7:30	24.069	29.457	0.307	24.729	29.775	
7/4/2014 7:45	23.912	29.403	0.193	24.723	29.748	
7/4/2014 8:00	23.745	29.361	0.080	24.679	29.649	
7/4/2014 8:15	23.517	29.230	-0.020	24.615	29.481	
7/4/2014 8:30	23.329	29.148	-0.133	24.538	29.313	
7/4/2014 8:45	23.11	28.893	-0.261	24.418	29.076	
7/4/2014 9:00	22.914	28.578	-0.388	24.286	28.724	
7/4/2014 9:15	22.76	28.070	-0.518	24.147	28.289	
7/4/2014 9:30	22.613	27.751	-0.640	23.961	27.746	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/4/2014 9:45	22.47	27.386	-0.661	23.704	27.306	
7/4/2014 10:00	22.415	26.982	-0.663	23.537	26.81	
7/4/2014 10:15	22.266	26.800	-0.662	23.468	26.479	
7/4/2014 10:30	22.086	26.712	-0.661	23.42	26.171	
7/4/2014 10:45	22.089	26.589	-0.663	23.398	26.024	
7/4/2014 11:00	22.248	26.391	-0.664	23.414	25.931	
7/4/2014 11:15	22.386	26.351	-0.666	23.482	26.158	
7/4/2014 11:30	22.409	26.502	-0.665	23.516	26.409	
7/4/2014 11:45	22.216	26.507	-0.670	23.625	26.416	
7/4/2014 12:00	22.037	26.395	-0.668	23.722	26.688	
7/4/2014 12:15	21.916	26.355	-0.666	23.739	26.847	
7/4/2014 12:30	21.737	26.279	-0.674	23.738	26.747	
7/4/2014 12:45	21.561	26.280	-0.670	23.838	26.543	
7/4/2014 13:00	21.475	26.289	-0.670	24.281	26.625	
7/4/2014 13:15	21.435	26.709	-0.597	24.61	27.131	
7/4/2014 13:30	21.57	26.855	-0.491	24.723	27.424	
7/4/2014 13:45	22.117	26.862	-0.375	24.768	27.638	
7/4/2014 14:00	22.496	26.708	-0.246	24.782	27.816	
7/4/2014 14:15	22.674	26.562	-0.124	24.775	27.969	
7/4/2014 14:30	22.779	26.348	0.024	24.734	28.147	
7/4/2014 14:45	23.068	26.594	0.184	24.636	28.345	
7/4/2014 15:00	23.305	26.952	0.337	24.545	28.511	
7/4/2014 15:15	23.557	27.237	0.478	24.467	28.633	
7/4/2014 15:30	23.757	27.515	0.622	24.322	28.733	
7/4/2014 15:45	23.743	27.624	0.744	24.137	28.858	
7/4/2014 16:00	23.82	27.852	0.894	23.944	28.936	
7/4/2014 16:15	23.867	28.004	1.022	23.624	29.068	
7/4/2014 16:30	23.862	28.121	1.089	23.217	29.196	
7/4/2014 16:45	23.842	28.206	1.128	23.011	29.272	
7/4/2014 17:00	23.804	28.258	1.138	22.779	29.279	
7/4/2014 17:15	23.766	28.358	1.177	22.618	29.389	
7/4/2014 17:30	23.722	28.415	1.215	22.283	29.469	
7/4/2014 17:45	23.714	28.494	1.217	22.04	29.502	
7/4/2014 18:00	23.713	28.551	1.111	22.338	29.548	
7/4/2014 18:15	23.769	28.563	1.001	22.98	29.497	
7/4/2014 18:30	23.769	28.572	0.972	23.307	29.299	
7/4/2014 18:45	23.72	28.504	0.900	23.481	29.131	
7/4/2014 19:00	23.722	28.353	0.777	23.576	28.934	
7/4/2014 19:15	23.698	28.275	0.690	23.78	28.729	
7/4/2014 19:30	23.7	28.207	0.618	23.847	28.579	
7/4/2014 19:45	23.691	28.123	0.520	23.875	28.256	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/4/2014 20:00	23.726	28.072	0.416	23.904	28.039	
7/4/2014 20:15	23.725	28.075	0.300	23.898	27.757	
7/4/2014 20:30	23.666	28.057	0.169	23.848	27.385	
7/4/2014 20:45	23.6	28.058	0.046	23.709	26.713	
7/4/2014 21:00	23.5	28.033	-0.060	23.52	25.794	
7/4/2014 21:15	23.322	28.026	-0.169	23.267	24.831	
7/4/2014 21:30	22.986	28.074	-0.272	23.019	23.437	
7/4/2014 21:45	22.219	27.739	-0.391	22.802	22.189	
7/4/2014 22:00	21.028	26.501	-0.517	22.338	20.212	
7/4/2014 22:15	20.445	24.929	-0.619	21.885	17.664	
7/4/2014 22:30	20.233	23.731	-0.662	21.482	16.261	
7/4/2014 22:45	20.053	22.507	-0.659	20.961	14.78	
7/4/2014 23:00	19.916	21.810	-0.658	20.769	14.067	
7/4/2014 23:15	19.745	21.664	-0.658	20.492	13.615	
7/4/2014 23:30	19.643	21.550	-0.660	20.256	13.457	
7/4/2014 23:45	19.381	21.447	-0.658	19.983	13.468	
7/5/2014 0:00	19.234	21.405	-0.662	19.726	13.918	
7/5/2014 0:15	19.144	21.662	-0.665	19.787	14.122	
7/5/2014 0:30	19.025	21.635	-0.665	20.062	13.806	
7/5/2014 0:45	18.889	21.584	-0.668	20.424	13.763	
7/5/2014 1:00	18.806	21.801	-0.638	20.455	13.762	
7/5/2014 1:15	18.854	22.616	-0.536	20.651	13.911	
7/5/2014 1:30	18.867	22.848	-0.430	21.815	18.961	
7/5/2014 1:45	18.802	22.824	-0.366	22.206	20.47	
7/5/2014 2:00	18.779	22.944	-0.278	22.337	20.859	
7/5/2014 2:15	18.727	23.009	-0.184	22.4	20.998	
7/5/2014 2:30	18.614	22.818	-0.055	22.499	21.452	
7/5/2014 2:45	18.747	22.666	0.077	22.544	22.531	
7/5/2014 3:00	18.946	22.625	0.166	22.574	23.08	
7/5/2014 3:15	19.739	23.163	0.285	22.593	23.552	
7/5/2014 3:30	20.296	22.867	0.414	22.559	24.108	
7/5/2014 3:45	20.69	22.728	0.548	22.493	24.727	
7/5/2014 4:00	20.956	22.638	0.653	22.434	25.12	
7/5/2014 4:15	21.146	22.708	0.773	22.332	25.439	
7/5/2014 4:30	21.336	22.811	0.856	22.193	25.658	
7/5/2014 4:45	21.41	23.076	0.932	22.079	25.913	
7/5/2014 5:00	21.561	23.262	0.975	21.995	26.067	
7/5/2014 5:15	21.625	23.684	0.948	21.933	26.152	
7/5/2014 5:30	21.67	23.938	0.883	21.94	26.19	
7/5/2014 5:45	21.734	24.096	0.908	21.935	26.185	
7/5/2014 6:00	21.729	24.212	0.962	21.902	26.142	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/5/2014 6:15	21.773	24.256	0.911	21.889	26.142	
7/5/2014 6:30	21.791	24.293	0.839	21.908	26.164	
7/5/2014 6:45	21.769	24.248	0.752	21.94	26.155	
7/5/2014 7:00	21.777	24.198	0.655	21.962	26.003	
7/5/2014 7:15	21.704	24.156	0.564	21.99	25.73	
7/5/2014 7:30	21.729	24.154	0.471	22.001	25.541	
7/5/2014 7:45	21.728	24.125	0.364	21.983	25.283	
7/5/2014 8:00	21.709	24.059	0.261	21.934	24.808	
7/5/2014 8:15	21.652	23.957	0.173	21.897	24.45	
7/5/2014 8:30	21.58	23.906	0.072	21.789	24.066	
7/5/2014 8:45	21.395	23.796	-0.040	21.67	23.578	
7/5/2014 9:00	20.762	23.725	-0.161	21.522	22.89	
7/5/2014 9:15	19.871	23.367	-0.277	21.36	22.266	
7/5/2014 9:30	19.893	22.678	-0.388	21.281	22.017	
7/5/2014 9:45	19.875	22.150	-0.513	21.086	21.232	
7/5/2014 10:00	20.084	21.888	-0.632	20.451	18.482	
7/5/2014 10:15	20.403	21.481	-0.651	20.109	16.559	
7/5/2014 10:30	20.652	21.060	-0.655	20.133	15.471	
7/5/2014 10:45	20.978	20.928	-0.652	20.489	16.267	
7/5/2014 11:00	21.239	20.976	-0.654	21.197	17.188	
7/5/2014 11:15	21.592	21.209	-0.657	21.562	17.292	
7/5/2014 11:30	21.838	21.663	-0.659	22.084	17.541	
7/5/2014 11:45	22.1	22.005	-0.657	22.493	17.541	
7/5/2014 12:00	22.411	22.370	-0.659	22.832	17.68	
7/5/2014 12:15	22.74	22.565	-0.657	23.129	17.838	
7/5/2014 12:30	23.077	22.783	-0.660	23.499	18.199	
7/5/2014 12:45	23.365	22.982	-0.662	24.105	19.393	
7/5/2014 13:00	23.667	23.320	-0.662	24.203	19.548	
7/5/2014 13:15	23.881	23.398	-0.664	24.058	19.433	
7/5/2014 13:30	24.014	23.554	-0.666	24.161	19.046	
7/5/2014 13:45	24.156	23.675	-0.671	24.311	19.815	
7/5/2014 14:00	24.386	23.710	-0.671	23.407	19.136	
7/5/2014 14:15	24.61	23.682	-0.645	23.006	18.731	
7/5/2014 14:30	24.537	24.059	-0.546	22.881	18.81	
7/5/2014 14:45	24.945	24.524	-0.436	22.795	19.081	
7/5/2014 15:00	25.262	24.873	-0.293	22.594	19.457	
7/5/2014 15:15	25.353	25.100	-0.141	22.501	20.186	
7/5/2014 15:30	24.144	25.080	0.023	22.474	20.939	
7/5/2014 15:45	23.508	24.779	0.180	22.465	21.515	
7/5/2014 16:00	23.101	24.270	0.353	22.418	22.156	
7/5/2014 16:15	22.833	23.754	0.520	22.303	22.888	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/5/2014 16:30	22.684	23.107	0.659	22.163	23.434	
7/5/2014 16:45	22.579	22.743	0.794	21.851	24.181	
7/5/2014 17:00	22.489	22.343	0.926	21.355	25.021	
7/5/2014 17:15	22.414	22.329	1.012	20.864	25.74	
7/5/2014 17:30	22.353	22.506	1.063	20.554	26.125	
7/5/2014 17:45	22.286	22.628	1.126	20.123	26.641	
7/5/2014 18:00	22.151	22.806	1.188	19.568	27.202	
7/5/2014 18:15	22.003	23.159	1.183	19.261	27.505	
7/5/2014 18:30	21.955	23.511	1.112	19.41	27.519	
7/5/2014 18:45	21.958	23.634	1.048	19.776	27.499	
7/5/2014 19:00	21.942	23.697	1.036	19.947	27.267	
7/5/2014 19:15	21.947	23.805	0.966	20.003	27.168	
7/5/2014 19:30	21.979	23.853	0.857	20.348	26.937	
7/5/2014 19:45	21.954	23.858	0.787	20.501	26.677	
7/5/2014 20:00	21.96	23.850	0.711	20.499	26.597	
7/5/2014 20:15	21.959	23.822	0.606	20.853	26.371	
7/5/2014 20:30	21.997	23.797	0.478	21.19	25.644	
7/5/2014 20:45	22.005	23.647	0.373	21.29	25.415	
7/5/2014 21:00	22.033	23.582	0.274	21.231	25.298	
7/5/2014 21:15	22.066	23.513	0.159	21.719	24.167	
7/5/2014 21:30	22.198	23.402	0.037	22.02	22.827	
7/5/2014 21:45	22.128	23.113	-0.088	22.123	22.374	
7/5/2014 22:00	22.109	22.496	-0.212	22.151	21.977	
7/5/2014 22:15	21.881	21.967	-0.344	22.154	21.547	
7/5/2014 22:30	21.531	21.499	-0.476	22.149	21.235	
7/5/2014 22:45	20.9	21.419	-0.605	22.101	20.982	
7/5/2014 23:00	20.227	21.534	-0.658	21.998	20.707	
7/5/2014 23:15	19.694	21.546	-0.659	21.863	20.375	
7/5/2014 23:30	19.248	21.699	-0.659	21.709	20.158	
7/5/2014 23:45	18.77	21.840	-0.656	21.35	20.157	
7/6/2014 0:00	18.453	21.988	-0.659	20.672	21.214	
7/6/2014 0:15	18.062	22.157	-0.660	20.384	21.587	
7/6/2014 0:30	17.76	22.315	-0.661	20.26	21.717	
7/6/2014 0:45	17.454	22.415	-0.662	19.966	22.193	
7/6/2014 1:00	17.192	22.498	-0.665	19.815	22.349	
7/6/2014 1:15	16.889	22.627	-0.667	19.579	22.91	
7/6/2014 1:30	16.658	22.693	-0.668	19.646	22.916	
7/6/2014 1:45	16.46	22.802	-0.670	19.744	22.557	
7/6/2014 2:00	16.252	22.786	-0.673	19.622	23.283	
7/6/2014 2:15	16.076	22.876	-0.670	19.643	23.21	
7/6/2014 2:30	15.915	22.956	-0.671	20.023	23.047	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/6/2014 2:45	15.905	23.117	-0.569	20.561	22.216	
7/6/2014 3:00	16.032	23.424	-0.470	20.626	22.085	
7/6/2014 3:15	16.212	23.527	-0.360	20.786	22.063	
7/6/2014 3:30	16.455	23.600	-0.240	20.792	22.038	
7/6/2014 3:45	16.914	23.552	-0.110	20.759	22.189	
7/6/2014 4:00	19.036	24.035	0.024	20.625	22.487	
7/6/2014 4:15	19.687	24.272	0.151	20.524	22.842	
7/6/2014 4:30	20.046	24.446	0.289	20.437	23.121	
7/6/2014 4:45	20.225	24.531	0.428	20.296	23.457	
7/6/2014 5:00	20.286	24.518	0.562	20.106	23.841	
7/6/2014 5:15	20.206	24.557	0.683	19.832	24.348	
7/6/2014 5:30	20.173	24.538	0.780	19.539	24.718	
7/6/2014 5:45	20.142	24.531	0.854	19.258	25.072	
7/6/2014 6:00	20.119	24.488	0.918	18.945	25.489	
7/6/2014 6:15	20.081	24.425	0.938	18.659	25.815	
7/6/2014 6:30	20.041	24.325	0.888	18.53	25.931	
7/6/2014 6:45	20.048	24.268	0.849	18.553	25.932	
7/6/2014 7:00	20.067	24.204	0.798	18.57	25.975	
7/6/2014 7:15	20.071	24.111	0.737	18.589	25.991	
7/6/2014 7:30	20.111	24.082	0.662	18.785	25.939	
7/6/2014 7:45	20.116	23.952	0.609	18.872	25.939	
7/6/2014 8:00	20.155	23.902	0.549	18.886	25.887	
7/6/2014 8:15	20.135	23.862	0.472	19.101	25.748	
7/6/2014 8:30	20.046	23.881	0.374	19.433	25.31	
7/6/2014 8:45	19.968	23.902	0.274	19.642	24.984	
7/6/2014 9:00	19.775	23.897	0.183	19.882	24.501	
7/6/2014 9:15	19.51	23.885	0.084	20.049	23.974	
7/6/2014 9:30	19.336	23.897	-0.018	20.148	23.631	
7/6/2014 9:45	19.319	23.875	-0.127	20.209	23.394	
7/6/2014 10:00	19.374	23.557	-0.244	20.26	23.183	
7/6/2014 10:15	19.551	23.373	-0.363	20.3	22.986	
7/6/2014 10:30	19.973	23.266	-0.491	20.314	22.783	
7/6/2014 10:45	20.961	23.269	-0.603	20.346	22.654	
7/6/2014 11:00	21.808	23.245	-0.665	20.49	22.5	
7/6/2014 11:15	22.487	23.325	-0.662	20.693	22.325	
7/6/2014 11:30	22.743	23.706	-0.666	20.988	22.211	
7/6/2014 11:45	23.217	23.974	-0.667	21.422	22.169	
7/6/2014 12:00	23.67	24.176	-0.670	21.997	22.366	
7/6/2014 12:15	23.868	24.430	-0.671	22.47	22.526	
7/6/2014 12:30	24.364	24.498	-0.669	23.364	22.742	
7/6/2014 12:45	24.579	24.483	-0.669	23.674	23.4	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/6/2014 13:00	24.333	24.483	-0.671	23.749	23.481	
7/6/2014 13:15	24.467	24.510	-0.676	23.675	23.098	
7/6/2014 13:30	24.796	24.593	-0.673	23.796	23.307	
7/6/2014 13:45	25.087	24.576	-0.673	23.776	23.257	
7/6/2014 14:00	25.24	24.659	-0.675	23.697	23.012	
7/6/2014 14:15	25.531	24.690	-0.673	23.648	23.162	
7/6/2014 14:30	25.445	24.728	-0.669	22.908	22.969	
7/6/2014 14:45	25.082	24.949	-0.581	22.667	22.897	
7/6/2014 15:00	25.659	25.224	-0.464	22.513	22.916	
7/6/2014 15:15	24.84	25.684	-0.363	22.345	22.974	
7/6/2014 15:30	24.182	25.966	-0.252	22.189	23.064	
7/6/2014 15:45	23.762	26.040	-0.114	22.056	23.23	
7/6/2014 16:00	23.357	25.416	0.035	21.904	23.536	
7/6/2014 16:15	22.972	24.876	0.175	21.728	23.875	
7/6/2014 16:30	22.729	24.779	0.330	21.572	24.039	
7/6/2014 16:45	22.516	24.535	0.485	21.304	24.54	
7/6/2014 17:00	22.334	24.410	0.643	20.921	25.174	
7/6/2014 17:15	22.146	24.481	0.783	20.475	25.71	
7/6/2014 17:30	21.979	24.532	0.919	19.827	26.559	
7/6/2014 17:45	21.807	24.568	1.042	19.156	27.373	
7/6/2014 18:00	21.607	24.740	1.132	18.679	27.923	
7/6/2014 18:15	21.337	25.047	1.198	18.272	28.449	
7/6/2014 18:30	20.995	25.161	1.241	17.844	28.844	
7/6/2014 18:45	20.66	25.634	1.265	17.61	28.993	
7/6/2014 19:00	20.443	25.929	1.264	17.461	29.14	
7/6/2014 19:15	20.257	26.143	1.235	17.463	29.287	
7/6/2014 19:30	20.206	26.266	1.187	17.636	29.174	
7/6/2014 19:45	20.242	26.392	1.123	17.904	29.207	
7/6/2014 20:00	20.252	26.483	1.042	18.128	29.003	
7/6/2014 20:15	20.254	26.490	0.954	18.337	28.745	
7/6/2014 20:30	20.269	26.507	0.870	18.596	28.582	
7/6/2014 20:45	20.325	26.507	0.773	18.98	28.205	
7/6/2014 21:00	20.524	26.442	0.675	19.207	27.832	
7/6/2014 21:15	20.684	26.412	0.556	19.602	27.442	
7/6/2014 21:30	21.083	26.315	0.435	20.137	26.777	
7/6/2014 21:45	21.509	26.209	0.322	20.623	25.983	
7/6/2014 22:00	21.757	26.012	0.211	20.876	25.547	
7/6/2014 22:15	21.887	25.673	0.084	21.089	25.244	
7/6/2014 22:30	21.938	25.284	-0.036	21.302	24.868	
7/6/2014 22:45	21.89	24.995	-0.158	21.45	24.576	
7/6/2014 23:00	21.721	24.622	-0.286	21.638	24.326	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/6/2014 23:15	21.486	24.521	-0.412	21.759	24.12	
7/6/2014 23:30	21.137	24.627	-0.547	21.8	23.925	
7/6/2014 23:45	20.606	24.624	-0.652	21.795	23.872	
7/7/2014 0:00	20.203	24.339	-0.661	21.783	23.79	
7/7/2014 0:15	19.887	24.242	-0.665	21.708	23.65	
7/7/2014 0:30	19.638	24.227	-0.666	21.578	23.684	
7/7/2014 0:45	19.45	24.249	-0.666	21.277	23.739	
7/7/2014 1:00	19.256	24.207	-0.667	20.973	23.79	
7/7/2014 1:15	19.059	24.176	-0.667	20.732	24.014	
7/7/2014 1:30	18.828	24.159	-0.669	20.683	24.106	
7/7/2014 1:45	18.646	24.191	-0.670	20.45	24.353	
7/7/2014 2:00	18.445	24.155	-0.670	20.438	24.488	
7/7/2014 2:15	18.28	24.158	-0.670	20.406	24.572	
7/7/2014 2:30	18.138	24.090	-0.669	20.375	24.657	
7/7/2014 2:45	18.049	24.117	-0.673	20.386	24.686	
7/7/2014 3:00	17.964	24.220	-0.674	20.374	24.618	
7/7/2014 3:15	17.844	24.238	-0.667	20.41	24.763	
7/7/2014 3:30	17.815	25.002	-0.562	20.349	24.837	
7/7/2014 3:45	17.934	25.419	-0.460	20.35	24.815	
7/7/2014 4:00	18.149	25.744	-0.350	20.369	24.83	
7/7/2014 4:15	18.752	26.152	-0.219	20.353	24.874	
7/7/2014 4:30	19.572	25.997	-0.085	20.309	25.018	
7/7/2014 4:45	19.775	25.868	0.050	20.214	25.174	
7/7/2014 5:00	19.828	25.841	0.193	20.117	25.41	
7/7/2014 5:15	19.887	25.645	0.344	20.012	25.574	
7/7/2014 5:30	19.916	25.540	0.491	19.862	25.826	
7/7/2014 5:45	19.866	25.564	0.629	19.639	26.145	
7/7/2014 6:00	19.85	25.444	0.767	19.358	26.577	
7/7/2014 6:15	19.823	25.542	0.880	19.075	26.896	
7/7/2014 6:30	19.79	25.661	0.965	18.797	27.23	
7/7/2014 6:45	19.767	25.730	1.025	18.579	27.489	
7/7/2014 7:00	19.711	25.755	1.068	18.426	27.682	
7/7/2014 7:15	19.664	25.854	1.085	18.319	27.828	
7/7/2014 7:30	19.634	25.905	1.061	18.27	27.817	
7/7/2014 7:45	19.647	25.957	1.012	18.292	27.81	
7/7/2014 8:00	19.64	26.030	0.958	18.42	27.731	
7/7/2014 8:15	19.644	26.069	0.888	18.555	27.876	
7/7/2014 8:30	19.673	26.070	0.819	18.676	27.708	
7/7/2014 8:45	19.708	26.119	0.750	18.767	27.585	
7/7/2014 9:00	19.762	26.131	0.664	18.875	27.526	
7/7/2014 9:15	19.803	26.110	0.577	19.049	27.38	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/7/2014 9:30	19.886	26.115	0.480	19.372	26.906	
7/7/2014 9:45	20.011	26.088	0.372	19.665	26.523	
7/7/2014 10:00	20.121	25.908	0.266	19.897	26.255	
7/7/2014 10:15	20.207	25.827	0.162	20.105	26.141	
7/7/2014 10:30	20.322	25.929	0.052	20.346	25.94	
7/7/2014 10:45	20.4	26.179	-0.070	20.564	25.663	
7/7/2014 11:00	20.557	26.399	-0.187	20.746	25.427	
7/7/2014 11:15	20.788	26.286	-0.302	20.945	25.16	
7/7/2014 11:30	21.218	26.057	-0.420	21.172	25.16	
7/7/2014 11:45	21.879	25.839	-0.545	21.423	24.99	
7/7/2014 12:00	23.029	25.850	-0.656	21.705	24.871	
7/7/2014 12:15	23.662	25.304	-0.666	22.109	24.763	
7/7/2014 12:30	24.155	25.418	-0.670	22.643	24.657	
7/7/2014 12:45	24.759	25.420	-0.675	23.11	24.695	
7/7/2014 13:00	25.327	25.348	-0.674	23.788	24.65	
7/7/2014 13:15	25.831	25.451	-0.675	24.453	24.663	
7/7/2014 13:30	25.256	25.525	-0.672	24.821	24.652	
7/7/2014 13:45	24.921	25.173	-0.674	25.037	24.644	
7/7/2014 14:00	25.138	24.789	-0.676	24.935	24.615	
7/7/2014 14:15	25.225	25.135	-0.678	24.836	24.536	
7/7/2014 14:30	25.486	25.460	-0.680	24.681	24.522	
7/7/2014 14:45	25.797	25.635	-0.680	24.477	24.512	
7/7/2014 15:00	25.816	25.727	-0.682	24.357	24.491	
7/7/2014 15:15	25.912	25.900	-0.687	24.073	24.919	
7/7/2014 15:30	25.842	25.744	-0.604	23.402	25.317	
7/7/2014 15:45	26.064	25.794	-0.503	23.162	25.544	
7/7/2014 16:00	25.364	25.755	-0.368	22.962	25.417	
7/7/2014 16:15	24.936	25.853	-0.242	22.721	25.749	
7/7/2014 16:30	24.743	25.703	-0.104	22.565	25.863	
7/7/2014 16:45	24.286	25.651	0.037	22.48	25.852	
7/7/2014 17:00	23.845	25.589	0.185	22.33	25.922	
7/7/2014 17:15	23.436	25.709	0.344	22.15	26.273	
7/7/2014 17:30	23.112	25.988	0.510	21.903	26.408	
7/7/2014 17:45	22.842	26.085	0.672	21.636	26.753	
7/7/2014 18:00	22.593	26.577	0.845	21.229	27.101	
7/7/2014 18:15	22.394	26.207	0.979	20.791	27.304	
7/7/2014 18:30	22.199	26.305	1.099	20.501	27.747	
7/7/2014 18:45	21.963	26.536	1.199	20.114	28.432	
7/7/2014 19:00	21.678	26.685	1.276	19.692	28.901	
7/7/2014 19:15	21.326	27.063	1.338	19.324	29.284	
7/7/2014 19:30	20.947	27.386	1.387	19.074	29.33	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/7/2014 19:45	20.575	27.803	1.413	18.918	29.641	
7/7/2014 20:00	20.234	28.298	1.426	18.83	29.484	
7/7/2014 20:15	20.063	28.666	1.418	18.791	29.454	
7/7/2014 20:30	19.991	28.841	1.395	18.815	29.282	
7/7/2014 20:45	20.058	28.733	1.352	18.909	29.325	
7/7/2014 21:00	20.365	28.463	1.291	19.241	29.186	
7/7/2014 21:15	20.825	28.300	1.175	19.743	28.661	
7/7/2014 21:30	21.198		1.027	20.388	28.04	
7/7/2014 21:45	21.489	27.545	0.890	20.88	27.371	
7/7/2014 22:00	21.624	27.238	0.785	21.168	27.565	
7/7/2014 22:15	21.846	27.336	0.663	21.418	26.82	
7/7/2014 22:30	21.919	27.207	0.521	21.647	26.873	
7/7/2014 22:45	22.032	27.052	0.388	21.85	26.625	
7/7/2014 23:00	22.185	26.879	0.260	22.004	26.186	
7/7/2014 23:15	22.301	26.692	0.133	22.142	26.06	
7/7/2014 23:30	22.399	26.400	0.001	22.269	25.81	
7/7/2014 23:45	22.477	26.182	-0.130	22.385	25.863	
7/8/2014 0:00	22.49	25.824	-0.264	22.501	25.662	
7/8/2014 0:15	22.273	25.595	-0.405	22.594	25.316	
7/8/2014 0:30	21.982	25.400	-0.551	22.569	24.987	
7/8/2014 0:45	21.614	25.193	-0.650	22.586	24.889	
7/8/2014 1:00	21.319	24.866	-0.654	22.587	24.424	
7/8/2014 1:15	21.065	24.555	-0.662	22.572	24.007	
7/8/2014 1:30	20.777	24.315	-0.660	22.478	23.728	
7/8/2014 1:45	20.499	24.203	-0.664	22.222	23.693	
7/8/2014 2:00	20.22	24.174	-0.662	21.979	23.703	
7/8/2014 2:15	19.976	24.092	-0.665	21.782	23.789	
7/8/2014 2:30	19.767	24.024	-0.667	21.701	23.596	
7/8/2014 2:45	19.558	24.089	-0.668	21.475	24.223	
7/8/2014 3:00	19.382	24.168	-0.670	21.323	24.483	
7/8/2014 3:15	19.265	24.181	-0.670	21.315	24.341	
7/8/2014 3:30	19.179	24.243	-0.671	21.177	24.682	
7/8/2014 3:45	19.083	24.487	-0.671	21.202	24.698	
7/8/2014 4:00	18.934	24.575	-0.674	21.234	24.815	
7/8/2014 4:15	18.838	24.581	-0.641	21.688	24.699	
7/8/2014 4:30	18.879	24.575	-0.542	21.758	24.873	
7/8/2014 4:45	18.938	24.789	-0.434	21.738	25.164	
7/8/2014 5:00	19.043	24.984	-0.304	21.725	25.342	
7/8/2014 5:15	19.789	24.930	-0.164	21.698	25.104	
7/8/2014 5:30	20.576	25.060	-0.032	21.633	25.749	
7/8/2014 5:45	20.823	25.157	0.112	21.559	25.889	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/8/2014 6:00	20.943	25.001	0.272	21.461	25.727	
7/8/2014 6:15	21.036	24.962	0.432	21.331	26.391	
7/8/2014 6:30	21.103	25.079	0.587	21.184	26.597	
7/8/2014 6:45	21.101	25.240	0.734	21.033	26.751	
7/8/2014 7:00	21.089	25.393	0.865	20.861	27.101	
7/8/2014 7:15	21.063	25.523	0.979	20.646	27.388	
7/8/2014 7:30	21.03	25.713	1.070	20.388	27.401	
7/8/2014 7:45	20.994	25.871	1.139	20.192	27.93	
7/8/2014 8:00	20.969	25.991	1.163	20.079	28.058	
7/8/2014 8:15	20.943	26.091	1.158	20.009	28.083	
7/8/2014 8:30	20.942	26.208	1.131	20.014	28.147	
7/8/2014 8:45	20.94	26.294	1.095	20.072	28.141	
7/8/2014 9:00	20.999	26.173	1.022	20.189	27.93	
7/8/2014 9:15	21.051	26.024	0.949	20.343	28.143	
7/8/2014 9:30	21.137	25.786	0.894	20.523	28.039	
7/8/2014 9:45	21.235	26.387	0.803	20.644	27.902	
7/8/2014 10:00	21.402	26.471	0.695	21.152	27.646	
7/8/2014 10:15	21.571	26.474	0.603	21.397	27.326	
7/8/2014 10:30	21.734	26.403	0.500	21.665	27.081	
7/8/2014 10:45	21.911	26.283	0.399	21.909	26.861	
7/8/2014 11:00	22.041	26.187	0.293	22.063	26.688	
7/8/2014 11:15	22.194	26.049	0.179	22.216	26.511	
7/8/2014 11:30	22.26	25.855	0.065	22.383	26.349	
7/8/2014 11:45	22.391	25.420	-0.049	22.554	26.17	
7/8/2014 12:00	22.608	25.265	-0.167	22.739	26.008	
7/8/2014 12:15	22.85	25.128	-0.296	22.939	25.77	
7/8/2014 12:30	23.189	24.929	-0.421	23.138	25.498	
7/8/2014 12:45	23.79	25.108	-0.546	23.353	25.206	
7/8/2014 13:00	24.615	25.105	-0.661	23.613	24.975	
7/8/2014 13:15	25.107	24.488	-0.667	24.076	24.767	
7/8/2014 13:30	25.439	24.402	-0.669	24.577	24.706	
7/8/2014 13:45	25.677	24.378	-0.670	25.016	24.591	
7/8/2014 14:00	25.732	24.254	-0.672	25.512	24.496	
7/8/2014 14:15	26.011	24.720	-0.672	25.861	24.546	
7/8/2014 14:30	26.256	24.272	-0.675	26.292	24.591	
7/8/2014 14:45	26.377	24.641	-0.674	26.474	24.625	
7/8/2014 15:00	26.465	24.451	-0.674	26.527	24.526	
7/8/2014 15:15	26.524	24.681	-0.676	26.463	24.196	
7/8/2014 15:30	26.578	24.712	-0.676	26.182	24.447	
7/8/2014 15:45	26.11	24.714	-0.676	25.978	24.378	
7/8/2014 16:00	26.248	24.650	-0.678	25.826	24.468	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/8/2014 16:15	26.116	24.764	-0.651	24.897	25.551	
7/8/2014 16:30	25.872	25.125	-0.539	24.658	25.358	
7/8/2014 16:45	25.989	25.353	-0.400	24.547	25.858	
7/8/2014 17:00	25.753	24.448	-0.267	24.319	25.953	
7/8/2014 17:15	25.612	24.705	-0.139	24.084	26.005	
7/8/2014 17:30	25.277	25.198	0.021	23.97	26.371	
7/8/2014 17:45	24.717	25.912	0.179	23.849	26.538	
7/8/2014 18:00	24.391	26.235	0.350	23.745	26.679	
7/8/2014 18:15	24.161	25.961	0.534	23.57	26.9	
7/8/2014 18:30	23.975		0.713	23.291	27.142	
7/8/2014 18:45	23.82		0.885	22.813	27.448	
7/8/2014 19:00	23.678		1.036	22.366	28.011	
7/8/2014 19:15	23.503		1.179	21.762	28.666	
7/8/2014 19:30	23.188		1.282	21.086	28.813	
7/8/2014 19:45	22.72		1.359	20.571	29.525	
7/8/2014 20:00	22.176		1.412	20.256	29.71	
7/8/2014 20:15	21.575		1.458	20.041	29.835	
7/8/2014 20:30	21.117		1.504	19.889	29.7	
7/8/2014 20:45	20.743		1.540	19.746	29.808	
7/8/2014 21:00	20.546		1.560	19.643	30.1	
7/8/2014 21:15	20.419		1.555	19.597	30.111	
7/8/2014 21:30	20.322		1.533	19.592	30.082	
7/8/2014 21:45	20.287		1.505	19.634	29.779	
7/8/2014 22:00	20.352		1.452	19.867	30.046	
7/8/2014 22:15	20.56		1.386	20.18	29.87	
7/8/2014 22:30	20.973		1.294	20.587	29.551	
7/8/2014 22:45	21.434		1.155	21.075	29.178	
7/8/2014 23:00	21.846		0.961	21.557	28.786	
7/8/2014 23:15	22.115		0.751	22.022	28.261	
7/8/2014 23:30	22.334		0.580	22.275	27.953	
7/8/2014 23:45	22.453		0.423	22.423	27.725	
7/9/2014 0:00	22.548		0.268	22.553	27.545	
7/9/2014 0:15	22.692		0.125	22.65	27.376	
7/9/2014 0:30	22.788		-0.012	22.706	27.248	
7/9/2014 0:45	22.802		-0.154	22.713	27.186	
7/9/2014 1:00	22.753		-0.297	22.695	27.138	
7/9/2014 1:15	22.545		-0.441	22.65	26.896	
7/9/2014 1:30	22.216		-0.586	22.597	26.902	
7/9/2014 1:45	21.853		-0.658	22.576	26.766	
7/9/2014 2:00	21.57		-0.661	22.604	26.501	
7/9/2014 2:15	21.341		-0.661	22.577	26.157	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/9/2014 2:30	21.114		-0.663	22.42	25.865	
7/9/2014 2:45	20.88		-0.664	22.193	25.761	
7/9/2014 3:00	20.677		-0.667	21.989	25.664	
7/9/2014 3:15	20.493		-0.669	21.85	25.578	
7/9/2014 3:30	20.307		-0.670	21.722	25.657	
7/9/2014 3:45	20.142		-0.672	21.584	25.614	
7/9/2014 4:00	19.977		-0.670	21.369	25.707	
7/9/2014 4:15	19.832		-0.673	21.274	25.792	
7/9/2014 4:30	19.633		-0.671	21.22	25.842	
7/9/2014 4:45	19.46		-0.672	21.277	25.799	
7/9/2014 5:00	19.303		-0.667	21.477	25.729	
7/9/2014 5:15	19.163		-0.666	21.866	26.03	
7/9/2014 5:30	19.053		-0.613	22.193	26.534	
7/9/2014 5:45	19.09		-0.532	22.289	26.615	
7/9/2014 6:00	19.141		-0.393	22.293	26.779	
7/9/2014 6:15	19.565		-0.253	22.313	26.882	
7/9/2014 6:30	20.073		-0.103	22.313	27.045	
7/9/2014 6:45	20.638		0.058	22.284	27.216	
7/9/2014 7:00	21.079		0.222	22.241	27.362	
7/9/2014 7:15	21.367		0.391	22.172	27.545	
7/9/2014 7:30	21.551		0.559	22.077	27.716	
7/9/2014 7:45	21.64		0.724	21.976	27.83	
7/9/2014 8:00	21.665		0.881	21.799	27.728	
7/9/2014 8:15	21.667		1.006	21.53	28.26	
7/9/2014 8:30	21.667		1.100	21.18	28.417	
7/9/2014 8:45	21.677		1.161	20.91	28.717	
7/9/2014 9:00	21.671		1.215	20.706	28.958	
7/9/2014 9:15	21.668		1.227	20.601	28.785	
7/9/2014 9:30	21.659		1.162	20.638	28.938	
7/9/2014 9:45	21.738		1.091	21.056	29.085	
7/9/2014 10:00	21.827		1.072	21.177	29.086	
7/9/2014 10:15	21.928		1.004	21.258	29.041	
7/9/2014 10:30	22.026		0.891	21.711	28.927	
7/9/2014 10:45	22.146		0.811	22.072	28.605	
7/9/2014 11:00	22.277		0.721	22.286	28.458	
7/9/2014 11:15	22.411		0.608	22.636	28.36	
7/9/2014 11:30	22.546		0.484	22.896	27.971	
7/9/2014 11:45	22.692		0.361	23.076	27.967	
7/9/2014 12:00	22.865		0.246	23.248	27.858	
7/9/2014 12:15	23		0.131	23.43	27.73	
7/9/2014 12:30	23.159		0.010	23.631	27.65	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/9/2014 12:45	23.349		-0.119	23.837	27.516	
7/9/2014 13:00	23.463		-0.244	24.054	27.432	
7/9/2014 13:15	23.667		-0.375	24.268	27.048	
7/9/2014 13:30	23.915		-0.509	24.482	27.209	
7/9/2014 13:45	24.308		-0.638	24.69	27.087	
7/9/2014 14:00	24.655		-0.669	24.877	26.961	
7/9/2014 14:15	25.077		-0.669	25.108	26.719	
7/9/2014 14:30	25.44		-0.672	25.385	26.534	
7/9/2014 14:45	25.738		-0.674	25.846	26.287	
7/9/2014 15:00	25.995		-0.672	26.341	26.14	
7/9/2014 15:15	26.143		-0.674	26.717	25.88	
7/9/2014 15:30	26.032		-0.673	26.909	26.073	
7/9/2014 15:45	25.791		-0.678	27.025	26.011	
7/9/2014 16:00	25.579		-0.678	27.117	26.079	
7/9/2014 16:15	25.676		-0.679	27.068	26.128	
7/9/2014 16:30	25.227		-0.679	26.665	26.158	
7/9/2014 16:45	24.827		-0.683	26.462	26.134	
7/9/2014 17:00	24.735		-0.682	26.029	26.757	
7/9/2014 17:15	24.802		-0.677	25.45	27.194	
7/9/2014 17:30	24.628		-0.580	25.237	27.287	
7/9/2014 17:45	24.641		-0.442	25.134	27.36	
7/9/2014 18:00	24.955		-0.287	24.988	27.435	
7/9/2014 18:15	25.178		-0.132	24.797	27.589	
7/9/2014 18:30	25.15		0.029	24.641	27.734	
7/9/2014 18:45	24.976		0.194	24.51	27.84	
7/9/2014 19:00	24.766		0.380	24.363	27.951	
7/9/2014 19:15	24.551		0.573	24.108	28.102	
7/9/2014 19:30	24.373		0.772	23.741	28.245	
7/9/2014 19:45	24.243		0.964	23.288	28.491	
7/9/2014 20:00	24.084		1.132	22.676	28.939	
7/9/2014 20:15	23.912		1.258	22.089	29.295	
7/9/2014 20:30	23.62		1.341	21.665	29.491	
7/9/2014 20:45	23.229		1.405	21.352	29.631	
7/9/2014 21:00	22.823		1.464	21.096	29.66	
7/9/2014 21:15	22.432		1.513	20.74	29.887	
7/9/2014 21:30	22.09		1.554	20.494	29.969	
7/9/2014 21:45	21.813		1.589	20.367	29.98	
7/9/2014 22:00	21.551		1.619	20.269	30.077	
7/9/2014 22:15	21.335		1.630	20.211	30.132	
7/9/2014 22:30	21.176		1.596	20.217	30.109	
7/9/2014 22:45	21.081		1.553	20.269	30.003	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/9/2014 23:00	21.041		1.501	20.461	29.95	
7/9/2014 23:15	21.068		1.435	20.713	29.899	
7/9/2014 23:30	21.171		1.357	21.031	29.854	
7/9/2014 23:45	21.343		1.232	21.39	29.59	
7/10/2014 0:00	21.576		1.043	21.786	29.379	
7/10/2014 0:15	21.922		0.811	22.154	29.129	
7/10/2014 0:30	22.122		0.587	22.409	28.896	
7/10/2014 0:45	22.27		0.397	22.568	28.74	
7/10/2014 1:00	22.394		0.236	22.655	28.665	
7/10/2014 1:15	22.489		0.074	22.728	28.578	
7/10/2014 1:30	22.587		-0.078	22.783	28.485	
7/10/2014 1:45	22.605		-0.228	22.805	28.425	
7/10/2014 2:00	22.532		-0.383	22.793	28.353	
7/10/2014 2:15	22.405		-0.540	22.783	28.217	
7/10/2014 2:30	22.11		-0.652	22.711	28.075	
7/10/2014 2:45	21.592		-0.660	22.649	27.9	
7/10/2014 3:00	21.218		-0.660	22.533	27.781	
7/10/2014 3:15	20.931		-0.662	22.256	27.571	
7/10/2014 3:30	20.579		-0.660	21.988	27.479	
7/10/2014 3:45	20.308		-0.662	21.71	27.398	
7/10/2014 4:00	20.042		-0.661	21.433	27.341	
7/10/2014 4:15	19.705		-0.661	21.24	27.274	
7/10/2014 4:30	19.399		-0.662	21.088	27.235	
7/10/2014 4:45	19.123		-0.660	20.864	27.199	
7/10/2014 5:00	18.897		-0.663	20.683	27.171	
7/10/2014 5:15	18.677		-0.664	20.567	27.107	
7/10/2014 5:30	18.505		-0.666	20.349	27.089	
7/10/2014 5:45	18.373		-0.668	20.264	27.034	
7/10/2014 6:00	18.243		-0.669	20.327	27.003	
7/10/2014 6:15	18.13		-0.668	21.381	27.276	
7/10/2014 6:30	18.068		-0.670	21.88	27.536	
7/10/2014 6:45	18.131		-0.550	22.115	27.696	
7/10/2014 7:00	18.354		-0.426	22.275	27.844	
7/10/2014 7:15	18.838		-0.272	22.414	27.99	
7/10/2014 7:30	19.517		-0.088	22.477	28.136	
7/10/2014 7:45	20.251		0.069	22.447	28.253	
7/10/2014 8:00	20.713		0.238	22.398	28.341	
7/10/2014 8:15	21.059		0.432	22.355	28.429	
7/10/2014 8:30	21.269		0.623	22.346	28.364	
7/10/2014 8:45	21.422		0.801	22.231	28.43	
7/10/2014 9:00	21.524		0.945	22.002	28.575	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/10/2014 9:15	21.574		1.064	21.798	28.694	
7/10/2014 9:30	21.618		1.172	21.595	28.828	
7/10/2014 9:45	21.692		1.248	21.32	28.97	
7/10/2014 10:00	21.708		1.282	21.127	29.021	
7/10/2014 10:15	21.691		1.264	21.011	29.099	
7/10/2014 10:30	21.742		1.211	21.159	29.149	
7/10/2014 10:45	21.863		1.145	21.354	29.145	
7/10/2014 11:00	21.981		1.087	21.641	29.16	
7/10/2014 11:15	22.078		1.028	21.845	29.17	
7/10/2014 11:30	22.116		0.916	22.085	29.072	
7/10/2014 11:45	22.212		0.806	22.33	28.93	
7/10/2014 12:00	22.309		0.714	22.554	28.822	
7/10/2014 12:15	22.4		0.594	22.749	28.754	
7/10/2014 12:30	22.481		0.457	22.953	28.642	
7/10/2014 12:45	22.626		0.339	23.107	28.529	
7/10/2014 13:00	22.723		0.215	23.255	28.405	
7/10/2014 13:15	22.847		0.082	23.416	28.452	
7/10/2014 13:30	22.886		-0.052	23.574	28.409	
7/10/2014 13:45	23.041		-0.189	23.745	28.36	
7/10/2014 14:00	23.194		-0.329	23.925	28.286	
7/10/2014 14:15	23.323		-0.471	24.045	28.253	
7/10/2014 14:30	23.535		-0.615	24.154	28.122	
7/10/2014 14:45	23.503		-0.666	24.261	28.001	
7/10/2014 15:00	23.537		-0.665	24.363	27.824	
7/10/2014 15:15	23.513		-0.668	24.475	27.703	
7/10/2014 15:30	23.384		-0.665	24.564	27.411	
7/10/2014 15:45	23.241		-0.670	24.675	27.322	
7/10/2014 16:00	23.239		-0.671	24.738	27.288	
7/10/2014 16:15	23.468		-0.672	24.848	27.2	
7/10/2014 16:30	23.759		-0.674	25.019	27.05	
7/10/2014 16:45	23.947		-0.674	25.343	26.982	
7/10/2014 17:00	23.876		-0.677	25.621	26.941	
7/10/2014 17:15	23.678		-0.683	25.852	26.956	
7/10/2014 17:30	23.432		-0.680	25.704	26.858	
7/10/2014 17:45	23.185		-0.679	25.423	26.863	
7/10/2014 18:00	22.903		-0.679	25.052	27.657	
7/10/2014 18:15	22.579		-0.682	24.737	27.935	
7/10/2014 18:30	22.217		-0.609	24.56	28.046	
7/10/2014 18:45	22.085		-0.461	24.433	28.061	
7/10/2014 19:00	22.811		-0.300	24.328	28.041	
7/10/2014 19:15	23.276		-0.134	24.234	28.267	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/10/2014 19:30	23.328		0.055	24.113	28.441	
7/10/2014 19:45	23.421		0.250	23.973	28.515	
7/10/2014 20:00	23.429		0.459	23.779	28.545	
7/10/2014 20:15	23.409		0.661	23.49	28.571	
7/10/2014 20:30	23.396		0.867	22.989	28.697	
7/10/2014 20:45	23.291		1.066	22.13	29.009	
7/10/2014 21:00	23.098		1.227	21.136	29.268	
7/10/2014 21:15	22.809		1.328	20.039	29.53	
7/10/2014 21:30	22.329		1.405	18.967	29.71	
7/10/2014 21:45	21.679		1.469	18.157	29.87	
7/10/2014 22:00	20.945		1.529	17.257	29.992	
7/10/2014 22:15	20.114		1.581	16.613	30.061	
7/10/2014 22:30	19.318		1.629	16.189	30.108	
7/10/2014 22:45	18.635		1.664	15.912	30.12	
7/10/2014 23:00	18.072		1.683	15.759	30.09	
7/10/2014 23:15	17.738		1.677	15.746	30.098	
7/10/2014 23:30	17.576		1.639	15.789	30.101	
7/10/2014 23:45	17.506		1.592	15.941	30.127	
7/11/2014 0:00	17.583		1.541	16.291	29.796	
7/11/2014 0:15	17.665		1.472	16.841	29.982	
7/11/2014 0:30	17.951		1.391	17.479	29.785	
7/11/2014 0:45	18.453		1.273	18.211	29.663	
7/11/2014 1:00	19.041		1.098	18.992	29.436	
7/11/2014 1:15	19.546		0.865	19.751	29.281	
7/11/2014 1:30	19.985		0.609	20.364	28.996	
7/11/2014 1:45	20.27		0.380	20.728	28.883	
7/11/2014 2:00	20.42		0.194	20.942	28.758	
7/11/2014 2:15	20.535		0.026	21.077	28.637	
7/11/2014 2:30	20.673		-0.140	21.157	28.53	
7/11/2014 2:45	20.71		-0.310	21.201	28.443	
7/11/2014 3:00	20.649		-0.474	21.199	28.38	
7/11/2014 3:15	20.456		-0.628	21.083	28.214	
7/11/2014 3:30	20.157		-0.662	21.058	28.204	
7/11/2014 3:45	19.903		-0.664	20.912	28.126	
7/11/2014 4:00	19.67		-0.663	20.645	27.997	
7/11/2014 4:15	19.365		-0.663	20.405	27.939	
7/11/2014 4:30	19.161		-0.664	20.122	27.835	
7/11/2014 4:45	18.925		-0.662	19.882	27.781	
7/11/2014 5:00	18.728		-0.662	19.682	27.694	
7/11/2014 5:15	18.57		-0.664	19.521	27.656	
7/11/2014 5:30	18.334		-0.665	19.396	27.616	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/11/2014 5:45	18.116		-0.665	19.249	27.556	
7/11/2014 6:00	17.985		-0.665	19.122	27.494	
7/11/2014 6:15	17.848		-0.667	19.008	27.462	
7/11/2014 6:30	17.761		-0.664	18.879	27.398	
7/11/2014 6:45	17.697		-0.662	18.772	27.352	
7/11/2014 7:00	17.64		-0.664	18.751	27.27	
7/11/2014 7:15	17.622		-0.664	18.932	27.252	
7/11/2014 7:30	17.576		-0.664	19.987	27.29	
7/11/2014 7:45	17.572		-0.629	20.675	27.455	
7/11/2014 8:00	17.687		-0.468	20.944	27.514	
7/11/2014 8:15	17.985		-0.293	21.238	27.683	
7/11/2014 8:30	18.415		-0.118	21.266	27.828	
7/11/2014 8:45	19.053		0.073	21.144	27.947	
7/11/2014 9:00	19.574		0.277	21.019	28.007	
7/11/2014 9:15	19.973		0.487	20.937	28.032	
7/11/2014 9:30	20.237		0.687	20.709	28.074	
7/11/2014 9:45	20.345		0.867	20.319	28.113	
7/11/2014 10:00	20.45		1.036	19.871	28.203	
7/11/2014 10:15	20.475		1.170	19.271	28.319	
7/11/2014 10:30	20.439		1.256	18.725	28.417	
7/11/2014 10:45	20.305		1.318	18.191	28.481	
7/11/2014 11:00	20.112		1.361	17.771	28.579	
7/11/2014 11:15	19.886		1.367	17.53	28.65	
7/11/2014 11:30	19.746		1.328	17.533	28.809	
7/11/2014 11:45	19.839		1.251	17.816	28.846	
7/11/2014 12:00	20.176		1.166	18.595	28.839	
7/11/2014 12:15	20.509		1.059	19.38	28.859	
7/11/2014 12:30	20.837		0.944	20.043	28.802	
7/11/2014 12:45	21.055		0.827	20.621	28.334	
7/11/2014 13:00	21.294		0.706	21.087	28.461	
7/11/2014 13:15	21.583		0.573	21.497	28.338	
7/11/2014 13:30	21.808		0.435	21.851	28.165	
7/11/2014 13:45	22.115		0.298	22.164	28.093	
7/11/2014 14:00	22.255		0.166	22.449	28.02	
7/11/2014 14:15	22.443		0.032	22.729	27.887	
7/11/2014 14:30	22.567		-0.108	23.019	27.823	
7/11/2014 14:45	22.784		-0.251	23.316	27.724	
7/11/2014 15:00	22.969		-0.396	23.595	27.674	
7/11/2014 15:15	23.313		-0.547	23.876	27.613	
7/11/2014 15:30	23.744		-0.654	24.143	27.544	
7/11/2014 15:45	24.036		-0.662	24.403	27.406	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/11/2014 16:00	24.166		-0.664	24.684	27.295	
7/11/2014 16:15	24.191		-0.663	24.98	27.109	
7/11/2014 16:30	24.242		-0.664	25.276	26.935	
7/11/2014 16:45	24.15		-0.668	25.545	26.871	
7/11/2014 17:00	24.019		-0.668	25.755	26.787	
7/11/2014 17:15	23.789		-0.670	25.794	26.72	
7/11/2014 17:30	23.551		-0.672	25.747	26.685	
7/11/2014 17:45	23.19		-0.674	25.622	26.627	
7/11/2014 18:00	22.856		-0.672	25.47	26.589	
7/11/2014 18:15	22.432		-0.672	25.183	26.542	
7/11/2014 18:30	21.982		-0.672	25.095	26.495	
7/11/2014 18:45	21.477		-0.673	24.865	26.459	
7/11/2014 19:00	21.009		-0.674	24.558	26.408	
7/11/2014 19:15	20.513		-0.672	24.201	26.72	
7/11/2014 19:30	20.274		-0.614	23.963	26.879	
7/11/2014 19:45	20.329		-0.450	23.797	26.931	
7/11/2014 20:00	21.145		-0.279	23.639	27.002	
7/11/2014 20:15	21.952		-0.101	23.372	27.108	
7/11/2014 20:30	22.219		0.100	23.058	27.159	
7/11/2014 20:45	22.343		0.307	22.721	27.225	
7/11/2014 21:00	22.346		0.533	22.347	27.191	
7/11/2014 21:15	22.329		0.755	21.713	27.192	
7/11/2014 21:30	22.232		0.981	21.032	27.331	
7/11/2014 21:45	22.082		1.177	20.404	27.51	
7/11/2014 22:00	21.75		1.311	19.584	27.66	
7/11/2014 22:15	21.311		1.399	18.573	27.81	
7/11/2014 22:30	20.74		1.466	17.678	27.972	
7/11/2014 22:45	20.057		1.529	16.99	27.826	
7/11/2014 23:00	19.315		1.590	16.488	27.875	
7/11/2014 23:15	18.64		1.644	16.173	27.864	
7/11/2014 23:30	18.101		1.692	15.969	28.049	
7/11/2014 23:45	17.667		1.731	15.847	27.911	
7/12/2014 0:00	17.443		1.754	15.801	28.095	
7/12/2014 0:15	17.372		1.750	15.83	28.136	
7/12/2014 0:30	17.254		1.719	15.863	28.211	
7/12/2014 0:45	17.266		1.671	15.945	28.273	
7/12/2014 1:00	17.213		1.610	16.091	28.268	
7/12/2014 1:15	17.211		1.545	16.397	28.189	
7/12/2014 1:30	17.282		1.469	16.733	28.129	
7/12/2014 1:45	17.462		1.363	17.089	27.938	
7/12/2014 2:00	17.849		1.224	17.581	27.693	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/12/2014 2:15	18.359		1.022	18.162	27.255	
7/12/2014 2:30	18.831		0.771	18.696	27.063	
7/12/2014 2:45	19.2		0.506	19.114	26.941	
7/12/2014 3:00	19.465		0.268	19.364	26.83	
7/12/2014 3:15	19.672		0.066	19.53	26.754	
7/12/2014 3:30	19.724		-0.116	19.634	26.703	
7/12/2014 3:45	19.677		-0.288	19.685	26.587	
7/12/2014 4:00	19.559		-0.460	19.697	26.492	
7/12/2014 4:15	19.314		-0.622	19.648	26.426	
7/12/2014 4:30	18.973		-0.652	19.561	26.349	
7/12/2014 4:45	18.564		-0.655	19.417	26.271	
7/12/2014 5:00	18.277		-0.657	19.202	26.212	
7/12/2014 5:15	18.029		-0.659	18.951	26.163	
7/12/2014 5:30	17.82		-0.658	18.725	26.127	
7/12/2014 5:45	17.602		-0.658	18.493	26.125	
7/12/2014 6:00	17.379		-0.659	18.379	26.117	
7/12/2014 6:15	17.241		-0.660	18.258	26.095	
7/12/2014 6:30	17.274		-0.662	18.137	26.081	
7/12/2014 6:45	17.206		-0.663	18.078	26.052	
7/12/2014 7:00	17.172		-0.664	18.062	26.034	
7/12/2014 7:15	17.098		-0.663	18.082	26.012	
7/12/2014 7:30	17.119		-0.663	18.146	25.994	
7/12/2014 7:45	17.209		-0.667	18.259	25.968	
7/12/2014 8:00	17.356		-0.663	18.342	25.963	
7/12/2014 8:15	17.543		-0.661	18.439	25.93	
7/12/2014 8:30	17.776		-0.663	19.316	25.953	
7/12/2014 8:45	17.988		-0.578	19.965	26.037	
7/12/2014 9:00	18.168		-0.398	20.304	26.037	
7/12/2014 9:15	18.436		-0.213	20.446	26.09	
7/12/2014 9:30	18.714		-0.021	20.383	26.135	
7/12/2014 9:45	19.144		0.185	20.311	26.183	
7/12/2014 10:00	19.447		0.404	20.269	26.212	
7/12/2014 10:15	19.722		0.627	20.15	26.229	
7/12/2014 10:30	19.768		0.838	19.789	26.259	
7/12/2014 10:45	19.873		1.028	19.334	26.254	
7/12/2014 11:00	19.898		1.185	18.759	26.245	
7/12/2014 11:15	19.857		1.285	18.176	26.293	
7/12/2014 11:30	19.696		1.359	17.647	26.403	
7/12/2014 11:45	19.441		1.409	17.219	26.439	
7/12/2014 12:00	19.128		1.443	16.927	26.535	
7/12/2014 12:15	18.829		1.459	16.772	26.602	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/12/2014 12:30	18.64		1.450	16.734	26.708	
7/12/2014 12:45	18.54		1.416	16.783	26.901	
7/12/2014 13:00	18.601		1.363	17.062	26.835	
7/12/2014 13:15	18.865		1.276	17.9	27.12	
7/12/2014 13:30	19.341		1.135	18.973	27.092	
7/12/2014 13:45	19.83		0.949	20.124	26.975	
7/12/2014 14:00	20.387		0.773	20.997	26.93	
7/12/2014 14:15	20.793		0.614	21.644	26.881	
7/12/2014 14:30	20.959		0.464	22.143	26.792	
7/12/2014 14:45	21.237		0.318	22.591	26.758	
7/12/2014 15:00	21.544		0.178	22.983	26.713	
7/12/2014 15:15	21.794		0.025	23.352	26.694	
7/12/2014 15:30	22.162		-0.123	23.739	26.646	
7/12/2014 15:45	22.714		-0.273	24.11	26.422	
7/12/2014 16:00	22.927		-0.429	24.46	26.472	
7/12/2014 16:15	23.269		-0.584	24.783	26.403	
7/12/2014 16:30	23.921		-0.660	25.061	26.391	
7/12/2014 16:45	23.903		-0.659	25.31	26.328	
7/12/2014 17:00	23.771		-0.662	25.519	26.31	
7/12/2014 17:15	23.608		-0.662	25.674	26.258	
7/12/2014 17:30	23.357		-0.665	25.719	26.185	
7/12/2014 17:45	23.032		-0.668	25.669	26.159	
7/12/2014 18:00	22.668		-0.667	25.396	26.106	
7/12/2014 18:15	22.278		-0.666	25.177	26.053	
7/12/2014 18:30	21.861		-0.667	24.847	26.041	
7/12/2014 18:45	21.457		-0.670	24.496	26.042	
7/12/2014 19:00	21.065		-0.671	24.085	26.024	
7/12/2014 19:15	20.696		-0.670	23.779	25.994	
7/12/2014 19:30	20.391		-0.667	23.591	25.998	
7/12/2014 19:45	20.121		-0.667	23.465	25.951	
7/12/2014 20:00	19.77		-0.666	23.539	25.963	
7/12/2014 20:15	19.492		-0.670	23.546	25.936	
7/12/2014 20:30	19.41		-0.571	23.434	25.893	
7/12/2014 20:45	19.537		-0.401	23.327	25.866	
7/12/2014 21:00	20.436		-0.209	23.131	25.847	
7/12/2014 21:15	21.249		-0.013	22.78	25.856	
7/12/2014 21:30	21.626		0.204	22.446	25.896	
7/12/2014 21:45	21.748		0.429	22.102	25.947	
7/12/2014 22:00	21.766		0.671	21.589	25.982	
7/12/2014 22:15	21.737		0.909	20.934	26.051	
7/12/2014 22:30	21.612		1.130	20.385	26.135	

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/12/2014 22:45	21.355		1.290	19.64	26.297	
7/12/2014 23:00	20.994		1.392	18.84	26.321	
7/12/2014 23:15	20.53		1.467	18.054	26.53	
7/12/2014 23:30	19.95		1.536	17.441	26.63	
7/12/2014 23:45	19.328		1.599	17.139	26.646	
7/13/2014 0:00	18.858		1.665	16.893	26.645	
7/13/2014 0:15	18.4		1.721	16.749	26.722	
7/13/2014 0:30	18.133		1.773	16.667	26.793	
7/13/2014 0:45	17.835		1.816	16.624	26.814	
7/13/2014 1:00	17.771		1.838	16.618	26.806	
7/13/2014 1:15	17.703		1.831	16.674	26.812	
7/13/2014 1:30	17.687		1.798	16.719	26.797	
7/13/2014 1:45	17.669		1.748	16.745	26.842	
7/13/2014 2:00	17.695		1.689	16.823		
7/13/2014 2:15	17.733		1.626	16.963		
7/13/2014 2:30	17.739		1.547	17.187		
7/13/2014 2:45	17.843		1.454	17.406		
7/13/2014 3:00	17.977		1.336	17.708		
7/13/2014 3:15	18.151		1.166	18.083		
7/13/2014 3:30	18.364		0.946	18.448		
7/13/2014 3:45	18.589		0.678	18.801		
7/13/2014 4:00	18.839		0.412	19.064		
7/13/2014 4:15	19.066		0.170	19.27		
7/13/2014 4:30	19.258		-0.041	19.449		
7/13/2014 4:45	19.386		-0.230	19.572		
7/13/2014 5:00	19.419		-0.409	19.643		
7/13/2014 5:15	19.355		-0.574	19.646		
7/13/2014 5:30	19.204		-0.649	19.608		
7/13/2014 5:45	19.021		-0.652	19.529		
7/13/2014 6:00	18.845		-0.656	19.383		
7/13/2014 6:15	18.693		-0.652	19.242		
7/13/2014 6:30	18.57		-0.657	19.157		
7/13/2014 6:45	18.489		-0.657	19.107		
7/13/2014 7:00	18.431		-0.656	19.097		
7/13/2014 7:15	18.392		-0.658	19.107		
7/13/2014 7:30	18.398		-0.661	19.178		
7/13/2014 7:45	18.399		-0.660	19.256		
7/13/2014 8:00	18.382		-0.661	19.318		
7/13/2014 8:15	18.476		-0.662	19.47		
7/13/2014 8:30	18.613		-0.659	19.673		
7/13/2014 8:45	18.768		-0.660	19.953		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/13/2014 9:00	18.977		-0.662	20.058		
7/13/2014 9:15	19.169		-0.662	20.086		
7/13/2014 9:30	19.418		-0.630	20.234		
7/13/2014 9:45	19.508		-0.459	20.31		
7/13/2014 10:00	19.735		-0.269	20.33		
7/13/2014 10:15	19.844		-0.075	20.296		
7/13/2014 10:30	19.906		0.143	20.296		
7/13/2014 10:45	19.972		0.368	20.293		
7/13/2014 11:00	20.013		0.604	20.201		
7/13/2014 11:15	20.019		0.832	19.947		
7/13/2014 11:30	20.018		1.047	19.665		
7/13/2014 11:45	19.991		1.217	19.265		
7/13/2014 12:00	19.954		1.326	18.91		
7/13/2014 12:15	19.835		1.394	18.604		
7/13/2014 12:30	19.706		1.453	18.364		
7/13/2014 12:45	19.558		1.500	18.108		
7/13/2014 13:00	19.39		1.537	17.907		
7/13/2014 13:15	19.228		1.559	17.815		
7/13/2014 13:30	19.093		1.565	17.798		
7/13/2014 13:45	18.958		1.540	17.844		
7/13/2014 14:00	18.93		1.493	17.945		
7/13/2014 14:15	18.997		1.436	18.511		
7/13/2014 14:30	19.162		1.356	19.253		
7/13/2014 14:45	19.505		1.238	20.194		
7/13/2014 15:00	20.342		1.051	21.126		
7/13/2014 15:15	20.872		0.816	21.981		
7/13/2014 15:30	21.013		0.588	22.669		
7/13/2014 15:45	21.102		0.408	23.193		
7/13/2014 16:00	21.337		0.245	23.619		
7/13/2014 16:15	21.666		0.077	23.991		
7/13/2014 16:30	22.023		-0.083	24.289		
7/13/2014 16:45	22.34		-0.243	24.558		
7/13/2014 17:00	22.709		-0.401	24.785		
7/13/2014 17:15	22.833		-0.563	24.954		
7/13/2014 17:30	23.037		-0.663	25.01		
7/13/2014 17:45	22.58		-0.663	24.996		
7/13/2014 18:00	22.407		-0.668	24.977		
7/13/2014 18:15	22.35		-0.670	24.945		
7/13/2014 18:30	22.208		-0.670	24.807		
7/13/2014 18:45	21.875		-0.667	24.471		
7/13/2014 19:00	21.568		-0.666	24.064		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/13/2014 19:15	21.256		-0.669	23.695		
7/13/2014 19:30	20.988		-0.667	23.373		
7/13/2014 19:45	20.738		-0.667	23.021		
7/13/2014 20:00	20.501		-0.664	22.697		
7/13/2014 20:15	20.289		-0.665	22.44		
7/13/2014 20:30	20.08		-0.663	22.255		
7/13/2014 20:45	19.887		-0.667	22.219		
7/13/2014 21:00	19.725		-0.667	22.433		
7/13/2014 21:15	19.576		-0.665	22.604		
7/13/2014 21:30	19.524		-0.510	22.625		
7/13/2014 21:45	19.588		-0.330	22.598		
7/13/2014 22:00	19.996		-0.130	22.47		
7/13/2014 22:15	20.319		0.084	22.302		
7/13/2014 22:30	20.626		0.306	22.101		
7/13/2014 22:45	20.892		0.550	21.893		
7/13/2014 23:00	21.008		0.794	21.506		
7/13/2014 23:15	21.061		1.035	21.012		
7/13/2014 23:30	21.056		1.232	20.493		
7/13/2014 23:45	20.984		1.352	20.106		
7/14/2014 0:00	20.791		1.440	19.636		
7/14/2014 0:15	20.59		1.512	19.089		
7/14/2014 0:30	20.317		1.584	18.56		
7/14/2014 0:45	19.997		1.649	18.202		
7/14/2014 1:00	19.696		1.715	17.896		
7/14/2014 1:15	19.437		1.780	17.724		
7/14/2014 1:30	19.148		1.829	17.645		
7/14/2014 1:45	18.942		1.864	17.594		
7/14/2014 2:00	18.745		1.881	17.576		
7/14/2014 2:15	18.725		1.862	17.677		
7/14/2014 2:30	18.704		1.824	17.758		
7/14/2014 2:45	18.713		1.772	17.857		
7/14/2014 3:00	18.729		1.714	18.004		
7/14/2014 3:15	18.758		1.644	18.202		
7/14/2014 3:30	18.774		1.562	18.515		
7/14/2014 3:45	18.816		1.461	18.813		
7/14/2014 4:00	18.902		1.342	19.16		
7/14/2014 4:15	19.014		1.181	19.517		
7/14/2014 4:30	19.163		0.961	19.822		
7/14/2014 4:45	19.34		0.694	20.104		
7/14/2014 5:00	19.534		0.423	20.325		
7/14/2014 5:15	19.745		0.179	20.507		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/14/2014 5:30	19.898		-0.044	20.66		
7/14/2014 5:45	20.03		-0.242	20.776		
7/14/2014 6:00	20.121		-0.419	20.855		
7/14/2014 6:15	20.139		-0.583	20.899		
7/14/2014 6:30	20.19		-0.651	20.917		
7/14/2014 6:45	20.133		-0.651	20.917		
7/14/2014 7:00	20.039		-0.654	20.912		
7/14/2014 7:15	19.931		-0.657	20.914		
7/14/2014 7:30	19.848		-0.656	20.931		
7/14/2014 7:45	19.803		-0.658	20.973		
7/14/2014 8:00	19.745		-0.656	21.031		
7/14/2014 8:15	19.729		-0.657	21.091		
7/14/2014 8:30	19.722		-0.658	21.15		
7/14/2014 8:45	19.712		-0.657	21.189		
7/14/2014 9:00	19.754		-0.660	21.274		
7/14/2014 9:15	19.971		-0.659	21.462		
7/14/2014 9:30	20.1		-0.659	21.792		
7/14/2014 9:45	20.397		-0.661	22.045		
7/14/2014 10:00	20.77		-0.661	22.056		
7/14/2014 10:15	21.242		-0.648	21.874		
7/14/2014 10:30	21.174		-0.493	21.72		
7/14/2014 10:45	21.259		-0.308	21.705		
7/14/2014 11:00	21.282		-0.105	21.631		
7/14/2014 11:15	21.358		0.117	21.593		
7/14/2014 11:30	21.38		0.336	21.562		
7/14/2014 11:45	21.335		0.579	21.456		
7/14/2014 12:00	21.271		0.817	21.224		
7/14/2014 12:15	21.227		1.035	20.961		
7/14/2014 12:30	21.159		1.213	20.618		
7/14/2014 12:45	21.069		1.328	20.238		
7/14/2014 13:00	20.954		1.407	19.711		
7/14/2014 13:15	20.82		1.470	19.157		
7/14/2014 13:30	20.635		1.528	18.663		
7/14/2014 13:45	20.396		1.573	18.286		
7/14/2014 14:00	20.122		1.613	18.01		
7/14/2014 14:15	19.882		1.626	17.821		
7/14/2014 14:30	19.654		1.613	17.774		
7/14/2014 14:45	19.473		1.573	17.813		
7/14/2014 15:00	19.395		1.526	17.993		
7/14/2014 15:15	19.385		1.464	18.48		
7/14/2014 15:30	19.48		1.389	19.106		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/14/2014 15:45	19.634		1.280	19.808		
7/14/2014 16:00	19.911		1.112	20.572		
7/14/2014 16:15	20.234		0.882	21.322		
7/14/2014 16:30	20.551		0.627	21.951		
7/14/2014 16:45	21.003		0.405	22.458		
7/14/2014 17:00	21.302		0.225	22.844		
7/14/2014 17:15	21.412		0.060	23.161		
7/14/2014 17:30	21.683		-0.108	23.431		
7/14/2014 17:45	21.92		-0.266	23.66		
7/14/2014 18:00	22.085		-0.432	23.835		
7/14/2014 18:15	22.109		-0.592	23.959		
7/14/2014 18:30	22.11		-0.657	24.047		
7/14/2014 18:45	21.944		-0.658	24.091		
7/14/2014 19:00	21.698		-0.658	24.066		
7/14/2014 19:15	21.528		-0.662	23.955		
7/14/2014 19:30	21.329		-0.660	23.809		
7/14/2014 19:45	21.105		-0.660	23.592		
7/14/2014 20:00	20.902		-0.658	23.452		
7/14/2014 20:15	20.708		-0.662	23.344		
7/14/2014 20:30	20.534		-0.661	23.218		
7/14/2014 20:45	20.365		-0.660	23.068		
7/14/2014 21:00	20.21		-0.660	22.855		
7/14/2014 21:15	20.059		-0.662	22.636		
7/14/2014 21:30	19.899		-0.660	22.445		
7/14/2014 21:45	19.782		-0.662	22.385		
7/14/2014 22:00	19.652		-0.662	22.462		
7/14/2014 22:15	19.548		-0.617	22.577		
7/14/2014 22:30	19.513		-0.449	22.601		
7/14/2014 22:45	19.812		-0.251	22.569		
7/14/2014 23:00	20.205		-0.045	22.443		
7/14/2014 23:15	20.564		0.165	22.3		
7/14/2014 23:30	20.795		0.398	22.11		
7/14/2014 23:45	20.977		0.646	21.886		
7/15/2014 0:00	21.046		0.887	21.427		
7/15/2014 0:15	21.095		1.121	20.852		
7/15/2014 0:30	21.068		1.288	20.076		
7/15/2014 0:45	20.953		1.391	19.096		
7/15/2014 1:00	20.769		1.471	18.235		
7/15/2014 1:15	20.487		1.538	17.479		
7/15/2014 1:30	20.102		1.607	16.893		
7/15/2014 1:45	19.69		1.666	16.445		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/15/2014 2:00	19.186		1.730	16.129		
7/15/2014 2:15	18.808		1.783	16.001		
7/15/2014 2:30	18.526		1.831	16.018		
7/15/2014 2:45	18.365		1.856	16.025		
7/15/2014 3:00	18.142		1.852	16.128		
7/15/2014 3:15	18.022		1.821	16.215		
7/15/2014 3:30	17.856		1.777	16.23		
7/15/2014 3:45	17.871		1.723	16.353		
7/15/2014 4:00	17.782		1.664	16.585		
7/15/2014 4:15	17.899	30.185	1.581	16.952		
7/15/2014 4:30	17.907	30.102	1.490	17.323		
7/15/2014 4:45	18.074	30.004	1.386	17.781		
7/15/2014 5:00	18.203	29.950	1.242	18.368		
7/15/2014 5:15	18.353	29.938	1.038	18.896		
7/15/2014 5:30	18.521	29.918	0.789	19.396		
7/15/2014 5:45	18.745	29.933	0.514	19.85		
7/15/2014 6:00	18.975	29.854	0.255	20.197		
7/15/2014 6:15	19.302	29.852	0.028	20.489		
7/15/2014 6:30	19.573	29.799	-0.176	20.722		
7/15/2014 6:45	19.772	29.772	-0.359	20.893		
7/15/2014 7:00	19.903	29.734	-0.528	21.002		
7/15/2014 7:15	20.134	29.577	-0.647	21.064		
7/15/2014 7:30	20.09	29.362	-0.653	21.11		
7/15/2014 7:45	20.037	29.001	-0.654	21.148		
7/15/2014 8:00	19.967	28.619	-0.655	21.171		
7/15/2014 8:15	19.916	28.294	-0.653	21.209		
7/15/2014 8:30	19.891	27.928	-0.655	21.29		
7/15/2014 8:45	19.889	27.541	-0.660	21.415		
7/15/2014 9:00	20.051	27.211	-0.659	21.61		
7/15/2014 9:15	20.269	26.961	-0.660	21.896		
7/15/2014 9:30	20.469	26.659	-0.660	22.184		
7/15/2014 9:45	20.633	26.579	-0.659	22.423		
7/15/2014 10:00	20.635	26.353	-0.661	22.579		
7/15/2014 10:15	20.777	25.941	-0.661	22.777		
7/15/2014 10:30	21.11	25.527	-0.660	23.133		
7/15/2014 10:45	21.615	25.194	-0.660	23.135		
7/15/2014 11:00	21.96	25.043	-0.661	22.734		
7/15/2014 11:15	21.612	25.400	-0.531	21.999		
7/15/2014 11:30	21.529	25.874	-0.356	21.759		
7/15/2014 11:45	21.697	26.380	-0.156	21.607		
7/15/2014 12:00	21.793	26.781	0.055	21.548		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/15/2014 12:15	21.727	27.244	0.273	21.565		
7/15/2014 12:30	21.617	27.593	0.514	21.477		
7/15/2014 12:45	21.546	27.842	0.755	21.197		
7/15/2014 13:00	21.447	28.020	0.976	20.818		
7/15/2014 13:15	21.379	28.229	1.170	20.321		
7/15/2014 13:30	21.28	28.442	1.302	19.654		
7/15/2014 13:45	21.149	28.701	1.386	18.872		
7/15/2014 14:00	20.956	28.896	1.458	18.153		
7/15/2014 14:15	20.713	29.126	1.509	17.467		
7/15/2014 14:30	20.453	29.140	1.566	17.005		
7/15/2014 14:45	20.094	29.177	1.616	16.629		
7/15/2014 15:00	19.68	29.322	1.649	16.334		
7/15/2014 15:15	19.307	29.449	1.662	16.303		
7/15/2014 15:30	19.043	29.501	1.646	16.386		
7/15/2014 15:45	18.747	29.580	1.604	16.564		
7/15/2014 16:00	18.678	29.486	1.552	16.76		
7/15/2014 16:15	18.74	29.445	1.501	17.332		
7/15/2014 16:30	18.795	29.491	1.434	18.199		
7/15/2014 16:45	18.943	29.498	1.345	19.054		
7/15/2014 17:00	19.125	29.530	1.213	19.961		
7/15/2014 17:15	19.4	29.401	1.010	20.957		
7/15/2014 17:30	19.785	29.446	0.761	21.836		
7/15/2014 17:45	20.376	29.491	0.505	22.615		
7/15/2014 18:00	20.869	29.518	0.280	23.175		
7/15/2014 18:15	21.331	29.549	0.093	23.58		
7/15/2014 18:30	21.79	29.579	-0.075	23.876		
7/15/2014 18:45	22.139	29.564	-0.244	24.114		
7/15/2014 19:00	22.394	29.544	-0.408	24.29		
7/15/2014 19:15	22.564	29.529	-0.570	24.38		
7/15/2014 19:30	22.699	29.429	-0.655	24.401		
7/15/2014 19:45	22.297	29.340	-0.655	24.367		
7/15/2014 20:00	22.038	29.215	-0.658	24.281		
7/15/2014 20:15	21.808	29.097	-0.660	24.145		
7/15/2014 20:30	21.579	29.075	-0.658	23.915		
7/15/2014 20:45	21.354	28.833	-0.659	23.682		
7/15/2014 21:00	21.123	28.495	-0.657	23.481		
7/15/2014 21:15	20.935	28.478	-0.659	23.306		
7/15/2014 21:30	20.776	28.281	-0.658	23.194		
7/15/2014 21:45	20.61	27.960	-0.659	23.104		
7/15/2014 22:00	20.479	27.942	-0.656	22.992		
7/15/2014 22:15	20.356	27.504	-0.658	22.824		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/15/2014 22:30	20.249	27.245	-0.659	22.743		
7/15/2014 22:45	20.149	27.205	-0.662	22.664		
7/15/2014 23:00	20.048	27.124	-0.663	22.587		
7/15/2014 23:15	19.974	27.278	-0.545	22.515		
7/15/2014 23:30	19.942	27.257	-0.385	22.471		
7/15/2014 23:45	20.279	26.906	-0.199	22.387		
7/16/2014 0:00	20.546	26.916	0.001	22.268		
7/16/2014 0:15	20.784	27.122	0.207	22.168		
7/16/2014 0:30	20.977	27.386	0.435	22.009		
7/16/2014 0:45	21.079	27.662	0.673	21.749		
7/16/2014 1:00	21.08	27.922	0.916	21.209		
7/16/2014 1:15	21.14	28.321	1.135	20.684		
7/16/2014 1:30	21.091	28.696	1.291	19.982		
7/16/2014 1:45	20.943	28.812	1.381	19.218		
7/16/2014 2:00	20.715	28.803	1.454	18.492		
7/16/2014 2:15	20.477	28.960	1.515	17.815		
7/16/2014 2:30	20.261	28.996	1.579	17.335		
7/16/2014 2:45	19.946	29.070	1.638	16.961		
7/16/2014 3:00	19.679	28.401	1.692	16.628		
7/16/2014 3:15	19.297		1.739	16.39		
7/16/2014 3:30	19.014		1.759	16.336		
7/16/2014 3:45	18.803		1.771	16.414		
7/16/2014 4:00	18.573		1.759	16.484		
7/16/2014 4:15	18.39		1.721	16.528		
7/16/2014 4:30	18.412		1.674	16.678		
7/16/2014 4:45	18.368		1.615	16.866		
7/16/2014 5:00	18.409		1.554	17.252		
7/16/2014 5:15	18.312		1.477	17.698		
7/16/2014 5:30	18.455		1.375	18.173		
7/16/2014 5:45	18.562		1.229	18.728		
7/16/2014 6:00	18.733		1.028	19.293		
7/16/2014 6:15	18.917		0.775	19.84		
7/16/2014 6:30	19.191		0.503	20.283		
7/16/2014 6:45	19.451		0.251	20.605		
7/16/2014 7:00	19.686		0.036	20.845		
7/16/2014 7:15	19.895		-0.155	21.038		
7/16/2014 7:30	20.091		-0.332	21.192		
7/16/2014 7:45	20.181		-0.506	21.315		
7/16/2014 8:00	20.477		-0.641	21.427		
7/16/2014 8:15	20.639		-0.648	21.512		
7/16/2014 8:30	20.619		-0.648	21.565		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/16/2014 8:45	20.503		-0.653	21.642		
7/16/2014 9:00	20.364		-0.653	21.695		
7/16/2014 9:15	20.207		-0.653	21.742		
7/16/2014 9:30	20.044		-0.653	21.713		
7/16/2014 9:45	19.901		-0.652	21.659		
7/16/2014 10:00	19.803		-0.585	21.593		
7/16/2014 10:15	19.746		-0.573	21.447		
7/16/2014 10:30	19.756		-0.594	21.399		
7/16/2014 10:45	19.833		-0.611	21.302		
7/16/2014 11:00	19.906		-0.618	21.267		
7/16/2014 11:15	19.945		-0.627	21.285		
7/16/2014 11:30	19.982		-0.631	21.292		
7/16/2014 11:45	20.006		-0.638	21.336		
7/16/2014 12:00	19.901		-0.520	21.372		
7/16/2014 12:15	20.025		-0.341	21.415		
7/16/2014 12:30	20.183		-0.168	21.397		
7/16/2014 12:45	20.197		0.026	21.253		
7/16/2014 13:00	20.266		0.235	21.137		
7/16/2014 13:15	20.264		0.473	21.037		
7/16/2014 13:30	20.329		0.700	20.908		
7/16/2014 13:45	20.38		0.925	20.635		
7/16/2014 14:00	20.401		1.127	20.154		
7/16/2014 14:15	20.421		1.267	19.635		
7/16/2014 14:30	20.405		1.359	19.037		
7/16/2014 14:45	20.291		1.426	18.409		
7/16/2014 15:00	20.103		1.497	17.818		
7/16/2014 15:15	19.904		1.551	17.309		
7/16/2014 15:30	19.689		1.599	16.986		
7/16/2014 15:45	19.46		1.638	16.762		
7/16/2014 16:00	19.256		1.665	16.587		
7/16/2014 16:15	19.068		1.673	16.516		
7/16/2014 16:30	18.855		1.647	16.537		
7/16/2014 16:45	18.702	28.688	1.598	16.568		
7/16/2014 17:00	18.613	28.416	1.547	16.882		
7/16/2014 17:15	18.485	28.531	1.486	17.37		
7/16/2014 17:30	18.568	27.855	1.405	17.915		
7/16/2014 17:45	18.628	28.216	1.293	18.472		
7/16/2014 18:00	18.752	28.329	1.133	19.124		
7/16/2014 18:15	18.902	27.872	0.922	19.759		
7/16/2014 18:30	19.096	28.052	0.675	20.313		
7/16/2014 18:45	19.358	27.678	0.451	20.754		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/16/2014 19:00	19.704	27.790	0.248	21.064		
7/16/2014 19:15	19.913	27.570	0.069	21.196		
7/16/2014 19:30	20.162	27.432	-0.096	21.317		
7/16/2014 19:45	20.266	27.447	-0.261	21.441		
7/16/2014 20:00	20.336	26.966	-0.424	21.557		
7/16/2014 20:15	20.505	26.938	-0.587	21.659		
7/16/2014 20:30	20.405	26.244	-0.644	21.722		
7/16/2014 20:45	20.204	25.801	-0.641	21.733		
7/16/2014 21:00	20.05	25.274	-0.646	21.662		
7/16/2014 21:15	19.883	25.108	-0.647	21.527		
7/16/2014 21:30	19.714	24.616	-0.648	21.428		
7/16/2014 21:45	19.538	24.514	-0.648	21.299		
7/16/2014 22:00	19.347	24.148	-0.649	21.161		
7/16/2014 22:15	19.175	24.326	-0.649	21.053		
7/16/2014 22:30	18.976	23.960	-0.652	20.93		
7/16/2014 22:45	18.789	24.196	-0.648	20.801		
7/16/2014 23:00	18.615	23.888	-0.649	20.677		
7/16/2014 23:15	18.493	24.002	-0.651	20.43		
7/16/2014 23:30	18.347	23.797	-0.650	20.394		
7/16/2014 23:45	18.234	23.909	-0.653	20.458		
7/17/2014 0:00	18.093	23.667	-0.652	20.868		
7/17/2014 0:15	18.178	24.653	-0.511	21.144		
7/17/2014 0:30	18.114	24.413	-0.346	21.212		
7/17/2014 0:45	18.078	24.783	-0.176	21.162		
7/17/2014 1:00	18.336	24.188	0.014	21.021		
7/17/2014 1:15	18.689	24.407	0.216	20.872		
7/17/2014 1:30	19.026	23.782	0.436	20.753		
7/17/2014 1:45	19.281	24.124	0.659	20.578		
7/17/2014 2:00	19.501	23.886	0.879	20.238		
7/17/2014 2:15	19.639	24.197	1.079	19.768		
7/17/2014 2:30	19.713	24.622	1.239	19.16		
7/17/2014 2:45	19.728	24.806	1.340	18.311		
7/17/2014 3:00	19.686	24.771	1.410	17.367		
7/17/2014 3:15	19.546	25.270	1.476	16.626		
7/17/2014 3:30	19.318	25.126	1.535	16.008		
7/17/2014 3:45	19.064	25.863	1.585	15.585		
7/17/2014 4:00	18.797	25.552	1.627	15.294		
7/17/2014 4:15	18.499	26.419	1.657	15.087		
7/17/2014 4:30	18.261	25.952	1.674	14.953		
7/17/2014 4:45	18.13	26.677	1.652	14.931		
7/17/2014 5:00	17.804	26.632	1.613	15.022		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/17/2014 5:15	17.621	27.176	1.566	15.17		
7/17/2014 5:30	17.476	27.067	1.512	15.476		
7/17/2014 5:45	17.493	27.839	1.439	15.912		
7/17/2014 6:00	17.484	27.359	1.345	16.413		
7/17/2014 6:15	17.537		1.215	17.006		
7/17/2014 6:30	17.695		1.015	17.644		
7/17/2014 6:45	17.938		0.767	18.238		
7/17/2014 7:00	18.195		0.513	18.67		
7/17/2014 7:15	18.423		0.291	18.959		
7/17/2014 7:30	18.677		0.105	19.13		
7/17/2014 7:45	18.809		-0.058	19.23		
7/17/2014 8:00	18.878		-0.221	19.147		
7/17/2014 8:15	18.918		-0.387	19.13		
7/17/2014 8:30	19.012		-0.553	19.197		
7/17/2014 8:45	19.061		-0.641	19.355		
7/17/2014 9:00	19.08		-0.647	19.55		
7/17/2014 9:15	19.089		-0.644	19.774		
7/17/2014 9:30	19.135		-0.647	20.041		
7/17/2014 9:45	19.205		-0.647	20.233		
7/17/2014 10:00	19.295		-0.648	20.446		
7/17/2014 10:15	19.437		-0.653	20.742		
7/17/2014 10:30	19.594		-0.649	21.12		
7/17/2014 10:45	19.876		-0.651	21.671		
7/17/2014 11:00	20.31		-0.654	22.222		
7/17/2014 11:15	20.68		-0.652	22.847		
7/17/2014 11:30	20.796		-0.649	23.189		
7/17/2014 11:45	20.969		-0.653	23.47		
7/17/2014 12:00	21.266		-0.653	23.603		
7/17/2014 12:15	21.767		-0.654	23.554		
7/17/2014 12:30	22.221		-0.657	22.611		
7/17/2014 12:45	22.512		-0.643	21.66		
7/17/2014 13:00	22.07		-0.481	21.261		
7/17/2014 13:15	21.97		-0.307	21.095		
7/17/2014 13:30	22.12		-0.127	20.975		
7/17/2014 13:45	22.09		0.077	20.963		
7/17/2014 14:00	21.877		0.282	21.021		
7/17/2014 14:15	21.634		0.495	20.879		
7/17/2014 14:30	21.447		0.711	20.569		
7/17/2014 14:45	21.282		0.925	20.167		
7/17/2014 15:00	21.138		1.115	19.625		
7/17/2014 15:15	20.997		1.252	18.745		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/17/2014 15:30	20.833		1.345	17.663		
7/17/2014 15:45	20.609		1.410	16.825		
7/17/2014 16:00	20.37		1.461	16.148		
7/17/2014 16:15	20.031		1.514	15.614		
7/17/2014 16:30	19.504		1.555	15.33		
7/17/2014 16:45	19.028		1.585	15.168		
7/17/2014 17:00	18.625		1.605	15.087		
7/17/2014 17:15	18.268		1.591	15.1		
7/17/2014 17:30	18.023		1.545	15.138		
7/17/2014 17:45	17.821		1.494	15.344		
7/17/2014 18:00	17.677		1.435	15.828		
7/17/2014 18:15	17.629		1.353	16.574		
7/17/2014 18:30	17.765		1.242	17.502		
7/17/2014 18:45	18.022		1.068	18.495		
7/17/2014 19:00	18.435		0.840	19.521		
7/17/2014 19:15	18.883		0.602	20.303		
7/17/2014 19:30	19.326		0.403	20.842		
7/17/2014 19:45	19.738		0.222	21.217		
7/17/2014 20:00	20.06		0.061	21.491		
7/17/2014 20:15	20.345		-0.093	21.681		
7/17/2014 20:30	20.564		-0.251	21.81		
7/17/2014 20:45	20.732		-0.410	21.89		
7/17/2014 21:00	20.801		-0.566	21.945		
7/17/2014 21:15	20.767		-0.642	21.931		
7/17/2014 21:30	20.459		-0.645	21.86		
7/17/2014 21:45	20.213		-0.647	21.742		
7/17/2014 22:00	19.933		-0.649	21.475		
7/17/2014 22:15	19.649		-0.652	21.316		
7/17/2014 22:30	19.385		-0.652	21.183		
7/17/2014 22:45	19.107		-0.652	20.903		
7/17/2014 23:00	18.813		-0.651	20.624		
7/17/2014 23:15	18.569		-0.650	20.301		
7/17/2014 23:30	18.348		-0.652	20.057		
7/17/2014 23:45	18.154		-0.652	19.857		
7/18/2014 0:00	17.932		-0.651	19.704		
7/18/2014 0:15	17.764		-0.655	19.545		
7/18/2014 0:30	17.564		-0.658	19.411		
7/18/2014 0:45	17.455		-0.659	19.66		
7/18/2014 1:00	17.283		-0.661	20.041		
7/18/2014 1:15	17.416		-0.550	20.488		
7/18/2014 1:30	17.345		-0.404	20.655		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/18/2014 1:45	17.599		-0.247	20.688		
7/18/2014 2:00	17.936		-0.079	20.578		
7/18/2014 2:15	18.268		0.106	20.415		
7/18/2014 2:30	18.552		0.308	20.247		
7/18/2014 2:45	18.763		0.522	20.053		
7/18/2014 3:00	18.917		0.719	19.721		
7/18/2014 3:15	19.067		0.907	19.193		
7/18/2014 3:30	19.156		1.079	18.621		
7/18/2014 3:45	19.268		1.220	18		
7/18/2014 4:00	19.217		1.310	17.238		
7/18/2014 4:15	19.044		1.369	16.46		
7/18/2014 4:30	18.835		1.421	15.905		
7/18/2014 4:45	18.553		1.453	15.514		
7/18/2014 5:00	18.395		1.472	15.182		
7/18/2014 5:15	17.971		1.471	15.003		
7/18/2014 5:30	17.841		1.449	15.002		
7/18/2014 5:45	17.666		1.408	15.115		
7/18/2014 6:00	17.675		1.343	15.492		
7/18/2014 6:15	17.718		1.246	16.112		
7/18/2014 6:30	17.84		1.090	17.001		
7/18/2014 6:45	17.987		0.897	17.747		
7/18/2014 7:00	18.13		0.736	18.2		
7/18/2014 7:15	18.251		0.582	18.481		
7/18/2014 7:30	18.352		0.424	18.672		
7/18/2014 7:45	18.433		0.275	18.8		
7/18/2014 8:00	18.506		0.127	18.891		
7/18/2014 8:15	18.574		-0.018	18.957		
7/18/2014 8:30	18.584		-0.158	19.014		
7/18/2014 8:45	18.589		-0.309	19.074		
7/18/2014 9:00	18.602		-0.459	19.137		
7/18/2014 9:15	18.667		-0.608	19.209		
7/18/2014 9:30	18.876		-0.650	19.299		
7/18/2014 9:45	19.293		-0.653	19.459		
7/18/2014 10:00	19.541		-0.656	19.729		
7/18/2014 10:15	19.852		-0.654	20.168		
7/18/2014 10:30	20.132		-0.655	20.554		
7/18/2014 10:45	20.482		-0.654	20.915		
7/18/2014 11:00	20.843		-0.658	21.481		
7/18/2014 11:15	21.062		-0.658	22.374		
7/18/2014 11:30	21.291		-0.658	23.142		
7/18/2014 11:45	21.581		-0.658	23.777		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/18/2014 12:00	21.951		-0.659	24.235		
7/18/2014 12:15	22.151		-0.659	24.772		
7/18/2014 12:30	22.595		-0.655	25.077		
7/18/2014 12:45	22.715		-0.658	25.032		
7/18/2014 13:00	22.793		-0.660	24.732		
7/18/2014 13:15	23.028		-0.662	23.66		
7/18/2014 13:30	23.907		-0.662	22.266		
7/18/2014 13:45	23.498		-0.575	21.652		
7/18/2014 14:00	23.498		-0.429	21.394		
7/18/2014 14:15	22.98		-0.263	21.271		
7/18/2014 14:30	22.966		-0.078	21.156		
7/18/2014 14:45	22.784		0.112	21.125		
7/18/2014 15:00	22.411		0.309	21.076		
7/18/2014 15:15	22.172		0.509	20.883		
7/18/2014 15:30	21.943		0.709	20.476		
7/18/2014 15:45	21.697		0.902	19.959		
7/18/2014 16:00	21.465		1.081	19.572		
7/18/2014 16:15	21.277		1.212	19.027		
7/18/2014 16:30	21.078		1.302	18.366		
7/18/2014 16:45	20.731		1.365	17.684		
7/18/2014 17:00	20.583		1.415	17.136		
7/18/2014 17:15	20.286		1.449	16.673		
7/18/2014 17:30	19.977		1.469	16.436		
7/18/2014 17:45	19.673		1.484	16.346		
7/18/2014 18:00	19.366		1.472	16.343		
7/18/2014 18:15	19.051		1.433	16.365		
7/18/2014 18:30	18.704		1.374	16.591		
7/18/2014 18:45	18.732		1.299	17.199		
7/18/2014 19:00	18.918		1.167	18.141		
7/18/2014 19:15	19.147		0.985	19.124		
7/18/2014 19:30	19.41		0.798	19.86		
7/18/2014 19:45	19.676		0.638	20.339		
7/18/2014 20:00	19.937		0.482	20.663		
7/18/2014 20:15	20.195		0.337	20.909		
7/18/2014 20:30	20.411		0.192	21.109		
7/18/2014 20:45	20.572		0.045	21.276		
7/18/2014 21:00	20.77		-0.091	21.421		
7/18/2014 21:15	20.846		-0.234	21.556		
7/18/2014 21:30	20.902		-0.382	21.677		
7/18/2014 21:45	20.875		-0.534	21.767		
7/18/2014 22:00	20.687		-0.648	21.736		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/18/2014 22:15	20.285		-0.652	21.64		
7/18/2014 22:30	19.942		-0.657	21.537		
7/18/2014 22:45	19.673		-0.657	21.248		
7/18/2014 23:00	19.38		-0.658	20.952		
7/18/2014 23:15	19.104		-0.658	20.772		
7/18/2014 23:30	18.852		-0.657	20.514		
7/18/2014 23:45	18.632		-0.659	20.176		
7/19/2014 0:00	18.42		-0.660	19.871		
7/19/2014 0:15	18.212		-0.657	19.482		
7/19/2014 0:30	18.037		-0.659	19.198		
7/19/2014 0:45	17.956	25.308	-0.659	19.136		
7/19/2014 1:00	17.778	26.354	-0.662	19.159		
7/19/2014 1:15	17.565	23.551	-0.659	19.166		
7/19/2014 1:30	17.417	22.718	-0.658	19.001		
7/19/2014 1:45	17.3	23.215	-0.661	19.419		
7/19/2014 2:00	17.203	23.232	-0.662	19.943		
7/19/2014 2:15	17.158	23.115	-0.619	20.397		
7/19/2014 2:30	17.269	23.258	-0.479	20.518		
7/19/2014 2:45	17.345	23.344	-0.318	20.54		
7/19/2014 3:00	17.586	23.593	-0.154	20.475		
7/19/2014 3:15	17.865	24.122	0.008	20.323		
7/19/2014 3:30	18.173	24.505	0.186	20.168		
7/19/2014 3:45	18.447	24.748	0.381	19.994		
7/19/2014 4:00	18.677	25.091	0.570	19.827		
7/19/2014 4:15	18.852	25.316	0.744	19.512		
7/19/2014 4:30	19.037	25.591	0.910	19.091		
7/19/2014 4:45	19.134	25.860	1.055	18.638		
7/19/2014 5:00	19.169	26.086	1.178	18.206		
7/19/2014 5:15	19.149	26.071	1.256	17.735		
7/19/2014 5:30	19.081	26.183	1.298	17.304		
7/19/2014 5:45	18.993	26.187	1.304	17.025		
7/19/2014 6:00	18.922	26.438	1.298	16.925		
7/19/2014 6:15	18.875	26.572	1.276	16.905		
7/19/2014 6:30	18.835	26.616	1.195	17.145		
7/19/2014 6:45	18.855	26.674	1.076	17.65		
7/19/2014 7:00	18.891	26.739	0.976	18.164		
7/19/2014 7:15	18.91	26.658	0.880	18.511		
7/19/2014 7:30	18.937	26.669	0.770	18.759		
7/19/2014 7:45	18.965	26.626	0.648	19.045		
7/19/2014 8:00	18.974	26.588	0.522	19.244		
7/19/2014 8:15	19.007	26.578	0.406	19.383		

Date and Time	Mitigation Site A Site A Temperature (°C)	 Site A Salinity (PSU)	 Site A Water Surface Elevation (m)	Mitigation Site B Site B Temperature (°C)	 Site B Salinity (PSU)	
7/19/2014 8:30	19.035	26.545	0.280	19.499		
7/19/2014 8:45	19.081	26.504	0.148	19.604		
7/19/2014 9:00	19.094	26.414	0.016	19.673		
7/19/2014 9:15	19.088	26.361	-0.107	19.732		
7/19/2014 9:30	19.069	26.222	-0.245	19.767		
7/19/2014 9:45	19.057	26.111	-0.386	19.775		
7/19/2014 10:00	19.071	26.037	-0.535	19.785		
7/19/2014 10:15	19.279	26.148	-0.647	19.814		
7/19/2014 10:30	19.447	25.989	-0.655	19.849		
7/19/2014 10:45	19.605	25.643	-0.656	19.908		
7/19/2014 11:00	19.713	25.197	-0.656	20.05		
7/19/2014 11:15	19.917	25.025	-0.659	20.289		
7/19/2014 11:30	20.143	24.774	-0.659	20.53		
7/19/2014 11:45	20.231	24.713	-0.660	20.908		
7/19/2014 12:00	20.316	24.662	-0.657	21.218		
7/19/2014 12:15	20.381	24.587	-0.660	21.459		
7/19/2014 12:30	20.439	24.530	-0.665	21.757		
7/19/2014 12:45	20.51	24.431	-0.664	22.196		
7/19/2014 13:00	20.84	24.363	-0.663	22.328		
7/19/2014 13:15	21.223	24.284	-0.665	22.557		
7/19/2014 13:30	21.273	24.120	-0.665	22.615		
7/19/2014 13:45	21.347	23.899	-0.667	22.553		
7/19/2014 14:00	21.461	23.773	-0.665	22.175		
7/19/2014 14:15	21.349	23.581	-0.664	21.613		
7/19/2014 14:30	21.091	23.629	-0.620	21.288		
7/19/2014 14:45	20.756	23.680	-0.491	21.099		
7/19/2014 15:00	20.819	23.668	-0.338	21.001		
7/19/2014 15:15	20.937	23.932	-0.177	20.914		
7/19/2014 15:30	21.077	24.324	-0.005	20.816		
7/19/2014 15:45	21.035	24.927	0.172	20.71		
7/19/2014 16:00	20.95	25.291	0.362	20.572		
7/19/2014 16:15	20.801	25.527	0.565	20.358		
7/19/2014 16:30	20.701	25.851	0.751	19.998		
7/19/2014 16:45	20.608	26.064	0.923	19.529		
7/19/2014 17:00	20.509	26.245	1.076	19.096		
7/19/2014 17:15	20.392	26.334	1.211	18.701		
7/19/2014 17:30	20.234	26.465	1.299	18.321		
7/19/2014 17:45	20.017	26.760	1.355	17.845		
7/19/2014 18:00	19.753	27.127	1.397	17.298		
7/19/2014 18:15	19.488	27.286	1.427	16.998		
7/19/2014 18:30	19.193	27.536	1.457	16.832		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/19/2014 18:45	18.847	27.813	1.460	16.604		
7/19/2014 19:00	18.632	28.081	1.430	16.585		
7/19/2014 19:15	18.521	28.006	1.375	16.743		
7/19/2014 19:30	18.535	27.944	1.302	17.163		
7/19/2014 19:45	18.738	27.799	1.190	17.793		
7/19/2014 20:00	18.919	27.693	1.027	18.528		
7/19/2014 20:15	19.152	27.626	0.872	19.061		
7/19/2014 20:30	19.309	27.549	0.734	19.4		
7/19/2014 20:45	19.45	27.471	0.591	19.656		
7/19/2014 21:00	19.583	27.398	0.454	19.855		
7/19/2014 21:15	19.668	27.314	0.318	20.018		
7/19/2014 21:30	19.793	27.263	0.181	20.147		
7/19/2014 21:45	19.892	27.173	0.043	20.259		
7/19/2014 22:00	19.95	27.128	-0.090	20.351		
7/19/2014 22:15	20.042	26.998	-0.228	20.436		
7/19/2014 22:30	20.033	26.889	-0.367	20.515		
7/19/2014 22:45	20.004	26.778	-0.515	20.579		
7/19/2014 23:00	19.875	26.888	-0.643	20.605		
7/19/2014 23:15	19.671	26.283	-0.656	20.613		
7/19/2014 23:30	19.482	25.991	-0.659	20.552		
7/19/2014 23:45	19.298	25.943	-0.656	20.429		
7/20/2014 0:00	19.079	25.619	-0.657	20.216		
7/20/2014 0:15	18.874	25.080	-0.657	20.005		
7/20/2014 0:30	18.681	24.756	-0.659	19.788		
7/20/2014 0:45	18.512	24.510	-0.659	19.642		
7/20/2014 1:00	18.329	24.340	-0.659	19.475		
7/20/2014 1:15	18.132	24.364	-0.660	19.276		
7/20/2014 1:30	17.94	24.422	-0.659	19.106		
7/20/2014 1:45	17.789	24.434	-0.663	19.01		
7/20/2014 2:00	17.675	24.484	-0.663	18.91		
7/20/2014 2:15	17.562	24.467	-0.667	18.827		
7/20/2014 2:30	17.464	24.479	-0.668	18.97		
7/20/2014 2:45	17.359	24.470	-0.670	19.216		
7/20/2014 3:00	17.278	24.383	-0.670	19.679		
7/20/2014 3:15	17.342	24.451	-0.597	19.877		
7/20/2014 3:30	17.392	24.397	-0.458	19.95		
7/20/2014 3:45	17.61	24.136	-0.318	19.958		
7/20/2014 4:00	17.797	24.428	-0.171	19.898		
7/20/2014 4:15	18.072	24.681	-0.002	19.766		
7/20/2014 4:30	18.328	25.052	0.156	19.628		
7/20/2014 4:45	18.514	25.403	0.337	19.496		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/20/2014 5:00	18.624	25.720	0.513	19.345		
7/20/2014 5:15	18.768	25.864	0.678	19.179		
7/20/2014 5:30	18.82	26.046	0.824	18.939		
7/20/2014 5:45	18.852	26.130	0.974	18.612		
7/20/2014 6:00	18.85	26.251	1.089	18.234		
7/20/2014 6:15	18.87	26.322	1.156	17.974		
7/20/2014 6:30	18.859	26.475	1.203	17.791		
7/20/2014 6:45	18.846	26.651	1.233	17.625		
7/20/2014 7:00	18.821	26.773	1.214	17.524		
7/20/2014 7:15	18.793	26.872	1.148	17.637		
7/20/2014 7:30	18.81	26.970	1.090	17.815		
7/20/2014 7:45	18.817	26.971	1.019	18.02		
7/20/2014 8:00	18.852	26.990	0.919	18.192		
7/20/2014 8:15	18.886	26.996	0.842	18.422		
7/20/2014 8:30	18.917	27.012	0.750	18.66		
7/20/2014 8:45	18.944	27.025	0.635	18.889		
7/20/2014 9:00	18.971	27.024	0.524	19.082		
7/20/2014 9:15	19	27.028	0.414	19.206		
7/20/2014 9:30	19.01	27.012	0.298	19.295		
7/20/2014 9:45	19.009	26.933	0.180	19.355		
7/20/2014 10:00	19.015	26.878	0.049	19.407		
7/20/2014 10:15	18.974	26.822	-0.076	19.46		
7/20/2014 10:30	18.951	26.834	-0.199	19.495		
7/20/2014 10:45	18.92	26.775	-0.332	19.511		
7/20/2014 11:00	18.898	26.791	-0.473	19.51		
7/20/2014 11:15	18.955	26.936	-0.610	19.496		
7/20/2014 11:30	19.081	26.171	-0.657	19.506		
7/20/2014 11:45	19.277	25.340	-0.656	19.541		
7/20/2014 12:00	19.445	24.923	-0.658	19.617		
7/20/2014 12:15	19.506	24.488	-0.661	19.742		
7/20/2014 12:30	19.585	24.178	-0.660	19.932		
7/20/2014 12:45	19.763	23.947	-0.662	20.149		
7/20/2014 13:00	19.997	23.723	-0.665	20.378		
7/20/2014 13:15	20.379	23.781	-0.667	20.711		
7/20/2014 13:30	20.799	23.720	-0.669	21.083		
7/20/2014 13:45	21.146		-0.671	21.34		
7/20/2014 14:00	21.418		-0.670	21.484		
7/20/2014 14:15	21.838		-0.665	21.592		
7/20/2014 14:30	22.227		-0.669	21.691		
7/20/2014 14:45	22.558		-0.671	21.718		
7/20/2014 15:00	22.864		-0.670	21.423		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/20/2014 15:15	22.58		-0.618	21.209		
7/20/2014 15:30	22.327		-0.492	21.071		
7/20/2014 15:45	21.999		-0.353	20.9		
7/20/2014 16:00	22.078		-0.198	20.732		
7/20/2014 16:15	21.858		-0.043	20.643		
7/20/2014 16:30	21.679		0.116	20.573		
7/20/2014 16:45	21.442		0.281	20.49		
7/20/2014 17:00	21.209		0.460	20.379		
7/20/2014 17:15	21.003		0.634	20.211		
7/20/2014 17:30	20.863		0.811	19.967		
7/20/2014 17:45	20.699		0.962	19.645		
7/20/2014 18:00	20.589		1.110	19.255		
7/20/2014 18:15	20.454		1.222	18.849		
7/20/2014 18:30	20.278		1.305	18.531		
7/20/2014 18:45	20.098		1.362	18.203		
7/20/2014 19:00	19.871		1.401	17.847		
7/20/2014 19:15	19.628		1.431	17.556		
7/20/2014 19:30	19.396		1.450	17.416		
7/20/2014 19:45	19.194		1.453	17.283		
7/20/2014 20:00	19.003		1.426	17.255		
7/20/2014 20:15	18.892		1.374	17.364		
7/20/2014 20:30	18.868		1.302	17.706		
7/20/2014 20:45	18.974		1.182	18.234		
7/20/2014 21:00	19.142		1.032	18.803		
7/20/2014 21:15	19.293		0.876	19.234		
7/20/2014 21:30	19.384		0.739	19.518		
7/20/2014 21:45	19.503		0.598	19.722		
7/20/2014 22:00	19.61		0.467	19.887		
7/20/2014 22:15	19.741		0.337	20.021		
7/20/2014 22:30	19.84		0.199	20.126		
7/20/2014 22:45	19.892		0.065	20.219		
7/20/2014 23:00	19.983		-0.060	20.3		
7/20/2014 23:15	20.07		-0.194	20.377		
7/20/2014 23:30	20.127		-0.334	20.461		
7/20/2014 23:45	20.117		-0.484	20.553		
7/21/2014 0:00	20.004		-0.616	20.581		
7/21/2014 0:15	19.811		-0.657	20.572		
7/21/2014 0:30	19.567		-0.659	20.547		
7/21/2014 0:45	19.291		-0.659	20.463		
7/21/2014 1:00	19.027		-0.658	20.237		
7/21/2014 1:15	18.812		-0.660	20.027		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/21/2014 1:30	18.569		-0.660	19.801		
7/21/2014 1:45	18.352		-0.664	19.582		
7/21/2014 2:00	18.133		-0.661	19.435		
7/21/2014 2:15	17.95		-0.664	19.071		
7/21/2014 2:30	17.763		-0.665	18.834		
7/21/2014 2:45	17.627		-0.666	18.387		
7/21/2014 3:00	17.513		-0.667	18.324		
7/21/2014 3:15	17.402		-0.668	18.395		
7/21/2014 3:30	17.331		-0.671	18.873		
7/21/2014 3:45	17.252		-0.670	19.132		
7/21/2014 4:00	17.167		-0.672	19.557		
7/21/2014 4:15	17.322		-0.599	19.803		
7/21/2014 4:30	17.446		-0.472	19.915		
7/21/2014 4:45	17.581		-0.332	19.954		
7/21/2014 5:00	17.7		-0.177	19.941		
7/21/2014 5:15	17.911		-0.027	19.832		
7/21/2014 5:30	18.086		0.123	19.719		
7/21/2014 5:45	18.341		0.284	19.611		
7/21/2014 6:00	18.552		0.445	19.474		
7/21/2014 6:15	18.717		0.598	19.342		
7/21/2014 6:30	18.788		0.757	19.177		
7/21/2014 6:45	18.854		0.896	18.968		
7/21/2014 7:00	18.9		1.005	18.736		
7/21/2014 7:15	18.927		1.078	18.474		
7/21/2014 7:30	18.942		1.124	18.264		
7/21/2014 7:45	18.969		1.161	18.122		
7/21/2014 8:00	18.954		1.156	18.027		
7/21/2014 8:15	18.961		1.085	18.049		
7/21/2014 8:30	18.981		0.993	18.241		
7/21/2014 8:45	19.042		0.939	18.521		
7/21/2014 9:00	19.045		0.864	18.714		
7/21/2014 9:15	19.078		0.773	18.861		
7/21/2014 9:30	19.169		0.686	19.143		
7/21/2014 9:45	19.203		0.592	19.348		
7/21/2014 10:00	19.253		0.484	19.543		
7/21/2014 10:15	19.323		0.365	19.706		
7/21/2014 10:30	19.368		0.255	19.867		
7/21/2014 10:45	19.436		0.146	20.02		
7/21/2014 11:00	19.475		0.029	20.179		
7/21/2014 11:15	19.494		-0.089	20.342		
7/21/2014 11:30	19.561		-0.212	20.511		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/21/2014 11:45	19.669		-0.338	20.683		
7/21/2014 12:00	19.903		-0.475	20.868		
7/21/2014 12:15	20.377		-0.608	21.061		
7/21/2014 12:30	21.16		-0.664	21.296		
7/21/2014 12:45	21.684		-0.667	21.571		
7/21/2014 13:00	22.237		-0.669	21.952		
7/21/2014 13:15	22.858		-0.669	22.444		
7/21/2014 13:30	23.378		-0.668	23.075		
7/21/2014 13:45	23.856		-0.669	23.584		
7/21/2014 14:00	24.209		-0.668	24.25		
7/21/2014 14:15	24.551		-0.668	24.446		
7/21/2014 14:30	24.828		-0.670	24.907		
7/21/2014 14:45	25.077		-0.671	24.976		
7/21/2014 15:00	25.068		-0.670	24.809		
7/21/2014 15:15	25.134		-0.671	24.603		
7/21/2014 15:30	25.197		-0.669	24.519		
7/21/2014 15:45	25.259		-0.668	24.249		
7/21/2014 16:00	25.049		-0.656	23.506		
7/21/2014 16:15	24.171		-0.533	23.11		
7/21/2014 16:30	23.534		-0.416	22.823		
7/21/2014 16:45	24.018		-0.292	22.51		
7/21/2014 17:00	23.992		-0.147	22.282		
7/21/2014 17:15	23.826		0.005	22.186		
7/21/2014 17:30	23.473		0.156	22.042		
7/21/2014 17:45	23.077		0.321	21.887		
7/21/2014 18:00	22.719	26.136	0.487	21.737		
7/21/2014 18:15	22.476	25.156	0.667	21.518		
7/21/2014 18:30	22.253	26.338	0.833	21.207		
7/21/2014 18:45	22.057	26.188	0.981	20.84		
7/21/2014 19:00	21.904	26.460	1.123	20.47		
7/21/2014 19:15	21.71	26.477	1.232	20.046		
7/21/2014 19:30	21.463	26.603	1.305	19.673		
7/21/2014 19:45	21.181	26.794	1.357	19.334		
7/21/2014 20:00	20.926	26.889	1.394	19.042		
7/21/2014 20:15	20.591	27.067	1.421	18.847		
7/21/2014 20:30	20.339	27.195	1.436	18.717		
7/21/2014 20:45	20.107	27.309	1.436	18.614		
7/21/2014 21:00	19.946	27.347	1.408	18.601		
7/21/2014 21:15	19.89	27.286	1.359	18.71		
7/21/2014 21:30	19.964	27.326	1.284	19		
7/21/2014 21:45	20.125	27.324	1.159	19.428		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/21/2014 22:00	20.364	27.214	1.002	19.931		
7/21/2014 22:15	20.573	27.155	0.869	20.308		
7/21/2014 22:30	20.703	27.083	0.743	20.543		
7/21/2014 22:45	20.74	27.102	0.598	20.756		
7/21/2014 23:00	20.827	27.021	0.464	20.91		
7/21/2014 23:15	20.86	26.967	0.334	21.024		
7/21/2014 23:30	20.928	26.921	0.200	21.122		
7/21/2014 23:45	21.022	26.835	0.066	21.197		
7/22/2014 0:00	21.107	26.712	-0.060	21.248		
7/22/2014 0:15	21.109	26.590	-0.192	21.287		
7/22/2014 0:30	21.091	26.453	-0.334	21.354		
7/22/2014 0:45	21.016	26.354	-0.479	21.361		
7/22/2014 1:00	20.826	25.732	-0.612	21.283		
7/22/2014 1:15	20.579	25.762	-0.659	21.27		
7/22/2014 1:30	20.374	25.348	-0.659	21.242		
7/22/2014 1:45	20.098	25.225	-0.660	21.122		
7/22/2014 2:00	19.844	24.949	-0.661	20.914		
7/22/2014 2:15	19.596	24.702	-0.662	20.642		
7/22/2014 2:30	19.262	24.699	-0.665	20.423		
7/22/2014 2:45	18.986	24.769	-0.667	20.191		
7/22/2014 3:00	18.828	24.714	-0.667	20.091		
7/22/2014 3:15	18.669	24.668	-0.668	19.739		
7/22/2014 3:30	18.514	24.620	-0.667	19.406		
7/22/2014 3:45	18.343	24.579	-0.667	19.092		
7/22/2014 4:00	18.176	24.507	-0.668	19.099		
7/22/2014 4:15	18.013	24.474	-0.667	19.055		
7/22/2014 4:30	17.863	24.402	-0.667	19.334		
7/22/2014 4:45	17.741	24.474	-0.669	19.739		
7/22/2014 5:00	17.66	24.521	-0.667	20.322		
7/22/2014 5:15	17.756	25.368	-0.607	20.617		
7/22/2014 5:30	17.886	25.406	-0.477	20.759		
7/22/2014 5:45	17.999	24.973	-0.352	20.829		
7/22/2014 6:00	18.221	25.012	-0.214	20.841		
7/22/2014 6:15	18.48	25.170	-0.066	20.775		
7/22/2014 6:30	18.752	25.159	0.083	20.672		
7/22/2014 6:45	19.016	25.281	0.231	20.588		
7/22/2014 7:00	19.116	25.368	0.382	20.501		
7/22/2014 7:15	19.263	25.539	0.539	20.401		
7/22/2014 7:30	19.483	25.561	0.692	20.317		
7/22/2014 7:45	19.55	25.836	0.824	20.188		
7/22/2014 8:00	19.632	25.911	0.931	20.017		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/22/2014 8:15	19.702	26.227	1.019	19.805		
7/22/2014 8:30	19.732	26.229	1.077	19.606		
7/22/2014 8:45	19.813	26.260	1.104	19.486		
7/22/2014 9:00	19.84	26.514	1.076	19.447		
7/22/2014 9:15	19.889	26.270	1.011	19.488		
7/22/2014 9:30	19.915	26.522	0.945	19.635		
7/22/2014 9:45	19.935	26.652	0.893	19.791		
7/22/2014 10:00	20.014	26.544	0.832	19.938		
7/22/2014 10:15	20.04	26.612	0.750	20.088		
7/22/2014 10:30	20.173	26.695	0.656	20.382		
7/22/2014 10:45	20.159	26.454	0.567	20.684		
7/22/2014 11:00	20.304	26.735	0.473	20.878		
7/22/2014 11:15	20.329	26.571	0.372	21.075		
7/22/2014 11:30	20.409	26.765	0.255	21.252		
7/22/2014 11:45	20.491	26.620	0.143	21.438		
7/22/2014 12:00	20.667	26.564	0.029	21.639		
7/22/2014 12:15	20.73	26.489	-0.078	21.831		
7/22/2014 12:30	20.81	26.626	-0.193	22.028		
7/22/2014 12:45	20.996	26.482	-0.313	22.225		
7/22/2014 13:00	21.16	26.796	-0.442	22.428		
7/22/2014 13:15	21.577	25.793	-0.572	22.644		
7/22/2014 13:30	22.336	25.010	-0.657	22.873		
7/22/2014 13:45	22.443	24.487	-0.660	23.166		
7/22/2014 14:00	22.87	24.284	-0.666	23.517		
7/22/2014 14:15	23.197	24.024	-0.666	23.948		
7/22/2014 14:30	23.372	23.932	-0.666	24.581		
7/22/2014 14:45	23.631	23.709	-0.668	25.024		
7/22/2014 15:00	23.945	23.524	-0.671	25.511		
7/22/2014 15:15	24.423	23.296	-0.669	25.775		
7/22/2014 15:30	23.979	23.269	-0.673	25.858		
7/22/2014 15:45	24.208	23.129	-0.672	25.799		
7/22/2014 16:00	24.012	22.777	-0.669	25.713		
7/22/2014 16:15	24.233	22.710	-0.667	25.449		
7/22/2014 16:30	24.065	22.533	-0.669	25.338		
7/22/2014 16:45	24.105	22.514	-0.670	24.982		
7/22/2014 17:00	23.82	22.541	-0.625	24.457		
7/22/2014 17:15	23.597	23.005	-0.516	24.231		
7/22/2014 17:30	23.8	22.898	-0.386	24.052		
7/22/2014 17:45	24.152	23.208	-0.241	23.736		
7/22/2014 18:00	24.118	23.851	-0.089	23.495		
7/22/2014 18:15	23.963	24.586	0.056	23.334		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/22/2014 18:30	23.893	24.998	0.201	23.174		
7/22/2014 18:45	23.574	25.373	0.381	23.023		
7/22/2014 19:00	23.366	25.526	0.572	22.832		
7/22/2014 19:15	23.193	25.679	0.726	22.596		
7/22/2014 19:30	23.036	25.871	0.869	22.314		
7/22/2014 19:45	22.936	26.016	1.018	21.995		
7/22/2014 20:00	22.789	26.212	1.159	21.624		
7/22/2014 20:15	22.645	26.365	1.255	21.268		
7/22/2014 20:30	22.483	26.587	1.325	20.933		
7/22/2014 20:45	22.273	26.713	1.373	20.65		
7/22/2014 21:00	22.056	26.977	1.402	20.478		
7/22/2014 21:15	21.841	27.221	1.425	20.336		
7/22/2014 21:30	21.63	27.218	1.453	20.206		
7/22/2014 21:45	21.413	27.390	1.464	20.149		
7/22/2014 22:00	21.238	27.556	1.430	20.147		
7/22/2014 22:15	21.147	27.648	1.373	20.226		
7/22/2014 22:30	21.176	27.632	1.297	20.492		
7/22/2014 22:45	21.284	27.523	1.179	20.852		
7/22/2014 23:00	21.463	27.557	1.012	21.319		
7/22/2014 23:15	21.664	27.394	0.852	21.719		
7/22/2014 23:30	21.739	27.418	0.719	21.975		
7/22/2014 23:45	21.79	27.337	0.588	22.157		
7/23/2014 0:00	21.914	27.270	0.461	22.292		
7/23/2014 0:15	22.003	27.214	0.319	22.401		
7/23/2014 0:30	22.095	27.123	0.185	22.507		
7/23/2014 0:45	22.173	27.098	0.054	22.588		
7/23/2014 1:00	22.23	27.031	-0.077	22.661		
7/23/2014 1:15	22.225	26.948	-0.214	22.723		
7/23/2014 1:30	22.206	26.863	-0.351	22.785		
7/23/2014 1:45	22.111	26.816	-0.496	22.817		
7/23/2014 2:00	21.967	26.190	-0.634	22.791		
7/23/2014 2:15	21.771	25.869	-0.662	22.739		
7/23/2014 2:30	21.559	25.504	-0.662	22.696		
7/23/2014 2:45	21.316	25.536	-0.663	22.58		
7/23/2014 3:00	21.046	25.629	-0.667	22.368		
7/23/2014 3:15	20.801	25.503	-0.670	22.138		
7/23/2014 3:30	20.605	25.275	-0.668	21.862		
7/23/2014 3:45	20.404	25.111	-0.670	21.677		
7/23/2014 4:00	20.202	25.015	-0.669	21.499		
7/23/2014 4:15	20.054	24.915	-0.668	21.215		
7/23/2014 4:30	19.918	24.839	-0.669	20.951		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/23/2014 4:45	19.781	24.805	-0.671	20.738		
7/23/2014 5:00	19.776	23.861	-0.670	20.718		
7/23/2014 5:15	19.56	23.676	-0.671	20.737		
7/23/2014 5:30	19.395	23.715	-0.673	21.101		
7/23/2014 5:45	19.266	23.648	-0.672	21.464		
7/23/2014 6:00	19.196	23.560	-0.671	21.707		
7/23/2014 6:15	19.293	25.691	-0.578	21.851		
7/23/2014 6:30	19.357	25.574	-0.462	21.931		
7/23/2014 6:45	19.474	25.958	-0.327	21.974		
7/23/2014 7:00	19.696	26.256	-0.188	22.025		
7/23/2014 7:15	19.947	26.397	-0.041	22.042		
7/23/2014 7:30	20.179	26.497	0.110	22.024		
7/23/2014 7:45	20.339	26.546	0.270	22.001		
7/23/2014 8:00	20.511	26.604	0.424	21.953		
7/23/2014 8:15	20.645	26.650	0.583	21.911		
7/23/2014 8:30	20.727	26.680	0.735	21.851		
7/23/2014 8:45	20.921	26.651	0.872	21.743		
7/23/2014 9:00	20.946	26.615	0.979	21.571		
7/23/2014 9:15	21.127	26.668	1.056	21.348		
7/23/2014 9:30	21.201	26.650	1.123	21.133		
7/23/2014 9:45	21.229	26.719	1.152	20.979		
7/23/2014 10:00	21.278	26.701	1.119	20.949		
7/23/2014 10:15	21.414	26.714	1.060	21.013		
7/23/2014 10:30	21.395	26.709	1.013	21.199		
7/23/2014 10:45	21.434	26.704	0.943	21.361		
7/23/2014 11:00	21.525	26.737	0.856	21.634		
7/23/2014 11:15	21.606	26.710	0.782	22.051		
7/23/2014 11:30	21.717	26.803	0.697	22.355		
7/23/2014 11:45	21.803	26.862	0.599	22.528		
7/23/2014 12:00	21.937	26.845	0.499	22.734		
7/23/2014 12:15	22.08	26.839	0.389	22.937		
7/23/2014 12:30	22.226	26.794	0.273	23.14		
7/23/2014 12:45	22.401	26.769	0.157	23.346		
7/23/2014 13:00	22.538	26.726	0.041	23.566		
7/23/2014 13:15	22.647	26.787	-0.070	23.767		
7/23/2014 13:30	22.844	26.834	-0.192	23.996		
7/23/2014 13:45	23.057	26.950	-0.314	24.257		
7/23/2014 14:00	23.385	26.957	-0.443	24.514		
7/23/2014 14:15	23.713	26.588	-0.564	24.782		
7/23/2014 14:30	24.635	25.933	-0.665	25.047		
7/23/2014 14:45	24.751	25.343	-0.670	25.37		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/23/2014 15:00	24.878	25.001	-0.672	25.745		
7/23/2014 15:15	24.921	24.764	-0.678	26.133		
7/23/2014 15:30	25.043	24.514	-0.679	26.484		
7/23/2014 15:45	25.224	24.319	-0.680	26.891		
7/23/2014 16:00	25.284	24.235	-0.681	27.161		
7/23/2014 16:15	25.423	24.124	-0.682	27.224		
7/23/2014 16:30	25.354	23.810	-0.682	27.262		
7/23/2014 16:45	25.135	23.583	-0.681	27.137		
7/23/2014 17:00	25.087	23.450	-0.682	26.922		
7/23/2014 17:15	25.07	23.299	-0.683	26.766		
7/23/2014 17:30	25.058	23.134	-0.684	26.646		
7/23/2014 17:45	24.805	22.985	-0.666	26.06		
7/23/2014 18:00	24.416	23.039	-0.571	25.636		
7/23/2014 18:15	24.305	23.117	-0.431	25.453		
7/23/2014 18:30	24.468	23.345	-0.293	25.293		
7/23/2014 18:45	24.722	24.147	-0.161	25.107		
7/23/2014 19:00	24.702	25.025	-0.016	24.956		
7/23/2014 19:15	24.646	25.452	0.140	24.794		
7/23/2014 19:30	24.503	25.585	0.314	24.632		
7/23/2014 19:45	24.518	25.944	0.488	24.441		
7/23/2014 20:00	24.4	26.013	0.663	24.172		
7/23/2014 20:15	24.274	26.181	0.830	23.849		
7/23/2014 20:30	24.166	26.269	0.989	23.488		
7/23/2014 20:45	24.038	26.355	1.137	23.083		
7/23/2014 21:00	23.946	26.472	1.247	22.695		
7/23/2014 21:15	23.705	26.569	1.329	22.301		
7/23/2014 21:30	23.463	26.660	1.387	21.937		
7/23/2014 21:45	23.218	26.809	1.428	21.723		
7/23/2014 22:00	22.946	27.030	1.460	21.528		
7/23/2014 22:15	22.695	27.225	1.494	21.346		
7/23/2014 22:30	22.463	27.407	1.505	21.234		
7/23/2014 22:45	22.293	27.479	1.483	21.191		
7/23/2014 23:00	22.201	27.505	1.434	21.231		
7/23/2014 23:15	22.186	27.650	1.384	21.434		
7/23/2014 23:30	22.267	27.663	1.310	21.706		
7/23/2014 23:45	22.431	27.721	1.181	22.117		
7/24/2014 0:00	22.613	27.784	1.021	22.579		
7/24/2014 0:15	22.782	27.712	0.859	22.947		
7/24/2014 0:30	22.962	27.685	0.711	23.193		
7/24/2014 0:45	23.076	27.580	0.563	23.37		
7/24/2014 1:00	23.173	27.580	0.422	23.509		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/24/2014 1:15	23.223	27.540	0.287	23.604		
7/24/2014 1:30	23.36	27.511	0.152	23.686		
7/24/2014 1:45	23.383	27.478	0.024	23.737		
7/24/2014 2:00	23.416	27.432	-0.113	23.796		
7/24/2014 2:15	23.398	27.361	-0.252	23.803		
7/24/2014 2:30	23.294	27.260	-0.393	23.752		
7/24/2014 2:45	23.118	27.353	-0.536	23.716		
7/24/2014 3:00	22.895	26.715	-0.658	23.661		
7/24/2014 3:15	22.73	26.914	-0.666	23.639		
7/24/2014 3:30	22.443	27.240	-0.667	23.574		
7/24/2014 3:45	22.164	27.078	-0.666	23.484		
7/24/2014 4:00	21.935	27.074	-0.670	23.262		
7/24/2014 4:15	21.703	26.941	-0.670	23.062		
7/24/2014 4:30	21.518	26.950	-0.669	22.795		
7/24/2014 4:45	21.29	26.723	-0.668	22.626		
7/24/2014 5:00	21.214	26.775	-0.667	22.48		
7/24/2014 5:15	21.102	27.014	-0.666	22.277		
7/24/2014 5:30	20.955	27.080	-0.666	21.949		
7/24/2014 5:45	20.821	27.065	-0.667	22.008		
7/24/2014 6:00	20.674	27.057	-0.662	22.308		
7/24/2014 6:15	20.57	27.098	-0.665	22.508		
7/24/2014 6:30	20.437	27.061	-0.666	22.774		
7/24/2014 6:45	20.321	27.018	-0.668	23.016		
7/24/2014 7:00	20.343	27.453	-0.606	23.21		
7/24/2014 7:15	20.336	27.260	-0.487	23.313		
7/24/2014 7:30	20.429	27.126	-0.352	23.384		
7/24/2014 7:45	20.728	27.114	-0.209	23.439		
7/24/2014 8:00	21.009	27.111	-0.048	23.44		
7/24/2014 8:15	21.33	26.908	0.098	23.397		
7/24/2014 8:30	21.645	26.995	0.253	23.355		
7/24/2014 8:45	21.825	26.987	0.428	23.288		
7/24/2014 9:00	22.005	27.079	0.588	23.198		
7/24/2014 9:15	22.114	26.952	0.734	23.113		
7/24/2014 9:30	22.203	27.010	0.859	23.001		
7/24/2014 9:45	22.35	26.978	0.980	22.833		
7/24/2014 10:00	22.291	27.222	1.083	22.646		
7/24/2014 10:15	22.33	27.159	1.142	22.445		
7/24/2014 10:30	22.371	27.101	1.156	22.307		
7/24/2014 10:45	22.384	27.277	1.131	22.268		
7/24/2014 11:00	22.405	27.172	1.144	22.275		
7/24/2014 11:15	22.463	27.082	1.107	22.275		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/24/2014 11:30	22.497	27.374	1.017	22.362		
7/24/2014 11:45	22.496	27.333	0.934	22.558		
7/24/2014 12:00	22.519	27.305	0.873	22.743		
7/24/2014 12:15	22.636	27.354	0.786	22.889		
7/24/2014 12:30	22.657	27.540	0.672	23.083		
7/24/2014 12:45	22.581	27.398	0.563	23.246		
7/24/2014 13:00	22.705	27.516	0.466	23.362		
7/24/2014 13:15	22.707	27.354	0.361	23.453		
7/24/2014 13:30	22.75	27.406	0.239	23.553		
7/24/2014 13:45	22.862	27.392	0.119	23.663		
7/24/2014 14:00	22.877	27.371	0.008	23.79		
7/24/2014 14:15	22.958	27.363	-0.110	23.922		
7/24/2014 14:30	23.034	27.382	-0.230	24.053		
7/24/2014 14:45	23.03	27.360	-0.350	24.149		
7/24/2014 15:00	23.1	27.232	-0.482	24.24		
7/24/2014 15:15	23.341	26.255	-0.607	24.338		
7/24/2014 15:30	23.527	25.683	-0.668	24.42		
7/24/2014 15:45	23.326	25.481	-0.665	24.474		
7/24/2014 16:00	23.226	25.270	-0.667	24.527		
7/24/2014 16:15	23.268	25.355	-0.667	24.583		
7/24/2014 16:30	23.19	25.467	-0.672	24.6		
7/24/2014 16:45	23.092	25.579	-0.672	24.588		
7/24/2014 17:00	23.02	25.812	-0.674	24.611		
7/24/2014 17:15	23.023	25.899	-0.672	24.609		
7/24/2014 17:30	23.045	25.979	-0.672	24.631		
7/24/2014 17:45	23.019	25.970	-0.672	24.658		
7/24/2014 18:00	22.915	26.028	-0.672	24.611		
7/24/2014 18:15	22.706	26.021	-0.670	24.631		
7/24/2014 18:30	22.444	26.522	-0.650	24.617		
7/24/2014 18:45	22.234	27.153	-0.546	24.556		
7/24/2014 19:00	22.089	26.660	-0.429	24.521		
7/24/2014 19:15	22.229	26.152	-0.291	24.468		
7/24/2014 19:30	22.447	26.567	-0.152	24.376		
7/24/2014 19:45	22.694	26.896	-0.002	24.253		
7/24/2014 20:00	22.792	26.870	0.152	24.119		
7/24/2014 20:15	22.911	27.074	0.312	23.98		
7/24/2014 20:30	23.025	27.002	0.481	23.849		
7/24/2014 20:45	23.136	27.160	0.653	23.694		
7/24/2014 21:00	23.121	27.124	0.826	23.552		
7/24/2014 21:15	23.11	27.260	0.979	23.376		
7/24/2014 21:30	23.151	27.194	1.127	23.119		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/24/2014 21:45	23.083	27.089	1.247	22.782		
7/24/2014 22:00	23.014	27.286	1.313	22.444		
7/24/2014 22:15	22.953	27.198	1.368	22.063		
7/24/2014 22:30	22.849	27.453	1.414	21.646		
7/24/2014 22:45	22.705	27.541	1.456	21.4		
7/24/2014 23:00	22.538	27.663	1.488	20.853		
7/24/2014 23:15	22.293	27.675	1.505	20.562		
7/24/2014 23:30	22.07	27.743	1.509	20.425		
7/24/2014 23:45	21.927	27.796	1.483	20.375		
7/25/2014 0:00	21.841	27.862	1.433	20.442		
7/25/2014 0:15	21.849	27.900	1.373	20.796		
7/25/2014 0:30	21.916	27.933	1.289	21.336		
7/25/2014 0:45	21.982	27.942	1.150	21.801		
7/25/2014 1:00	22.036	27.899	0.962	22.147		
7/25/2014 1:15	22.092	27.957	0.773	22.343		
7/25/2014 1:30	22.131	27.922	0.618	22.419		
7/25/2014 1:45	22.112	27.833	0.473	22.44		
7/25/2014 2:00	22.118	27.793	0.326	22.431		
7/25/2014 2:15	22.08	27.751	0.181	22.387		
7/25/2014 2:30	22.057	27.715	0.052	22.304		
7/25/2014 2:45	21.997	27.653	-0.085	22.239		
7/25/2014 3:00	21.919	27.595	-0.219	22.121		
7/25/2014 3:15	21.782	27.483	-0.364	21.954		
7/25/2014 3:30	21.556	27.404	-0.513	21.746		
7/25/2014 3:45	21.13	26.771	-0.645	21.404		
7/25/2014 4:00	20.831	26.865	-0.665	21.218		
7/25/2014 4:15	20.578	27.174	-0.662	21.103		
7/25/2014 4:30	20.261	27.270	-0.662	20.889		
7/25/2014 4:45	19.942	27.240	-0.664	20.518		
7/25/2014 5:00	19.628	27.211	-0.663	20.191		
7/25/2014 5:15	19.365	27.193	-0.664	19.779		
7/25/2014 5:30	19.154	27.274	-0.665	19.545		
7/25/2014 5:45	18.959	27.296	-0.664	19.351		
7/25/2014 6:00	18.763	27.541	-0.663	19.059		
7/25/2014 6:15	18.593	27.489	-0.666	18.658		
7/25/2014 6:30	18.464	27.547	-0.664	18.46		
7/25/2014 6:45	18.319	27.605	-0.664	18.492		
7/25/2014 7:00	18.197	27.620	-0.665	18.687		
7/25/2014 7:15	18.193	27.605	-0.667	19.12		
7/25/2014 7:30	18.097	27.598	-0.666	19.919		
7/25/2014 7:45	18.119	27.787	-0.647	20.622		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/25/2014 8:00	18.442	27.598	-0.539	21.072		
7/25/2014 8:15	18.323	27.436	-0.424	21.435		
7/25/2014 8:30	18.796	26.763	-0.291	21.746		
7/25/2014 8:45	19.017	26.742	-0.133	21.987		
7/25/2014 9:00	19.463	26.728	0.017	22.081		
7/25/2014 9:15	19.867	26.640	0.164	22.116		
7/25/2014 9:30	20.194	26.849	0.332	22.129		
7/25/2014 9:45	20.482	26.811	0.496	22.123		
7/25/2014 10:00	20.674	26.813	0.642	22.131		
7/25/2014 10:15	20.858	27.038	0.796	22.125		
7/25/2014 10:30	21.027	26.912	0.942	22.015		
7/25/2014 10:45	21.029	27.055	1.035	21.806		
7/25/2014 11:00	21.065	27.025	1.091	21.605		
7/25/2014 11:15	21.192	27.070	1.135	21.441		
7/25/2014 11:30	21.348	27.061	1.156	21.326		
7/25/2014 11:45	21.367	27.105	1.167	21.234		
7/25/2014 12:00	21.386	27.108	1.107	21.232		
7/25/2014 12:15	21.52	27.105	1.011	21.54		
7/25/2014 12:30	21.667	27.151	0.942	21.885		
7/25/2014 12:45	21.715	27.221	0.878	22.158		
7/25/2014 13:00	21.833	27.267	0.772	22.465		
7/25/2014 13:15	21.959	27.263	0.668	22.714		
7/25/2014 13:30	22.082	27.328	0.579	22.925		
7/25/2014 13:45	22.175	27.342	0.483	23.101		
7/25/2014 14:00	22.289	27.341	0.357	23.248		
7/25/2014 14:15	22.45	27.382	0.229	23.407		
7/25/2014 14:30	22.465	27.355	0.117	23.547		
7/25/2014 14:45	22.49	27.363	0.000	23.688		
7/25/2014 15:00	22.57	27.308	-0.118	23.827		
7/25/2014 15:15	22.664	27.128	-0.239	23.965		
7/25/2014 15:30	22.817	27.110	-0.371	24.101		
7/25/2014 15:45	22.894	26.753	-0.506	24.227		
7/25/2014 16:00	23.364	26.143	-0.626	24.346		
7/25/2014 16:15	23.356	25.895	-0.670	24.461		
7/25/2014 16:30	23.524	26.198	-0.672	24.566		
7/25/2014 16:45	23.535	26.587	-0.672	24.671		
7/25/2014 17:00	23.398	26.657	-0.672	24.836		
7/25/2014 17:15	23.343	26.121	-0.673	24.98		
7/25/2014 17:30	23.362	25.936	-0.677	25.109		
7/25/2014 17:45	23.259	25.840	-0.674	25.122		
7/25/2014 18:00	22.996	25.630	-0.672	25.127		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/25/2014 18:15	22.729	25.497	-0.674	24.983		
7/25/2014 18:30	22.596	25.501	-0.674	24.794		
7/25/2014 18:45	22.36	25.699	-0.672	24.707		
7/25/2014 19:00	22.106	25.695	-0.674	24.671		
7/25/2014 19:15	21.872	25.659	-0.674	24.508		
7/25/2014 19:30	21.699	26.724	-0.590	24.386		
7/25/2014 19:45	21.49	26.674	-0.470	24.341		
7/25/2014 20:00	21.603	26.643	-0.331	24.29		
7/25/2014 20:15	21.839	26.879	-0.186	24.22		
7/25/2014 20:30	21.956	26.839	-0.043	24.127		
7/25/2014 20:45	22.037	27.005	0.110	24.001		
7/25/2014 21:00	22.178	27.079	0.270	23.877		
7/25/2014 21:15	22.341	27.053	0.443	23.73		
7/25/2014 21:30	22.461	27.248	0.625	23.502		
7/25/2014 21:45	22.535	27.283	0.797	23.239		
7/25/2014 22:00	22.61	27.324	0.956	22.914		
7/25/2014 22:15	22.674	27.402	1.084	22.496		
7/25/2014 22:30	22.638	27.381	1.198	22.077		
7/25/2014 22:45	22.663	27.340	1.288	21.645		
7/25/2014 23:00	22.557	27.493	1.356	21.267		
7/25/2014 23:15	22.471	27.603	1.401	20.92		
7/25/2014 23:30	22.312	27.762	1.433	20.634		
7/25/2014 23:45	22.151	27.828	1.459	20.467		
7/26/2014 0:00	21.971	27.760	1.480	20.349		
7/26/2014 0:15	21.781	28.064	1.475	20.291		
7/26/2014 0:30	21.637	27.870	1.437	20.28		
7/26/2014 0:45	21.54	28.104	1.383	20.356		
7/26/2014 1:00	21.488	28.155	1.315	20.578		
7/26/2014 1:15	21.502	27.998	1.196	20.935		
7/26/2014 1:30	21.569	27.818	1.022	21.394		
7/26/2014 1:45	21.667	27.968	0.848	21.762		
7/26/2014 2:00	21.694	27.918	0.702	21.974		
7/26/2014 2:15	21.767	27.749	0.560	22.102		
7/26/2014 2:30	21.771	27.763	0.413	22.167		
7/26/2014 2:45	21.775	27.650	0.278	22.191		
7/26/2014 3:00	21.816	27.633	0.137	22.169		
7/26/2014 3:15	21.746	27.607	0.003	22.126		
7/26/2014 3:30	21.702	27.598	-0.133	22.035		
7/26/2014 3:45	21.636	27.432	-0.268	21.962		
7/26/2014 4:00	21.509	27.358	-0.410	21.846		
7/26/2014 4:15	21.328	27.247	-0.554	21.699		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/26/2014 4:30	21.029	26.746	-0.660	21.55		
7/26/2014 4:45	20.834	26.061	-0.663	21.405		
7/26/2014 5:00	20.618	25.758	-0.666	21.252		
7/26/2014 5:15	20.363	25.541	-0.666	21.05		
7/26/2014 5:30	20.095	26.246	-0.669	20.739		
7/26/2014 5:45	19.902	26.549	-0.662	20.428		
7/26/2014 6:00	19.863	25.657	-0.664	20.146		
7/26/2014 6:15	19.731	25.302	-0.666	20.066		
7/26/2014 6:30	19.591	24.759	-0.665	19.891		
7/26/2014 6:45	19.472	24.505	-0.665	19.782		
7/26/2014 7:00	19.342	24.371	-0.665	19.644		
7/26/2014 7:15	19.196	24.738	-0.667	19.639		
7/26/2014 7:30	19.095	25.488	-0.668	19.658		
7/26/2014 7:45	19.132	26.001	-0.670	19.749		
7/26/2014 8:00	19.039	26.435	-0.669	20.051		
7/26/2014 8:15	18.97	26.801	-0.665	20.726		
7/26/2014 8:30	19.092	27.035	-0.644	21.475		
7/26/2014 8:45	19.272	26.984	-0.522	21.776		
7/26/2014 9:00	19.348	26.824	-0.396	21.923		
7/26/2014 9:15	19.528	26.661	-0.254	22.041		
7/26/2014 9:30	19.71	26.573	-0.107	22.122		
7/26/2014 9:45	19.928	26.701	0.044	22.136		
7/26/2014 10:00	20.202	26.860	0.195	22.141		
7/26/2014 10:15	20.438	26.942	0.365	22.154		
7/26/2014 10:30	20.55	26.982	0.544	22.158		
7/26/2014 10:45	20.685	27.024	0.706	22.14		
7/26/2014 11:00	20.888	27.144	0.850	22.068		
7/26/2014 11:15	21.053	27.118	0.984	21.91		
7/26/2014 11:30	21.147	27.083	1.088	21.685		
7/26/2014 11:45	21.246	27.135	1.163	21.521		
7/26/2014 12:00	21.313	27.216	1.199	21.387		
7/26/2014 12:15	21.361	27.311	1.204	21.309		
7/26/2014 12:30	21.388	27.347	1.158	21.311		
7/26/2014 12:45	21.467	27.401	1.086	21.557		
7/26/2014 13:00	21.575	27.386	1.021	21.796		
7/26/2014 13:15	21.629	27.422	0.952	22.073		
7/26/2014 13:30	21.726	27.449	0.870	22.282		
7/26/2014 13:45	21.826	27.519	0.800	22.541		
7/26/2014 14:00	21.966	27.542	0.715	22.717		
7/26/2014 14:15	21.97	27.552	0.592	22.868		
7/26/2014 14:30	22.086	27.575	0.458	23.077		

Date and Time	Mitigation Site A			Mitigation Site B		
	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/26/2014 14:45	22.195	27.632	0.351	23.234		
7/26/2014 15:00	22.293	27.604	0.242	23.351		
7/26/2014 15:15	22.397	27.648	0.118	23.49		
7/26/2014 15:30	22.477	27.613	-0.008	23.634		
7/26/2014 15:45	22.586	27.643	-0.126	23.731		
7/26/2014 16:00	22.596	27.596	-0.254	23.818		
7/26/2014 16:15	22.659	27.508	-0.381	23.911		
7/26/2014 16:30	22.628	27.391	-0.519	24.005		
7/26/2014 16:45	22.899	26.670	-0.640	24.069		
7/26/2014 17:00	22.751	26.480	-0.667	24.115		
7/26/2014 17:15	22.543	26.185	-0.670	24.097		
7/26/2014 17:30	22.654	26.158	-0.673	24.129		
7/26/2014 17:45	22.663	26.681	-0.674	24.15		
7/26/2014 18:00	22.578	27.037	-0.671	24.13		
7/26/2014 18:15	22.425	27.188	-0.674	24.028		
7/26/2014 18:30	22.165	27.263	-0.671	23.888		
7/26/2014 18:45	21.91	27.334	-0.669	23.785		
7/26/2014 19:00	21.679	27.389	-0.671	23.72		
7/26/2014 19:15	21.374	26.430	-0.670	23.582		
7/26/2014 19:30	21.133	25.431	-0.670	23.521		
7/26/2014 19:45	20.913	25.212	-0.670	23.508		
7/26/2014 20:00	20.721	25.513	-0.665	23.401		
7/26/2014 20:15	20.681	26.951	-0.554	23.352		
7/26/2014 20:30	20.586	27.080	-0.423	23.344		
7/26/2014 20:45	20.738	27.081	-0.300	23.31		
7/26/2014 21:00	20.953	27.118	-0.161	23.278		
7/26/2014 21:15	21.118	27.128	-0.006	23.227		
7/26/2014 21:30	21.289	27.184	0.145	23.153		
7/26/2014 21:45	21.427	27.193	0.302	23.082		
7/26/2014 22:00	21.466	27.184	0.474	22.966		
7/26/2014 22:15	21.643	27.230	0.643	22.789		
7/26/2014 22:30	21.674	27.224	0.810	22.592		
7/26/2014 22:45	21.726	27.259	0.967	22.353		
7/26/2014 23:00	21.745	27.277	1.110	22.02		
7/26/2014 23:15	21.755	27.292	1.229	21.612		
7/26/2014 23:30	21.776	27.274	1.313	21.195		
7/26/2014 23:45	21.745	27.414	1.371	20.855		
7/27/2014 0:00	21.662	27.513	1.414	20.598		
7/27/2014 0:15	21.576	27.523	1.449	20.423		
7/27/2014 0:30	21.426	27.547	1.479	20.294		
7/27/2014 0:45	21.311	27.613	1.493	20.207		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/27/2014 1:00	21.169	27.762	1.487	20.168		
7/27/2014 1:15	21.045	27.574	1.451	20.162		
7/27/2014 1:30	20.994	27.743	1.398	20.217		
7/27/2014 1:45	20.966	27.690	1.325	20.383		
7/27/2014 2:00	20.977	27.693	1.202	20.648		
7/27/2014 2:15	21.014	27.748	1.026	21.01		
7/27/2014 2:30	21.071	27.768	0.835	21.306		
7/27/2014 2:45	21.115	27.784	0.681	21.479		
7/27/2014 3:00	21.129	28.018	0.528	21.571		
7/27/2014 3:15	21.201	27.813	0.383	21.62		
7/27/2014 3:30	21.175	28.031	0.243	21.63		
7/27/2014 3:45	21.174	27.858	0.108	21.606		
7/27/2014 4:00	21.217	27.887	-0.019	21.522		
7/27/2014 4:15	21.13	27.880	-0.158	21.497		
7/27/2014 4:30	21.097	27.904	-0.291	21.416		
7/27/2014 4:45	20.986	27.708	-0.427	21.344		
7/27/2014 5:00	20.857	27.148	-0.567	21.211		
7/27/2014 5:15	20.697	26.893	-0.656	21.091		
7/27/2014 5:30	20.576	26.542	-0.661	20.994		
7/27/2014 5:45	20.487	25.854	-0.663	20.919		
7/27/2014 6:00	20.325	25.632	-0.663	20.794		
7/27/2014 6:15	20.167	26.865	-0.664	20.63		
7/27/2014 6:30	20.041	27.323	-0.663	20.524		
7/27/2014 6:45	19.977	26.565	-0.663	20.389		
7/27/2014 7:00	19.879	26.666	-0.662	20.371		
7/27/2014 7:15	19.878	25.906	-0.665	20.365		
7/27/2014 7:30	19.774	26.269	-0.666	20.348		
7/27/2014 7:45	19.744	26.508	-0.666	20.295		
7/27/2014 8:00	19.704	26.554	-0.666	20.294		
7/27/2014 8:15	19.732	26.991	-0.663	20.39		
7/27/2014 8:30	19.686	26.930	-0.665	20.754		
7/27/2014 8:45	19.69	26.908	-0.663	21.259		
7/27/2014 9:00	19.699	26.941	-0.633	21.465		
7/27/2014 9:15	19.741	26.954	-0.493	21.573		
7/27/2014 9:30	19.786	26.778	-0.371	21.647		
7/27/2014 9:45	19.875	27.148	-0.235	21.712		
7/27/2014 10:00	20.008	27.194	-0.086	21.783		
7/27/2014 10:15	20.158	27.204	0.062	21.846		
7/27/2014 10:30	20.302	27.238	0.217	21.895		
7/27/2014 10:45	20.516	27.238	0.396	21.909		
7/27/2014 11:00	20.547	27.282	0.569	21.897		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/27/2014 11:15	20.668	27.275	0.728	21.88		
7/27/2014 11:30	20.731	27.272	0.881	21.817		
7/27/2014 11:45	20.986	27.463	1.022	21.667		
7/27/2014 12:00	21.019	27.269	1.132	21.484		
7/27/2014 12:15	21.041	27.291	1.214	21.313		
7/27/2014 12:30	21.109	27.279	1.266	21.144		
7/27/2014 12:45	21.107	27.367	1.305	21.013		
7/27/2014 13:00	20.956	27.577	1.312	20.956		
7/27/2014 13:15	20.986	27.650	1.271	20.956		
7/27/2014 13:30	21.156	27.704	1.190	21.055		
7/27/2014 13:45	21.056	27.486	1.101	21.266		
7/27/2014 14:00	21.069	27.589	1.041	21.452		
7/27/2014 14:15	21.154	27.393	0.952	21.58		
7/27/2014 14:30	21.166	27.416	0.831	21.702		
7/27/2014 14:45	21.186	27.371	0.719	21.804		
7/27/2014 15:00	21.244	27.348	0.622	21.873		
7/27/2014 15:15	21.249	27.360	0.502	21.933		
7/27/2014 15:30	21.251	27.387	0.367	21.996		
7/27/2014 15:45	21.269	27.320	0.239	22.045		
7/27/2014 16:00	21.298	27.363	0.127	22.103		
7/27/2014 16:15	21.303	27.402	0.016	22.17		
7/27/2014 16:30	21.361	27.403	-0.112	22.235		
7/27/2014 16:45	21.378	27.401	-0.243	22.303		
7/27/2014 17:00	21.406	27.382	-0.371	22.367		
7/27/2014 17:15	21.471	27.369	-0.499	22.434		
7/27/2014 17:30	21.555	26.645	-0.632	22.487		
7/27/2014 17:45	21.542	26.391	-0.670	22.543		
7/27/2014 18:00	21.554	26.255	-0.672	22.608		
7/27/2014 18:15	21.518	26.610	-0.669	22.637		
7/27/2014 18:30	21.465	26.522	-0.673	22.637		
7/27/2014 18:45	21.342	26.473	-0.668	22.654		
7/27/2014 19:00	21.231	26.627	-0.665	22.582		
7/27/2014 19:15	21.035	25.857	-0.669	22.525		
7/27/2014 19:30	20.93	25.058	-0.670	22.525		
7/27/2014 19:45	20.844	24.959	-0.667	22.507		
7/27/2014 20:00	20.715	24.580	-0.659	22.457		
7/27/2014 20:15	20.551	24.170	-0.665	22.451		
7/27/2014 20:30	20.438	24.057	-0.649	22.449		
7/27/2014 20:45	20.359	23.928	-0.544	22.437		
7/27/2014 21:00	20.359	25.846	-0.419	22.452		
7/27/2014 21:15	20.437	26.156	-0.293	22.452		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/27/2014 21:30	20.549	26.490	-0.169	22.427		
7/27/2014 21:45	20.633	26.626	-0.019	22.366		
7/27/2014 22:00	20.711	26.697	0.137	22.288		
7/27/2014 22:15	20.746	26.759	0.287	22.218		
7/27/2014 22:30	20.842	26.877	0.459	22.142		
7/27/2014 22:45	20.936	26.855	0.648	22.024		
7/27/2014 23:00	21.067	26.881	0.826	21.92		
7/27/2014 23:15	21.077	26.920	0.989	21.801		
7/27/2014 23:30	21.108	26.882	1.131	21.604		
7/27/2014 23:45	21.026	26.890	1.243	21.381		
7/28/2014 0:00	21.133	26.905	1.320	21.104		
7/28/2014 0:15	21.101	26.907	1.384	20.843		
7/28/2014 0:30	20.993	26.897	1.430	20.617		
7/28/2014 0:45	20.981	27.230	1.471	20.437		
7/28/2014 1:00	20.949	27.085	1.509	20.267		
7/28/2014 1:15	20.923	27.079	1.536	20.119		
7/28/2014 1:30	20.834	27.194	1.547	20.036		
7/28/2014 1:45	20.772	27.417	1.526	19.991		
7/28/2014 2:00	20.684	27.601	1.488	19.991		
7/28/2014 2:15	20.663	27.652	1.435	20.081		
7/28/2014 2:30	20.632	27.480	1.377	20.255		
7/28/2014 2:45	20.641	27.471	1.287	20.491		
7/28/2014 3:00	20.66	27.362	1.136	20.751		
7/28/2014 3:15	20.716	27.387	0.935	20.993		
7/28/2014 3:30	20.765	27.388	0.732	21.16		
7/28/2014 3:45	20.801	27.403	0.567	21.248		
7/28/2014 4:00	20.833	27.351	0.415	21.289		
7/28/2014 4:15	20.844	27.373	0.273	21.3		
7/28/2014 4:30	20.869	27.379	0.133	21.302		
7/28/2014 4:45	20.856	27.365	-0.003	21.29		
7/28/2014 5:00	20.835	27.365	-0.146	21.268		
7/28/2014 5:15	20.799	27.349	-0.271	21.242		
7/28/2014 5:30	20.731	27.337	-0.404	21.211		
7/28/2014 5:45	20.64	27.156	-0.553	21.178		
7/28/2014 6:00	20.547	26.500	-0.650	21.126		
7/28/2014 6:15	20.452	26.405	-0.647	21.058		
7/28/2014 6:30	20.344	26.081	-0.650	20.988		
7/28/2014 6:45	20.232	25.841	-0.652	20.871		
7/28/2014 7:00	20.081	25.788	-0.654	20.76		
7/28/2014 7:15	19.962	25.931	-0.655	20.676		
7/28/2014 7:30	19.88	26.126	-0.651	20.585		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/28/2014 7:45	19.764	26.007	-0.655	20.504		
7/28/2014 8:00	19.672	25.928	-0.655	20.438		
7/28/2014 8:15	19.665	25.933	-0.657	20.462		
7/28/2014 8:30	19.535	25.735	-0.659	20.488		
7/28/2014 8:45	19.481	25.615	-0.658	20.523		
7/28/2014 9:00	19.398	25.528	-0.653	20.61		
7/28/2014 9:15	19.411	25.467	-0.658	20.947		
7/28/2014 9:30	19.38	25.072	-0.612	21.229		
7/28/2014 9:45	19.4	25.108	-0.421	21.375		
7/28/2014 10:00	19.418	25.466	-0.281	21.432		
7/28/2014 10:15	19.468	25.768	-0.150	21.427		
7/28/2014 10:30	19.581	25.899	0.016	21.454		
7/28/2014 10:45	19.72	25.954	0.160	21.496		
7/28/2014 11:00	19.907	25.923	0.299	21.54		
7/28/2014 11:15	20.076	26.023	0.472	21.587		
7/28/2014 11:30	20.258	26.029	0.635	21.614		
7/28/2014 11:45	20.407	26.014	0.798	21.638		
7/28/2014 12:00	20.463	26.128	0.949	21.646		
7/28/2014 12:15	20.513	26.177	1.084	21.606		
7/28/2014 12:30	20.619	26.277	1.194	21.553		
7/28/2014 12:45	20.697	26.290	1.263	21.484		
7/28/2014 13:00	20.855	26.400	1.332	21.41		
7/28/2014 13:15	20.884	26.308	1.377	21.303		
7/28/2014 13:30	20.882	26.352	1.395	21.274		
7/28/2014 13:45	20.939	26.390	1.372	21.261		
7/28/2014 14:00	20.983	26.464	1.325	21.335		
7/28/2014 14:15	21.042	26.551	1.275	21.541		
7/28/2014 14:30	21.11	26.558	1.204	21.782		
7/28/2014 14:45	21.331	26.608	1.110	22.008		
7/28/2014 15:00	21.445	26.655	1.000	22.239		
7/28/2014 15:15	21.632	26.670	0.884	22.466		
7/28/2014 15:30	21.627	26.652	0.775	22.671		
7/28/2014 15:45	21.729	26.648	0.658	22.889		
7/28/2014 16:00	21.789	26.667	0.542	23.054		
7/28/2014 16:15	21.898	26.667	0.420	23.205		
7/28/2014 16:30	21.988	26.646	0.282	23.34		
7/28/2014 16:45	22.091	26.640	0.151	23.468		
7/28/2014 17:00	22.269	26.622	0.035	23.526		
7/28/2014 17:15	22.168	26.455	-0.082	23.573		
7/28/2014 17:30	22.263	26.397	-0.208	23.697		
7/28/2014 17:45	22.292	26.195	-0.343	23.887		

Date and Time	Mitigation Site A			Mitigation Site B		
	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/28/2014 18:00	22.315	26.153	-0.480	23.95		
7/28/2014 18:15	22.586	24.797	-0.609	23.985		
7/28/2014 18:30	22.571	24.472	-0.670	24		
7/28/2014 18:45	22.327	25.561	-0.669	24		
7/28/2014 19:00	22.077	25.136	-0.665	24.019		
7/28/2014 19:15	21.883	24.588	-0.664	23.84		
7/28/2014 19:30	21.761	24.646	-0.660	23.536		
7/28/2014 19:45	21.555	24.544	-0.658	23.339		
7/28/2014 20:00	21.415	24.275	-0.657	23.109		
7/28/2014 20:15	21.328	25.027	-0.660	23.028		
7/28/2014 20:30	21.204	25.313	-0.662	22.923		
7/28/2014 20:45	21.067	25.580	-0.659	22.894		
7/28/2014 21:00	20.94	25.796	-0.645	22.877		
7/28/2014 21:15	20.822	26.124	-0.573	23.076		
7/28/2014 21:30	20.685	26.256	-0.469	22.984		
7/28/2014 21:45	20.537	26.016	-0.332	22.816		
7/28/2014 22:00	20.513	25.134	-0.217	22.789		
7/28/2014 22:15	20.624	24.689	-0.086	22.783		
7/28/2014 22:30	20.797	24.940	0.069	22.777		
7/28/2014 22:45	20.924	25.413	0.222	22.77		
7/28/2014 23:00	21.015	25.719	0.389	22.745		
7/28/2014 23:15	21.067	25.698	0.537	22.672		
7/28/2014 23:30	21.091	25.716	0.706	22.568		
7/28/2014 23:45	21.192	25.693	0.879	22.442		
7/29/2014 0:00	21.305	25.708	1.035	22.266		
7/29/2014 0:15	21.369	25.759	1.169	21.935		
7/29/2014 0:30	21.415	25.716	1.271	21.471		
7/29/2014 0:45	21.33	25.710	1.342	20.962		
7/29/2014 1:00	21.314	25.728	1.397	20.414		
7/29/2014 1:15	21.26	25.634	1.441	20.07		
7/29/2014 1:30	21.197	25.575	1.478	19.864		
7/29/2014 1:45	21.056	25.596	1.502	19.703		
7/29/2014 2:00	20.932	25.642	1.506	19.621		
7/29/2014 2:15	20.802	25.678	1.496	19.591		
7/29/2014 2:30	20.667	25.742	1.469	19.612		
7/29/2014 2:45	20.592	25.952	1.429	19.626		
7/29/2014 3:00	20.576	25.984	1.367	19.816		
7/29/2014 3:15	20.606	25.917	1.274	20.129		
7/29/2014 3:30	20.641	25.902	1.130	20.606		
7/29/2014 3:45	20.701	25.843	0.940	20.98		
7/29/2014 4:00	20.757	25.826	0.753	21.191		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/29/2014 4:15	20.742	25.807	0.596	21.271		
7/29/2014 4:30	20.772	25.746	0.444	21.297		
7/29/2014 4:45	20.785	25.707	0.304	21.282		
7/29/2014 5:00	20.764	25.575	0.162	21.238		
7/29/2014 5:15	20.757	25.471	0.023	21.166		
7/29/2014 5:30	20.696	25.520	-0.113	21.068		
7/29/2014 5:45	20.627	25.558	-0.245	20.867		
7/29/2014 6:00	20.554	25.492	-0.385	20.618		
7/29/2014 6:15	20.324	25.368	-0.537	20.411		
7/29/2014 6:30	19.978	24.856	-0.649	20.25		
7/29/2014 6:45	19.897	24.784	-0.656	20.123		
7/29/2014 7:00	19.709	24.798	-0.658	20.03		
7/29/2014 7:15	19.594	24.816	-0.656	19.836		
7/29/2014 7:30	19.523	24.657	-0.656	19.62		
7/29/2014 7:45	19.374	24.738	-0.659	19.485		
7/29/2014 8:00	19.306	24.818	-0.661	19.438		
7/29/2014 8:15	19.236	24.708	-0.660	19.462		
7/29/2014 8:30	19.225	24.772	-0.661	19.547		
7/29/2014 8:45	19.256	24.706	-0.659	19.682		
7/29/2014 9:00	19.265	24.606	-0.657	19.732		
7/29/2014 9:15	19.344	24.708	-0.656	19.775		
7/29/2014 9:30	19.468	24.725	-0.659	19.841		
7/29/2014 9:45	19.577	24.767	-0.658	20.185		
7/29/2014 10:00	19.722	24.610	-0.660	21.02		
7/29/2014 10:15	19.811	25.078	-0.562	21.303		
7/29/2014 10:30	19.934	25.000	-0.465	21.431		
7/29/2014 10:45	20.005	25.019	-0.348	21.514		
7/29/2014 11:00	20.145	25.528	-0.194	21.576		
7/29/2014 11:15	20.187	25.636	-0.034	21.634		
7/29/2014 11:30	20.316	25.698	0.122	21.675		
7/29/2014 11:45	20.453	25.665	0.292	21.719		
7/29/2014 12:00	20.595	25.684	0.459	21.755		
7/29/2014 12:15	20.707	25.879	0.626	21.77		
7/29/2014 12:30	20.767	25.899	0.793	21.737		
7/29/2014 12:45	20.838	25.979	0.943	21.623		
7/29/2014 13:00	20.927	25.970	1.066	21.396		
7/29/2014 13:15	20.957	25.904	1.156	21.09		
7/29/2014 13:30	20.986	25.888	1.234	20.8		
7/29/2014 13:45	21.048	25.861	1.288	20.599		
7/29/2014 14:00	21.074	25.799	1.314	20.441		
7/29/2014 14:15	20.977	25.729	1.292	20.373		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/29/2014 14:30	21.042	25.632	1.250	20.493		
7/29/2014 14:45	21.176	25.462	1.205	20.673		
7/29/2014 15:00	21.19	25.427	1.136	20.824		
7/29/2014 15:15	21.291	25.367	1.019	21.321		
7/29/2014 15:30	21.406	25.350	0.926	21.81		
7/29/2014 15:45	21.485	25.466	0.836	22.037		
7/29/2014 16:00	21.59	25.463	0.722	22.248		
7/29/2014 16:15	21.697	25.452	0.604	22.523		
7/29/2014 16:30	21.764	25.424	0.478	22.74		
7/29/2014 16:45	21.84	25.436	0.346	22.856		
7/29/2014 17:00	21.927	25.429	0.218	22.955		
7/29/2014 17:15	22.024	25.432	0.101	23.054		
7/29/2014 17:30	22.025	25.497	-0.017	23.156		
7/29/2014 17:45	22.186	25.454	-0.144	23.258		
7/29/2014 18:00	22.187	25.552	-0.272	23.353		
7/29/2014 18:15	22.175	25.499	-0.403	23.437		
7/29/2014 18:30	22.186	25.529	-0.540	23.519		
7/29/2014 18:45	22.168	25.101	-0.650	23.571		
7/29/2014 19:00	21.91	24.954	-0.655	23.577		
7/29/2014 19:15	21.735	24.966	-0.658	23.526		
7/29/2014 19:30	21.501	24.800	-0.658	23.378		
7/29/2014 19:45	21.276	24.755	-0.655	23.088		
7/29/2014 20:00	21.112	24.711	-0.660	22.717		
7/29/2014 20:15	20.965	24.810	-0.660	22.275		
7/29/2014 20:30	20.735	25.009	-0.663	21.987		
7/29/2014 20:45	20.511	25.051	-0.661	22.006		
7/29/2014 21:00	20.336	25.148	-0.662	22.182		
7/29/2014 21:15	20.109	25.243	-0.661	22.33		
7/29/2014 21:30	19.9	25.275	-0.662	22.373		
7/29/2014 21:45	19.796	25.223	-0.664	22.373		
7/29/2014 22:00	19.549	25.203	-0.661	22.318		
7/29/2014 22:15	19.799	26.332	-0.558	22.249		
7/29/2014 22:30	19.652	26.291	-0.419	22.216		
7/29/2014 22:45	19.806	26.106	-0.288	22.22		
7/29/2014 23:00	20	26.032	-0.146	22.203		
7/29/2014 23:15	20.165	26.159	-0.015	22.139		
7/29/2014 23:30	20.287	26.172	0.138	22.073		
7/29/2014 23:45	20.418	26.191	0.302	22.014		
7/30/2014 0:00	20.515	26.127	0.472	21.931		
7/30/2014 0:15	20.599	26.064	0.643	21.807		
7/30/2014 0:30	20.62	26.097	0.807	21.638		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/30/2014 0:45	20.699	26.023	0.959	21.393		
7/30/2014 1:00	20.749	25.985	1.088	20.979		
7/30/2014 1:15	20.767	25.942	1.191	20.542		
7/30/2014 1:30	20.777	25.911	1.263	20.1		
7/30/2014 1:45	20.771	25.859	1.324	19.677		
7/30/2014 2:00	20.729	25.822	1.360	19.284		
7/30/2014 2:15	20.661	25.802	1.383	19.053		
7/30/2014 2:30	20.593	25.789	1.383	18.898		
7/30/2014 2:45	20.539	25.790	1.363	18.855		
7/30/2014 3:00	20.512	25.713	1.306	18.966		
7/30/2014 3:15	20.502	25.684	1.228	19.31		
7/30/2014 3:30	20.515	25.726	1.121	19.842		
7/30/2014 3:45	20.527	25.584	0.997	20.32		
7/30/2014 4:00	20.562	25.550	0.874	20.657		
7/30/2014 4:15	20.57	25.613	0.751	20.865		
7/30/2014 4:30	20.568	25.599	0.641	20.966		
7/30/2014 4:45	20.583	25.519	0.528	21.01		
7/30/2014 5:00	20.533	25.621	0.393	21.036		
7/30/2014 5:15	20.513	25.584	0.254	21.032		
7/30/2014 5:30	20.471	25.589	0.122	21.003		
7/30/2014 5:45	20.419	25.573	-0.006	20.941		
7/30/2014 6:00	20.359	25.669	-0.134	20.854		
7/30/2014 6:15	20.256	25.687	-0.268	20.743		
7/30/2014 6:30	20.142	25.682	-0.407	20.598		
7/30/2014 6:45	19.942	25.676	-0.546	20.39		
7/30/2014 7:00	19.716	25.300	-0.652	20.184		
7/30/2014 7:15	19.627	24.980	-0.656	20.019		
7/30/2014 7:30	19.595	25.021	-0.657	19.87		
7/30/2014 7:45	19.46	25.039	-0.659	19.756		
7/30/2014 8:00	19.373	25.035	-0.659	19.595		
7/30/2014 8:15	19.335	25.002	-0.660	19.581		
7/30/2014 8:30	19.352	24.960	-0.659	19.7		
7/30/2014 8:45	19.355	24.860	-0.662	19.828		
7/30/2014 9:00	19.368	24.798	-0.661	19.975		
7/30/2014 9:15	19.437	24.727	-0.661	20.161		
7/30/2014 9:30	19.537	24.590	-0.662	20.322		
7/30/2014 9:45	19.681	24.504	-0.662	20.446		
7/30/2014 10:00	19.804	24.442	-0.660	20.527		
7/30/2014 10:15	19.988	24.431	-0.660	20.725		
7/30/2014 10:30	20.19	24.358	-0.661	21.029		
7/30/2014 10:45	20.245	24.474	-0.631	21.356		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/30/2014 11:00	20.229	26.155	-0.523	21.476		
7/30/2014 11:15	20.529	26.332	-0.392	21.543		
7/30/2014 11:30	20.703	26.320	-0.256	21.575		
7/30/2014 11:45	20.714	26.346	-0.110	21.583		
7/30/2014 12:00	20.839	26.345	0.034	21.597		
7/30/2014 12:15	20.898	26.244	0.176	21.595		
7/30/2014 12:30	20.941	26.273	0.355	21.57		
7/30/2014 12:45	20.968	26.166	0.523	21.524		
7/30/2014 13:00	20.981	26.117	0.684	21.427		
7/30/2014 13:15	21.01	26.073	0.827	21.261		
7/30/2014 13:30	21.025	26.068	0.966	20.992		
7/30/2014 13:45	21.026	26.045	1.078	20.649		
7/30/2014 14:00	21.033	26.010	1.163	20.325		
7/30/2014 14:15	21.027	25.848	1.223	20.055		
7/30/2014 14:30	21.015	25.745	1.269	19.817		
7/30/2014 14:45	20.975	25.714	1.283	19.67		
7/30/2014 15:00	20.994	25.640	1.263	19.628		
7/30/2014 15:15	20.963	25.655	1.200	19.775		
7/30/2014 15:30	20.97	25.621	1.118	20.035		
7/30/2014 15:45	20.994	25.604	1.038	20.373		
7/30/2014 16:00	21.043	25.590	0.938	20.706		
7/30/2014 16:15	21.144	25.604	0.823	21.117		
7/30/2014 16:30	21.227	25.598	0.725	21.495		
7/30/2014 16:45	21.32	25.610	0.615	21.76		
7/30/2014 17:00	21.392	25.619	0.492	21.97		
7/30/2014 17:15	21.443	25.615	0.375	22.125		
7/30/2014 17:30	21.443	25.674	0.250	22.246		
7/30/2014 17:45	21.437	25.668	0.125	22.379		
7/30/2014 18:00	21.465	25.727	0.006	22.514		
7/30/2014 18:15	21.573	25.752	-0.118	22.634		
7/30/2014 18:30	21.669	25.773	-0.241	22.75		
7/30/2014 18:45	21.704	25.752	-0.375	22.864		
7/30/2014 19:00	21.641	25.743	-0.510	22.969		
7/30/2014 19:15	21.705	25.468	-0.634	23.045		
7/30/2014 19:30	21.543	25.235	-0.659	23.07		
7/30/2014 19:45	21.323	25.113	-0.659	23.069		
7/30/2014 20:00	21.082	24.768	-0.660	22.982		
7/30/2014 20:15	20.834	24.394	-0.661	22.797		
7/30/2014 20:30	20.65	24.044	-0.662	22.464		
7/30/2014 20:45	20.459	23.857	-0.659	22.086		
7/30/2014 21:00	20.241	23.630	-0.658	22.002		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/30/2014 21:15	20.055	23.462	-0.658	21.757		
7/30/2014 21:30	19.894	23.319	-0.658	21.481		
7/30/2014 21:45	19.656	23.171	-0.660	21.46		
7/30/2014 22:00	19.607	23.170	-0.657	21.737		
7/30/2014 22:15	19.442	23.082	-0.657	21.917		
7/30/2014 22:30	19.333	23.655	-0.658	21.986		
7/30/2014 22:45	19.39	23.379	-0.652	21.944		
7/30/2014 23:00	19.45	23.794	-0.532	21.924		
7/30/2014 23:15	19.349	25.048	-0.414	21.903		
7/30/2014 23:30	19.403	25.460	-0.292	21.88		
7/30/2014 23:45	19.549	25.707	-0.152	21.848		
7/31/2014 0:00	19.679	25.853	-0.007	21.731		
7/31/2014 0:15	19.788	26.070	0.143	21.591		
7/31/2014 0:30	19.91	26.154	0.303	21.471		
7/31/2014 0:45	19.966	26.107	0.472	21.307		
7/31/2014 1:00	20.111	26.163	0.635	21.123		
7/31/2014 1:15	20.163	26.302	0.785	20.927		
7/31/2014 1:30	20.206	26.263	0.921	20.7		
7/31/2014 1:45	20.263	26.195	1.042	20.43		
7/31/2014 2:00	20.29	26.129	1.157	20.11		
7/31/2014 2:15	20.316	26.093	1.235	19.777		
7/31/2014 2:30	20.319	26.047	1.279	19.467		
7/31/2014 2:45	20.285	26.010	1.293	19.24		
7/31/2014 3:00	20.305	25.961	1.280	19.171		
7/31/2014 3:15	20.258	25.924	1.277	19.161		
7/31/2014 3:30	20.248	25.901	1.244	19.185		
7/31/2014 3:45	20.241	25.875	1.162	19.338		
7/31/2014 4:00	20.233	25.844	1.052	19.684		
7/31/2014 4:15	20.234	25.834	0.964	19.99		
7/31/2014 4:30	20.227	25.797	0.853	20.195		
7/31/2014 4:45	20.243	25.766	0.734	20.361		
7/31/2014 5:00	20.216	25.768	0.631	20.473		
7/31/2014 5:15	20.239	25.748	0.527	20.522		
7/31/2014 5:30	20.18	25.764	0.399	20.559		
7/31/2014 5:45	20.153	25.718	0.264	20.576		
7/31/2014 6:00	20.107	25.736	0.132	20.568		
7/31/2014 6:15	20.049	25.754	0.011	20.533		
7/31/2014 6:30	19.967	25.851	-0.119	20.47		
7/31/2014 6:45	19.854	25.810	-0.251	20.377		
7/31/2014 7:00	19.735	25.836	-0.385	20.257		
7/31/2014 7:15	19.604	25.833	-0.522	20.104		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/31/2014 7:30	19.259	25.299	-0.643	19.928		
7/31/2014 7:45	19.36	24.853	-0.660	19.771		
7/31/2014 8:00	19.326	24.628	-0.661	19.6		
7/31/2014 8:15	19.295	24.391	-0.660	19.506		
7/31/2014 8:30	19.303	24.132	-0.661	19.455		
7/31/2014 8:45	19.326	23.946	-0.664	19.536		
7/31/2014 9:00	19.392	23.811	-0.664	19.725		
7/31/2014 9:15	19.466	23.780	-0.666	20.063		
7/31/2014 9:30	19.574	23.806	-0.662	20.412		
7/31/2014 9:45	19.704	23.697	-0.661	20.833		
7/31/2014 10:00	19.866	23.592	-0.660	21.043		
7/31/2014 10:15	20.05	23.447	-0.663	21.044		
7/31/2014 10:30	20.219	23.337	-0.662	21.035		
7/31/2014 10:45	20.385	23.267	-0.665	21.156		
7/31/2014 11:00	20.459	23.132	-0.660	21.335		
7/31/2014 11:15	20.598	22.957	-0.663	21.489		
7/31/2014 11:30	20.745	23.049	-0.606	21.551		
7/31/2014 11:45	20.651	23.767	-0.478	21.529		
7/31/2014 12:00	20.83	25.165	-0.343	21.491		
7/31/2014 12:15	21.242	25.680	-0.208	21.447		
7/31/2014 12:30	21.183	26.041	-0.061	21.429		
7/31/2014 12:45	21.21	26.169	0.086	21.407		
7/31/2014 13:00	21.257	26.131	0.250	21.404		
7/31/2014 13:15	21.29	26.130	0.431	21.4		
7/31/2014 13:30	21.329	26.112	0.597	21.318		
7/31/2014 13:45	21.227	26.069	0.740	21.169		
7/31/2014 14:00	21.263	25.999	0.879	21.022		
7/31/2014 14:15	21.244	26.055	1.004	20.805		
7/31/2014 14:30	21.19	25.940	1.113	20.522		
7/31/2014 14:45	21.199	25.882	1.193	20.281		
7/31/2014 15:00	21.146	25.916	1.238	20.12		
7/31/2014 15:15	21.091	25.907	1.249	20.015		
7/31/2014 15:30	21.109	25.937	1.208	20.029		
7/31/2014 15:45	21.041	25.908	1.160	20.153		
7/31/2014 16:00	21.095	25.820	1.117	20.317		
7/31/2014 16:15	21.105	25.847	1.037	20.467		
7/31/2014 16:30	21.142	25.813	0.951	20.853		
7/31/2014 16:45	21.235	25.813	0.869	21.074		
7/31/2014 17:00	21.261	25.792	0.758	21.38		
7/31/2014 17:15	21.386	25.796	0.644	21.66		
7/31/2014 17:30	21.507	25.783	0.534	21.874		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
7/31/2014 17:45	21.648	25.759	0.417	22.045		
7/31/2014 18:00	21.678	25.772	0.299	22.187		
7/31/2014 18:15	21.816	25.768	0.184	22.306		
7/31/2014 18:30	21.842	25.732	0.071	22.414		
7/31/2014 18:45	21.88	25.691	-0.050	22.519		
7/31/2014 19:00	22.001	25.617	-0.172	22.619		
7/31/2014 19:15	21.997	25.633	-0.298	22.718		
7/31/2014 19:30	21.985	25.569	-0.429	22.809		
7/31/2014 19:45	21.913	25.341	-0.559	22.881		
7/31/2014 20:00	21.79	24.768	-0.658	22.916		
7/31/2014 20:15	21.415	24.357	-0.658	22.925		
7/31/2014 20:30	21.235	24.132	-0.658	22.85		
7/31/2014 20:45	21.116	24.565	-0.659	22.681		
7/31/2014 21:00	20.908	25.053	-0.658	22.393		
7/31/2014 21:15	20.679	25.310	-0.658	22.007		
7/31/2014 21:30	20.493	25.273	-0.658	21.665		
7/31/2014 21:45	20.327	25.322	-0.656	21.372		
7/31/2014 22:00	20.233	24.488	-0.654	21.163		
7/31/2014 22:15	20.095	23.901	-0.655	21.054		
7/31/2014 22:30	19.938	23.559	-0.657	21.066		
7/31/2014 22:45	19.83	23.333	-0.654	21.323		
7/31/2014 23:00	19.676	23.150	-0.655	21.54		
7/31/2014 23:15	19.536	23.019	-0.655	21.612		
7/31/2014 23:30	19.36	22.983	-0.650	21.511		
7/31/2014 23:45	19.486	23.459	-0.541	21.476		
8/1/2014 0:00	19.435	24.213	-0.418	21.449		
8/1/2014 0:15	19.491	25.010	-0.279	21.457		
8/1/2014 0:30	19.653	25.564	-0.159	21.504		
8/1/2014 0:45	19.793	25.717	-0.027	21.509		
8/1/2014 1:00	19.915	25.869	0.126	21.474		
8/1/2014 1:15	19.997	26.011	0.274	21.43		
8/1/2014 1:30	20.121	26.018	0.423	21.362		
8/1/2014 1:45	20.156	26.029	0.564	21.237		
8/1/2014 2:00	20.219	26.010	0.716	21.09		
8/1/2014 2:15	20.355	26.039	0.853	20.905		
8/1/2014 2:30	20.374	26.068	0.972	20.646		
8/1/2014 2:45	20.401	26.048	1.067	20.324		
8/1/2014 3:00	20.425	26.060	1.138	20.066		
8/1/2014 3:15	20.481	26.074	1.188	19.822		
8/1/2014 3:30	20.504	26.021	1.190	19.658		
8/1/2014 3:45	20.44	26.005	1.170	19.615		

	Mitigation Site A			Mitigation Site B		
Date and Time	Site A Temperature (°C)	Site A Salinity (PSU)	Site A Water Surface Elevation (m)	Site B Temperature (°C)	Site B Salinity (PSU)	
8/1/2014 4:00	20.46	26.023	1.141	19.62		
8/1/2014 4:15	20.471	26.042	1.086	19.693		
8/1/2014 4:30	20.444	26.034	0.993	19.894		
8/1/2014 4:45	20.457	25.965	0.920	20.128		
8/1/2014 5:00	20.447	25.950	0.835	20.316		
8/1/2014 5:15	20.45	25.956	0.717	20.529		
8/1/2014 5:30	20.43	25.966	0.601	20.724		
8/1/2014 5:45	20.448	25.953	0.495	20.817		
8/1/2014 6:00	20.406	25.951	0.385	20.864		
8/1/2014 6:15	20.453	26.018	0.267	20.889		
8/1/2014 6:30	20.372	26.007	0.145	20.885		
8/1/2014 6:45	20.306	26.018	0.025	20.864		
8/1/2014 7:00	20.231	25.958	-0.097	20.823		
8/1/2014 7:15	20.167	26.068	-0.218	20.769		
8/1/2014 7:30	20.08	26.085	-0.343	20.695		
8/1/2014 7:45	19.99	25.976	-0.478	20.611		
8/1/2014 8:00	19.879	25.454	-0.609	20.508		
8/1/2014 8:15	19.865	25.107	-0.662	20.418		
8/1/2014 8:30	19.897	25.097	-0.659	20.333		
8/1/2014 8:45	19.903	24.904	-0.664	20.281		
8/1/2014 9:00	19.965	24.719	-0.663	20.296		
8/1/2014 9:15	20.04	24.437	-0.666	20.44		
8/1/2014 9:30	20.182	24.670	-0.662	20.682		
8/1/2014 9:45	20.317	24.586	-0.662	20.948		
8/1/2014 10:00	20.456	24.547	-0.662	21.25		
8/1/2014 10:15	20.554	24.567	-0.660	21.437		
A blank cell indicates an outlier data point removed during the QC process						

Appendix 6: Ballard Street Marsh (Saugus, Ma) May 2005 Sediment and Vegetation Survey GeoSyntec Consultants January 31, 2006

BALLARD STREET MARSH (SAUGUS, MA)

MAY 2005 SEDIMENT AND VEGETATION SURVEY

Prepared for:

Massachusetts Office of Coastal Zone Management
Wetlands Restoration Program
251 Causeway Street, Suite 800

Prepared by:

GEOSYNTEC CONSULTANTS
289 Great Road
Acton, MA 01720
(978) 263-9588 www.geosyntec.com

January 31st, 2006

BALLARD STREET MARSH SEDIMENT AND VEGETATION SURVEY

MAY 2005

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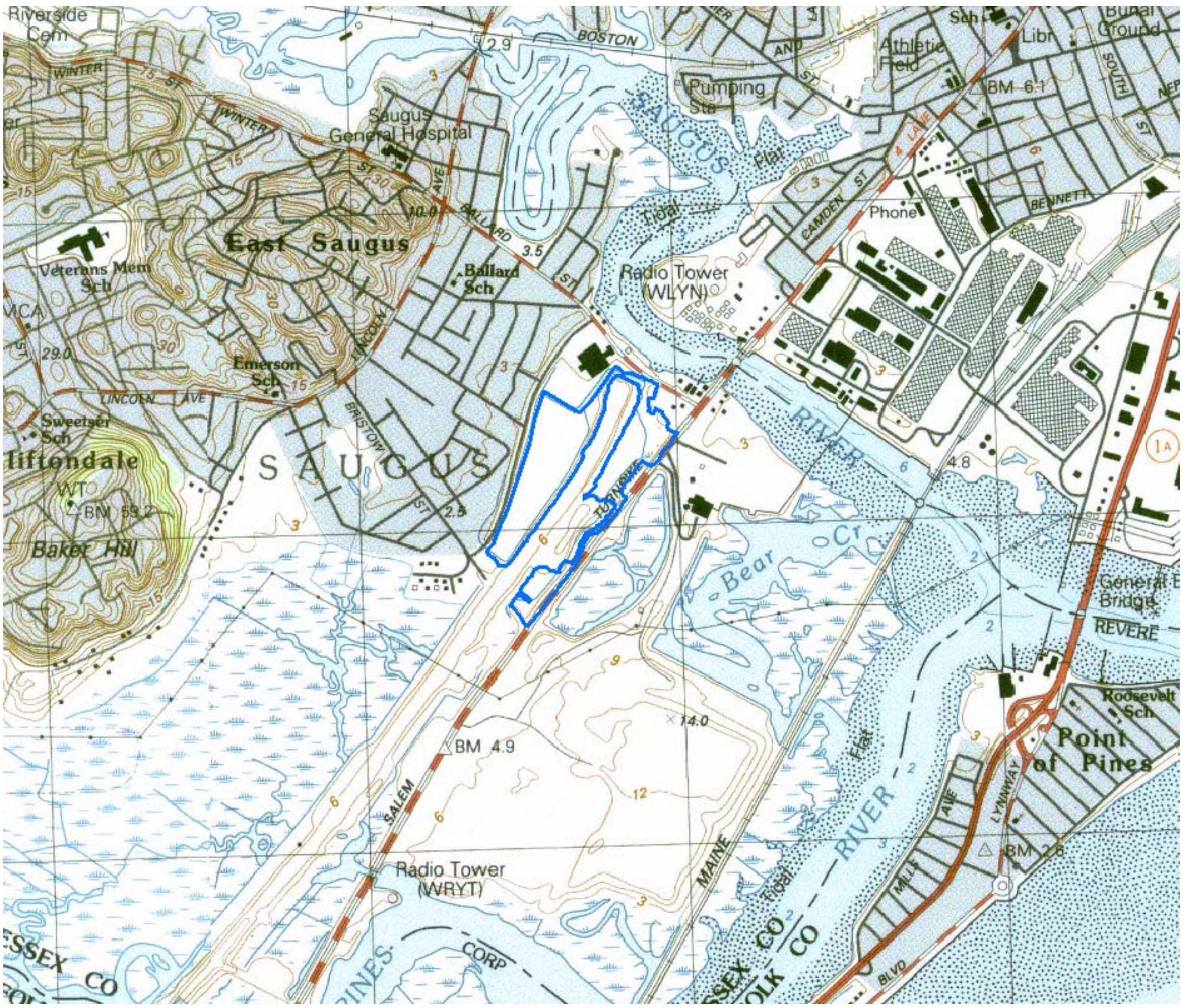
APPENDICES

SECTION 1: INTRODUCTION

GeoSyntec Consultants (GeoSyntec) was contracted by the Massachusetts Wetland Restoration Program to conduct a comprehensive sediment investigation and wetland delineation of the Ballard St. Marsh Restoration site in Saugus, MA during the spring of 2005. This was done in anticipation of a Phase II restoration project. The purpose of the investigation was to:

1. Provide sediment chemistry data for 25 locations throughout the proposed removal area to determine disposal or site reuse options.

2. Provide a delineation of wetland resource areas and vegetative community information to satisfy the requirement of MEPA for the EIR.



Ballard St Marsh (Saugus, MA)

SECTION 2: SEDIMENT SAMPLING AND ANALYSIS

2.1 METHODOLOGY

On May 10, 11, and 18th, 2005, GeoSyntec conducted a sediment investigation of the Ballard Street Salt Marsh Restoration Phase II site. Sampling was undertaken following the protocol developed under the sediment sampling plan dated Jan. 2003 and then modified in the Quality Assurance Project Plan (QAPP) included in the appendix of this report. Sediment was sampled in 25 – 3 ft core locations using a hand auger and composites were collected for analysis. Sample locations were homogenously distributed throughout the proposed removal area each sampling location being approximately 150 feet apart and mapped with a sub-meter Global Positioning System (GPS) unit (QAPP figure 1). Sediment cores were logged and can be summarized in table 1. Samples were sent to EPA Region 1 Laboratory and Alpha Analytical Laboratories for analyses identified in QAPP table 1.

2.2 SEDIMENT SURVEY RESULTS

The project area can be subdivided into two sections, North and South, based primarily on groundwater conditions. The South section, which covers about two thirds the proposed restoration area, has high water table elevations, standing water and is dominated by *Phragmites australis*. The sediment in this section is dark brown peat to a depth of at least 1 foot underlain by fine to medium sand. The North section is primarily covered by trees, shrubs and grasses with sediment in this section consisting of about 1 foot black to dark brown peat underlain by brown sand to sandy silt. At Station S-11, Boston Blue Clay was discovered under the peat layer. The PID measurements were zero for most of the locations except for two locations in the wet section (Sample ID# S-1 and S-7).

Laboratory analysis of the samples conducted by EPA Region 1 Labs suggests that much of the site sediment is well below the reuse criteria guidelines for all tested analytes. However, three sample locations produced a slight exceedance of the reuse guidance for Chromium as defined in the QAPP. At S-03 (33 mg/Kg), S-05 (45 mg/Kg), and S-18 (47 mg/Kg) chromium was in higher than 29 mg/Kg (Table 2).

2.3 SEDIMENT REUSE OPTIONS

Onsite reuse of the sediments is the desired alternative from a logistical and financial perspective. Based on a discussion with Yvonne Unger from DEP, GeoSyntec believes that beneficial onsite reuse of the materials is attainable (see email dated 1/31/06). According to Yvonne, all results were below the RCS1 criteria allowing DEP flexibility in determining beneficial onsite reuse. Discussions have been underway for years between CZM and the Army Corps of Engineers regarding the potential for the project becoming a training exercise. The feasibility of this exercise occurring under ACOE's current constraints (i.e. Iraq and Afghanistan Wars) is unknown and further discussions with ACOE should be undertaken to ensure the viability of this option. The alternative to the ACOE conducting the work would be to hire a private earth moving company. For the onsite reuse option, sediment would be excavated, lowering the restoration area by up to 3 ft providing flood storage. Sediment would be dewatered and used to cover/stabilize I-95 berm that runs through the center of the site. Due to the large amount of invasive Phragmites vegetation present in the sediment, steps will need to be taken to sterilize the sediment. These may include any one or combination of the following.

- Prescriptive Burn
- Sifting dried sediment for plant matter removal (specifically rhizomes)

- Herbicide treatment
- Natural competition once soil is removed from the wetland hydrology.

Discussions will continue with DEP the sediment reuse policy during the permitting of the phase II restoration project. In addition, potential off site alternatives and associated costs will be detailed in a supplemental memo to this report.

SECTION 3: VEGETATION SURVEY

3.1 INTRODUCTION

The Ballard Street Salt Marsh is located in Saugus, MA (see Figure 1). For purposes of this report, the Ballard Street Salt Marsh is defined as the area bounded to the north by Ballard Street, to the east by Salem Turnpike (Rt. 107), to the west by Eastern Avenue, and to the south by the unpaved extension of Bristow Street.

The area described above was historically a salt marsh ecosystem influenced by tidal action of the Saugus River (located to the north of Ballard Street). As a result of development (road construction, etc.) and the installation of tide gates for flood control, the natural flow of salt water into the area has been greatly restricted. As a result, the salt marsh salt marsh community was lost as the plant communities adapted to the altered hydrologic regime and reduced salt water inundation. Typical salt marsh species such as *Spartina alterniflora* (tall salt marsh cordgrass) and *Spartina patens* (salt meadow hay) have been displaced by the invasive *Phragmites australis* (common reed) and other non-tidal wetland species, as described below.

In addition to the hydrologic alterations described above, the area has also been significantly altered by other human activities. The most significant and obvious alteration is the incomplete Interstate-95 berm that roughly bisects the area. This area of the salt marsh was filled to provide a base for an extension of I-95 that was never completed. Other areas within the salt marsh were altered by being filled with dredge spoils.

The description and mapping of wetland resource areas provided below and in Figure 1 is intended to provide documentation as needed to support to permitting for the proposed Ballard Street Salt Marsh Restoration. This project, which will restore regular salt water inundation to the area by means of a culvert replacement and installation of self-regulating tidegates (SRTs), is described in detail in the project Notice of Intent (ESS, 2002).

3.2 DESCRIPTION OF WETLAND RESOURCE AREAS

On June 17th and June 23rd, 2005, GeoSyntec Consultants conducted a delineation and mapping of wetland resource areas within the Ballard Street Salt Marsh. Flagging tape was used to mark the delineated wetland boundary as shown on Figure 1. A Trimble mapping-grade (sub-meter) Global Positioning System (GPS) unit was used to field-locate the wetland flag locations. Figure 1 shows these locations as an overlay on 2001 aerial orthophotograpghy that was obtained from the Massachusetts Geographic Information System (MassGIS).

The following should be noted with regard to numbering of the wetland flags:

- As described above, the wetland area delineated by GeoSyntec is roughly bisected by the abandoned I-95 berm. GeoSyntec's wetland flags to the west of the berm run sequentially in a counterclockwise direction from Flag #1 (just north of a channel between Ballard Street and the northern terminus of the berm) to Flag #77.
- From Flag #77, the wetland flags continue sequentially (to the east of the berm) up to Flag # 100, which then connects to Flag #126.
- From Flag #126, the wetland flags continue sequentially to Flag #220 (located just west of Rt. 107 at the northeast corner of the wetland system). Flag #220 connects with Flag #328.

- Wetland flags #300 to #328 bound the northeast edge of the wetland, with flag #300 connecting to Flag #1.

The bordering vegetated wetland (BVW) community delineated by GeoSyntec is adjacent to a channel system which can be seen clearly on Figure 1. Variations in the generally flat topography of the site appear to be due to the human disturbances described above (e.g. fill from dredge spoils, the I-95 berm).

The BVW area delineated by GeoSyntec totals approximately 47.5 acres in size, with 23.8 acres to the west of the I-95 berm and 23.7 acres to the east of the berm. GeoSyntec found the species composition of the wetland community to be quite similar on both sides of the I-95 berm. A vast majority of the BVW area was dominated by Common Reed (*Phragmites australis*), with a near mono-culture of this plant growing in dense stands in many areas. Other common species found within the wetland area included:

- Gray Birch (*Betula populifolia*)
- Sensitive Fern (*Onoclea sensibilis*)
- Sweet Gale (*Myrica gale)*
- Purple Loosestrife (*Lythrum salicaria*)
- Swamp Rose (*Rosa palustris*)
- Jewelweed (*Impatiens capensis*)
- Steeplebush (*Spirea tomentosa*)
- Giant goldenrod (*Solidago gigantea*)

Species commonly found in transitional and adjacent upland areas included:

- White Birch (*Betula papyrifera*)
- Staghorn Sumac (*Rhus typhina*)
- Quaking Aspen (*Populus tremula*)
- Sweet Fern (*Comptonia peregrina*)
- Japanese Knotweed (*Polygonum cuspidatum*)
- Stinging Nettle (*Urtica dioica)*
- Hair-cap Moss (*Polytrichum sp.*)
- Black Cherry (*Prunus serotina*)
- Common Mullein (*Verbascum thapsus*)
- Multiflora Rose (*Rosa rugosa*)

In addition to the BVW area described above, GeoSyntec also delineated a portion of the southern bank of the Saugus River. This delineation was conducted so that the area of proposed salt marsh restoration work within the 200-foot Riverfront Area could be depicted, pursuant to the Massachusetts Wetlands Protection Act. The bank of the Saugus River is depicted by wetland flags #400 to #415.

Phase II Sediment Sampling Locations

GeoSyntec Consultants
ACTON, MASSACHUSETTS

DATE: 5/26/04	1 inch equals 300 feet
PROJECT NO. BW0044	FIGURE NO. 1
DOCUMENT NO.	samplemap-05202005.mxd

Prepared for

State of Massachusetts
Coastal Zone Management
Wetlands Restoration Program
251 Causeway Street
Boston, MA 02114

QUALITY ASSURANCE PROJECT PLAN FOR SEDIMENT SAMPLE COLLECTION AND ANALYSIS AT BALLARD STREET MARSH PHASE II RESTORATION SITE

Saugus, MA

Prepared by

GEOSYNTEC CONSULTANTS
289 Great Road
Acton, Massachusetts 01720

Project Number BW0062

May 4, 2005

TABLE OF CONTENTS

APPROVALS

Prepared by: ________________________________ _5/4/05______
Steven P. Roy, GeoSyntec Project Manager Date

Reviewed by: ________________________________ ________
Ed Reiner, EPA Project Manager Date

Approved by: ________________________________ ________
Steven Lipman, MADEP Date

Approved by: ________________________________ ________
Stephen DiMattei, EPA QA Officer Date

1. PROBLEM DEFINITION AND BACKGROUND

This Quality Assurance and Project Plan (QAPP) was developed on behalf of the Town of Saugus, with support from MA CZM and EPA Region 1, in anticipation of design and permitting for the Phase II Ballard Street Marsh restoration project.

The Project Area is 57-acres bordered by Eastern Avenue on the west, Ballard Street on the north, Route 107 on the south and the abandoned Bristow Street right-of-way to the south. The Project Area contains two areas of former and degraded Ballard Street salt marshes, which are separated by large linear berm of sand and gravel fill from former I-95 construction activities, abandoned in 1972. Lands within the Project Area are owned by the Massachusetts Department of Conservation and Recreation (DCR) or by the Town of Saugus, subject to a care and control agreement running to the DCR.

Completion of the Project will accomplish two goals: 1) restore 22.5 acres of former and degraded salt marsh in an ACEC; and 2) provide improved flood protection for area residents. The Project proposes to increase tidal flow and flushing within the two areas of former and existing Ballard Street salt marshes, thereby restoring coastal salt marshes, wildlife habitat, fisheries and potentially shellfish habitat functions and values in these resource areas within the Rumney Marshes ACEC. The Project also proposes to improve and enhance flood storage and storm damage prevention for a westerly abutting low-lying East Saugus residential neighborhood while enhancing existing wetland resources within the Project.

Phase II of this project involves the creation of compensatory flood storage area west of I-95 berm. To accomplish this, the relocation of the existing tidal flooding control point from Ballard Street to the end of the I-95 berm will be necessary. This action would cause the loss of critical interior flood storage capacity without the excavation of approximately 22.5 acres of former salt marsh (including 11 acres of existing bordering vegetated wetland (BVW) dominated by invasive species and adjacent uplands) to a suitable depth. This will compensate for the loss of flood storage volume east of the I-95 berm and, through the action of the self-regulating tide gate (SRTG), provide for reestablishment of salt marsh vegetation and tidal creeks in the area west of the I-95 berm and east of Eastern Avenue. The total required volume of flood storage identified by NRCS (60 acre-feet below elevation 6.4 NGVD) west of the I-95 berm will compensate for the loss of flood storage from the East Saugus neighborhood now available in the salt marshes west of the I-95 berm. Phase II will involve the removal approximately 80,000 cubic yards of sediment for the purposes of flood management and salt marsh restoration. Reuse or disposal of these sediments will be determined by a screening level sampling of sediment quality. Once the SRTG is operational and the Ballard and Bristow Street culverts are open, full tidal flow will be restored to the salt marshes.

2. SEDIMENT SAMPLING METHODS

2.1 Task Description

The extent of sediment removal within Phase II of Ballard Street Marsh extends on the north side of the unfinished I-95 berm from the tidal channel west of the Eastern Tool Facility to Bristow Street (Figure 1). A two-tiered approach to characterizing the sediments in the Ballard St. Phase II area will be conducted. The first tier is the collection of 25 - 3ft cores for composite samples spaced systematically over the Phase II area so that the average separation is approximately 50 m. The full suite of parameters (see Table 1) required by DEP, as part of MA DEP Interim Policy #COMM-94-007, will be analyzed to characterize this uniform and likely uncontaminated marsh sediment. Composite samples composed from three discrete sub-samples (~1 foot intervals) will be submitted to the laboratory. All portions of the sub-samples shall be represented in the resulting composite sample. Sub-samples for VOC analysis shall be obtained from the sample directly and not from the composites. The results of the analysis will be reported to DEP for discussions on whether the sediments have been properly characterized for onsite reuse over the abandoned I-95 berm as outlined in the Hydrology and Hydraulics study prepared by the USDA Natural Resources Conservation Service (NRCS). Secondly, in consultation with DEP, further sampling may be performed using a reduced parameter list based on the discovered contaminants to further characterize the sediment or localized “hot spots”. This proposed method balances the public need for flood control, environmental restoration of salt marsh habitat, the need to properly characterize the sediment for contaminants.

2.2 Sampling Equipment

The following field equipment recommended for sediment sampling includes the following:

- stainless steel hand coring device (solid sides) capable of at least 3 ft penetration;
- large stainless steel bowls;
- Isopropyl alcohol dispenser bottle;
- Alconox or other non-phosphate soap;
- scrub brush;
- protective gloves;
- Zip-lock bags;
- boots/waders (1 set);
- field photo-ionization detector (PID);
- DI water and dispenser bottle;
- DGPS Unit
- camera;

- notebook; and
- indelible ink pens.

Supplied by Lab:

- prepared sample jars;
- preservation solutions;
- chain of custody forms;
- ice and/or ice packs; and
- cooler.

2.3 Sampling Methods and Design

All samples will be collected in compliance with the Interim Policy for Sampling, Analysis, Handling and Tracking Requirements for Sediment Reused or Disposed at Massachusetts Permitted Landfills and will be compliant with this QAPP.

Prior to sample collection, if surface water exists, characteristics (size, depth, apparent flow direction) will be documented in a field logbook and/or sampling form. The sequence of sample collection will be based on these observations. The sediment samples, if taken in a tidal channel, will be collected in an upstream sequence, so that the bottom sediments are not agitated and become suspended in the water column impacting downstream sampling locations.

The depth of each sample shall correspond to the removal depth at the sample site (approximately 3 ft). All samples should contain greater than 30% solids. If necessary, excess liquid should be decanted from the sample prior to field preservation. Three sub-samples at approximately 1 foot. depth intervals will be used for assembling each composite sample.

Samples will be collected using the following approach:

1. Collect DGPS location of the sediment sampling station.
2. Clean sampling equipment (stainless steel bowl, scoop) with Alconox. Rinse with deionized (DI) water. Clean with isopropyl alcohol. Rinse with DI water.
3. Advance the coring device at each location to the maximum anticipated depth of removal. Excess water should be decanted prior to removing sediment from the sampler. Cores found with a high level of contaminants will be resampled with an adjacent core and the analysis performed by Alpha Lab will be conducted.
4. Photograph core with tape measure defining depth increments.
5. A field photo-ionization detector (PID) or similar field VOC monitoring equipment will be used to screen the core for areas where VOCs are present.

These areas of the core will then be subsampled for VOC analysis. Where the PID does not detect any VOCs, subsamples will be obtained representing all visually different areas of the core. Collect the VOC sample from a single sample. Sub-samples for VOC analysis will be obtained from the sample directly and not from composite samples.

6. Extract sub samples based on the VOC screening, in visually different areas of the core, or approximately in one foot increments if the core is uniform with no PID readings. Record the sub-sample depths in log book.
7. Place sub-samples in stainless steel bowl and mix composite thoroughly.
8. Collect sample(s) for non-volatile parameters from composite.
9. Decontaminate all sampling devices and reusable personal protective equipment immediately after each use with a direct application of isopropanol followed by a rinse with distilled water. A scrub brush may be used to assure proper decontamination. Expended decontamination fluids are to be containerized for proper disposal making sure that any accidental loss of these fluids has no chance of entering surface waters. Protective gloves will be disposed between each sampling location.

3. DOCUMENTATION AND RECORDS

Indelible ink pens and waterproof labels will be used to label sample containers. All samples will be labeled with the following information:

- project name;
- unique location-specific identification;
- date and time of collection;
- analysis to be performed;
- preservation chemical (if used); and
- initials of the person(s) collecting the sample.

Samples will be delivered to the EPA Lab in Chelmsford at the end of each field day when samples are taken. Ice, or reusable ice packs, will be evenly distributed between the samples. Complete chain of custody (COC) documentation with complete information for each sample. The samplers will double check that the COC corresponds with the actual samples in the cooler. Sign the COC form including the date and time before relinquishing custody of the cooler and samples. Remove the appropriate copy from the COC or make copies as necessary and retain with other field notes. Place original and remaining copies in a zip lock bag to prevent damage from melting ice. Close the cooler or container. If the cooler is to be transported to the laboratory by a third party, secure signed COC seals over the cooler such that they span the lid and the side it contacts. Transparent tape should be wrapped around the cooler over the COC seals to secure the lid to the cooler.

3.1 Analytical Methods

The analytical information is in Tables 1 and 2.

Table 1: Reporting Criteria and Laboratory Reference

Parameter	**Reporting Limits (mg/kg)**	**Required Criteria (mg/kg)**	**Required criteria reference**	**Laboratory Performing work**
Total Metals				
arsenic	10 - 20	17	On-site Reuse	EPA
cadmium	1.5 - 3.0	2	On-site Reuse	EPA
chromium	3.0	29	On-site Reuse	EPA
copper	3.0		On-site Reuse	EPA
lead	10	99	On-site Reuse	EPA
mercury	0.06	0.3	On-site Reuse	EPA
Total PCBs	0.1 (individual)	<2[b]	Unlined Landfill[a]	EPA
Grains size	NA	NA	On-site Reuse	EPA & contractor
PAHs (target)	.165 (individual)	4	On-site Reuse	EPA
SVOCs[c]	.165 (individual)	100	Unlined Landfill[a]	EPA
VOCs[d]	1.0	4	Unlined Landfill[a]	EPA
EPH		0.7	On-site Reuse	Alpha Analytical
TPH		2,500	Unlined Landfill[a]	Alpha Analytical
Conductivity		4,000 umhos/cm	Unlined Landfill[a]	Alpha Analytical

Notes:

a. TCLP will not be analyzed in this phase of the project.

b. The reuse levels are expressed as total levels of mg/kg and apply to reuse of soil as daily cover, intermediate cover, and pre-capping contour material at lined landfills and unlined landfills as described in the DEP policy.

c. Total concentration of PCBs (polychlorinated biphenyls) EPA Method 8080

d. Total concentration of compounds listed in EPA Method 8260

Table 2: Analytical information and Quality Assurance Goals

Parameter	Container	SOP Reference	Preservative	Holding Time	Quality Assurance Goals		
					Precision	Accuracy	Completeness
Total Metals	4oz WM Glass Teflon lined cap	EIASOP-INGICP6			Lab dup<30%	MS RPD 75-125%	
arsenic			Ice to 4^{o}C	6 months			90 %
cadmium			Ice to 4^{o}C	6 months			90 %
chromium			Ice to 4^{o}C	6 months			90 %
copper			Ice to 4^{o}C	6 months			90 %
lead			Ice to 4^{o}C	6 months			90 %
mercury		EIASOP-INGMERC6	Ice to 4^{o}C	28 days	MS/MSD RPD < 30%	MS RPD 75-125% LFB RPD 85-115%	90 %
Total PCBs	4oz WM Glass Teflon lined cap	EIASOP-PESTSOIL2	Ice to 4^{o}C	14 days	MS/MSD RPD < 50%	MS RPD 70-130% LFB RPD 70-130%	90 %
Grains size	12"X 12' Zip lock ½ full	Grain Size Analysis - Rev.3	Ice to 4^{o}C	NA	NA	NA	90 %
PAHs (target) SVOCs	4 oz jar Glass with teflon lined cap	EIASOP-PAHSOLL4	Ice to 4^{o}C	14 days	LFB/LFBD RPD < 30%	LFB RPD 70-130%	90 %
VOCs	2 @ 40 ml VOA vials	EIASOP-VOAGCMS7	Methanol & Ice to 4^{o}C	14 days	LFB/LFBD < 50% MS/MSD < 40%	LFB RPD 60-140%	90 %
Contracted Analysis – Alpha Laboratories							
EPH	8 oz jar Amber Glass With Teflon lined	EPH-SOP/04-07	Ice to 4^{o}C	14 days	Lab Dup <50%	LCS 40%-140%	90 %
TPH	8 oz jar Amber Glass With Teflon lined	TPH-8100M (Alpha Modification) – SOP/04-11	Ice to 4^{o}C	14 days	Lab Dup <40%	LCS 60%-140%	90 %
Conductivity	8 oz jar Amber Glass With Teflon lined	Specific Conductance-SOP/07-43	Ice to 4^{o}C	28 days	Lab Dup RPD <20%	N/A	90 %
Equipment blank							
PCBs	1 liter glass jar with teflon lined cap	EIASOP-GCPESWALL6	Ice to 4^{o}C	7 days	MS/MSD RPD < 50%	MS RPD 70-130% LFB RPD 70-130%	90 %
PAHs (target)	1 liter glass jar with teflon lined cap	EIASOP-PAHWALL4	Ice to 4^{o}C	14 days	MS/MSD RPD < 30%	MS RPD 31-142%	90 %
Metals	250ml Glass or plastic	EIASOP-INGICP6	Ice to 4^{o}C &HNO_3 to pH<2	6 months	Lab dup<30%	LFB RPD 95-115	90 %
Mercury		EIASOP-INGMERC6	Ice to 4^{o}C &HNO_3 to pH<2	28 days	Lab Dup RPD < 20%	MS RPD 75-125% LFB RPD 85-115%	90 %

4. QUALITY CONTROL REQUIREMENTS

In accordance with the QA objectives of the program, two blind duplicates of a single sample will be collected during each sampling event. The location of this blind duplicate will be determined in advance by the Field Program Coordinator and rotated among the sampling stations. Every duplicate sample will be labeled as DUP-# so that its source remains blind to the laboratory performing the analyses, and submitted for testing of the same parameters as the other samples. The Field Program Coordinator will provide advance notification to field crews when and where these duplicates are to be taken.

An equipment blank will be collected in the field following decontamination of the field sampling equipment. The equipment blank will be collected by running deionized water through clean field equipment. The water will be collected in appropriate containers for analyses according to Table 2.

Accuracy of the laboratory analyses will be verified through the use of equipment blank analyses, duplicate analyses, laboratory control spikes and matrix spikes in accordance with the EPA methods employed and the QAC plan of the laboratory performing the analyses. The laboratories utilized in the program will be responsible for conducting internal quality control and quality assurance measures in accordance with their own QAC plans.

4.1 Validation and Verification Methods

The GeoSyntec Field Program Coordinator will be responsible for ensuring the quality of information on field data sheets by ensuring the legibility of data, checking for outliers and, if necessary, re-sampling during the monitoring event. Data validation will be performed after each sampling event to ensure the raw data are not altered and that an audit trail is developed.

The combination of field duplicates and accuracy checks by the laboratory will be sufficient to ensure adequate care is being taken to maintain the necessary quality of data. The GeoSyntec Field Program Coordinator Officer will make the determination if re-sampling will be required. Circumstances, which may result in re-sampling, include

Data will be accepted if they meet the following criteria:

1. Field data sheets are complete.
2. Field data and laboratory data were validated
3. Actual sample locations and collection procedures match the proposed sample locations and collection procedures
4. Sample handling procedures documented on chain-of-custody forms match the sample handling and custody requirements as described in

Section 2 of this document

5. Quality control samples were conducted as planned and meet the acceptance criteria in Section 4 of this document.

Any deviations from this QAPP will be reported in the field log sheets. If the data fails to meet the criteria, they will be flagged by the GeoSyntec Field Program Coordinato Officer as "estimated". Any flagged data will be discussed with the project team to determine if the data point will be rejected and re-sampling done.

4.2 Corrective Action

When it is found that data is incomplete or that results are unacceptable, the Project Officer and Geosyntec Consultants may determine that one or more of the following procedures for corrective action shall be undertaken:

1. Incomplete data: Omissions from logs, notebooks and worksheets place the entire analysis in question. If data does not meet the 90% data completeness requirement, a meeting will be held with the Project officer, GeoSyntec Consultants, and QA officer to determine an appropriate response. Incomplete field sampling data may require resampling of the questionable location.

2. Conflicting or poor quality data: When results do not meet the described QC goals, the available data will be reviewed by the project officer, GeoSyntec Consultants, and QA officer. Upon examination, all or some of the following actions may be applied:
   a. Systems audit for analyte in question.
   b. Determination of matrix interference.
   c. Re-sampling of the questionable sample.
   d. Reconsideration of acceptable limits with statements explaining the results of the action/rationale taken.
   e. Rejection of data and exclusion from the report with written explanation.
   f. Rejection of the entire sample/site location with recommendation for relocation of sample site or reconsideration of results.

5. DATA REVIEW, VALIDATION, AND VERIFICATION REQUIREMENTS

Field data will be reviewed by GeoSyntec Consultants. Daniel Boudreau will review the OEME Laboratory data. The data produced in the EPA Chemistry Laboratory is reported and verified following the procedures found in the Chemistry Laboratory QA Plan, rev 7, 7/8/04. The data produced by Alpha Analytical Laboratories is reported and verified following the labs QA plan dated July 13, 2004.

Phase II Proposed Sediment Sampling Locations

0 100 200 400 Feet

GeoSyntec Consultants
ACTON, MASSACHUSETTS

DATE: 5/26/04	1 inch equals 200 feet
PROJECT NO. BW0044	FIGURE NO. 1
DOCUMENT NO.	ballardstmarsh-samplemap.mxd

Q:\GISProjects\BW0044-ballardst\ballardstmarsh-samplemap.mxd

Appendix 7: Tidal Flows and Public Safety Issues at Project Culverts Providing Tidal Exchange

Parsons Brinckerhoff, Inc. and Applied Coastal Research and Engineering, Inc.

March 2015

Appendix 7

Tidal Flows and Public Safety Issues at Project Culverts Providing Tidal Exchange

Parsons Brinkerhoff, Inc. & Applied Coastal Research and Engineering, Inc.

March 2015

Evaluation of Public Safety Based on Hydraulic Modeling

Modeling efforts by Woods Hole Group, Inc. and Applied Coastal Research & Engineering, Inc. have determined that potentially hazardous occur at the Project Area culverts that provide tidal exchange to the Eastern and Western Marshes. Specifically, this includes the Ballard Street culvert ("BA-1") and the proposed Bristow Street west culvert ("BR-2") that is included in Alternatives 3 and 4 in the EENF. See Fig. 1. These potentially hazardous conditions occur for portions of the tidal cycles. This Appendix provides additional details of these conditions and the feasibility of mitigating the hazardous conditions.

Fig. Location of Ballard St. culvert ("BA-1") and Bristow St. west culvert ("BR-2")

Elevations of Culverts in Relation to Tidal Range

Tables 1 and 2 indicate the elevations of the two culverts in relationship to the tidal range of the respective waterway that provide, or would provide in the case of "BR-2," tidal exchange to the Project Area. The tidal ranges are based on tide data included in Appendices 1 and 2.

Table 1
Ballard Street Culvert "BA-1"
Elevation of Culvert in Relationship to Tidal Range

Culvert Invert and Overt (Crown)	Tide Range in Saugus River	Elevation (ft.)
	MHW	+5.3
Overt or crown of culvert		+0.8
	MTL	+0.1
Invert(s)		-3.14 to -3.23 ft.
	MLW	-5.1

Tide range based on Table 3, Appendix 2. Assumes same tidal range is Saugus and Pines Rivers

MHW = Mean High Water
MTL = Mean Tide Level
MLW = Mean Low Water

Table 2
Bristow Street West Culvert "BR-2"
Elevation of Culvert in Relationship to Tidal Range

Culvert Invert and Overt (Crown)	Tide Range in Pines RiverChannel	Elevation (ft.)
Overt or crown of culvert		(Open top)
	MHW	+5.6
	MTL	+2.6
Invert of culvert		0.0
	MLW	-0.4

Tide range based on Table 3, Appendix 2

MHW = Mean High Water
MTL = Mean Tide Level
MLW = Mean Low Water

Table 1 shows that the Ballard Street culvert is set low in the tidal range, with its overt just above MTL and its invert about 1.7 ft. above MLW. Table 2 shows that the proposed Bristow Street West Culvert will be set high in the tidal range, with its invert only 0.4 ft. above MLW. This is an open top culvert to provide headroom above MHW.

Basis of Evaluation

Many studies on safe flow velocities demonstrate a critical relationship between flow velocities, water depth and human safety. For example, Cox, *et al.* (2010) developed a plot illustrating potentially dangerous conditions for both adults and children, as shown in Fig. 2. This graph illustrates different combinations of flow depth and flow velocities that present different levels of hazard to children and adults.

Note that the graph indicates that about 1.2 m (about 3.9 ft.) is the limiting flow depth for adults. For example, this means that when the Ballard Street culvert is running full (i.e., at 4 ft. depth), it is not a safe condition for adults. For children, the maximum safe depth is 0.5 m (about 1.7 ft.), which is less than half full flow for this culvert. ~~This means that full flow in the culvert is an unsafe condition for children.~~

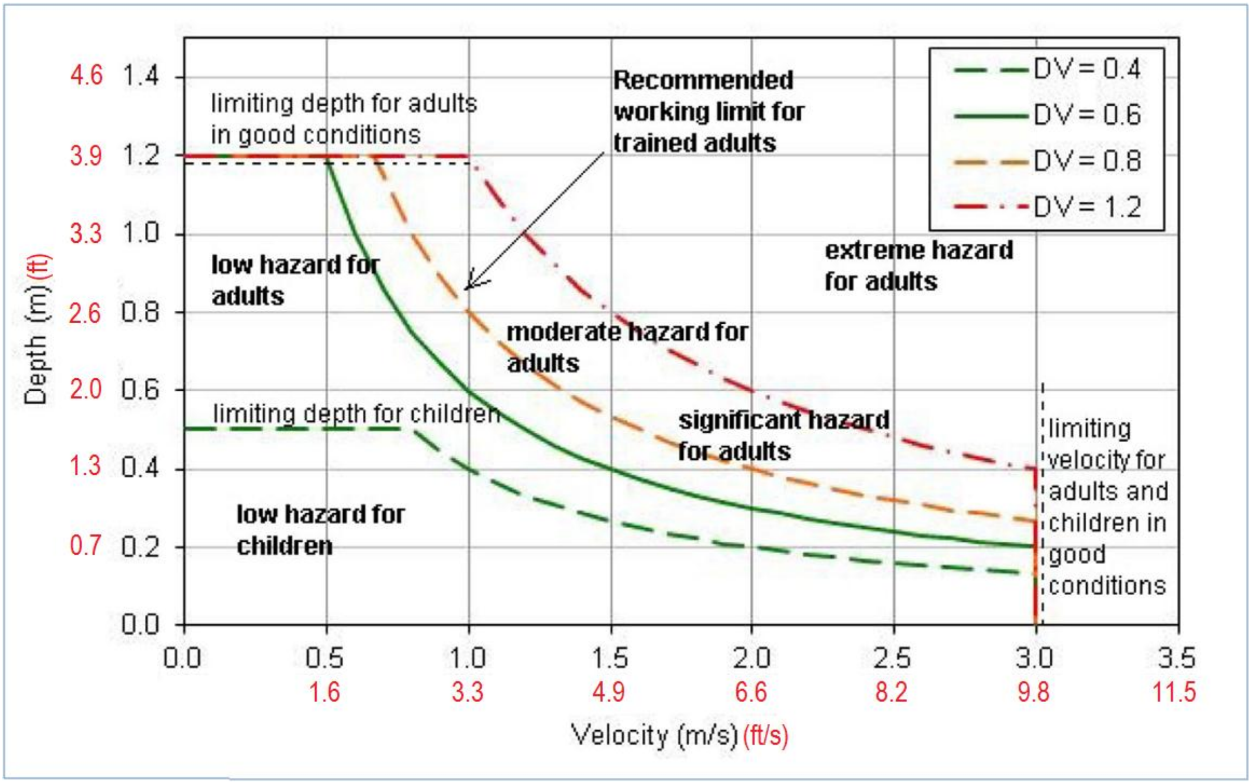


Fig. 2 Flow velocities versus depth indicating safe flow conditions associated with both adults and children (plot from Cox *et al*., 2010).
(Note: velocities are in meters per second and depths are in meters.
Values for velocity given in red are in feet per second and depths in feet have been added by Parsons Brinckerhoff.)

Results of Hydraulic Modeling

Hydraulic modeling was used to determine flow depth and flow velocities for each of the four alternatives[1]. The analysis was for the culvert(s) that provides tidal exchange. Table 3 indicates which culverts provide tidal exchange in each alternative.

Tables 4 through 8 present the flow velocities and depths through the tidal cycle for each culvert and each alternative. The table also states the hazards for adults and children, based on Fig. 2.

[1] For description of alternatives, see Section 3.3 of the EENF narrative.

Table 3
Culverts Providing Tidal Exchange in Each Alternative

Alternative	Ballard Street culvert ("BA-1")	Bristow Street west culvert ("BR-2")
Alternative 1	√	N/A
Alternative 2	√	N/A
Alternative 3	(closed)	√
Alternative 4	√	√

Note: √ = Culvert used for tidal exchange in the alternative

Table 4
Flow Velocity & Depth and Hazard for Adults & Children
Ballard Street Culvert ("BA-1") – Alternative 1

Tide	Flow Velocity (ft./sec.)	Flow Depth (Ft.)	Hazard for Adults	Hazard for Children
Low Tide	0	1	Low	Low
Mid Tide	1	1.2	Low	Low
Max. Flood	1.4	2.5	Low	Over limit
Mid Tide	1	3.7	Near limit	Over limit
High Tide	0	5	Over limit	Over limit
Mid Tide	1.6	3.7	Near limit	Over limit
Max. Ebb	3.2	2.5	Low	Over limit
Mid Tide	1.6	1.2	Low	Low
Low Tide	0	1	Low	Low

Table 5
Flow Velocity & Depth and Hazard for Adults & Children
Ballard Street Culvert ("BA-1") – Alternative 2

Tide	Flow Velocity (ft./sec.)	Flow Depth (Ft.)	Hazard for Adults	Hazard for Children
Low Tide	0	1	Low	Low
Mid Tide	1.6	1.5	Low	Near limit
Max. Flood	3.2	3	Working limit	Over limit
Mid Tide	1.6	4.5	Over limit	Over limit
High Tide	0	6	Over limit	Over limit
Mid Tide	3.7	4.5	Over limit	Over limit
Max. Ebb	7.3	3	Over limit	Over limit
Mid Tide	3.7	1.5	Moderate limit	Over limit
Low Tide	0	1	Low	Low

Table 6
Flow Velocity & Depth and Hazard for Adults & Children
Bristow Street Culvert ("BR-2") – Alternative 3

Tide	Flow Velocity (ft./sec.)	Flow Depth (Ft.)	Hazard for Adults	Hazard for Children
Low Tide	0	1	Low	Low
Mid Tide	6	1.2	Near limit	Over limit
Max. Flood	12	2.5	Over limit	Over limit
Mid Tide	6	3.7	Over limit	Over limit
High Tide	0	5	Over limit	Over limit
Mid Tide	4	3.7	Over limit	Over limit
Max. Ebb	6.5	2.5	Over limit	Over limit
Mid Tide	4	1.2	Low	Over limit
Low Tide	0	1	Low	Low

Table 7
Flow Velocity & Depth and Hazard for Adults & Children
Ballard Street Culvert ("BA-1") – Alternative 4

Tide	Flow Velocity (ft./sec.)	Flow Depth (Ft.)	Hazard for Adults	Hazard for Children
Low Tide	0	1	Low	Low
Mid Tide	0	1.5	Low	Low
Max. Flood	8	3	Over limit	Over limit
Mid Tide	3	4.5	Over limit	Over limit
High Tide	0	6	Over limit	Over limit
Mid Tide	1.8	4.5	Over limit	Over limit
Max. Ebb	3.5	3	Over limit	Over limit
Mid Tide	1.8	1.5	Low	Over limit
Low Tide	0	1	Low	Low

Table 8
Flow Velocity & Depth and Hazard for Adults & Children
Bristow Street Culvert ("BR-2") – Alternative 4

Tide	Flow Velocity (ft./sec.)	Flow Depth (Ft.)	Hazard for Adults	Hazard for Children
Low Tide	0	1	Low	Low
Mid Tide	3	1.2	Low	Low
Max. Flood	6.2	2.5	Over limit	Over limit
Mid Tide	4	3.7	Over limit	Over limit
High Tide	0	5	Over limit	Over limit
Mid Tide	6	3.7	Over limit	Over limit
Max. Ebb	10	2.5	Over limit	Over limit
Mid Tide	4	1.2	Low	Over limit
Low Tide	0	1	Low	Low

Table 9 presents the portion a summary for each alternative indicating the portion of the tidal cycle when a hazard exists for an adult or child at each of the culverts.

Table 9
Hazard for Adults & Children as Portion of Tidal Cycle

	Ballard Street Culvert ("BA-1")		**Bristow Street West Culvert ("BR-2")**	
	Hazard for Adults	**Hazard for Children**	**Hazard for Adults**	**Hazard for Children**
	Approx. Hrs. per 12-hr. Tide Cycle	**Approx. Hrs. per 12-hr. Tide Cycle**	**Approx. Hrs. per 12-hr. Tide Cycle**	**Approx. Hrs. per 12-hr. Tide Cycle**
Alternative 1	4 hrs. (33%)	9 to 10 hrs. (80%)	N/A	N/A
Alternative 2	7 to 8 hrs. (65%)	10 hrs. (85%)	N/A	N/A
Alternative 3	(Closed)	(Closed)	8 hrs. (65%)	9 to 10 hrs. (80%)
Alternative 4	7 to 8 hrs. (65%)	9 to 10 hrs. (80%)	7 to 8 hrs. (65%)	9 to 10 hrs. (80%)

Hazard Mitigation

The evaluation of methods to mitigate the hazard due to flow depth and velocity is a two-step process:

1) Is the culvert short in length (40 ft. or less) and with headroom (at least 1 ft. between water elevation and the crown of the culvert)? If yes, the culvert passes this criterion, because a person could safely pass through the culvert. No other mitigation measures are needed.
2) If no, are there practical mitigation measures (e.g., use of a grating or "trash rack") to prevent a person from being pulled into the culvert?

The proposed Bristow Street West Culvert ("BR-2") passes the first step. It will be under 40 ft. and its height can be designed so that there is headroom under design conditions. On the other hand, the Ballard Street Culvert ("BA-1") does not pass this step, as it is both longer than 40 ft. and sets low in the tide range. Its crown is only 1 ft. above MTL, so therefore, it flow for nearly half the tide cycle. Therefore, the evaluation of hazard for the Ballard Street culvert continues to step 2 of the process.

Fig. 3 Blocked culvert grate ("trash rack") with wide bar spacing (*photo credit*: environment-agency.gov.uk).

In general guidance for trash racks produced by Urban Drainage and Flood Control District (UDFCD) (2001), a maximum safe flow velocity at the front of the trash rack was determined to be 2 feet per second at every stage of the flow entering the culvert. It would be possible to find a location in front of both ends of the culvert where velocities meet the velocity criteria. So, a trash rack would be feasible.

A second criterion is whether the trash rack is practical. A principal concern in the use of trash racks is clogging, which can reduce hydraulic capacity. See Fig. 3. During the flood tide, clogging can reduce tidal exchange and rob the marsh of salinity. In the case of the ebb tide and rain events, loss of hydraulic capacity would lead to upland flooding. For the Ballard Street Culvert, this would translate into flooding in the Project Area and the residential area to the west. Therefore the use of trash racks is only considered practical where clogging and loss of hydraulic capacity will not lead to a decrease in tidal exchange and/or lead to upland flooding.

Evaluation for Alternative 2
In Alternative 2, the Ballard Street culvert is the sole source of tidal exchange for the Project Area, as well as the sole conduit to discharge stormwater runoff from the residential areas west of Eastern Avenue. Therefore, clogging of trash racks would reduce tidal exchange and stormwater discharge capacity, resulting in upstream flooding. Of particular concern is that experience with trash racks indicates that often the clogging occurs during major storm events, the very time the maximum hydraulic capacity is needed. This results in the need for emergency maintenance in the midst of the storm event. The conclusion is that for this alternative, the use of trash rack may be feasible, but is not practical.

Evaluation for Alternative 4
In Alternative 4, the Ballard Street culvert is not the sole source of tidal exchange for the Project Area, as two new culverts are proposed at Bristow Street west ("BR-2" and "BR-3"). In this alternative, these two conduits will to discharge stormwater runoff from the residential areas west of Eastern Avenue. Therefore, clogging of trash racks at the Ballard Street culvert would not reduce stormwater discharge capacity. In this alternative, should clogging occur, the removal of the debris is not as urgent as in Alternative 2 and there would not be a need for emergency maintenance in the midst of major storm events. The conclusion is that for this alternative, the use of trash rack is both feasible and practical.

Summary
A summary of this evaluation is presented in Table 10.

Table 10
Mitigation for Culvert Hazards

Alternative	**Ballard Street - ("BA-1")**		**Bristow Street west - ("BR-2")**		**Rating**
	Short culvert with headroom?	**Grate ("trash rack") practical?**	**Short culvert with headroom?**	**Grate ("trash rack") practical?**	
Alternative 1	No	No existing grates	N/A	N/A	Fail
Alternative 2	No	No (see discussion)	N/A	N/A	Fail
Alternative 3	(closed)	(closed)	Yes	Not required	Pass
Alternative 4	No	Yes (see discussion)	Yes	Not required	Pass

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Attachment 1: Graphs of Modeling Results

Figures 4 through 6 illustrate graphs of culvert velocities for Alternatives 2 through 4.

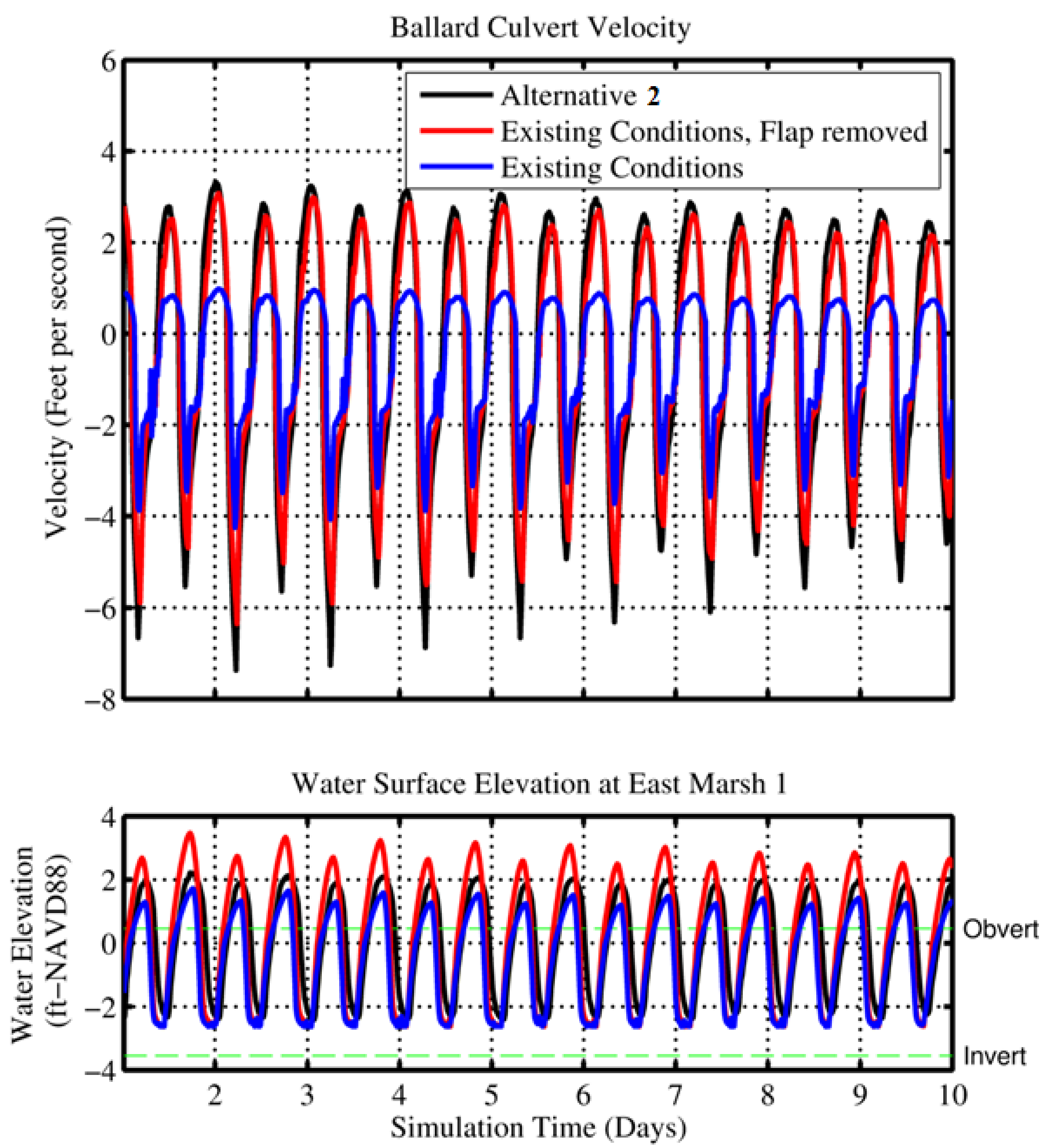

Fig. 4. Flow velocities through the Ballard Street culvert and water elevations immediately upstream of the culvert for existing conditions and Alternative 2. This graph is from Woods Hole Group, Inc. analysis (Appendix 1). In that report "Alternative 2" is labeled as "preferred alternative".

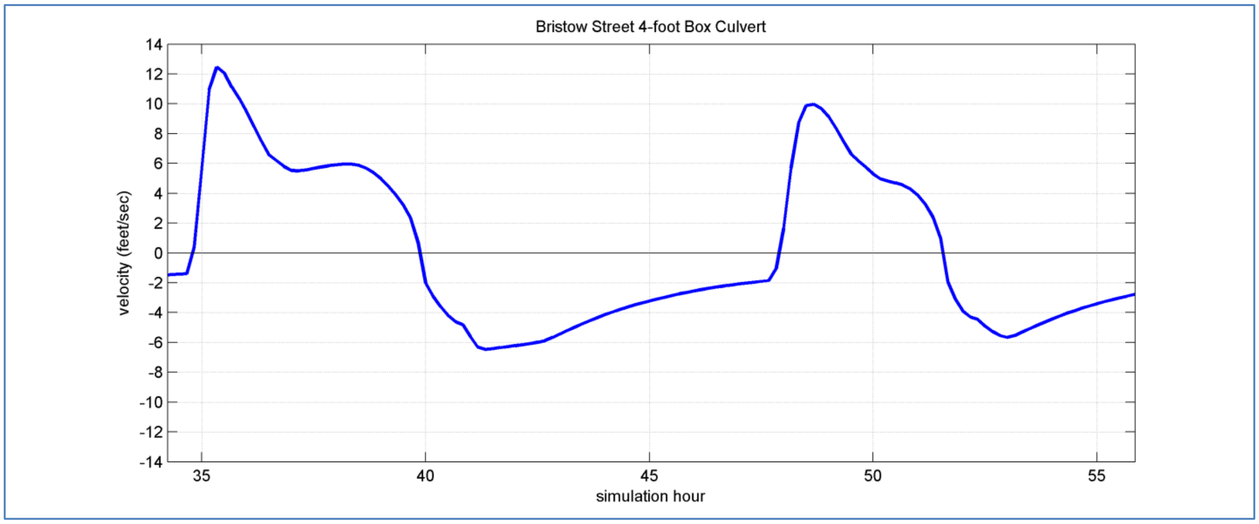

Fig. 5 Modeled flow velocities through the Bristow West culvert ("BR-2") as described for Alternative 3. In this case, flood flows into the marsh are positive velocities and ebb flows are negative velocities.

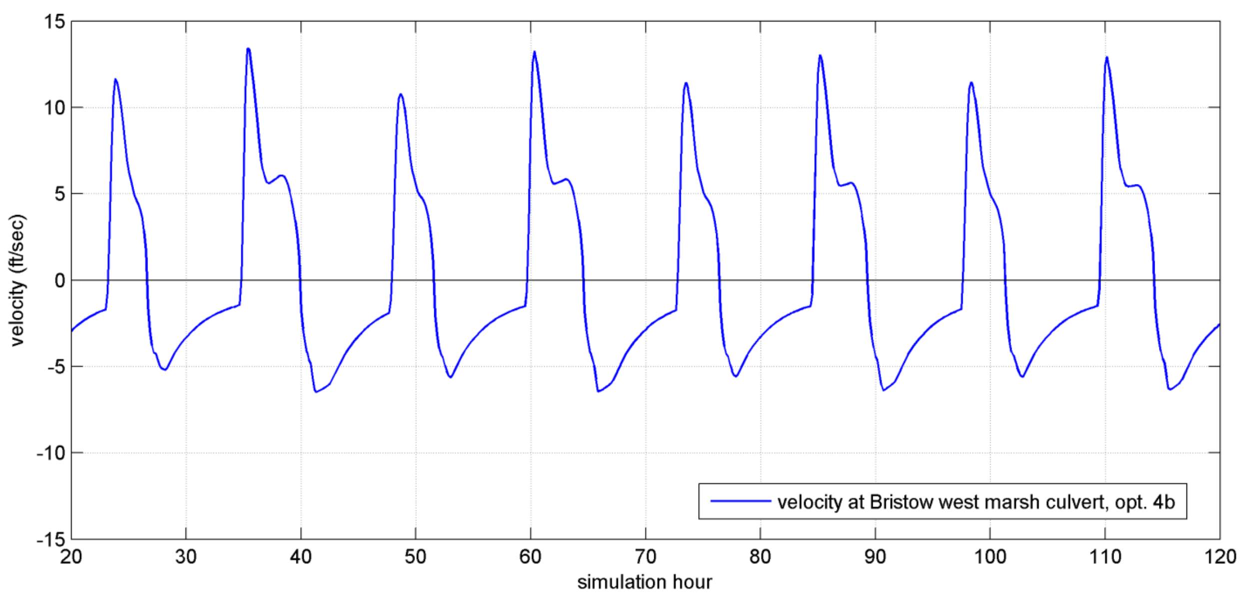

Fig.6 Modeled flow velocities through the Bristow Street West culvert ("BR-2") for Alternative 4. In this case, flood flows into the marsh are positive velocities and ebb flows are negative velocities.