MASSACHUSETTS DEPARTMENT OF TRANSPORTATION

massDOT
Massachusetts Department of Transportation
Highway Division

Boxford Salt Study

MassDOT Contract # 71869

September 30, 2014

CDM Smith

Boxford Salt Study

MassDOT Contract #71869

COMMONWEALTH OF MASSACHUSETTS
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9/30/2014

Massachusetts Department of Transportation (MassDOT)

September 30, 2014

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September 30, 2014

Ms. Laurene Poland, Contract Manager
Salt Remediation Program
MassDOT, Highway Division, Environmental Services
10 Park Plaza, Room 4260
Boston, Massachusetts 02116

Subject: Boxford Salt Study - MassDOT Contract #71869

Dear Ms. Poland:

CDM Smith Inc. (CDM Smith) is pleased to present the Boxford Salt Study (#71869) to the Massachusetts Department of Transportation (MassDOT). Accompanying the report is a separate bound set of associated Appendices.

Submission of this report is intended to satisfy requirements of the Commonwealth of Massachusetts *Chapter 199 of the Acts of 2010, An Act to Conduct a Study of Chemicals Infiltrating Aquifers and Bedrock Fissures Along the Interstate 95 Corridor* (July 30, 2010) and *Chapter 239 of the Acts of 2012, Section 57* (July 31, 2013).

We understand that the comments offered by each of MassDOT and the Boxford Task Force to the Draft Final Report dated September 3, 2014 remain on file at MassDOT's office.

We appreciate the opportunity to have worked with MassDOT and the Boxford Task Force on this assignment and remain available at your request to assist in the implementation of recommendations. Please feel free to call me at (617) 452-6000 if you have any questions or require additional information.

Very truly yours,

Andrew B. Miller, P.E.
Project Manager
CDM Smith Inc.

Enclosures

cc: David White, MassDOT, Highway Division, Environmental Services
Boxford Task Force c/o Alan Benson, Boxford Town Administrator
Kevin Johnson, CDM Smith

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The Boxford Salt Study (the Study) was prepared on behalf of the Massachusetts Department of Transportation (MassDOT) Highway Division as a requirement of Legislation enacted by the Commonwealth of Massachusetts *Chapter 199 of the Acts of 2010* and *Chapter 239 of the Acts of 2012, Section 57*.

CDM Smith gratefully acknowledges all personnel at MassDOT who contributed and assisted in field programs, in particular: David White, Laurene Poland, Catherine Kenna, Richard Mantha, Brett Loosian, and Michael Pelletier. In addition, thanks are extended to members of the Town of Boxford Task Force: Alan Benson, Barbara Jessel, and John Antczak and other personnel of the Town of Boxford who worked to gather and provide information.

CDM Smith would also like to thank Erica Burns and Dr. Erich Hinlein of the University of Massachusetts (UMass) Amherst, Civil and Environmental Engineering Department for their site knowledge and field assistance.

Many other parties contributed to the Study with respect to the gathering of data and providing information including Masconomet Regional School District and the Andrews Farm Water Co. In addition, credit goes to AECOM Technology Corp. (AECOM) who developed drainage conceptual design plans for the Study as part of the MassDOT Impaired Waters Program.

Field program coordination and implementation was conducted by CDM Smith with primary support from sub-contractors including Hager-Richter Geoscience, Inc.; Skillings and Sons, Inc.; Geosearch, Inc.; and Absolute Resource Associates.

List of Acronyms and Abbreviations

A

ABP: agricultural byproducts
AECOM: AECOM Technology Corporation
ARA: Absolute Resource Associates
ATV: acoustic televiewer
Avg.: average

B

BGS: below ground surface
BMP: best management practices
BOD: Biochemical Oxygen Demand
BOH: Board of Health
BOS: Board of Selectmen
BTC: below top of casing
BW: bedrock well
BWA: Boxford Watershed Association

C

^{o}C: degrees Celsius
Ca: Calcium
$CaCl_2$: calcium chloride
$CaCO_3$: calcium carbonate
CB: Catch Basin
C, c: coarse grained strata
Ch.: chapter
Cl: chloride
cm: centimeter
CMA: calcium magnesium acetate
CMR: Code of Massachusetts Regulations
CoCoRaHS: Community Collaborative Rain, Hail and Snow Network
Commission: Boxford Conservation Commission

D

DCR: Department of Conservation and Recreation
DO: Dissolved Oxygen
DPW: Town of Boxford Department of Public Works
DUP: duplicate sample

E

E: east
EM: electromagnetic induction
ENR: Engineering News Record
EOEA: Massachusetts Executive Office of Environmental Affairs
EPA: Environmental Protection Agency
ESRI: Environmental Systems Research Institute
ESS: environmental sensor station

F

^{o}F: degrees Fahrenheit
FAST: Fixed Automated Spray Technology
FB: Fish Brook
FBW: Fish Brook Sub-watershed
F, f: fine grained strata
ft: feet
ft-BGS: feet below ground surface

G

g: grams
Gal: gallons
GIS: Geographic Information Systems
gpd: gallons per day
gpm: gallons per minute
GPS: Global Positioning System

H

Hager-Richter: Hager-Richter Geoscience, Inc.
HCO_3: bicarbonate
HPFM: Heat Pulse Flow Meter

I

IMA: Intermunicipal Agreement
I-95: Interstate 95
in: inches
IR: Ipswich River
IRW: Ipswich River Watershed
L: liters

J

K

KAc: Potassium acetate

L

lbs: pounds
LiDAR: Light Detection and Ranging
L-M: lane-miles

M

M, m: medium grained strata
MASCO: Masconomet Regional High School
MassDEP: Massachusetts Department of Environmental Protection
MassDOT: Massachusetts Department of Transportation
MESA: Massachusetts Endangered Species Act
MassGIS: Massachusetts Geographic Information Systems
MCL: Maximum Contaminant Level
MDOT: Massachusetts Department of Transportation
meq: milliequivalents
mg: micrograms
mg: milligrams
Mg: magnesium
$MgCl_2$: magnesium chloride
MGL: Massachusetts General Law
MH: manhole
mph: miles per hour
mS: microsiemens
MS4: Small Municipal Separate Storm Sewer Systems
MSL: mean sea level
MTAP: MassDOT Training Assistance Program
mV: millivolts
mvmt: million vehicle miles traveled
MVPC: Merrimack Valley Planning Commission
MW: monitoring well

N

N: north
N/A: not applicable
Na: sodium
NaCl: sodium chloride
NB: northbound
NHESP: Massachusetts Natural Heritage and Endangered Species Program
NHDES: New Hampshire Department of Environmental Services
NPDES: National Pollutant Discharge Elimination System
NPV: net present value
NS: not sampled
NTU: Nephelometric Turbidity Unit
NWS COOP: National Weather Service cooperative monitoring station

O

O&M: Operations & Maintenance
OGFC: Open-Graded Friction Course
ORP: oxygen reduction potential
ORSG: Massachusetts Office of Research and Standards Guideline

OTV: optical televiewer
OW: town observation well

P

PB: Pye Brook
PBW: Pye Brook Sub-watershed
POE: point-of-entry
POU: point-of-use
ppt: parts per thousand
PR: Parker River
PRW: Parker River Watershed
psi: pounds per square inch
PVC: polyvinyl chloride

Q

QA/QC: Quality Assurance/Quality Control
QAP: Quality Assurance Plan

R

R: drilling refusal
RO: reverse osmosis
ROW: right-of-way
RSZ: Reduced Salt Zone
RWIS: Road Weather Information Sensor
Rt.: route

S

S: south
SB: Silver Brook
SB: soil boring
SB: southbound
SBW: Silver Brook Sub-watershed
SCAV: Scavenger Well
SDWA: Safe Drinking Water Act
SMCL: Secondary Maximum Contaminant Level
SOP: Standard Operating Procedure
sq ft: square feet
SU: standard units
SWMM: Stormwater Management Model

T

The Task Force: Boxford I-95 Salt Study Task Force
TBD: To be determined
TD: town drainage
TDS: total dissolved solids
The Commonwealth: The Commonwealth of Massachusetts
the Study: the Boxford Salt Study
the Town: the Town of Boxford
TMDL: Total Maximum Daily Load
TSS: total suspended solids
TW: test well

U

µg: micrograms
UMass: University of Massachusetts - Amherst
USGS: United States Geological Survey
UST: underground storage tank

V

VOC: Volatile Organic Compound
VHB: Vanasse Hangen and Brustlin, Inc.

W

W: west
WMA: Massachusetts Water Management Act
WS: watershed

X

Y

Z

Executive Summary

In 2012, the Massachusetts Department of Transportation (MassDOT) retained CDM Smith Inc. (CDM Smith) to perform the Boxford Salt Study (the Study), MassDOT Contract #71869.

The Study is a requirement of the Commonwealth of Massachusetts (the Commonwealth) *Chapter 199 of the Acts of 2010, An Act to Conduct a Study of Chemicals Infiltrating Aquifers and Bedrock Fissures Along the Interstate 95 Corridor* (approved July 30, 2010). The Interstate 95 (I-95) corridor, identified herein as "the Study Area," is defined in the Legislation as the area within the municipal limits of the Town of Boxford (the Town) that lies within 1,500 feet from any portion of I-95 (see Study Area Overview on following page).

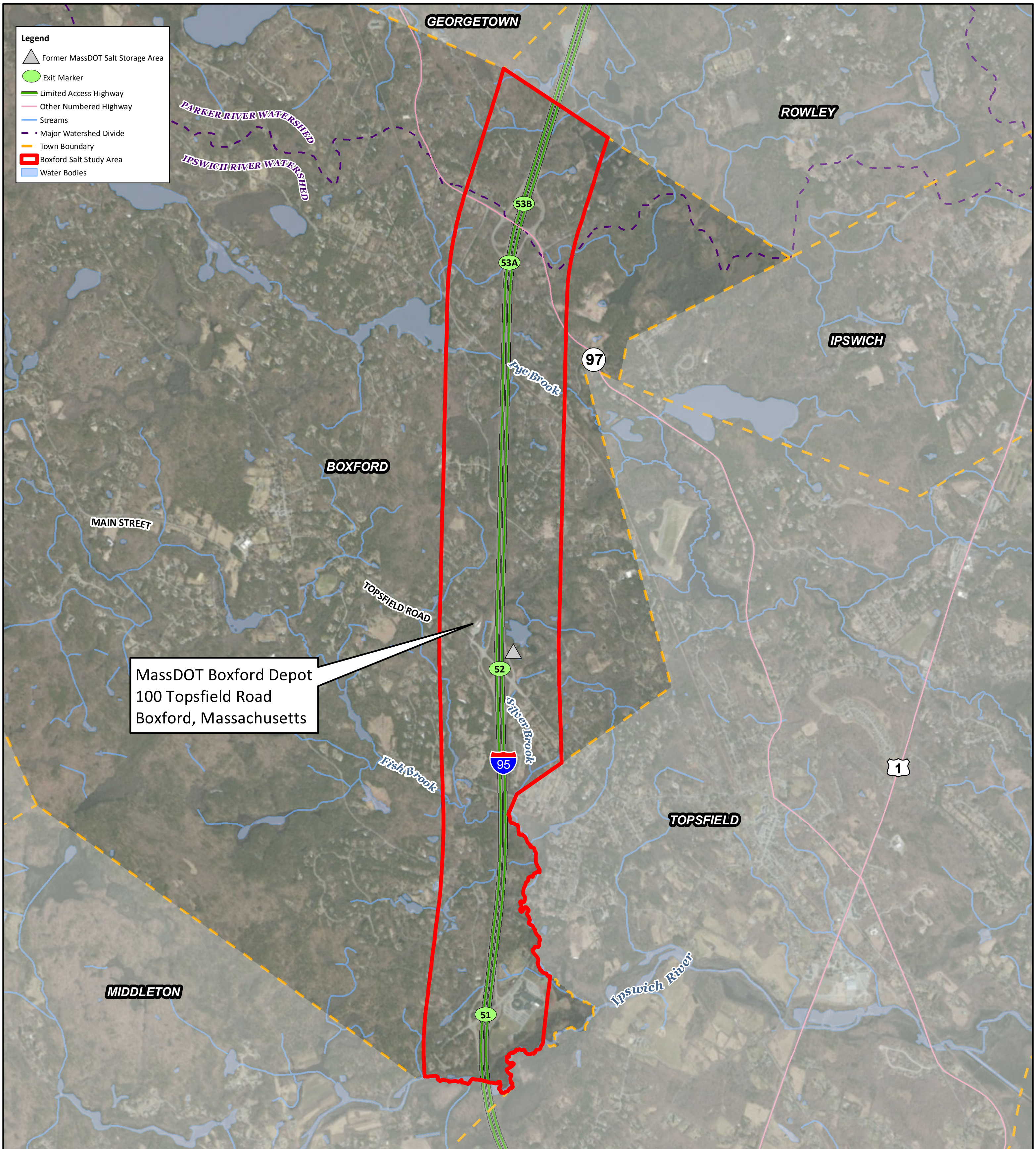
The specific objectives of the Study cited in the Legislation include:

- To "determine the cumulative and immediate effects of deicing chemical storage and deicing operations on the groundwater aquifers and bedrock fissures within the I-95 corridor."
- To determine "the proximate causes of deicing chemicals, including sodium and chloride infiltration into the groundwater aquifers and bedrock fissures within the I-95 corridor."
- To determine "what measures need to be taken to prevent [infiltration of deicing chemicals to groundwater aquifers and bedrock fissures] from occurring in the future."
- To develop recommendations for "short-term and long-term remedial actions necessary to restore groundwater quality to a safe drinking water standard within the I-95 corridor."
- To develop "a plan to modify highway drainage systems to prevent storm water run-off and highway drainage from adversely impacting aquifers, bedrock and adjacent wetland resource areas."
- To develop "an alternative means to provide a reliable and adequate safe drinking water supply to the residents located within the I-95 corridor meeting all state and local requirements."

The Boxford Task Force, a three-member committee appointed by the Town, has been participating in the Study in an advisory role per Legislation requirements.

E.1 Study Area and Background

There is no municipal water supply system serving residents in Boxford. Rather, residents of the Town obtain their drinking water from individual domestic wells or small community water supply systems served by wells. Since the 1980s, some residents living along the I-95 corridor in Boxford have noted increased salt (sodium [Na] and chloride [Cl]) concentrations in their well water. Potential causes of these impacts have been attributed to MassDOT's application of road salt as part of its deicing operations along I-95, as well as the MassDOT Salt Shed (the Boxford Depot) located at 100 Topsfield Road in Boxford which operated from 1974 to June 2009. The sand and salt historically stored at the Boxford Depot were used as part of MassDOT's I-95 winter deicing program for the Boxford Depot Service Area, since the I-95 lane expansion in 1974.



CDM Smith

MassDOT Boxford Salt Study

Study Area Overview

Source: MassGIS, CDM Smith

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

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Domestic Well Water Quality and Drinking Water Standards

Domestic wells in the Study Area are predominantly installed in bedrock, with a small number also installed in the overburden sand and gravel deposits. Bedrock domestic well depths range from less than 100 feet to more than 1,000 feet below ground surface (BGS) throughout the Study Area. Historically, sodium and chloride concentrations in groundwater of the Study Area have ranged from 8 milligrams per liter (mg/L) to 1,200 mg/L, and 19 mg/L to 2,300 mg/L, respectively. Background unimpacted sodium and chloride groundwater concentrations in the Study Area are typically less than 50 mg/L (Baker and Sammel, 1962).

The Legislation defines safe drinking water as “water meeting or exceeding all primary and secondary standards and recommended guidelines for drinking water as defined by [the Massachusetts Department of Environmental Protection (MassDEP)].” Primary standards are health-based drinking water standards referred to as Maximum Contaminant Levels (MCLs) which are set by the Environmental Protection Agency (EPA). Secondary standards, commonly known as Secondary Maximum Contaminant Levels (SMCLs), are non-enforceable standards established by EPA for which there is no direct risk to consumer health. SMCLs are meant to address aesthetic effects (undesirable tastes or odors), cosmetic effects (effects which do not damage the body but are still undesirable), and technical effects (damage to water equipment or reduced effectiveness of treatment for other contaminants). MassDEP, being a primacy agency managing the Safe Drinking Water Act (SDWA) in the Commonwealth, has the authority to make these standards more stringent if the science, as well as benefits versus costs, justifies the change.

While there is no health-based drinking water MCL for sodium or chloride, MassDEP has established guidelines or secondary limits for these parameters. Specifically, sodium has a MassDEP Office of Research and Standards Guideline (ORSG) of 20 mg/L which is meant to be protective of individuals on a sodium-restricted diet (U.S. EPA, 2003). Chloride has a SMCL of 250 mg/L in drinking water (MassDEP, 2012), established in consideration of the aesthetic and technical effects. Aesthetically, some individuals may experience a salty taste when chloride concentrations exceed 250 mg/L. Technically, chloride in sufficient concentrations can lead to the corrosion of home piping systems and other household appliances, however, the rate and extensiveness of corrosion depends on several water quality characteristics including hardness, pH, and/or sulfate concentrations.

MassDOT Salt Remediation Program

The MassDOT Salt Remediation Program (the Program) was established in 1986 to address the impacts associated with winter deicing activities performed on state roads throughout the Commonwealth. The Program was specifically developed to investigate salt impacts on privately owned wells and to remediate impacted water supplies where necessary. In Boxford, the Program has assessed 48 domestic wells within the Study Area. Remediation efforts (replacement wells, treatment, or scavenger well operation) have been conducted at 26 of the 48 homeowner parcels to improve drinking water quality.

E.2 Study Approach

The Study consisted of the following three elements, focusing on an evaluation of the causes and effects of deicing materials in the groundwater and identifying potential solutions to minimize future impacts:

- ***A hydrogeologic assessment*** was conducted to assess the source and extent of groundwater impacts from deicing chemicals. The assessment included data collection and review, development of a conceptual hydrogeologic model (which is an understanding of how water and deicing constituents move through the Study Area), field program implementation, and analyses to refine the conceptual model. The field programs included:
  - Stormwater drainage system reconnaissance of both I-95 and Town country drainage
  - Screening and focused surface water quality sampling of outfalls and streams
  - Shallow monitoring well installations
  - Sampling and analyses of soil samples along I-95 and at the Boxford Depot
  - Groundwater sampling and analysis of shallow monitoring wells and other overburden wells in the Study Area
  - Bedrock investigations including fracture trace analysis, outcrop investigations, and borehole geophysics
  - Domestic well sampling and analysis for deicing material indicator parameters
  - A winter sampling program focused on three weather events
- ***An alternatives analysis*** identified and evaluated potentially applicable technologies and mitigation measures needed to address impacts from deicing operations and salt storage/handling, with the intent of improving groundwater quality and providing safe drinking water to Study Area residents.
- ***Reporting*** included progress meetings and reports, an Interim Report (CDM Smith, July 2013), as well as a Final Report presenting findings of the hydrogeologic assessment and recommendations for consideration based on results of the alternatives analysis.

E.3 Overview of Deicing Operations in Study Area

Data collection and review was performed to better understand the MassDOT and Town deicing operations.

MassDOT Deicing Operations and Material Storage

The Boxford Depot Service Area is a Reduced Salt Zone (RSZ), requiring MassDOT to apply a combination of sand and salt at a 1:1 ratio for deicing. The sand-salt mixture is pre-wetted with liquid magnesium chloride as it is applied to the roadway. These materials are applied by combination spreader/plow units that are automated to drop materials at a constant rate accounting for vehicle speed. When weather conditions allow, MassDOT also performs pre-treatment along the mainline of I-95 using liquid magnesium chloride ($MgCl_2$). Under severe weather conditions, straight salt may be applied to maintain safe road conditions.

Prior to shutdown of the salt shed in 2009, deicing of the nearly 87 lane-miles[1] in the Boxford Depot Service Area was conducted out of the Boxford Depot. Salt was stored in the shed, with salt handling

[1] A lane-mile is a measure of road length which represents the number of miles in every travel and breakdown lane. For example, a one mile length of highway with four travel lanes and a breakdown lane is equivalent to 5 lane-miles.

and loading of spreaders conducted in the open from 1974 until 2005 when a fabric extension was constructed. Since closure of the salt shed, deicing operations for the Boxford Depot Service Area are based primarily out of the Rowley Depot, and sometimes out of the Newbury and Peabody Depots. A liquid $MgCl_2$ tank was installed at the Boxford Depot in 2008 and remains in operation today for refilling of pre-treatment tankers and pre-wetting saddle tanks.

Town of Boxford Deicing Operations and Material Storage

The Town applies sand and salt at a 3:1 ratio using spreaders. Sand and salt are pre-wet with liquid $MgCl_2$ applied as the solids are dispersed. The Town's spreaders are not automated and do not account for vehicle speed, resulting in varying application rates. The Town does not pre-treat its roadways. The Town services approximately 187 lane-miles of roadway, 27 of which are in the Study Area. Sand and salt are stored and loaded in the Town's salt shed at the Town DPW yard off of Spofford Road, outside of the Study Area.

E.4 Study Findings and Alternatives Analysis

Study findings based on the hydrogeologic assessment and proposed alternatives are presented below in terms of the stated objectives in the Legislation that guided this Study.

Objective: To "determine the cumulative and immediate effects of deicing chemical storage and deicing operations on the groundwater aquifers and bedrock fissures within the I-95 corridor."

Groundwater in the Study Area has been impacted by deicing materials, primarily road salt (sodium and chloride), but also by the pre-wetting and pre-treatment agents magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$). Discussion of the impact of deicing materials relative to location, effects, concentration, and movement in the environment is presented below.

- ***Areas of Domestic Well Impact***: Bedrock groundwater quality impacts associated with deicing have been observed at parcels up to and more than 1,500 feet east of I-95, at parcels up to 1,500 feet west of I-95, and at depths of 440 feet and possibly deeper. The areas most affected by groundwater deicing impacts are:
  - Areas east of the Exit 53 northbound on-ramp (north of Rowley Road and Killam Hill Road) and southeast of Exit 53 (from Killam Hill Road south to Pye Brook).
  - Areas in the vicinity of Exit 52 including the Boxford Depot, the Titus Lane area south of the Boxford Depot, and in the Silverbrook Road area southeast of Exit 52.
  - Two smaller areas located in the southern portion of the Study Area adjacent to Fuller Lane and Middleton Road near Exit 51.
- ***Effects of Deicing Operations and Salt Storage/Handling:*** Bedrock groundwater deicing impacts in the Exit 52 vicinity, including the Boxford Depot and the Titus Lane and Silverbrook Road areas likely reflect contributions from earlier sources (Boxford Depot), as well as more recent sources (I-95 deicing operations) of deicing materials. Salt impacted domestic wells in other portions of the Study Area such as at the Exit 53 interchange, and in areas south of Lockwood Lane including the Exit 51 vicinity, likely reflect contributions from I-95 deicing operations.

- ***Salt Constituent Groundwater Quality:*** Sodium and chloride concentrations at domestic wells sampled during the Study in 2014 ranged from 9 to 230 mg/L and 16 to 390 mg/L, respectively. Twenty of the 22 wells sampled exhibited sodium concentrations in excess of the MassDEP ORSG of 20 mg/L. Concentrations at 6 of the 22 wells sampled exceeded the EPA SMCL of 250 mg/L for chloride. At nine locations where historical documentation was believed sufficient to correlate 2014 data with earlier data, reported 2014 groundwater concentrations were generally similar to earlier reported concentrations from sampling events conducted during different periods in 2006 - 2013.

- ***Remediation Efforts at the Boxford Depot:*** Scavenger Well #3, which pumps salt-impacted groundwater from the bedrock at the Boxford Depot with discharge to a nearby stream, has been in operation since 2005. Pumped sodium and chloride concentrations at the well have significantly declined from about 1,000 mg/L and 3,600 mg/L, respectively in 2005, to 240 mg/L and 600 mg/L, respectively in January 2014. The decline in concentrations is consistent with reduced loading due to improved salt handling practices after 2005 and shutdown of the shed in 2009, in addition to other factors such as the location of the pumping well relative to the limits of the salt impacted groundwater. The amount of mass extracted by Scavenger Well #3 pumping is estimated to be equivalent to about 120-150 tons of deicing materials.

- ***Mobility of Salt Constituents in Bedrock*:** Bedrock investigations revealed a complex fractured bedrock system in the Study Area. The extensive bedrock fracturing likely allows a high degree of mobility of salt constituents both horizontally and vertically through the bedrock aquifer, and provides a direct pathway from the overburden to deeper portions of the bedrock. Fractured groundwater sampling results conducted at three locations indicate that salt concentrations are distributed vertically throughout the depth of each borehole (up to 440 feet-BGS). The highly fractured nature of the bedrock, the varying fracture orientations, well construction (long open boreholes), continuous pumping of scavenger wells (past and present), and extended daily intermittent pumping of the numerous domestic wells installed at various depths throughout the Study Area, are all potentially contributing factors to the distribution of deicing materials in bedrock groundwater within the Study Area.

- ***Stormwater Drainage System Effects*:** In general, higher concentrations of salt were observed in I-95 drainage outfalls in comparison to outfalls at remote locations associated with the Town's drainage system.

Objective: To determine "the proximate causes of deicing chemicals, including sodium and chloride, infiltration into the groundwater aquifers and bedrock fissures within the I-95 corridor."

The two most significant sources of deicing material impacts to bedrock in the Study Area are MassDOT deicing operations and former materials storage and handling at the Boxford Depot.

- ***I-95 Deicing Operations:*** MassDOT maintains responsibility for ensuring snow removal and deicing along I-95 and the associated ramps and overpasses at Exits 51, 52, and 53 within the Study Area. During winter precipitation events, when deicing materials are applied to I-95, and during snowmelt events, deicing materials in the surface water runoff are transported by roadway drainage systems to drainage channels and local streams. Once in stream channels or wetlands, surface water transport of deicing materials is governed by watershed hydrology. In other areas, I-95 runoff and snowbank melt infiltrates directly through overburden into the underlying bedrock. Locations in the Study Area most sensitive to deicing material impacts in bedrock are locations where the top of bedrock is close to the land surface (i.e., areas of shallow overburden thickness). Along I-95, shallow bedrock has been observed in the Exit 53 vicinity, near Exit 52, and in Study Area locations south of Lockwood Lane. In these locations, there is a shorter pathway from surface water and shallow groundwater to the deeper bedrock groundwater system.

- ***Boxford Depot:*** The Boxford Depot was operational from 1974 until 2009. There are no records of materials spillage or releases during this period, but it is reasonable to believe that deicing materials were introduced to the subsurface during the course of operations, especially prior to 2005. After 2005, salt loading was conducted under cover and additional measures were implemented by MassDOT to reduce and minimize spillage. There is no stormwater drainage system or runoff control at the Boxford Depot. As a result, runoff from the paved area of the facility entered shallow overburden onsite. The bedrock at the Boxford Depot is within ten feet of land surface, resulting in a short pathway from overburden groundwater to bedrock. Groundwater impacts from past Boxford Depot operations have been observed at the Boxford Depot overburden monitoring wells in addition to Scavenger Well #3. It is likely that salt impacts to bedrock domestic wells downgradient of the Boxford Depot in both the Titus Lane and Silverbrook Road neighborhoods are also a result of Boxford Depot operations.

- ***Other More Minor Contributions of Salt Constituents:*** In addition to past salt storage at the Boxford Depot and I-95 deicing operations, there are other more minor contributions of salt constituents to groundwater. These include Town deicing operations, deicing operations at the Masconomet Regional High School, home septic system discharges, contributions from domestic well treatment systems (i.e., softeners using sodium chloride to reduce hardness discharging to on-site septic systems and reverse osmosis treatment systems to remove salt which discharge to dry wells), and home owner use of road salt on driveways and walkways.

Objective: To determine "what measures need to be taken to prevent [infiltration of deicing chemicals to groundwater aquifers and bedrock fissures] from occurring in the future."

Roadway deicing operations and related materials storage alternatives were evaluated to identify measures that would reduce the likelihood of deicing material infiltration to the subsurface. The results of these evaluations are summarized below.

MassDOT Deicing Operations

A review of MassDOT material use records for the Boxford Depot Service Area suggests that the sand to salt ratio over the last four winter seasons has averaged 1:1.1 which is close to the 1:1 protocol for RSZs. However, there is no conclusive way to determine if the actual sand and salt application rates are as prescribed in MassDOT protocol (120 lbs/lane-mile each), since the number of spreader passes is unknown. Also, the pre-wetting and pre-treatment application rates for $MgCl_2$ are less than recommended by MassDOT protocols. Some discrepancies were also noted in the MassDOT record keeping. The following measures should be implemented by MassDOT to improve operations with the goal being to achieve a reduction in overall salt use.

- ***Meeting Established Operating Protocols:*** Whenever possible, efforts should be directed at meeting established protocols for pre-wetting and pre-treatment applications of the liquid deicing agent $MgCl_2$. Liquid deicing agents increase the effectiveness of salt which should reduce the amount of salt required.

- ***Enhancement of Quality Assurance Procedures/Programs:*** Improve recording and tracking of material usage and application rates for both salt and $MgCl_2$ to provide a better guide for future operations. Such efforts should include: measurements of material loading, annual benchmarking, improved and frequent equipment calibration, and increased training including a contractor certification program.

- ***Enhanced Roadway Pre-Treatment Program:*** Currently, MassDOT only provides pre-treatment of I-95 mainlines. Such pre-treatment should be expanded to interchanges, overpasses, and ramps to further the reduction in salt usage. Similarly, there may be opportunities to perform pre-treatment for an increased number of storm events. A commitment to an enhanced roadway pre-treatment program would require increasing the number of pre-treatment tankers serving the Boxford Depot Service Area.

- ***Pilot Testing:*** MassDOT has ongoing pilot programs in several areas of the Commonwealth to explore the potential of eliminating or reducing sand application in RSZs. Future pilot studies could include testing alternative products for pre-wetting and pre-treatment (such as salt brine, agricultural byproducts, and blended chemicals). Pilot test results could be shared with Boxford should the Town wish to incorporate these technologies in its own deicing operations.

- ***Continued Use of Technology:*** MassDOT currently employs closed-loop controllers, mobile pavement temperature sensors, and Remote Roadway Weather Information Systems (RWIS) in its operations. Continued use of these technologies is recommended.

- ***Introduction and Expansion of New Equipment and Technologies:*** To compensate for any modified application rates of sand and/or salt, tools such as mobile friction meters to monitor roadway traction or flexible/segmented plow blades to achieve greater mechanical removal of winter precipitation should be considered in order to maintain road safety.

- ***Local Road Weather Information System:*** Consider implementation of a local RWIS in Boxford to provide more accurate and relevant weather data for use in storm tracking and deicing event scheduling. This may enhance decisions for pre-treatment based upon anticipated storm events.

- ***Geofencing:*** As a new technology, geofencing offers the best means currently available of controlling and monitoring material application rates. Over the long-term, consider implementation of a geofencing system to improve the efficiency of plow and deicing routes, eliminate duplicate or over-applications, and optimize material application.

MassDOT Deicing Material Storage

Deicing operations require access to deicing materials and rapid deployment of spreaders to roadways. Alternatives for salt storage include either maintaining current operations at the Boxford Depot with salt handling conducted at other depots, or constructing a new storage and handling facility on the existing Boxford Depot parcel. Better management and environmental protections were considered as appropriate for both options.

- ***Maintaining the Status Quo:*** This option includes the continued partial closure of the Boxford Depot, with deicing operations for the Boxford Depot Service Area being conducted primarily out of the Rowley Depot. There would be no salt storage at the Boxford Depot under this alternative. However, the Boxford Depot would continue to provide sand storage and liquid $MgCl_2$ storage/loading with the associated truck operations. Site improvements to enhance environmental protection would include: double walled chemical storage tanks for additional leakage protection, new drainage infrastructure, and pavement replacement. The estimated project cost is $1,300,000.

- ***Resumption of Salt Storage and Handling at the Boxford Depot with a New Salt Shed:*** For this option, existing facilities at the Boxford Depot would be removed and a new salt shed would be constructed for a resumption of salt storage and handling at the site. Storage and loading of both sand and liquid $MgCl_2$ would continue, with the possibility of other liquid deicing chemicals also to be stored at the Boxford Depot. The resumption of salt storage and handling would require implementation of environmental protection measures such as: construction of a state-of-the-art salt shed to minimize salt loss during operations, stormwater drainage facilities, re-pavement with an impermeable liner to limit infiltration, double walled storage tanks for chemicals, and a pre- and post-operation monitoring program to identify noticeable changes in water quality. The estimated project cost is $4,200,000.

Town of Boxford Deicing Recommendations

The Town's winter season salt usage within the Study Area is significantly less than that of MassDOT's I-95 deicing operations. Review of Town salt and sand purchase records suggests that over the last four winter seasons, the sand to salt ratio has been 2.9:1, which is close to the Town's prescribed ratio of 3:1. There are no records available of salt/sand application rates. Records of $MgCl_2$ use for pre-wetting were made available for the most recent winter season suggesting an application rate below typically accepted protocols.

Based on these findings, some improvements should be made to Boxford's deicing operations. Initial efforts should focus on improved recording and tracking of material usage and application rates. These include improved measurement and recording of materials during loading; meeting industry standard protocols for the application of the deicing agent $MgCl_2$; continued annual employee training on material handling, usage, equipment operation, and BMPs; and annual benchmarking to identify deficiencies and/or areas for further improvement.

Public Education

To a lesser extent, the public also has a role in helping to maintain water quality and reducing salt impacts to the environment. For example, domestic well softening units add sodium and chloride to the water which is then released to on-site septic systems. An alternative may be for homeowners to switch to potassium-generating softening units. Also, increased public awareness that rock salt placed on driveways and walkways can result in localized, though minor, salt impacts on surface water and groundwater, should be promoted.

Objective: To develop recommendations for "short-term and long-term remedial actions necessary to restore groundwater quality to a safe drinking water standard within the I-95 corridor."

Short-term and long-term measures which may be implemented to improve groundwater quality are identified below.

- ***Scavenger Well #3 Hydrogeologic Assessment (short-term):*** The objective of this assessment would be to evaluate the Scavenger Well #3 capture zone extent, the mass of salt constituents remaining in the groundwater near the Boxford Depot, and the groundwater-surface water interactions near the onsite stream where Scavenger Well #3 pumped groundwater is discharged. This would allow development of a long-term operations plan and help to establish criteria for eventual shutdown based on monitoring data. The range of estimated costs for a hydrogeologic assessment is $100,000 to $150,000.

- ***Future Scavenger Well #3 Operation and Discharge (long-term):*** Continued operation of Scavenger Well #3 will depend on the assessment results and recommended monitoring. Results of the hydrogeological evaluation may suggest the need for alternative approaches to well discharge.

- ***Proper Well Abandonment (short and long-term):*** Any test wells installed in the Study Area that are not used for drinking water or monitoring purposes should be immediately and properly abandoned to ensure that the well does not serve as a conduit for salt constituent transport.

- ***Groundwater and Surface Water Monitoring (short- and long-term):*** Groundwater and surface water monitoring should continue with an expanded focus on known impact areas to track water quality changes over time.

- ***Improved Record Keeping (short- and long-term):*** It is recommended that MassDOT develop a Standard Operating Procedure (SOP) for data collection and record keeping related to domestic well assessments performed by the Salt Remediation Program. Such an SOP would be applicable to all such data collection efforts in the Commonwealth.

Groundwater quality improvements associated with operational changes at the Boxford Depot from 2005 to present, or from I-95 drainage modifications constructed in 2005 and 2006, may not be evident for many years because of the scale of impacts and the rate of groundwater flow in the bedrock of the Study Area. Likewise, groundwater quality changes associated with any measures that are implemented in the future may not be immediate, and long-term monitoring is recommended to track groundwater quality changes over time.

Objectives: To develop "a plan to modify highway drainage systems to prevent storm water run-off and highway drainage from adversely impacting aquifers, bedrock and adjacent wetland resource areas."

Candidate drainage system modifications were identified to address infiltration of runoff potentially having high concentrations of deicing materials. Modifications include combining and rerouting drain pipe networks so that runoff discharges to areas that are less susceptible to infiltration to the bedrock. Where appropriate, snow berms were identified as a means of redirecting snowbank melt to highway drainage systems that may otherwise infiltrate into the groundwater or drain to adjacent wetland resource areas. Target areas for improvements are summarized below:

- ***Exit 53 Area***: Improvements include two snow berms along interchange ramps and a drainage modification. Project cost estimate: $750,000.
- ***Exit 52 – Silverbrook Road and Titus Lane Areas:*** Two options for combining and rerouting drainage systems along Topsfield Road are presented, including the provision for connecting a new drainage system at the Boxford Depot. Rerouting these flows further downstream will help bypass slower moving open channels over shallow bedrock that are more susceptible to infiltration. Project cost estimate: $1,800,000 - $2,100,000.
- ***Fuller Lane Area:*** To help capture and redirect stormwater and snowmelt off the I-95 overpass at Fuller lane, improvements include a snow berm and drainage modifications, one of which is to a Town drainage system. Project cost estimate: $1,390,000.

Objective: To develop "an alternative means to provide a reliable and adequate safe drinking water supply to the residents located within the I-95 corridor meeting all state and local requirements."

Several water supply alternatives were identified for residents in impacted areas. Community water system options are summarized below followed by a discussion of options for continued individual residential supply.

Options for Community Systems

- ***Exit 53 Area:*** Water service in this area would be provided by a community water system served by new production wells. New Source Approval would be required from the MassDEP including evidence of technical, financial, and managerial capacity by either a new municipal water department, Water District, or private homeowners association for system operations. Additional permits/approvals may be required from federal, state, and/or local agencies depending on the final well location. Project cost estimate: $4,000,000 - $5,000,000.
- ***Exit 52 - Silverbrook Road and Titus Lane Areas:*** The Town of Topsfield has indicated water supply availability to service areas of salt impacted domestic wells in the Silverbrook Road area east of Exit 52 and to extend this service area to the Titus Lane area west of Exit 52. Alternatively, potential groundwater supply testing sites have been identified should there be interest in pursuing a community water system served by new groundwater supply wells in these areas. Such an approach would require establishment of a municipal water department, Water District, or private homeowners association. A community system in either the Silverbrook Road or Titus Lane area served by wells would be similar in cost to that of Exit 53, with similarly applicable permitting

efforts. Project cost estimate for Topsfield connection: $2,600,000 (Silverbrook Road area) - $6,400,000 (Silverbrook Road and Titus Lane areas combined).

- ***Fuller Lane Area:*** If desired, Topsfield water could be extended to a small area of known salt impacted domestic wells on Fuller Lane, just east of I-95. Project cost estimate: $1,000,000.

Options for Continued Residential Supply

- ***Residential Home Treatment Systems:*** Homes with salt impacted wells may elect to install point-of-entry (POE, whole house treatment) or point-of-use (POU, treatment at the faucet) treatment systems. One means of obtaining such a treatment system is via application to the MassDOT Salt Remediation Program assuming acceptance by MassDOT. Estimated costs range from $25,000 - $28,500 for whole house POE systems, and $3,500 for POU systems. Combination units (POE/POU) are about $10,000. The treatment of salt in these systems is accomplished by reverse osmosis, with brine waste to a dry well. These systems require annual maintenance in order to maintain treatment efficiency.

- ***Community Approach to Residential Water Treatment System Operations and Maintenance (O&M):*** Consideration may be given to establishing a "District" or private homeowners association to address annual O&M of home treatment systems. Under this scenario, a group of residents would join together to create a formal entity which could then engage the services of a licensed plumber or certified water system operator to perform vendor recommended maintenance activities on each member's home treatment system. The entity would likely be funded via annual payments by property owners.

- ***Replacement Wells:*** Given the new information of this study relative to the highly fractured nature of the bedrock and the extent of salt concentrations vertically in the bedrock, use of replacement wells to secure a safe drinking water supply for residents should proceed with caution in consideration of site specific geologic characteristics. In cases of declining yield, replacement wells are recommended. Otherwise, home treatment should be considered.

- ***Town Regulation Modification:*** The Town's "Private Water Supply Regulations" (Chapter 202 of the Town Code, Section 202-3E(1)) prohibits water supply wells from being installed in sand and gravel deposits which overlie bedrock. This restriction unnecessarily burdens homeowners who may need a new or replacement well. CDM Smith recommends that the Town regulation be revised to allow sand and gravel wells for domestic water supply purposes.

- ***Public Education:*** Efforts by MassDOT and the Town to educate the public relative to such items as well construction and maintenance, drinking water quality and public health, maintenance of residential water treatment systems, and groundwater quality protection should be continued. These efforts are directed at helping homeowners ensure a safe and adequate drinking water supply.

E.5 Example Implementation Plans

Example implementation plans were developed for the four areas of impact: Exit 53; the Boxford Depot; Exit 52/Titus Lane and Silverbrook Road Areas; and South of Lockwood Lane including Exit 51. Within the example implementation plans for each area are three Plans termed Plan A, Plan B, and Plan C. Plan A includes the least number of items and would be expected to involve the least cost of the three plans while still addressing the most-critical issues. Plan A may be considered to offer some short-term actions while long-term implementation planning proceeds. Items in Plans B and C include additional, more involved and potentially more costly items. For the Boxford Depot, Plan C includes a replacement salt shed to illustrate the associated environmental protections required should a shed be returned to the site.

Each plan includes the following elements:

- Roadway Deicing Materials and Methods
- Approach to Salt Storage and Associated O&M
- Stormwater Drainage Approaches
- Community Water System Approaches
- Residential Water System Approaches
- Remediation Approaches

The plans are meant to illustrate how different measures can be implemented together, however, in practice different measures and combinations may be selected to achieve the objective of reducing impacts of salt and deicing chemicals on area domestic wells and providing alternative water supply options.

The example plans are presented in Section 6 of the report.

E.6 Concluding Remarks

A number of strategies and improvements have been identified to reduce future impacts to groundwater from deicing materials, and to identify alternative water supply sources for residents whose domestic wells have been impacted.

Implementation of improvements could proceed in a phased approach starting with some short-term measures such as MassDOT and the Town adopting the recommended deicing practices, developing a monitoring program to track water quality trends at impacted wells for signs of water quality improvement, and evaluating the effectiveness of Scavenger Well #3 operations. While these measures are being implemented, a more comprehensive and holistic approach to improving groundwater quality and providing safe drinking water to residents based on the Example Implementation Plans can be developed. A key success factor with these more extensive plans is collaboration between MassDOT and the Town. Working together, both entities can develop long-term capital improvement plans that complement each other but also take into consideration the important mission of maintaining safe roadways for the traveling public.

Section 1

Introduction

In 2012, CDM Smith Inc. (CDM Smith) was retained by the Massachusetts Department of Transportation (MassDOT) to perform the Boxford Salt Study (the Study), MassDOT Contract #71869.

The Study is a requirement of the Commonwealth of Massachusetts *Chapter 199 of the Acts of 2010, An Act to Conduct a Study of Chemicals Infiltrating Aquifers and Bedrock Fissures Along the Interstate 95 Corridor* (approved July 30, 2010). Subsequently, *Chapter 239 of the Acts of 2012, Section 57* modified the original Legislation to require: (1) an Interim Report which was submitted by CDM Smith on July 31, 2013, and (2) an extension of the final report submission date to July 31, 2014. Copies of the Legislation and Interim Report are attached in **Appendix A** for reference.

Specific objectives of the Study cited in the Legislation include:

- "To determine the cumulative and immediate effects of deicing chemical storage and deicing operations on the groundwater aquifers and bedrock fissures within the I-95 corridor."
- To determine "the proximate causes of deicing chemicals, including sodium and chloride infiltration into the groundwater aquifers and bedrock fissures within the I-95 corridor."
- To determine "what measures need to be taken to prevent [infiltration of deicing chemicals to groundwater aquifers and bedrock fissures] from occurring in the future."
- To develop recommendations for "short-term and long-term remedial actions necessary to restore groundwater quality to a safe drinking water standard within the I-95 corridor."
- To develop "a plan to modify highway drainage systems to prevent stormwater run-off and highway drainage from adversely impacting aquifers, bedrock and adjacent wetland resource areas."
- To develop "an alternative means to provide a reliable and adequate safe drinking water supply to the residents located within the I-95 corridor meeting all state and local requirements."

The Boxford Task Force, a three-member committee appointed by the Town of Boxford (the Town), has been participating in the Study in an advisory role, as required by the Legislation.

I-95N, Exit 52 (Source: MassDOT)

1.0 Organization of Report

This report presents the findings, conclusions, and recommendations of the Boxford Salt Study. Each section of the report presents the following key elements of the Study:

Section 1 - Introduction – This section introduces the project relative to the Study's objectives, describes the Study Area, provides background relative to the presence of salt constituents in groundwater and related drinking water standards, and presents the Study approach.

Section 2 - History of Operations and Mitigation Measures within the Study Area – A timeline presents the history of operations and mitigation measures relative to roadway deicing for MassDOT and the Town. Details are provided of the deicing operations and stormwater drainage systems for both MassDOT and the Town, as well as mitigation measures undertaken by each party.

Section 3 - Boxford Salt Study Field Programs - Data Collection and Presentation – This section describes the field programs performed by CDM Smith. The objective of each field program relative to data collection and program approach is presented, along with an interpretation of results.

Section 4 - Study Area Conceptual Model – Based on historical data and the field programs, a conceptual model has been developed of the Study Area relative to sources and flowpaths of deicing constituents. The conceptual model is built upon an understanding of area geology; surface water hydrology and roadway drainage systems; historical and recent surface water and groundwater quality data; and known deicing practices and materials storage.

Section 5 - Analysis of Alternatives – An evaluation of alternatives is presented in Section 5. These alternatives focus on reducing the impacts of deicing constituents on area domestic wells. The alternatives analysis includes the identification of potentially applicable technologies and mitigation approaches, screening of the identified technologies and approaches, focused evaluation, and the development of recommendations.

Section 6 - Summary of Study Findings and Implementation Planning – A summary of the Study's findings is presented in Section 6, including possible implementation plans based on recommendations of the alternatives analysis.

Section 7 - References – This section contains a list of references used throughout the report.

Appendices – Appendices are included to supplement the information presented in this report.

1.1 Study Area and Background

Residents of the Town obtain their drinking water from individual domestic wells or small community water supply systems served by wells, as there is no municipal water system in Boxford. Since the late 1980s, some residents living along the Interstate 95 (I-95) corridor in Boxford have noted increased salt concentrations in their well water. Potential causes have been attributed to MassDOT's deicing operations along I-95 as well as the MassDOT Salt Shed located at 100 Topsfield Road in Boxford which operated from 1974 to June 2009. The MassDOT Salt Shed, also referred to as the Boxford Depot, historically stored sand and salt for loading onto contract vehicles at the site. These materials were used as part of MassDOT's I-95 winter deicing program for the Boxford Depot Service Area. The following provides a description of the I-95 corridor in Boxford and the Boxford Depot.

1.1.1 I-95 Corridor in Boxford

The I-95 corridor, identified herein as "the Study Area", is defined in the Legislation as that area within the municipal limits of the Town of Boxford that lies within 1,500 feet from any portion of I-95. **Figure 1-1** shows the limits of the Study Area which is approximately 2.7 square miles in size, with boundaries described as follows:

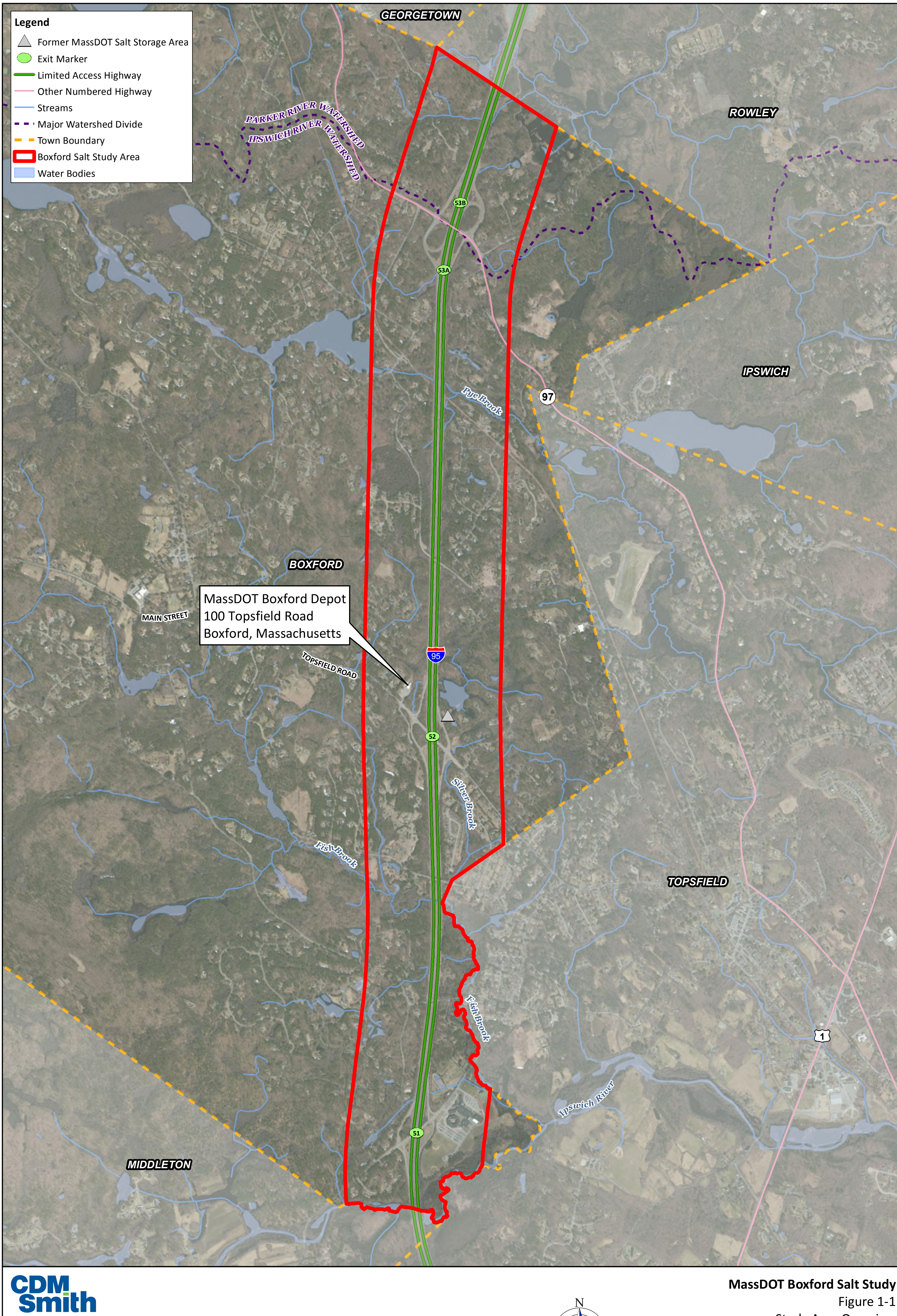
- ***North***: The northern limit of the Study Area is the Boxford municipal boundary with Rowley.
- ***South***: The southern limit of the Study Area is the Boxford municipal boundary with Middleton and Topsfield. These townlines coincide with the Ipswich River at this location.
- ***West***: The entire western edge of the Study Area is based on the 1,500 foot distance from the southbound lanes of I-95.
- ***East***: The eastern limit of the Study Area is predominantly based on the 1,500 foot distance from the northbound lanes of I-95, except for the area in which the Boxford/Topsfield municipal boundary is less than 1,500 feet from I-95. Much of the municipal boundary in this area coincides with Fish Brook.

I-95 within the Study Area includes 4.9 linear-miles comprised of an eight-lane, north-south interstate highway, with four lanes and a breakdown lane in each direction. There are also three interchanges within the Study Area along I-95: Exit 51 to the south, Exit 52 in the middle and Exit 53 to the north.

I-95 (Source: MassDOT)

Land use in the Study Area is predominantly single-family residential, with approximately 440 homes. Many of the residential lots are multiple acres in size and include wooded areas. Based on a review of the 2008 Town of Boxford Open Space and Recreation Plan, most land area within the Study Area is developed, with the exception of wetlands, state forest, and municipal owned properties. Approximately 1,000 feet southeast of Exit 53, the Study Area includes a small portion of Cleaveland Farm State Forest which extends well beyond the Study Area boundary within Boxford. To the south, Masconomet Regional High School (MASCO) is located east of Exit 51. Water supply to MASCO is provided by the Town of Topsfield.

The Town of Boxford reports that there are approximately 27 lane-miles of town roads within the Study Area. The Town is responsible for snow removal and deicing of town roads.



CDM Smith

Source: MassGIS, CDM Smith

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

0 1,000 2,000 3,000 4,000 Feet

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MassDOT Boxford Salt Study

Figure 1-1

Study Area Overview

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The Study Area includes portions of two primary watershed areas. The Parker River Watershed extends from approximately Exit 53 north. The Ipswich River Watershed comprises the remainder of the Study Area, inclusive of four sub-drainage basins, one draining directly to the Ipswich River itself and three draining to smaller tributary brooks that flow through the Study Area and join the Ipswich River downstream. These brooks, from north to south, are Pye Brook, Silver Brook, and Fish Brook. Silver Brook flows into Fish Brook, which enters the Ipswich River east of the Study Area limits. Pye Brook eventually flows into Howlett Brook, which enters the Ipswich River farther east of the Study Area in Topsfield.

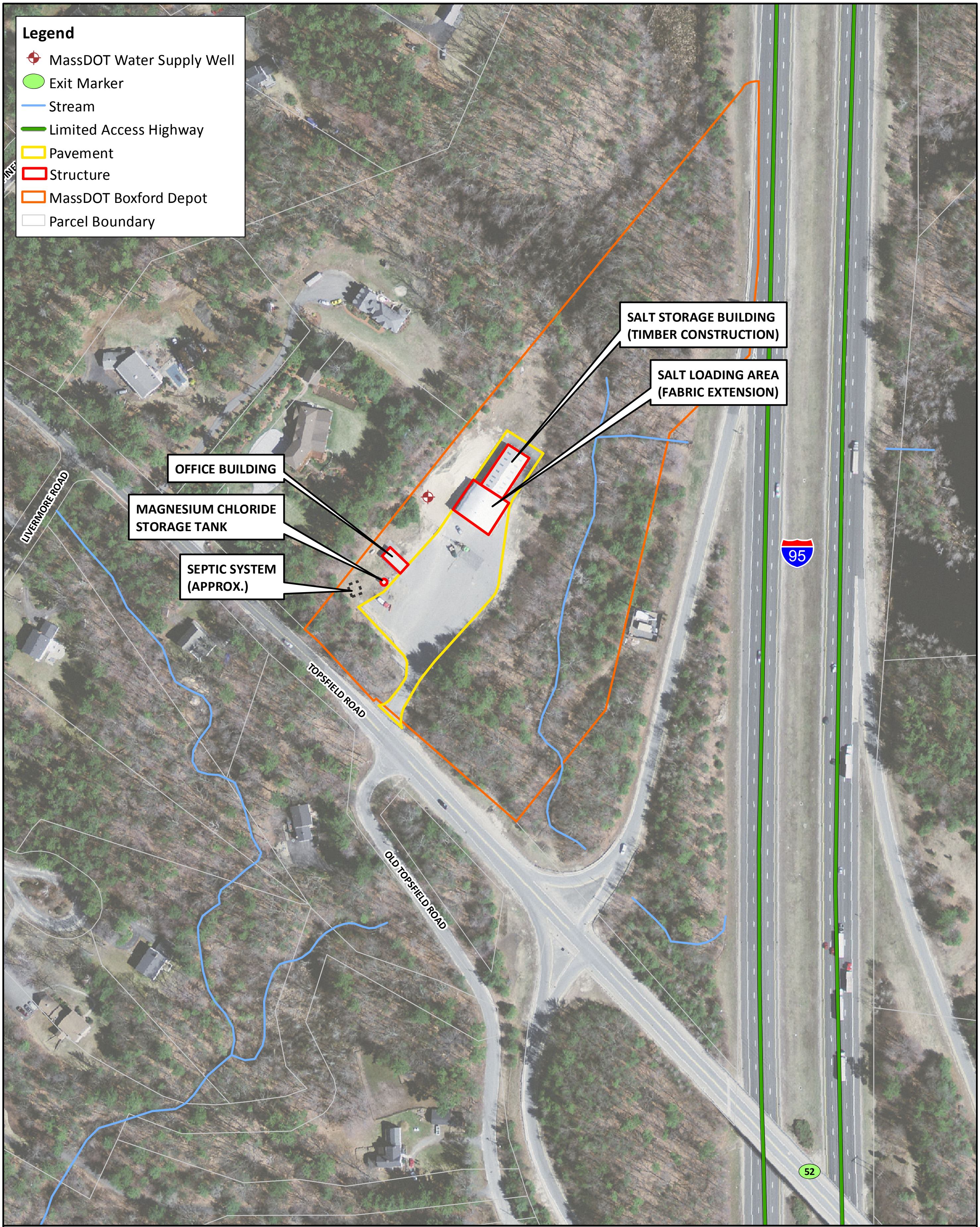
Pye Brook East of I-95

1.1.2 The Boxford Depot

The MassDOT Boxford Depot is located northwest of the Exit 52 interchange at 100 Topsfield Road. The Boxford Depot inclusive of the salt shed and surroundings are shown on **Figure 1-2**. Residences are located west and south of the Boxford Depot property, while land immediately north and east of the shed is undeveloped and wetland. Farther east of the Boxford Depot is a cell tower and the I-95 southbound Exit 52 ramp. Facilities on the Boxford Depot property include:

Boxford Depot Property
100 Topsfield Road, Boxford, Massachusetts

- The salt storage building and extension which provided cover for salt handling and loading onto vehicles.
- The paved area in front of the shed for vehicle access and operations from Topsfield Road.
- A 5,000 gallon storage tank for magnesium chloride ($MgCl_2$), which is a liquid deicing material. Although sand and salt loading operations ceased in June 2009, $MgCl_2$ continues to be stored at the Boxford Depot for use in anti-icing/deicing operations.
- An office building for site management personnel responsible for deicing operations of the Boxford Depot Service Area which includes 7.1 linear miles of I-95. The office building is served by an on-site septic system.
- A water supply well to serve the office building. This well also serves as a scavenger (extraction) well that pumps salt-impacted groundwater from the bedrock, discharging to a nearby stream.



CDM Smith

MassDOT Boxford Salt Study

Figure 1-2

MassDOT Boxford Depot and Surroundings

0 100 200 300 Feet

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Source: MassGIS, CDM Smith

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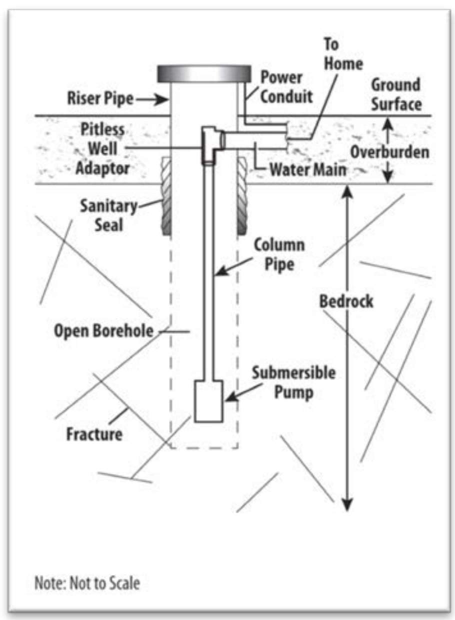
MassDOT initiated use of the Boxford Depot in 1974, following reconstruction of I-95 in the same year. Prior to that, MassDOT operated an unlined and uncovered salt storage area east of Exit 52 (see location on **Figure 1-1**). While this land is still owned by MassDOT, it is no longer in active use by MassDOT. In fact, the land is now grass fields and woods with adjacent wetland. A portion of that property now includes the I-95 northbound Exit 52 on-ramp.

1.1.3 Background - Domestic Wells and Drinking Water Quality

Boxford residents along the I-95 corridor have expressed concern regarding the presence of road salt constituents in their domestic well water. Road salt commonly dissolves in water releasing the constituents sodium (Na) and chloride (Cl). Sodium concentrations in water may be of concern to individuals on a sodium restricted diet. Chloride in sufficient concentration can lead to accelerated corrosion of home copper plumbing systems and household appliances, but the rate and extensiveness of corrosion is dependent on a host of water quality characteristics. These concerns related to sodium and chloride have resulted in some residents requesting entry into the MassDOT Salt Remediation Program.

Typical Domestic Well Head

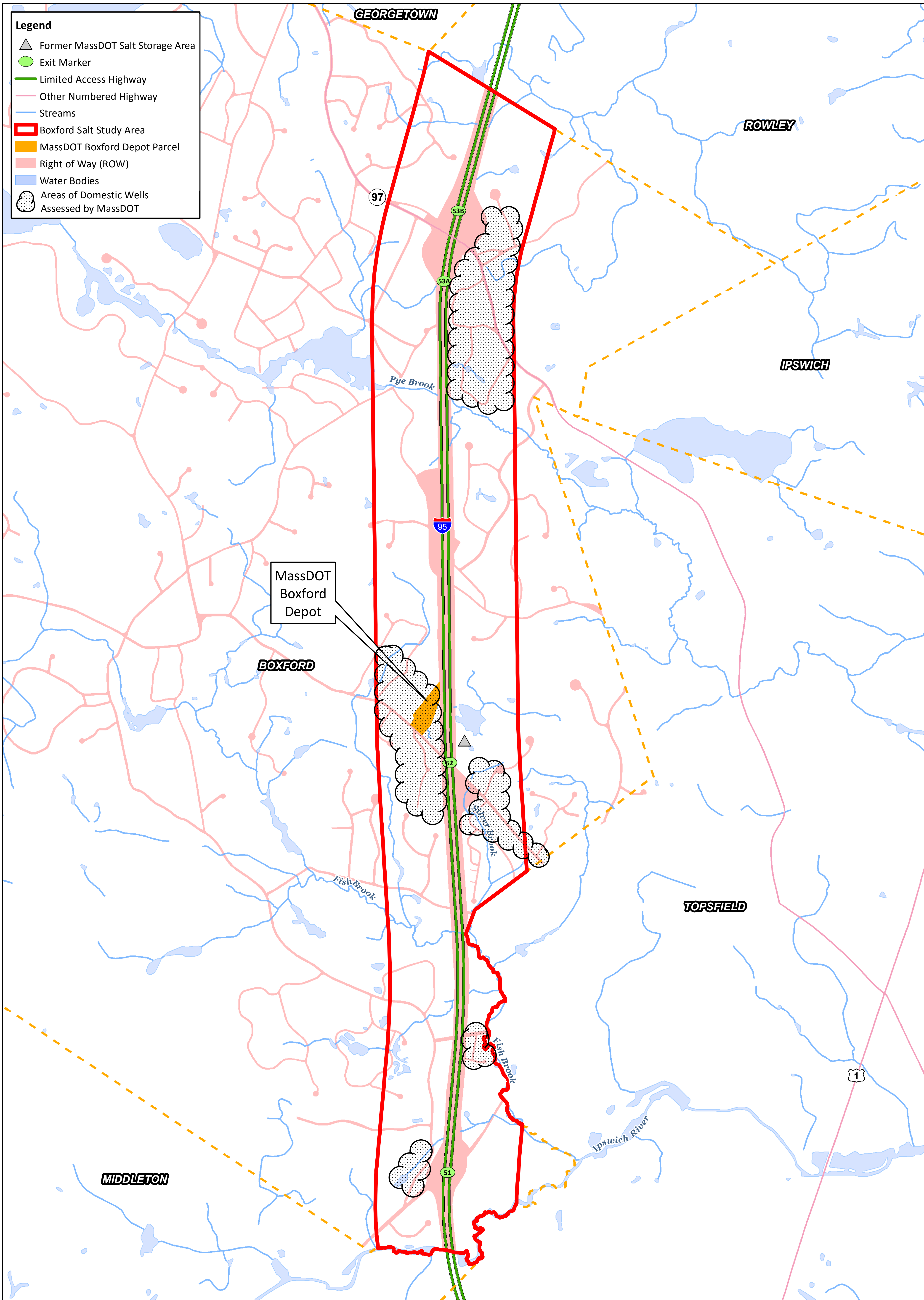
This program was established in 1986 by MassHighway (subsequently MassDOT) to address the impacts associated with winter deicing activities performed on state roads in the Commonwealth of Massachusetts. The Salt Remediation Program was specifically developed to investigate salt impacts on privately-owned wells, and remediate them where necessary. Typically, remediation includes such actions as providing replacement wells or treatment systems. Further details of the Program are provided in **Section 2.4.**



Cross-Section Schematic of Typical Domestic Bedrock Well

Based on records of the MassDOT Salt Remediation Program, **Figure 1-3** shows those areas where domestic wells have been evaluated for impacts from salt. This includes areas east of the Exit 53 northbound on-ramp (north of Rowley Road and Killam Hill Road) and southeast of Exit 53 (from Killam Hill Road south to Pye Brook). Also included are areas in the vicinity of Exit 52 including the Titus Lane area south of the Boxford Depot and the Silverbrook Road area southeast of Exit 52. Two smaller areas located in the southern portion of the Study Area adjacent to Fuller Lane and Middleton Road near Exit 51 are included as well.

Domestic wells in the Study Area are predominantly installed in bedrock, with only a small number of sand and gravel wells known to be present. Bedrock well depths range from less than 100 feet to more than 1,000 feet below ground surface throughout the Study Area.



CDM Smith

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MassDOT Boxford Salt Study

Figure 1-3

Areas of Domestic Wells within the Study Area Assessed by the MassDOT Salt Remediation Program

Source: MassGIS, CDM Smith

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Reported sodium and chloride concentrations in groundwater of the Study Area have ranged from 8 mg/L to 1,200 mg/L and 19 mg/L to 2,300 mg/L, respectively. Background unimpacted sodium and chloride groundwater concentrations in the Study Area are typically less than 50 mg/L (Baker and Sammel, 1962).

1.1.4 Drinking Water Guidelines for Sodium and Chloride

The Environmental Protection Agency (EPA), as required by the Safe Drinking Water Act (SDWA) and its amendments, sets water quality standards for elements and compounds that pose a direct health risk to the consumer (e.g. cancer causing) when water is consumed in typical amounts. These primary standards are referred to as Maximum Contaminant Levels or MCLs. The EPA also sets non-enforceable Secondary Maximum Contaminant Levels (SMCL) for select compounds and elements. The SMCLs are established for aesthetic, cosmetic, or technical reasons as there is no direct risk to consumer health. State agencies that have primacy to manage the SDWA, such as the Massachusetts Department of Environmental Protection (MassDEP), can elect to make standards more stringent if the science supports the action.

There is no health-based drinking water MCL set by either the EPA or MassDEP for sodium or chloride. Nevertheless, EPA recommends that sodium in drinking water not exceed 20 milligrams per liter (mg/L) which is intended to be protective of individuals on a sodium-restricted diet (U.S. EPA, 2003). MassDEP has established an Office of Research and Standards Guideline (ORSG) for sodium of 20 mg/L. The ORSG is not a health based concentration but rather is based on the U.S. Food and Drug Administration's approach to labeling bottled water with regard to sodium content (MassDEP, 2013). When exceeded, the ORSG of 20 mg/L for sodium does not require treatment, however sodium sensitive individuals should be aware of such concentrations[1].

Chloride has a SMCL of 250 mg/L in drinking water (MassDEP, 2012), established in consideration of its aesthetic and technical effects. Aesthetically, some individuals may experience a salty taste when chloride concentrations exceed 250 mg/L. Technically, chloride in sufficient concentrations can lead to the corrosion of home piping systems and household appliances, dependent upon the associated water quality characteristics such as hardness, high pH and sulfate concentrations.

1.2 Study Approach

Given the technical challenges associated with assessing the cause and effect of deicing constituents in bedrock groundwater and recognizing the Study's objective that engineering solutions be identified, the project has included the following three elements:

- ***A hydrogeologic assessment*** to assess the source and extent of groundwater impacts from deicing chemicals based on geology, hydrology, and water quality data in the Study Area. The assessment approach included data collection and review, development of a conceptual hydrogeologic model (which is an understanding of how water and deicing constituents move through the Study Area), field program implementation, and analyses to refine the conceptual model.

[1] MassDEP. Sodium Fact Sheet. 2006. Web. <www.mass.gov/eea/docs/dep/water/drinking/alpha/i-thru-z/sodguide.pdf>

- ***An alternatives analysis*** to identify and evaluate potentially applicable technologies and mitigation measures needed to address impacts from deicing operations and salt storage/handling, with the intent of improving groundwater quality and providing safe drinking water to Study Area residents. Six broad categories of alternatives were identified for evaluation:

Typical I-95 Drainage Outlet

  - Alternative materials and methods to improve the roadway deicing programs of MassDOT and the Town of Boxford.
  - Improvements to the MassDOT Boxford Depot and associated operations and maintenance (O&M) procedures.
  - Stormwater drainage system improvements, particularly along I-95.
  - Water supply options to provide safe drinking water to area residents.
  - Residential water supply options such as home treatment and replacement wells to better ensure safe drinking water.
  - Remediation as a means of potentially improving groundwater quality.

- ***Reporting*** which included progress reports describing project status, such as the Interim Report submitted in July 2013, as well as this Final Report presenting findings of the hydrogeologic assessment and recommendations of the alternatives analysis.

Section 2

History of Operations and Mitigation Measures within the Study Area

To obtain a complete understanding of the hydrogeology, water quality, and engineered drainage systems as they relate to salt storage and deicing operations within the Study Area, a thorough data collection and review process was undertaken including interviews, on-line searches, file reviews, and literature searches. A summary tabulation of historical data collected by source, type, and date range is provided in Appendix A. Primary data sources were the Massachusetts Department of Transportation (MassDOT), the Town of Boxford (the Town) and the Massachusetts Department of Environmental Protection (MassDEP). Key types of data collected included:

- ***Well completion reports*** – Approximately 500 well completion reports were collected for the Study Area including domestic wells, community wells, test wells, replacement wells, monitoring wells, and United States Geological Survey (USGS) observation wells. These reports provided such information as overburden stratigraphy, bedrock type, depth to bedrock, groundwater level, and pump test yields. Collection and review of this data was the first step in developing the conceptual hydrogeological model of the Study Area.

- ***Water quality data*** – Groundwater, stormwater, and surface water quality data from the MassDOT Salt Remediation Program were compiled and included data from the University of Massachusetts (UMass) Amherst, Town files, the Masconomet Regional School District (MASCO), MassDEP files, and area residents.

Boxford Depot – Aerial View

- ***Engineering plans*** – Historic highway and salt shed design plans, stormwater drainage plans, Boxford subdivision plans, and other such documents were collected and reviewed to develop an understanding of man-made features which may have bearing on the cause of salt constituents in groundwater.

- ***Deicing operations*** – Deicing materials and operations data were collected from MassDOT and the Town to both assess deicing material loading within the Study Area and help in the evaluation of possible improvements.

- ***Available mapping*** – Available maps from Massachusetts Geographic Information Systems (MassGIS), USGS, MassDOT, and MassDEP were gathered and compiled. Together, these provided the basis for development of a comprehensive project mapping and geo-database.

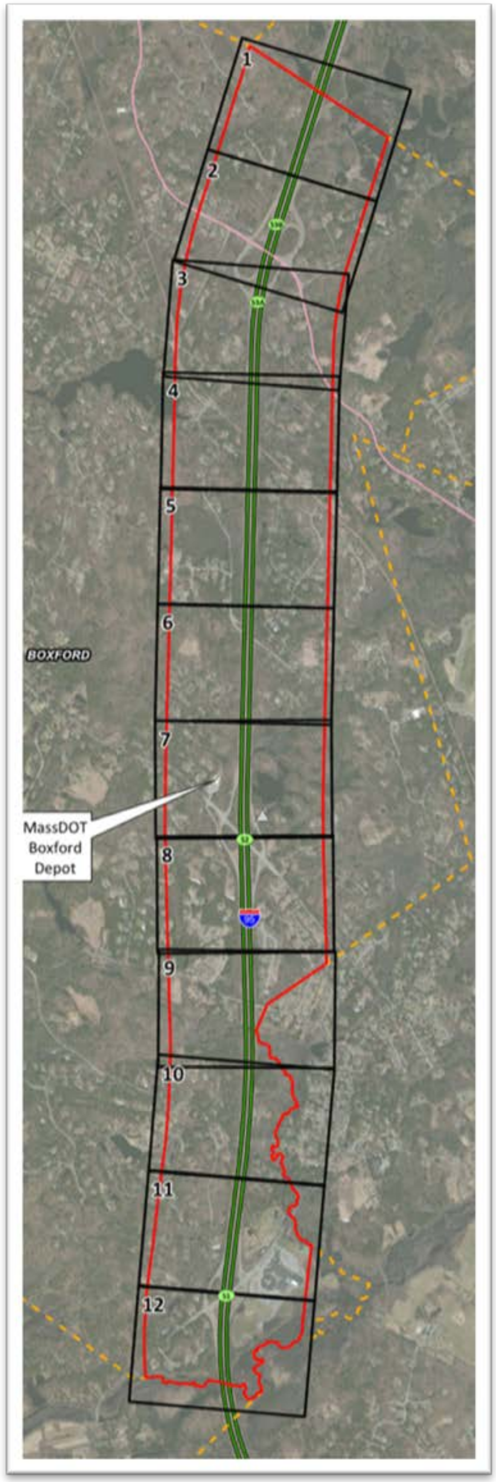
Data mapping of the project area was performed using Geographic Information Systems (GIS). Given the size of the Study Area, a series of twelve adjoining map panels (numbered 1-to-12 from north to south) were developed and are included in **Appendix B**.

2.1 Historical Timeline

Figure 2-1 is a timeline relative to I-95 construction, salt storage, and deicing operations in the Study Area, as well as a chronology of mitigation measures implemented to address issues related to road salt impacts on private wells. The timeline begins in the early 1970s, when I-95 was widened from three to four lanes (1974). This date also corresponds to the construction and activation of the MassDOT Boxford Depot located at 100 Topsfield Road to service the newly expanded highway. At the same time, the former salt storage area located east of the I-95 Exit 52 interchange (see Map Panel 7 in **Appendix B**) ceased operation and was abandoned. That uncovered and unlined salt storage area dated back to the 1950s and operated in conjunction with a former MassDOT maintenance area at the same location.

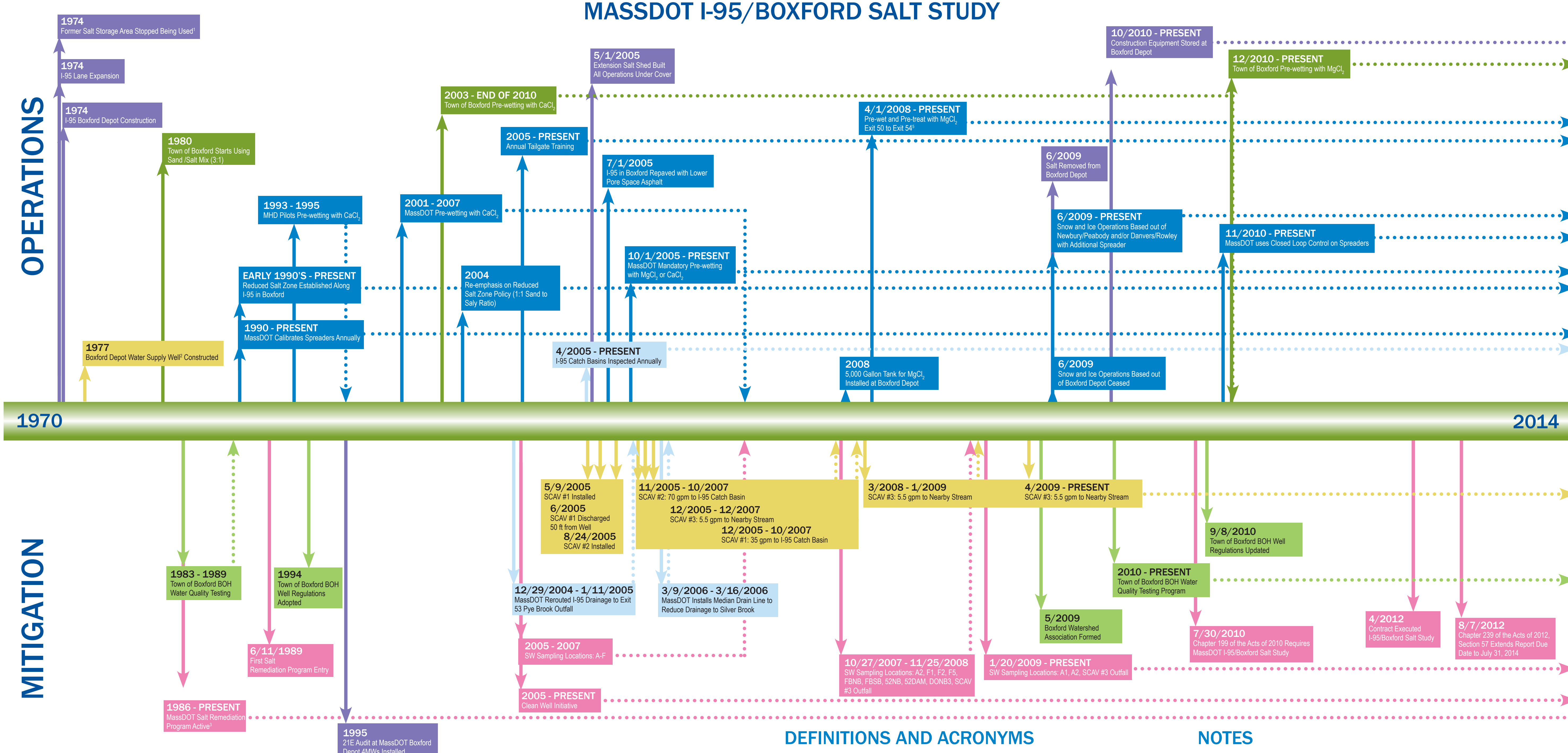
From the period 1970 to the present, the historical timeline presents MassDOT operations relative to salt storage, deicing practices, and drainage maintenance for I-95 in Boxford. Deicing practices by the Town are also shown for this same time period. Operations measures are presented above the timeline using a color coding system to distinguish between the type of operation and responsible party (i.e., MassDOT or the Town). Mitigation measures undertaken by MassDOT and the Town are presented below the timeline on **Figure 2-1**, and are color coded by mitigation type and responsible party.

Several key operational and mitigation events important to the Study are introduced below, and discussed in greater detail later in this section.



Map Panel Index (see Appendix B)

HISTORY OF OPERATIONS AND MITIGATION MEASURES
MASSDOT I-95/BOXFORD SALT STUDY



KEY

MassDOT Salt Shed Operations	MassDOT I-95 Drainage Improvements	MassDOT Scavenger Wells	Boxford BOH Private Wells
MassDOT Salting/Deicing	MassDOT Salt Remediation Program	Boxford Salting/Deicing	

SCAVENGER WELL LOCATIONS

SCAV #1: Silverbrook Road

SCAV #2: Titus Lane

SCAV #3: MassDOT Boxford Depot

DEFINITIONS AND ACRONYMS

BOH:	Board of Health
$CaCl_2$:	Calcium Chloride
Closed Loop:	Control system installed on spreaders to match deicing chemical application based on speed of the spreaders
gpm:	gallons per minute
MassDOT:	Massachusetts Department of Transportation
$MgCl_2$:	Magnesium Chloride
MW:	Monitoring Wells
Pre-treating:	Wetting roads before winter storm with liquid $MgCl_2$ or $CaCl_2$
Pre-wetting:	Wetting sand/salt mix with liquid $MgCl_2$ or $CaCl_2$
SCAV:	Scavenger Well
Spreaders:	Trucks spreading sand/salt mix and liquid $MgCl_2$ or $CaCl_2$ on roads
SW:	Surface Water

NOTES

1 Unlined, uncovered salt storage began in the 1950s, east of I-95 at Exit 52

2 Boxford Depot Supply Well is the same well as SCAV #3

3 Entries into Salt Remediation Program investigated by MassDOT with replacement supply and/or treatment where warranted

4 Catch basins inspected every year and cleaned if needed

5 Pre-treatment performed when conditions and resources allow (not every snow/ice event)

2.1.1 Historic Operational Items Important to the Study

The following identifies key historic operational items related to deicing and salt storage within the Study Area:

- ***MassDOT Deicing Methods and Equipment:*** Since the early 1990s, MassDOT has continually worked to assess methods and equipment to improve deicing operations in the Study Area. Several operational changes dating as far back as 1993 are identified on the timeline including use of deicing chemicals for pre-wetting and roadway pre-treatment to reduce the quantity of salt used.

- ***Reduced Salt Zone (RSZ):*** In 1986, there was increased awareness regarding the impact of road salt on water supply sources which subsequently resulted in the establishment of the MassDOT Salt Remediation Program Standard Operating Procedure (SOP). Over the years, MassDOT continued to re-evaluate its approach to deicing, particularly in areas where water supply protection was of concern. The Boxford Depot Service Area was designated as an RSZ in the early 1990s and in 2004 renewed attention was afforded to the Boxford RSZ to adhere to a 1:1 sand to salt ratio in an effort to reduce salt impacts to area domestic wells. However, if roadway safety becomes a concern during a winter storm, straight salt may be used within a RSZ at the discretion of the area foreman.

- ***Salt Shed Extension:*** In 2005, MassDOT added an extension to the salt shed at the Boxford Depot that allowed salt handling and loading operations to be conducted under cover, thereby reducing the contributions of salt released to the environment at the site. Prior to that date, handling (delivery, mixing, and all spreader loading) was conducted in the open. Note that salt storage has always been under cover at this location. The Boxford Depot's layout and features, including the extension, are shown in **Figure 2-2**.

Boxford Depot – Salt Shed Extension

- ***Shutdown of the Boxford Depot:*** In June 2009, the MassDOT Boxford Depot was closed to salt storage. Since shut down of the Salt Shed, the only operations have been sand storage and liquid deicing chemical storage (magnesium chloride). MassDOT has since been running deicing operations for the Boxford Depot Service Area out of other facilities, including the Rowley, Newbury, and Peabody Depots. MassDOT has added a fifth spreader to the Boxford Depot Service Area during larger storm events, as the increased drive time during more severe storms coupled with more rapidly deteriorating road conditions requires an additional vehicle to help prevent time gaps in deicing coverage.

- ***Town Deicing Operations:*** Since the 1980s, the Town reports treating town roads with a sand/salt mix. Since 2003, the Town has used liquid agents for pre-wetting to help improve winter treatment of roadways. This operational change coincided with increased awareness of salt impacts on water supply sources.


Legend
MassDOT Scavenger Well
Soil Borings
Scavenger Well Discharge Point
MassDOT Monitoring Well
MassDOT Monitoring Station
Flow Arrow
Catchbasin
Outlet
Closed Drainage Pipe
Open Drainage Ditch
Scavenger Well Discharge Pipe
Stream
Topographic Contour (feet-MSL)
Paved Area
Structure
MassDOT Salt Shed Parcel
WS-4
TW-1
A1/West Branch
A2/East Branch
MHD-SB
A3
SCAVENGER WELL DISCHARGE
MDOT-SB-4
SALT STORAGE BUILDING (TIMBER CONSTRUCTION)
SALT DELIVERY/LOADING AREA (FABRIC EXTENSION)
SCAVENGER WELL DISCHARGE PIPE
SCAVENGER WELL # 3
MDOT-SB-3
WS-3
MDOT-SB-5
WS-2
OFFICE BUILDING
MDOT-SB-2
WS-1
MAGNESIUM CHLORIDE STORAGE TANK
Boring MW-D
SEPTIC SYSTEM (APPROX.)
MDOT-SB-6
MDOT-SB-1
POINT OF EXIT FOR PAVED AREA RUNOFF
A4/Cell Tower Culvert West
PONDING AREA
MDOT-MW-5
CDM Smith
Source: MassGIS, CDM Smith
0 25 50 75 100 Feet
N
MassDOT Boxford Salt Study
Figure 2-2
MassDOT Boxford Depot Layout
billingsmc Z:\Boxford\MXD\Fig2_2_SaltShed_Layout_copy.mxd 8/26/2014

2.1.2 Historic Mitigation Measures Important to the Study

The following identifies key mitigation measures implemented within the Study Area relative to road salt impacts on domestic wells:

- ***MassDOT Salt Remediation Program:*** In 1986, MassDOT established the Salt Remediation Program. This program allows private well owners impacted by MassDOT road salt operations to apply for and if qualified receive assistance for addressing elevated sodium and chloride concentrations in their domestic water supply. The Program is available to private well owners throughout the Commonwealth of Massachusetts and remains in effect today. Since 1989, MassDOT has performed assessments on forty-eight domestic well supplies within the Study Area.

- ***MassDOT Clean Well Initiative:*** In 2005, MassDOT established the Clean Well Initiative, a state-wide program focusing on the advancement of anti-icing strategies to preserve environmentally sensitive areas, protect domestic wells and reduce the likelihood of additional salt complaints. This effort included but was not limited to: assessment of salt storage facilities (repair or structure replacement where necessary), training, continued use of designated RSZs where appropriate, pre-wetting, and pre-treatment. MassDOT continues to explore and study the feasibility of cost-effective deicing materials, technology, and Best Management Practices (BMPs) to further reduce salt impacts from winter snow and ice operations.

- ***MassDOT Surface Water Quality Sampling:*** UMass Amherst, under contract with MassDOT, has conducted surface water quality sampling in the Study Area since 2005.

- ***MassDOT Scavenger Wells:*** In 2005, MassDOT initiated operation of three Scavenger Wells in the Study Area, one of which continues to operate today. The Scavenger Well operations included continuous groundwater pumping with discharge to either local streams or the I-95 stormwater drainage system, with no treatment. The objective of these operations has been to provide localized remediation of high salt concentrations in groundwater via mass removal of road salt constituents, to limit the further spread of road salt constituents in the bedrock groundwater, and to provide water quality improvement to nearby impacted domestic wells.

- ***MassDOT Stormwater Drainage Improvements:*** In 2005 and 2006, MassDOT implemented two stormwater drainage system improvements along I-95 in the Study Area to redirect highway drainage away from swales along the roadway to area streams via closed drainage systems. Stormwater drainage improvements are shown in Drainage Area Map Panels located in **Appendix C**

- ***Town Board of Health Activities:*** Since the early 1980s, the Town, acting through its Board of Health (BOH), has taken an active role in helping residents understand domestic well water quality issues and has implemented private water supply regulations and guidelines directed at helping protect domestic water supplies. In addition, there were several time periods during which the BOH facilitated domestic well water quality testing on behalf of residents.

- ***Boxford Watershed Association:*** In 2009, Boxford residents in the vicinity of I-95 privately formed the Boxford Watershed Association. Its charge per the Articles of Organization[1] is to promote public education and awareness regarding the health risks and impacts of road salt on domestic wells along the I-95 corridor in Boxford as well as promote efforts for resolution of these impacts so as to improve and protect drinking water supplies.

2.2 Deicing Operations and Material Storage

This section provides an overview of the materials and methods used by MassDOT and the Town for deicing, including material storage, handling, and application.

For the purposes of this study, the following definitions apply:

- ***Deicing materials,*** which are the active chemical agents applied to roadway surfaces. These include road salt which in the Study Area is sodium chloride (NaCl), as well as liquid deicing agents such as calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$). Deicing materials do not include sand which is an abrasive used to provide traction at lower speeds of travel.

- ***Pre-mixed material***, used by MassDOT only, is used in place of NaCl, though very rarely. It combines four parts by weight NaCl with one part by weight solid $CaCl_2$ and is used to reduce sodium in the RSZs. Pre-mixed material does not include sand. Pre-mix has never been stored or loaded at the Boxford Depot, though it has been applied in the Boxford Depot Service Area on rare occasions by spreaders based out of other Depots..

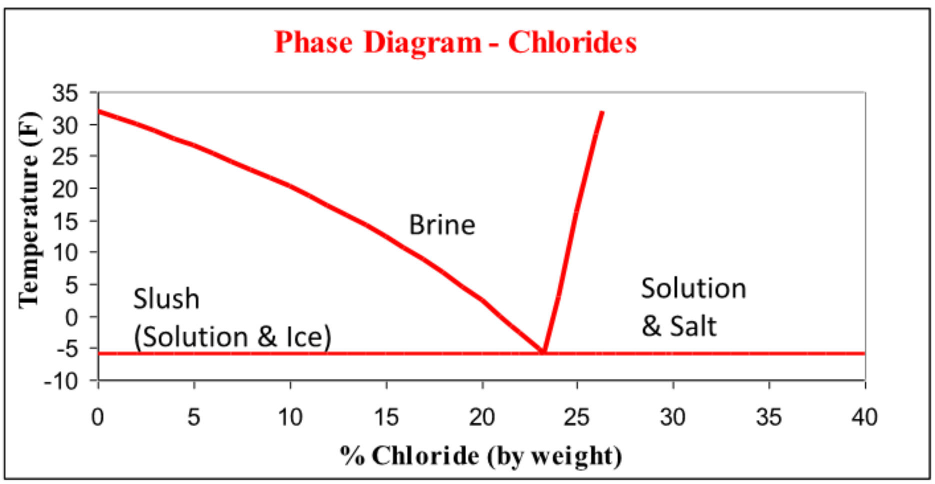
- ***Roadway Pre-treatment***, performed by MassDOT only, is a process whereby the roadway surface is treated with a liquid deicing material (for example $MgCl_2$ or $CaCl_2$) in advance of a storm event. Pre-treatment, also known as anti-icing, prevents ice and snow pack from forming thereby lessening the amount of NaCl subsequently needed to achieve bare pavement. MassDOT currently uses $MgCl_2$ for pre-treatment within the Boxford Depot Service Area. MassDOT no longer pre-treats with $CaCl_2$ and hasn't used it in the Boxford Depot Service Area since 2010. Although $CaCl_2$ has some deicing advantages, its disadvantages are significant as it is more costly, harder to obtain, and more corrosive thereby requiring a corrosion inhibitor. Pre-treatment is only an option when pavement temperatures are between approximately 20 and 32° F. At pavement temperatures below 20° F the material can freeze; at pavement or air temperatures above 32° F there is potential for rain or melting which would carry the material off the road surface. The properties of $MgCl_2$ or $CaCl_2$ can also make roads slick when applied at warmer temperatures. Pre-treatment is only conducted along the mainline of I-95 in the Boxford Depot Service Area.

Tanker Truck Performing a Pre-treatment Application
(Source: MassDOT)

[1] Boxford Watershed Association. Articles of Organization; filed with the Secretary of the Commonwealth of Massachusetts. Web. May 27, 2009. <corp.sec.state.ma.us/CorpWeb/CorpSearch/CorpSummary.aspx?FEIN=001003789&SEARCH_TYPE=1>

- ***Pre-wetting***, performed by both MassDOT and the Town, is an on-board process whereby the solid deicing agent (NaCl) and sand are sprayed with a liquid deicing agent (for example $MgCl_2$ or $CaCl_2$) as the solids are deposited on the roadway. Both parties use $MgCl_2$ for pre-wetting. MassDOT has selected $MgCl_2$ as its preferred deicing agent for pre-treatment and pre-wetting. Pre-wetting accelerates the process by which rock salt becomes brine, thereby improving its deicing effectiveness and helps to reduce the amount of salt lost from the roadway due to bounce, scatter, and wind. Through this process, pre-wetting agents help reduce the overall quantity of salt applied during a storm event. Pre-wetting may be performed at any temperature.

The lowest point at which a chemical suppresses freezing depends on temperature and concentration. The phase diagram below for salt solution or brine, shows the temperature at which various concentrations stop thawing or change "phase" for salt. At 20° F, salt will melt ice at an 11% solution. At 10° F, it must be at 18% solution. The freezing point continues to decrease with higher concentrations until the maximum freezing point, or "eutectic" point, is reached. Salt brine stops working at about -6° F and 23% concentration (23% salt, 77% water by weight).



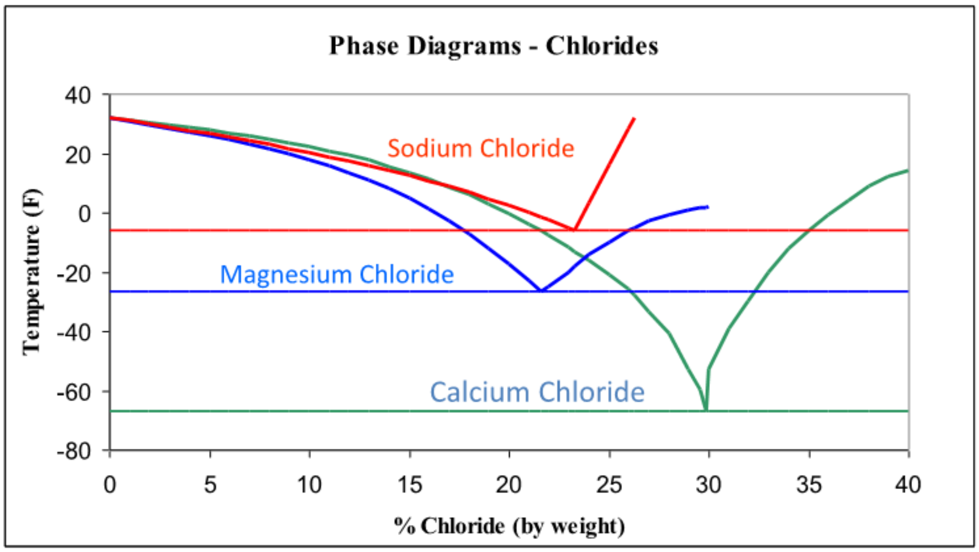
From: Minsk, David. *Snow and Ice Control Manual for Transportation Facilities.* L., McGraw Hill, 1998, ISBN 0-07-042809-3.

Notice that at concentrations above 23%, the freezing point of the liquid chemical increases sharply. It is important to understand the concept of phase change in order to use liquid chemicals effectively and avoid waste. The curved lines on the diagram separate the phases of the solution:

- Above the curve—all liquid solution; melting action.
- Below the curve—mixture of solution and ice or salt; refreezing action.
- Below the eutectic point—solid ice.

In snow and ice control operations, and particularly during pre-treatment, it is important to know what chemical concentrations are being applied. The phase diagram shows how deicing and refreezing can occur on pavement. When a liquid chemical is applied, snow or ice on the pavement will melt as long as the temperature on the roadway is above the freezing temperature for the concentration of the chemical. As ice is melted, the water combines with the solution already on the pavement, causing dilution. Dilution lowers the concentration, meaning that the freezing point goes up. Melting and dilution continue until either all of the ice is melted or the solution is too diluted to work. Snow, rain or freezing rain after application will also cause dilution. Refreezing will occur if the chemical concentration is not adequate to produce melting at the actual pavement temperatures.

Salt is the least expensive product but it has temperature use limitations. Liquid calcium chloride and magnesium chloride are more expensive but can be used at lower temperatures, as shown on the phase diagram below.



From: Minsk, David. *Snow and Ice Control Manual for Transportation Facilities.* L., McGraw Hill, 1998, ISBN 0-07-042809-3.

When selecting liquid chemicals, it is important to consider the percentage solution. Liquid magnesium chloride products may vary between 23% and 30%. As the concentration governs the effectiveness of the chemical, it is critical that the solution be purchased at an appropriate concentration.

2.2.1 MassDOT Deicing Operations and Material Storage

CDM Smith's review of MassDOT's deicing operations and material storage included the following:

- MassDOT Standard Operating Procedures – Reduced Salt Policy (SOP No. HMD-01-01-1-000) dated April 2014 (included in **Appendix D**).
- *MassDOT Snow & Ice Control Program, 2012 Environmental Status and Planning Report*, which discusses MassDOT's preferred deicing materials and operations throughout the Commonwealth of Massachusetts.

- The "YEAR END MATERIAL REPORT 1995-present" spreadsheet provided by MassDOT in July 2012, with additional data received in May 2013 and April 2014, summarizing the sand and deicing materials used annually at the Boxford Depot Service Area.

- *Critical Operational Factors that Affect Road Salt Usage and Effectiveness and Efficiency of Salt Spreading Operations and Equipment* Final Report by Geosphere Environmental Management, Inc., and Vanasse Hangen Brustlin, Inc., (June 2012) which summarizes MassDOT's snow and ice operations, discusses data analysis and reconnaissance findings, and presents recommendations for improving operations.

- Meetings, conversations, and correspondence with MassDOT personnel responsible for snow and ice removal statewide as well as those individuals within District 4 responsible for snow and ice removal in the Boxford Depot Service Area.

- A storm event reconnaissance conducted on March 7, 2013 to view MassDOT snow removal and deicing efforts. The reconnaissance included visits to the Lexington, Rowley, and Boxford Depots to observe operations and materials handling.

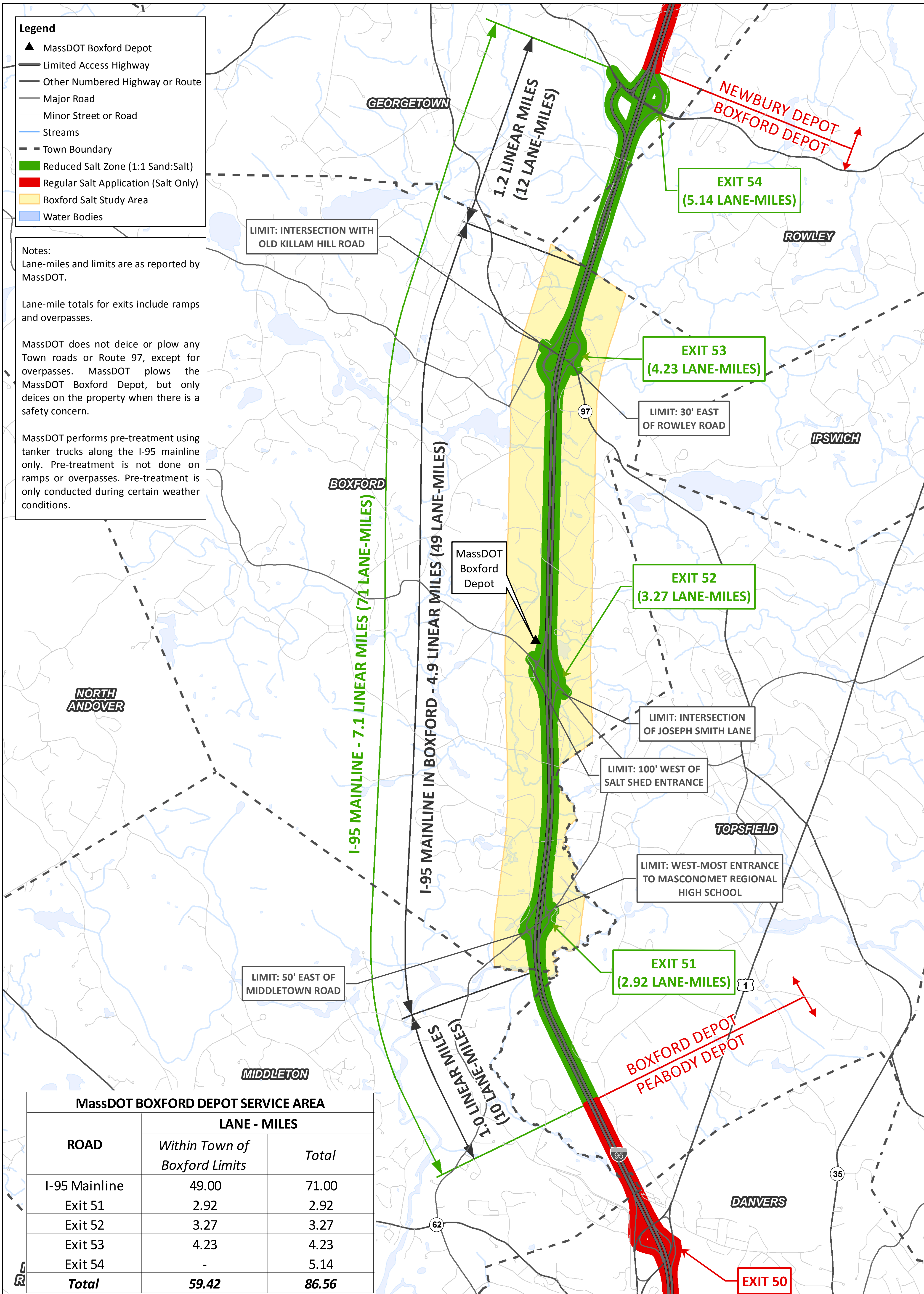
- A site visit on May 29, 2014 to MassDOT Depots in Braintree and Andover. These sites include state-of-the-art salt shed facilities which are under construction. These facilities have been designed to substantially mitigate the release of salt to the environment. The intention of the visit was to observe various design features and layouts. The Andover facility has included background groundwater monitoring prior to salt storage implementation. It is intended to continue monitoring after the facility is operational to assess the effectiveness of the facility's design in mitigating the release of salt to the environment.

2.2.1.1 Deicing Operations (MassDOT)

Although the MassDOT Boxford Depot remains closed for salt storage and handling, it still maintains responsibility for ensuring snow removal and deicing along I-95 and the associated ramps and overpasses at Exits 51, 52, and 53 within the Study Area. There are no other roads in Boxford for which MassDOT is responsible. The Boxford Depot Service Area was formally designated as a RSZ in the early 1990s with a re-emphasis of the RSZ policy in 2004. As shown on **Figure 2-3**, the limits of the RSZ include all of I-95 and the associated exit interchanges within Boxford, as well as portions of I-95 immediately north and south of the Boxford town line and Exit 54 in Rowley. The lane-mile[2] total within the service area is 86.56, of which 59.42 lane-miles are within the Study Area.

On-Ramp to I-95N (Source: MassDOT)

[2] A lane-mile is a measure of road length which represents the number of miles in every travel and breakdown lane. For example, a one mile length of highway with four travel lanes and a breakdown lane is equivalent to 5 lane-miles.



Notes:
Lane-miles and limits are as reported by MassDOT.

Lane-mile totals for exits include ramps and overpasses.

MassDOT does not deice or plow any Town roads or Route 97, except for overpasses. MassDOT plows the MassDOT Boxford Depot, but only deices on the property when there is a safety concern.

MassDOT performs pre-treatment using tanker trucks along the I-95 mainline only. Pre-treatment is not done on ramps or overpasses. Pre-treatment is only conducted during certain weather conditions.

MassDOT BOXFORD DEPOT SERVICE AREA

ROAD	LANE - MILES	
	Within Town of Boxford Limits	*Total*
I-95 Mainline	49.00	71.00
Exit 51	2.92	2.92
Exit 52	3.27	3.27
Exit 53	4.23	4.23
Exit 54	-	5.14
Total	***59.42***	***86.56***

CDM Smith

0 1,500 3,000 4,500 6,000 Feet

N

MassDOT Boxford Salt Study
Figure 2-3
MassDOT Deicing Responsibilities for the Boxford Depot Service Area

Source: MassGIS, CDM Smith

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MassDOT mostly performs mechanical snow removal at the Boxford Depot, only using deicing materials on the pavement when safety is a concern. Prior to 2004, deicing materials were more regularly applied to the paved area during winter storm events. However, once the impact of road salt to domestic wells became a highlighted concern, the Boxford Depot Service Area was designated a RSZ and deicing of the Boxford Depot pavement essentially ceased.

Since June 2009, when the Boxford Depot Salt Shed was shutdown, deicing operations for the RSZ have been conducted primarily out of the MassDOT Rowley Depot, located approximately 5 miles northeast of the MassDOT Boxford Depot along Route 1, just north of Route 133. Based on weather and traffic conditions, material stores, and equipment queuing, spreaders sometimes operate out of and/or refill their payloads at either the Newbury Depot located approximately 8 miles north of the MassDOT Boxford Depot, just off I-95 at Exit 55, or the Peabody Depot located approximately 8 miles south of the MassDOT Boxford Depot along Route 1, just south of I-95 Exit 46. During inclement weather, it takes approximately 15-30 minutes to travel to the Study Area from the Rowley, Newbury, or Peabody Depots. Liquid magnesium chloride for pre-wetting and pre-treatment is still stored at the Boxford facility and loaded into spreaders on-site. Sand is still stored at the Boxford Depot, though spreaders are not loaded on site since the sand is not mixed with salt.

MassDOT employs contractors to perform plowing and deicing operations within the Boxford Depot Service Area. Currently, five combination units (vehicles with plows and spreaders) are required to perform deicing operations in the Area. Prior to shutdown of the MassDOT Boxford Depot, only three to four vehicles were required. The additional vehicle is now needed because of the added drive time from the Rowley, Newbury, and Peabody Depots. For snow removal purposes, up to 15 plows are used in addition to the five combination units. One tow plow, which is a second plow pulled behind a traditional plow truck, was used in the Boxford Depot Service Area on an experimental basis during winter 2013/2014.

Contracted Combination Unit Deicing in Boxford Depot Service Area

As of 2014, all contracted spreaders deployed in the Boxford Depot Service Area use combination units that are equipped with closed-loop controllers which allow for more controlled and efficient application of sand and deicing materials, resulting in reductions in material use. Closed-loop controllers are computerized mechanisms that allow materials to be distributed at a uniform rate taking into consideration truck speed, auger speed, and other spreader conditions.

District 4 has two contracted tanker trucks available to perform pre-treatment. One of these vehicles is assigned to the Boxford Depot Service Area for pre-treatment of the I-95 mainlines as weather and time allows. Tanker trucks refill with $MgCl_2$ at various depots, including Boxford.

MassDOT uses several means to determine when to begin and end roadway pre-treatment and deicing activities. MassDOT subscribes to advanced weather forecasting information services, solicits feedback from roadside weather information systems (RWIS), and patrols roads checking conditions using mobile temperature sensors to determine pavement and air temperature levels. **Table 2-1** summarizes the operational methods currently employed by MassDOT and those specific to the Boxford Depot Service Area.

The operations center for the Boxford Depot Service Area remains in the office building located at the Boxford Depot at 100 Topsfield Road. The foreman of the Boxford Depot is responsible for the decision to initiate plowing and/or deicing operations.

2.2.1.2 Materials Storage and Handling (MassDOT)

Prior to June 2009, salt and sand applied in the Boxford Deport Service Area was stored at the Boxford Depot. The salt was stored within the metal gable roof, timber structure while sand was stored outside. Sand and salt were mixed in small piles in advance of deicing events using front-end loaders. The front-end loaders then placed the mixed material in the spreader. Material usage was tracked by counting the number of buckets of sand and salt used to create the piles, with predetermined weights assigned to the bucket volumes for each material. Today, similar procedures are used for mixing and measuring of sand and salt in Rowley, Newbury, or Peabody for application in the Boxford Depot Service Area.

Boxford Depot Salt Shed Extension

In May 2005, a fabric extension was added to the salt shed, thereby allowing material deliveries, mixing, and spreader loading to be conducted under cover. This operational change helped limit further exposure of salt handling to precipitation events, in order to lessen salt laden runoff and associated impacts.

A 5,000 gallon magnesium chloride tank was installed at the Boxford Depot in 2008. The single-walled polyethylene tank sits atop a crushed stone base with wooden planks holding the crushed stone in place. Material from the tank is pumped into the truck. MassDOT reports that there is no specific operations and maintenance program for the tank.

Magnesium Chloride Storage Tank at the Boxford Depot

Table 2-1
MassDOT Existing Highway Deicing Operations

Operation	Description	Boxford Depot Service Area
District Management	MassDOT has established six Highway Districts in the Commonwealth of Massachusetts whose responsibilities include maintenance of MassDOT highways and roadways within the District's jurisdiction.	▪ District 4 is responsible for northeastern Massachusetts, including the Study Area and the Boxford Depot Service Area (see **Figure 2-3**).
Depot Service Area	For snow and ice management, MassDOT established a system of Depots, each with a specific service area. The Depots are responsible for all decisions relative to snow removal and deicing operations within the specified Depot Service Area.	▪ The office building at the Boxford Depot at 100 Topsfield Road remains the operations center for the Boxford Depot Service Area. ▪ The Foreman at the Boxford Depot makes all decisions relative to initiation of snow removal and deicing on I-95. ▪ There is currently no salt storage at the Boxford Depot. When solids are required, the salt and sand mix is obtained from the Rowley, Newbury, or Peabody Depots. ▪ Liquid magnesium chloride is stored at the Boxford Depot facility and continues to be loaded into spreader saddle tanks at that location.
Vehicles	MassDOT employs a system of MassDOT and contract vehicles for snow removal and deicing operations.	▪ Currently five contract combination units (vehicles equipped with plows and spreaders) perform deicing in the Boxford Depot Service Area operating out of the Rowley, Newbury, or Peabody Depots; this adds a 15-30 minute drive time depending on the severity of inclement weather. ▪ Previous to shutdown of the Boxford Depot, only three or four contract vehicles were used to perform deicing. ▪ Up to 15 additional contracted plows are used for snow removal. ▪ Contracts extend for a 1-2 year period. ▪ District 4 has two contracted tanker trucks available to perform pre-treatment, one of which is assigned to the Boxford Depot. ▪ Fleet vehicles patrol roadways to assist in anti-icing, deicing, and snow removal decisions.
Closed Loop Controllers / Ground Speed Controllers	Apparatus that automatically adjusts the rate of material feed in proportion to truck and feed-belt/auger speed.	▪ Closed loop controllers are required and in use on all contract vehicles working within the Boxford Depot Service Area. ▪ Material feed rates, distance traveled, vehicle speed, and auger speed can be recorded and reviewed.

Table 2-1 (Cont'd)
MassDOT Existing Highway Deicing Operations

Operation	Description	Boxford Depot Service Area
Weather Forecasting	MassDOT uses various weather forecasting tools to assess potential deicing/snow removal events.	▪ Forecast information is distributed to MassDOT by Schneider Electric meteorologists. ▪ Information is taken from various local and national forecasts. ▪ Conference calls are held in advance of potential storms to inform MassDOT decision-making personnel and discuss upcoming operations.
Pavement Temperature Sensors	MassDOT uses mobile temperature sensors - small units attached to the vehicle's bumper that transmit air and road surface temperature to the driver. These instruments help determine if and when pre-treatment and deicing should be applied.	▪ Several MassDOT vehicles used in the Boxford area have pavement sensors, including those used by the District Manager and Boxford Depot foreman. ▪ MassDOT employees drive the Boxford Depot Service Area with an air/pavement temperature sensor to determine if pre-treatment or deicing efforts should be initiated.
Roadway Weather Information System (RWIS)	A network of roadside weather stations that collect and transmit via internet pertinent weather data (e.g., air temperature, humidity, wind speed/direction, precipitation rate, etc.) and pavement data (e.g., pavement temperature, condition, freezing point) using a variety of meteorological and pavement sensors. This regional real time data is a critical component of the snow/ice management program for decision making.	▪ RWIS stations near the Boxford Depot Service Area are Peabody, Salisbury, and Tyngsboro; at distances of 4, 16, and 30+ miles, respectively. ▪ Weather information from the RWIS is transmitted to District 4 for decisions on deicing operations on a per storm basis.
Equipment Calibration Program	MassDOT calibrates spreaders annually, before each winter, and periodically throughout the winter.	▪ Spreaders are calibrated prior to each winter. ▪ Calibration teams perform calibration checks during each winter season. ▪ A "drop" test is performed, measuring material dispensed by spreaders over a given period of time.
Record Keeping Program	Total facility and individual equipment / operator material usage tracking, and annual benchmarking.	▪ Record keeping of deicing product usage is the responsibility of District 4 for the Boxford Depot Service Area. ▪ Records are kept by winter season and beginning during the Winter 2013/2014, by storm event. ▪ Sand, salt, and liquid deicing product volumes are recorded as they are loaded into vehicles.

Table 2-1 (Cont'd)
MassDOT Existing Highway Deicing Operations

Operation	Description	Boxford Depot Service Area
Staff Training Program	Annual training on proper material handling, usage, equipment operation and calibration, and environmental impacts, as well as best management practices for new staff and refresher trainings for existing staff.	▪ Drivers of contract vehicles are invited to participate in operations training administered by MassDOT. ▪ MassDOT staff participate in required training programs for management and operations.
Good Practices	Maintaining best management practices for snow/ice control, including but not limited to regular calibration of spreading equipment, tracking of conditions/salt use, proper covering of product to prevent loss, and optimization of routes.	▪ District 4 is responsible for maintaining snow/ice control best management practices.
Reduced Salt Zone (RSZ)	Areas in which a reduced application of salt is used on the roadways during deicing events. The salt is combined with sand at a 1:1 ratio of sand to salt, to maintain a combined 240 lb/lane-mile application rate.	▪ The Boxford Depot Service Area is a RSZ. ▪ Solid application is a mix of sand and salt at a 1:1 ratio.
Pre-treatment	Prior to the onset of a storm, tanker trucks fitted with a spreader bar and nozzles at the rear of the truck apply a liquid material at an intended rate of 20-30 gallons per lane mile. This anti-icing measure is meant to lessen the need for salt application during the storm.	▪ The decision to pre-treat is made by District 4 personnel based on predicted weather and actual weather conditions gathered from RWIS and pavement temperature sensors. ▪ When used, only main-lines receive pre-treatment; ramps and overpasses are not pre-treated. ▪ Liquid agent used for pre-treatment is magnesium chloride. ▪ One tanker truck operates within the Boxford Depot Service Area to provide pre-treatment.
Pre-wetting	As solid material is placed on the road, it is sprayed with a liquid material to enhance adhesion of salt to the pavement and further melting. Pre-wetting reduces bounce and scatter, which at application speeds in excess of 25-30 mph can cause dry salt to migrate off the roadway. Protocol requires that pre-wetting material be delivered at a rate of 8-10 gallons per ton of salt.	▪ Pre-wetting is performed by all spreaders in District 4. ▪ Pre-wetting material is liquid magnesium chloride.

2.2.1.3 Materials and Application (MassDOT)

Material application protocols are presented below followed by an analysis of application rates during the 2013/2014 winter season.

Application Protocols

MassDOT has established protocol for the application of materials in a RSZ which is described in the MassDOT Snow & Ice Control Program, 2012 Environmental Status and Planning Report, and must be implemented in accordance with MassDOT SOP No. HMD-01-01-1-000 Reduced Salt Policy. **Table 2-2** summarizes the material and application rates used in RSZs such as the Boxford Depot Service Area, based on this protocol.

Table 2-2
MassDOT Material and Application Rate Protocol in Reduced Salt Zones[1]

Material	Application Rate[2]	
Solids		
Road Salt (NaCl)	120 lbs/L-M	
Sand	120 lbs/L-M	
Sand:Salt Ratio	1:1	
Liquids		
100% $MgCl_2$ (30% solution)	Pre-treatment 20-30 gal/L-M	Pre-wetting 8-10 gallons per ton of solids

Notes:
[1]The Boxford Depot Service Area is a Reduced Salt Zone.
[2]Application rates are based on MassDOT protocol for RSZs as set forth by the MassDOT *SOP No. HMD-01-01-1-000 Reduced Salt Policy* located in Appendix D.

Abbreviations:
gal/L-M: gallons per lane-mile
lbs/L-M: pounds per lane-mile
$MgCl_2$: magnesium chloride
NaCl: sodium chloride

Typically, MassDOT delivers rock salt at a rate of 240 pounds per lane-mile (lbs/L-M) throughout the Commonwealth. In RSZs such as Boxford, salt is mixed with sand at a ratio of 1:1 and the mixed materials are delivered at the 240 lbs/L-M rate, resulting in a salt application rate of 120 lbs/L-M and a sand application rate of 120 lbs/L-M. Material is distributed by combination units that are calibrated by MassDOT calibration teams and periodically during the winter season. Calibration at the beginning of the season is completed by certified calibration vendors. Contractors receive a calibration certificate which is submitted to MassDOT before each winter season. This is a requirement.

The MassDOT Reduced Salt Policy (SOP, No. HMD-01-01-1-000 included in Appendix D) allows that during more intense storm events, pre-wetted salt without sand may be applied to maintain passable roads. Similar practices were reported in other RSZs in the *Critical Operational Factors that Affect Road Salt Usage and Effectiveness and Efficiency of Salt Spreading Operations and Equipment* Final Report (Geosphere and VHB, 2012).

In the Boxford Depot Service Area, MassDOT occasionally substitutes pre-mix material for salt. Over the period evaluated for this Study (2007/2008 through 2013/2014), use of pre-mix material was very limited. The total quantity of pre-mix used in the Boxford Depot Service Area over the time period was

71 tons, compared to 12,910 tons of salt and 8,950 tons of sand. Pre-mix can be difficult to store and handle as it contains solid calcium chloride, which is hydroscopic and can harden into clumps or a solid mass in a short period of time.

When roadway pre-treatment is conducted, MassDOT protocol requires that $MgCl_2$ be applied at an application rate of 20-30 gallons per lane-mile (gal/L-M), while for pre-wetting, the $MgCl_2$ application rate is 8-10 gallons per ton of solids.

Analysis of Deicing Material Application Rates

CDM Smith analyzed annual records of material usage provided by MassDOT for the winter periods 2007/2008 through 2013/2014. The purpose of this analysis was to confirm that material usage corresponds with the application rates specified by MassDOT protocol for RSZs. Data for this analysis were provided in the MassDOT "YEAR END MATERIAL REPORT 1995-present" spreadsheet containing data through April 2012, as well as data provided by District 4 for the 2012/2013 and 2013/2014 winter seasons.

Table 2-3 presents sand and deicing material use and computed application rates for the MassDOT Boxford Depot Service Area on an annual basis from 2007/2008 through 2013/2014. Data is provided for continuous "winters" or deicing seasons (i.e., 2012/2013 represents the time period from the first deicing event in Fall 2012 to the last event in Spring 2013). The use of materials during a given winter varies with the number and severity of deicing events. The total amount of sand, salt, and $MgCl_2$ used during a given winter is proportional to that winter's overall severity.

In summary, the analyses indicate the following:

- ***Sand to Salt Ratio:*** The average sand to salt ratio for the winter seasons 2007/2008 through-2013/2014 was 1:1.4, which has more salt than sand and does not achieve the prescribed ratio of 1:1 for RSZs such as the Boxford Depot Service Area. Salt use totals greater than sand may reflect straight salt application when necessary to maintain passable roads. Over the past four winters, the average sand to salt ratio is 1:1.1 which is much closer to the 1:1 protocol. The results of this analysis do not reflect the occasional undocumented treatment received by the Boxford Depot Service Area from remote Depots since closure of the Boxford Depot as a means of helping to maintain roadway conditions.

- ***$MgCl_2$ for Pre-wetting:*** As previously stated, $MgCl_2$ is used for both pre-treatment and pre-wetting. MassDOT does not keep independent records relative to the use of $MgCl_2$ for each of these stated purposes. While pre-treatment is only performed prior to certain storm events, pre-wetting is always conducted. Therefore, to assess $MgCl_2$ use in comparison to the MassDOT protocol application rates, it was assumed that all $MgCl_2$ used was for pre-wetting. For the winter seasons 2007/2008 through 2013/2014, the average use of $MgCl_2$ (assuming all for pre-wetting) was 4.9 gallons per ton of solids used which is lower than the 8-10 gallons per ton of solids identified in the RSZ protocol. Further, for each of the seven winter seasons analyzed, the $MgCl_2$ application rate (assuming all for pre-wetting) was also below the MassDOT protocol of 8-10 gallons per ton of solid material. This shortfall is compounded when considering that an unknown quantity of the reported $MgCl_2$ used was applied during pre-treatment. Therefore, it can be concluded that $MgCl_2$ pre-wetting application rates in the Boxford Depot Service Area are below the MassDOT protocol.

Table 2-3
Material Use Quantities and Application Rates
MassDOT Boxford Depot Service Area

Winter Season	Material Use				Computed Application Rates[1]					
	Sand *(ton)*	Salt *(ton)*	Pre-Mix *(ton)*	$MgCl_2$ *(gal)*	Sand Applied per L-M[A] *(ton/L-M)*	Salt Applied per L-M[A] *(ton/L-M)*	Pre-Mix Applied per L-M[A] *(ton/L-M)*	$MgCl_2$ Applied per L-M[B] *(gal/L-M)*	Sand: Salt Ratio[C]	$MgCl_2$ per Total Solids[D] 2 *(gal/ton of solids)*
2013/2014	1,280.6	1,498.2	0	11,395	14.8	17.3	-	131.6	1:1.2	4.1
2012/2013	930.5	820.4	0	8,175	10.8	9.5	-	94.4	1:0.9	4.7
2011/2012	379.2	421.5	0	5,880	4.4	4.9	-	67.9	1:1.1	7.3
2010/2011	1,468.0	1,637.2	0	15,175	17.0	18.9	-	175.3	1:1.1	4.9
2009/2010	781.1	2,142.0	57	8,100	9.0	24.8	0.7	93.6	1:2.7	2.7
2008/2009	1,869.9	3,575.9	0	27,260	21.6	41.3	-	314.9	1:1.9	5.0
2007/2008	2,242.0	2,815.0	14	27,650	25.9	32.5	0.2	319.4	1:1.3	5.5
2007/2008 to 2013/2014 Avg.[E]	1,278.8	1,844.3	10.1	14,805	14.8	21.3	0.1	171.0	1:1.4	4.9
2010/2011 to 2013/2014 Avg.[F]	1,014.6	1,094.3	0	10,156	11.7	12.6	0.00	117.3	1:1.1	5.3

Notes:
[1] Computations based on 86.56 lane-miles for the Boxford Depot Service Area.
[2]Premix assumed as 100% salt when computing Sand: Salt Ratio and $MgCl_2$ per Total Solids.

Equations:
[A] Material/L-M (Total for Winter Season) [ton/L-M] = Applied Material [ton]/86.56 L-M
[B] $MgCl_2$/L-M (Total for Winter Season) [gal/L-M] = Applied $MgCl_2$ [gal]/86.56 L-M
[C] Sand: Salt Ratio = 1:(Applied Salt [ton]/Applied Sand [ton])
[D] $MgCl_2$/Total Solid Material [gal/ton] = Applied $MgCl_2$ [gal]/(Applied Salt [ton] + Applied Sand [ton] + Applied Pre-Mix [ton])
[E] 2007/2008-2013/2014 AVERAGE = sum of values in column from [2007/2008] to [2013/2014]/7
[F] 2010/2011-2013/2014 AVERAGE = sum of values in column from [2010/2011] to [2013/2014]/4

Abbreviations:
gal: gallons
L-M: lane-miles
$MgCl_2$: magnesium chloride

Review of Record Keeping

There are also some discrepancies between the data provided in the "YEAR END MATERIAL REPORT 1995-present" and the "BOXFORD MATERIAL USAGE 1994-2012"spreadsheets provided by MassDOT. Several of the reported annual material totals were not the same in the two references. Based on discussions with MassDOT, the former was used for calculations. Discrepancies in material use record keeping and reporting were also discussed in the *Critical Operational Factors that Affect Road Salt Usage and Effectiveness and Efficiency of Salt Spreading Operations and Equipment* Final Report (Geosphere and VHB, 2012). While discrepancies in material use recordkeeping should be investigated and addressed, it should be noted that the differences were small and would not significantly impact the results of the analyses presented in **Table 2-3**.

Summary of Materials Application Review

It appears that MassDOT is on average currently applying salt within the Boxford Depot RSZ at a rate slightly higher than sand (computed 1:1.1 sand to salt ratio over the last four winter seasons from 2010/2011 through 2013/2014). As a result of the recording methods used by MassDOT, there is no conclusive way to determine if and when sand and salt are being applied at the prescribed rate. While the total material use for each season is recorded, the number of passes made by spreaders is unknown, meaning the application rate of the spreaders, intended to be 240 lbs/L-M of combined sand and salt, cannot be checked. The measurement of sand and salt, conducted by counting buckets loaded into trucks, is prone to inaccuracy.

The $MgCl_2$ pre-wetting application rate is not optimal to help reduce the bounce and scatter of the salt and optimize melting of the snow and ice. The computed average rate of 4.9 gallons per ton of solid material is well below the prescribed rate of 8-10 gallons per ton of solid material. This shortfall is compounded when considering a portion of the reported $MgCl_2$ applied is used for pre-treatment. The result may be a greater application of salt than necessary to ensure adequate deicing.

Data provided by MassDOT was limited regarding the quantity and frequency of $MgCl_2$ pre-treatment application. It is likely that such applications are below the prescribed rate of 20-30 gal/L-M.

2.2.2 Town of Boxford Deicing Operations

The review of the Town's deicing operations on Town roads included the following:

- Review of material receipts for the quantities of delivered sand and salt for Town-wide use provided by the Town for the winter seasons 2004/2005 through 2012/2013.
- Review of a spreadsheet provided by the Town in April 2014 summarizing deicing material use throughout the Town during the winter of 2013/2014.
- Meetings, discussions, and correspondence with Town personnel.
- A storm event reconnaissance conducted on March 7, 2013 with MassDOT, which included a visit to the Town of Boxford Department of Public Works (DPW) to view the Town's salt material storage and handling operations. The Town's salt storage is at the DPW yard off Spofford Road, which is approximately 2 miles west of the Study Area.

2.2.2.1 Operations (Town of Boxford)

The Town of Boxford reports that it performs deicing on 187 lane-miles of town roads throughout the Town, including Town-owned parking lots. Approximately 27 of the reported 187 lane-miles of Town roads are within the Study Area. The application of deicing materials is performed by Town employees using five spreader trucks. Mechanical snow removal (i.e., plowing) in the Town is performed by contractors.

The Town reportedly uses a sand to salt ratio of 3:1 for all deicing operations. All material is pre-wetted with $MgCl_2$. The Town does not have digitally calibrated methods for measurement and/or control of deicing material distribution (i.e., closed-loop controllers). Operators open vehicle tailgates sufficiently to provide distribution of the deicing materials and sand, and drive the routes as assigned.

Along with the main line of I-95, MassDOT is responsible for deicing and snow removal on the ramps and highway overpasses associated with the three exits in the Study Area. At either end of the three exit overpasses, Killam Hill Road (Exit 53), Topsfield Road (Exit 52), and Endicott Road (Exit 51), there is an interface between the Town's and MassDOT's responsibility. These interfaces are marked by changes in the pavement. These limits coincide with intersecting streets, which are used by operators as landmarks. There are no signs along these roads to denote state highway or treatment limits. The limits of the MassDOT deicing treatment, and by default the limits of the Town's treatment, are shown on **Figure 2-3**.

Table 2-4 presents a summary of the Town's snow removal and deicing operations.

Table 2-4
Town of Boxford Existing Roadway Deicing Operations

Operation	Description
Vehicle Fleet	▪ Five spreader trucks apply material to roads; one additional spreader truck applies material at school facilities and parking lots; all operated by town employees. ▪ Mechanical snow removal (i.e., plowing) is performed by contractors.
Road Salt and Sand Mix Application	▪ Solids are applied at a 3:1 sand to salt ratio to reduce the amount of salt applied per pass while maintaining safe driving conditions. ▪ Material is mixed by bucket equipment (i.e., front-end loader) in the shed at the DPW yard. ▪ Road application rate is not known; the Town does not have equipment capable of controlling application rate.
Pre-wetting	▪ Solid material placed on the road is sprayed with a liquid material (magnesium chloride) as it is ejected. ▪ Pre-wetting material application rate is unknown.
Good Practices	▪ Best management practices for snow/ice control. ▪ Tracking of weather/road conditions to determine need for deicing. ▪ Proper covering of product to prevent loss. ▪ Optimization of routes.
Record Keeping	▪ Town maintains invoice records as to the quantity of sand and salt purchased.
Staff Training	▪ Town performs training of staff in material handling, usage, equipment operations, and best management practices.

2.2.2.2 Storage and Handling (Town of Boxford)

The Town of Boxford Salt Shed is located outside of the Study Area at the Town's DPW yard off of Spofford Road, approximately 4 miles northwest of the MassDOT Boxford Depot. Sand and salt are mixed using bucket equipment (i.e., front-end loader) upon delivery and stored in an arched fabric structure. Mixing occurs under cover, within the Town's salt shed. The Town also stores $MgCl_2$ in a storage tank at its DPW yard.

2.2.2.3 Materials and Application (Town of Boxford)

A summary of the Town's solid material use and computed application rates are presented in **Table 2-5**. Based on sand and salt material slips provided by the Town for the winters of 2004/2005 through 2013/2014, the Town averages a sand to salt ratio of 2.0:1, which is below the Town's prescribed 3:1 sand to salt ratio. The average ratio of 2.0:1 is mainly due to the winter seasons of 2004/2005 to 2008/2009, when the average ratio was 1.5:1. During the winters of 2009/2010 through 2013/2014 the ratio improved to 2.9:1.

Table 2-5
Town of Boxford Solid Material Use Quantities and Computed Application Rates

Winter Season	Material Use		Computed Application Rate [1]		
	Sand *(ton)*	Salt *(ton)*	Sand Applied per L-M[A] *(ton/L-M)*	Salt Applied per L-M[A] *(ton/L-M)*	Sand: Salt Ratio[B]
2013/2014	3,094	1,173	16.6	6.3	2.6:1
2012/2013	2,418	806	12.9	4.3	3.0:1
2011/2012	941	400	5.0	2.1	2.4:1
2010/2011	2,960	856	15.8	4.6	3.5:1
2009/2010	2,108	705	11.3	3.8	3.0:1
2008/2009	2,345	1,319	12.5	7.1	1.8:1
2007/2008	1,954	2,557	10.5	13.7	0.8:1
2006/2007	1,409	1,056	7.5	5.7	1.3:1
2005/2006	3,000	1,764	16.0	9.4	1.7:1
2004/2005	4,513	1,961	24.1	10.5	2.3:1
2004/2005 to 2013/2014 Avg.[C]	2,474	1,260	13.2	6.7	2.0:1
2010/2011 to 2013/2014 Avg.[D]	2,353	809	12.6	4.3	2.9:1

Notes:
[1] Based on 187 lane-miles townwide

Equations:
[A] Material/L-M (Total for Winter Season) [ton/L-M] = Applied Material [ton]/187 L-M
[B] Sand: Salt Ratio = 1:(Applied Salt [ton]/Applied Sand [ton])
[C] 2004/2005-2013/2014 AVERAGE = sum of values in column from [2004/2005] to [2013/2014]/10
[D] 2010/2011-2013/2014 AVERAGE = sum of values in column from [2010/2011] to [2013/2014]/4

Abbreviations:
L-M: lane miles

The Town did not present any data regarding the volume of liquid deicing use prior to the winter of 2013/2014, although the Town reports having pre-wetted since 2003. Data provided for the winter of 2013/2014 included liquid use rates. The reported value of 10,222 gallons of $MgCl_2$ equates to 2.4 gallons per ton of solid material applied. While the Town does not have a known prescribed application rate, this value is below the established optimal range that MassDOT uses (8-10 gallons per ton of solid materials applied).

2.2.3 Other Sources of Salt Constituents

Aside from the Town and MassDOT, deicing materials (i.e., rock salt) and/or sand are typically applied by residents, institutions, and business owners on walkways and driveways.

Within the Study Area, MASCO performs deicing on its access road and parking areas. MASCO also provides covered salt storage for their use (see location on Map Panels 11 and 12 in **Appendix B**). According to information obtained from MASCO representatives during a meeting on May 17, 2013, pre-mixed sand and salt is delivered to the school (3:1 sand to salt ratio) and stored between jersey barriers on a paved surface under an extended canopy to allow material loading under cover. The sand and salt combination is applied throughout the parking lots and roadways on the school's campus by a single truck at an unknown rate. There are no pre-treatment or pre-wetting practices at the school.

Other sources of salt impacting groundwater include domestic wastewater as the Town is not sewered. Water softeners use sodium in a chemical process to remove calcium and magnesium, increasing the overall quantity of salt in the domestic waste stream.

2.3 Roadway Drainage Systems

Roadway and highway drainage systems are responsible for the capture and conveyance of stormwater runoff as point source discharges. MassDOT has a fairly complex stormwater drainage network along I-95, with numerous catch basins, manholes, and discharge points as well as extensive pipe runs. The Town’s stormwater drainage system is best classified as country-drainage, which is comprised of a few localized short pipe runs with associated manholes, catch basins, and discharge points. In other areas, the Town's stormwater drainage simply consists of a catch basin with direct discharge or connection to a culvert crossing. Other drainage contributions from both I-95 and Town roads are non-point source discharges such as overland runoff from roadways and meltwater from snowbanks (**Section 2.3.3**).

Stormwater drainage along roadways and highways is important to the Study as it provides a potential flow pathway for deicing constituent migration in the environment. Specifically, during rain and melting events, road contaminants including salt and other deicing chemicals are mobilized with runoff to the local drainage system. The discharge of stormwater to receiving water bodies, channels/swales, wetlands, or dry land may pose an opportunity for such road contaminant constituents to enter the surface water system and/or infiltrate the groundwater.

For these reasons, an important component of the Study has been to develop an understanding of highway and roadway drainage and the associated stormwater collection systems. This section describes these systems. Furthermore, the stormwater drainage systems have been incorporated into the project geo-database and onto the Study Area Map Panels presented in **Appendix B**. Note that all stormwater drainage systems shown on these map panels are approximate based on available mapping or field reconnaissance using a Global Positioning System (GPS) instrument. Also shown on a set of Map Panels in **Appendix C** is a series of catchment delineations along I-95. Typically, the catchments were delineated based on a common discharge point. In some cases, multiple catch basins with individual outfalls were grouped together into a single catchment delineation if their discharges are to a common drainage ditch. An example of the stormwater drainage mapping included on the Map Panels is shown in **Figure 2-4**, which presents a portion of Map Panel 7 from the area of the MassDOT Boxford Depot.

For this study, specific sources of stormwater system mapping include the following:

- MassDOT I-95 design plans, (U.S. DOT Federal Highway Administration, 1974)
- MassDOT I-95 drainage modification plans, (2005 and 2006)
- Town of Boxford stormwater drainage mapping in GIS, (Haley & Ward, October, 2011)
- Subdivision plans provided by the Town
- Field checks and reconnaissance performed by CDM Smith throughout the course of the project related to stormwater drainage along I-95 and the Town's country drainage

The maintenance of stormwater collection systems is critical in ensuring proper drainage and water quality. For this reason, this section also includes a review of both MassDOT and Town stormwater drainage operations and maintenance programs.

2.3.1 MassDOT Stormwater Drainage Review

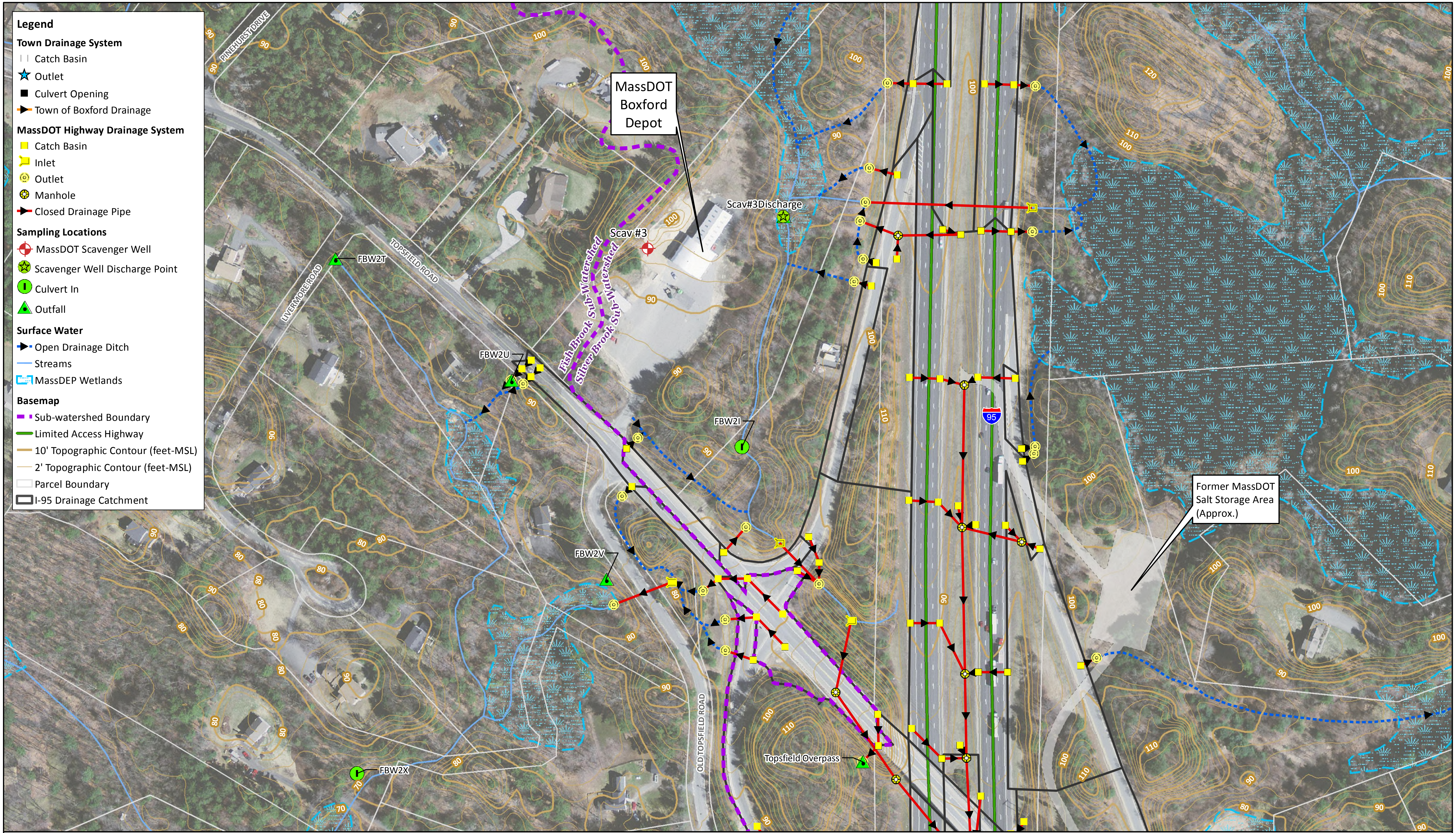
Presented below is a description of the I-95 stormwater drainage system and related hydrology, review of stormwater drainage modifications implemented by MassDOT within the Study Area, and a review of MassDOT's stormwater operations and maintenance (O&M) practices.

2.3.1.1 Description of I-95 Stormwater Drainage System

The drainage systems serving I-95 and the associated ramps and overpasses are owned and operated by MassDOT. The highway drainage systems found in the Study Area are typical for interstates and other major highways in Massachusetts. In addition to the paved lanes and shoulders, MassDOT's drainage system serves the grassed medians between the north and southbound lanes, and areas between the ramps and main highway.

Exit 53 Ramp Curbing

Catch basins are used to collect runoff from paved areas and most medians. Runoff from paved areas is directed to gutters where gutter flow is captured by the catch basins located along the edge of the pavement. Gutters are formed by the slope of the pavement meeting either granite curbing, bituminous concrete berms, or grassed areas sloped back toward the roadway. There are no man-made open channels, such as grassed swales, intended to serve as a means of collecting runoff directly from paved areas. However, there are instances where runoff collected by catch basins associated



CDM Smith

MassDOT Boxford Salt Study

Figure 2-4

Drainage Area Map Example at Exit 52

Source: MassGIS, CDM Smith

billingsmc Z:\Boxford\MXD\DRAFT_Report_Figures\Section2\Fig2_4_DrainageAreaMapExample_Exit52.mxd 8/26/2014 with highway drainage systems is discharged to man-made open channels. Most of the median area between the northbound and southbound lanes forms a parabolic grassed channel. Runoff from the median area accumulates and flows along the bottom of the channel where it is captured by catch basins. Depending on topography, runoff from ramps either flows to catch basins along the paved edge of the ramps or into small drainage ditches which enter the drainage system via pipe inlets.

Once flow is captured by catch basins, it enters piped systems. The drainage networks created by these piped connections range in size. Smaller systems connect one or two catch basins by a single pipe whereas larger systems connect dozens of catch basins and manholes. There are numerous catch basins interconnected via direct piping as a means of eliminating manholes from the paved areas. Manholes are located in the median area and at the end of ramps.

The I-95 drainage systems discharge to wetlands or open channels ranging from small drainage ditches to major channels such as Pye Brook or Silver Brook. The smaller drainage ditches, located along the outer lanes of I-95, often serve numerous small drainage systems before joining larger watercourses. At the exit ramps, small sections of concrete lined channels convey stormwater.

Figure 2-5 shows the major watersheds and sub-watershed divides within the Study Area. These delineations have been modified on the Map Panels in **Appendix C** to account for I-95 engineered stormwater drainage systems.

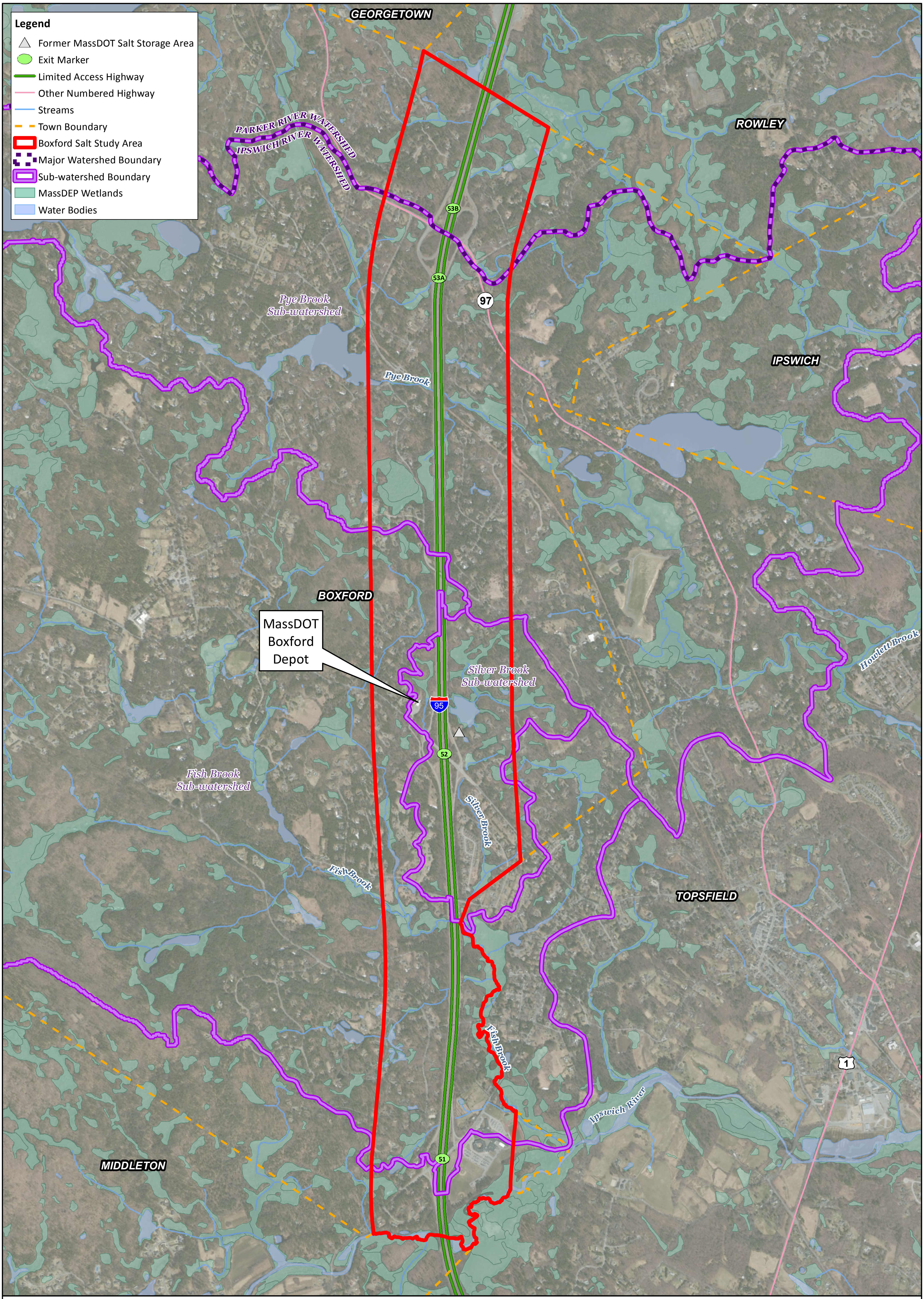
From Exit 53 north, all stormwater from I-95 as well as the Exit 53 ramps and overpasses discharges to the Parker River Watershed. The one exception is the I-95 southbound on-ramp at Exit 53; drainage from this area flows into the Ipswich River Watershed.

Exit 53 Ramp - Drainage Swale to Catch Basin

Stormwater from the remainder of I-95, including Exits 51 and 52, ultimately drains to the Ipswich River Watershed. Sub-drainage basins in this area of the Ipswich River Watershed include Pye Brook, Silver Brook, and Fish Brook.

The Pye Brook sub-drainage basin receives I-95 stormwater drainage from Pye Brook Lane north to Exit 53. There is a substantive amount of stormwater piping, including an approximate 1,750 linear-foot trunk line, along I-95 from the vicinity of School Street that drains south, discharging to Pye Brook. The remainder of the drainage in this area flows to small streams and wetlands which also drain to Pye Brook. Pye Brook eventually flows to Howlett Brook which flows directly into the Ipswich River approximately 2 miles east of the Study Area limit.

The Silver Brook drainage basin receives I-95 stormwater from just south of Bare Hill Road, south to the point at which Silver Brook flows into Fish Brook (Map Panel 9). This area includes the MassDOT Boxford Depot and former salt storage area (Map Panel 7). This stretch of I-95 includes at least two long stormwater pipe lengths which discharge to streams that flow directly into Silver Brook.



CDM Smith

Source: MassGIS, CDM Smith

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

0 1,000 2,000 3,000 4,000 Feet

N

MassDOT Boxford Salt Study

Figure 2-5

Watershed and Sub-watershed Divides within the Study Area

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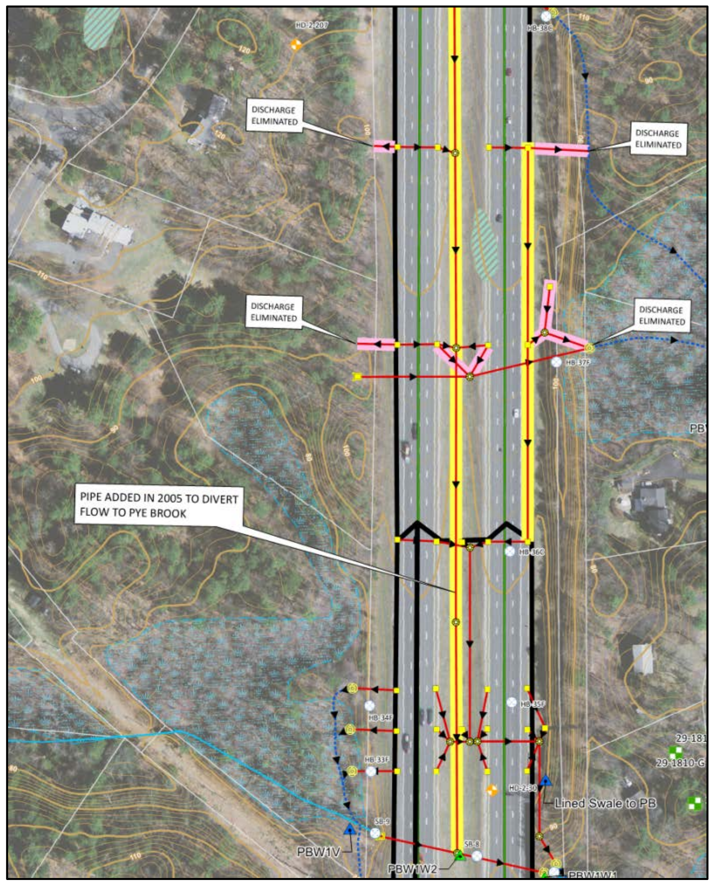
The Fish Brook drainage basin receives stormwater drainage from a short length of I-95 at Bare Hill Road (Map Panel 6). However, the predominant stormwater drainage from I-95 to the Fish Brook drainage basin extends from Lockwood Lane (Map Panel 9) south through Exit 51 (Map Panel 12). Most of the I-95 stormwater pipes within these areas are short lengths, discharging to streams that flow to Fish Brook. The most substantial drainage network in this area is at Exit 51, discharging to a stream north of MASCO which flows into Fish Brook.

The southern end of the Study Area including the I-95 southbound on-ramp at Exit 51 drains into the Ipswich Watershed, with discharge to area streams and wetlands that flow to the Ipswich River.

2.3.1.2 Stormwater Drainage Modifications by MassDOT

In an effort to reduce highway drainage discharges near residential wells with salt impacts, MassDOT identified and implemented two stormwater drainage system modifications along I-95. The purpose of these modifications was to re-route highway drainage to faster moving streams. The two improvements are described below and highlighted on Map Panels 3, 4, and 8 of **Appendix C**.



Southern Portion of Pye Brook Drainage Modification (Appendix C)

- ***Pye Brook Drainage Modification:*** In 2005, two new drain pipes, one in the median of I-95 (approximately 1,650 feet in length) and one along the east side of the I-95 northbound lanes (approximately 600 feet in length) were installed to redirect the discharge of highway runoff collected by catch basins. The installation of the new pipes brought flow that had previously discharged via several small networks and outfalls to drainage ditches and paved swales on either side of the highway directly to Pye Brook by connecting into the culvert conveying Pye Brook under I-95 (see Map Panels 3 and 4 in **Appendix C**). The small systems and outfalls affected by these changes were abandoned as part of the project. This modification greatly reduced the amount of stormwater discharge to the Roberts Road area.

- ***Exit 52 Drainage Modification:*** In 2006, a drainage modification was implemented south of Exit 52 to redirect a portion of the exit's stormwater discharge that was entering Silver Brook north of Silverbrook Road (see Map Panel 8 in **Appendix C**). The modification provided an approximate 350-foot pipe connection to the drainage system immediately to the south. That system discharges to a channel further south which flows into the southern end of Silver Brook, north of its confluence with Fish Brook. This improvement eliminated a drainage discharge from Exit 52 to the Silverbrook Road area.

2.3.1.3 MassDOT Stormwater Operations and Management Practices

In 2012, MassDOT completed a National Pollutant Discharge Elimination System (NPDES) Phase II Small Municipal Separate Storm Sewer Systems (MS4) General Permit Annual Report. The report serves as a self-assessment which concluded that MassDOT continues to be in full compliance with the MS4 permit conditions. To help ensure MS4 permit compliance, MassDOT implements the following stormwater BMPs and programs as part of its O&M of state-owned roads and drainage systems, such as those within the Study Area in Boxford:

- ***Catch Basins*** - All catch basins are inspected annually and cleaned as necessary.
- ***Swales*** - Swales are inspected annually and cleaned as necessary.
- ***Channel Systems*** - Channel systems are cleaned annually.
- ***Municipal Training Assistance Program (MTAP)*** - MassDOT personnel attend annual training programs related to stormwater and snow and ice control as a means of reducing source pollution.
- ***River and Stream Signs*** - Signs identifying rivers and streams crossed by MassDOT roads are maintained.
- ***Street Sweeping*** - Street sweeping is performed annually and wastes are properly disposed of off-site (MassDOT, 2012). Street sweeping is particularly important in RSZs like the Boxford Depot Service Area and throughout the Town where sand is applied with deicing materials.

These activities are managed and executed by District 4 of MassDOT. According to MassDOT, physical practices such as catch basin, swale, and channel system inspection and cleaning typically occur during the summer months. Street sweeping typically occurs in the spring. These activities are important because they allow drainage systems to function properly, free from siltation and debris. Sand and silt removal is important as they likely accumulate roadway runoff constituents, inclusive of deicing materials that would otherwise remain in and migrate throughout the environment.

2.3.1.4 MassDOT Impaired Waters Program

In compliance with requirements of the U.S. Environmental Protection Agency (EPA), MassDOT is conducting an Impaired Waters Program aimed at improving stormwater discharges from MassDOT roadways to impaired water bodies in the Commonwealth of Massachusetts. Improvements to impaired waters are being accomplished through the implementation of structural stormwater BMPs. Included on the list of impaired waters is the Ipswich River, with the identified water quality impairments being elevated mercury concentrations and low dissolved oxygen.

To help mitigate the water quality issues of the Ipswich River, MassDOT has considered implementation of certain BMPs along I-95 at the far southern end of the Study Area relative to dissolved oxygen. Such improvements would capture stormwater runoff from the southeast portion of Exit 51 and areas south of Exit 51 along I-95.

Ipswich River (Source: USGS)

Although there are no specific stormwater BMPs for road salt, MassDOT has elected to merge the objective of the Impaired Waters Program for the Ipswich River with that of this study. Alternatives to an infiltration BMP are being considered so as to not further contribute to salt impacts on groundwater. Further discussions of such potential improvements are presented in **Section 5.6**.

2.3.2 Town of Boxford Stormwater Drainage Review

Presented below is an overview of the Town's drainage systems and stormwater O&M practices.

2.3.2.1 Description of Town Stormwater Drainage Facilities

In 2011, the Town performed town-wide mapping of its stormwater drainage facilities which was incorporated into GIS (Haley and Ward, 2011) and provided to CDM Smith. These facilities are incorporated onto the Map Panels in **Appendix C**.

Town Drainage Catch Basin

The Town's drainage systems in the Study Area are similar to typical country drainage. Many of the roads do not have curbing, allowing for roadway runoff to enter roadside ditches or flow overland across parcels adjacent to the roadway. Where catch basins are present, they tend to be isolated, with two catch basins connected by a pipe having a single outlet. There are only a limited number of systems in the Study Area with manholes and/or more than two catch basins.

Town drainage system discharges are primarily to small ditches and wetlands or in some cases direct discharges to major watercourses. Similar to I-95 drainage, all town drainage systems in the Study Area ultimately discharge to the Parker River or the Ipswich River Watershed. Runoff destined for the Ipswich River either flows directly to the Ipswich River; or flows via Pye Brook, via Silver Brook to Fish Brook, or via Fish Brook to the Ipswich River.

2.3.2.2 Town Stormwater Operations and Maintenance Practices

The DPW is responsible for the O&M of the Town's stormwater drainage facilities inclusive of storm drains, culverts, and catch basins. In 2004, the Town developed a stormwater management program for the purpose of reducing the discharge of pollutants to water bodies from the drainage system. This program provides protection of water quality, and satisfies the appropriate water quality requirements of the Clean Water Act (Weston and Sampson, 2004).

Based on the stormwater management program, the Town implements the following stormwater BMPs as part of their O&M of town roads and drainage:

- ***Catch Basins*** - catch basins are cleaned every fall during the month of October.
- ***Street Sweeping*** - streets are swept annually, typically in the spring.
- ***Municipal Employee Training*** - new municipal employees receive training to learn proper stormwater practices.

These activities are important because they allow drainage systems to function properly, free from siltation and debris. Sand and silt removal is important as they likely accumulate roadway runoff constituents, inclusive of deicing materials that would otherwise remain in and migrate throughout the environment.

2.3.3 Drainage of Snowmelt along I-95 and Town Roads

The drainage systems along highways and roadways are designed to collect and convey runoff from precipitation. Typically, precipitation falling within a catchment that drains to a catch basin will stay in that catchment until it is collected by the catch basin. However, snow that falls in that catchment may be piled into snowbanks by plows. Both the Town and MassDOT plow snow into snowbanks (to the right-hand side of highways and ramps and to either side of the road where there is two-way traffic) that go beyond the curbs and/or gutters that serve as catchment boundaries. As a result, a portion of snow that falls on pavement may be piled into snowbanks, which subsequently melts and flows off the roadway into upland, wetland areas, or water courses, bypassing the catchment drainage system. This is important as it represents a mechanism in which precipitation containing deicing materials can enter points in the environment other than the known discharge locations of the drainage systems.

2.3.4 MassDOT Boxford Depot Drainage

Boxford Depot Entrance
Looking Southeast

The MassDOT Boxford Depot does not have stormwater drainage infrastructure. As shown on **Figure 2-2**, the salt shed structure is at a high point, with site grading draining stormwater away from the structure. Areas north and west of the salt shed drain to the stream which flows from north to south on the eastern portion of the property. The large paved area drains to the southeast by sheet flow and shallow concentrated flow to a point on the east side of the driveway entrance to the facility. From that point, runoff flows to a depressed area where ponding occurs before flow enters a small stream that later joins the larger stream on the eastern portion of the property. The larger stream eventually enters a MassDOT drainage system under I-95 that discharges to Silver Brook (see Map Panel 7 in **Appendix C**).

Snow plowing of the Boxford Depot is conducted such that snow is piled around the pavement perimeter. Melt water from the piles follows similar drainage patterns described above, in addition to the possibility of direct infiltration in the immediate location of the piles.

Pavement at the Boxford Depot has significant cracking throughout the surface, with openings of up to 2-3 inches. This condition likely allows for direct infiltration of runoff.

2.4 Mitigation Measures

Both MassDOT and the Town have undertaken a number of efforts over the last 30 years to help understand and mitigate the impacts of deicing constituents in domestic wells within the Study Area. These efforts have included public education, data collection, and remediation efforts. The following provides an overview of past mitigation measures undertaken by MassDOT and the Town.

2.4.1 Description of MassDOT Mitigation Measures

MassDOT efforts to address impacts of road salt on area domestic wells have included the following:

- Respond to resident requests relative to salt impacted domestic wells via the Salt Remediation Program, (**Section 2.4.1.1**).
- Surface water sampling programs, (**Section 2.4.1.3**).
- Implementation of scavenger wells, (**Section 2.4.1.4**).
- Implementation of stormwater drainage improvements, (**Section 2.4.1.5**).

Other mitigation efforts implemented by MassDOT relate to better salt storage, handling, and deicing operations practices as described in **Section 2.2** and listed below:

- Salt shed extension construction in May 2005 to provide cover for salt handling and spreader loading under cover.
- Designation of the Boxford Depot Service Area as a RSZ.
- The installation of high density, low pore space pavement along I-95 in the Study Area in 2005. The lower pore space associated with this pavement application reduces the amount of water entering the pavement section, thereby reducing the amount of potentially salt laden runoff infiltrating the soils.
- Annual training of MassDOT staff, which is also available to contractors.
- Use of deicing/anti-icing chemicals ($MgCl_2$) for pre-wetting and pre-treatment in order to reduce overall salt usage.

2.4.1.1 MassDOT Salt Remediation Program Overview

In 1986, MassDOT, formerly MassHighway, began the Salt Remediation Program to address the environmental and health impacts associated with winter deicing activities performed on state-owned roads throughout the Commonwealth of Massachusetts. The Salt Remediation Program was specifically developed to investigate and remediate salt impacted domestic wells where necessary (MassDOT, July, 2011)[3].

A resident is required to undertake some or all of the following steps to report a suspected well impact:

1. Submit to the appropriate MassDOT District Highway Director (in the case of Boxford the submission would be to District 4) a recent water quality analysis performed by a Massachusetts Department of Environmental Protection (MassDEP) certified laboratory for road salt constituents.

2. Complete a Private Well Data Form - This form requests information from residents such as well type, well use, well construction data (e.g., depth), water quality issues, water treatment systems or filters (if present), and a sketch of the property including buildings, wells, and septic systems.

3. Complete a Right of Entry Form - The purpose of this form is to grant MassDOT permission to enter onto a resident's private property for the purpose of collecting monthly water samples and data related to the water supply well and plumbing system in order to evaluate the impact highway deicing salt may have on the water supply.

If the resident filing with the Salt Remediation Program is on a physician recommended sodium restricted diet, then the resident must also:

- Complete a Certification Form for Bottled Water Request
- Complete a Physician's Form for Bottled Water Request

MassDOT reviews these forms to determine if a site visit is warranted. MassDOT will perform a site visit if the Secondary Maximum Contaminant Level (SMCL) of 250 milligrams per liter (mg/L) for chloride is exceeded, or if the resident is on a physician documented sodium-restricted diet and sodium exceeds the Massachusetts Office of Research and Standard Guideline (ORSG) of 20 mg/L (MassDEP, 2012).

During the initial site visit, MassDOT personnel investigate the property and perform a preliminary comprehensive water analysis. If the initial site visit and preliminary water sample suggest that MassDOT deicing activities may be contributing to the high levels of sodium and chloride in the domestic well, MassDOT will continue with their investigation.

If further investigation is necessary, MassDOT will collect monthly samples of the resident's drinking water to determine seasonal fluctuation of road salt constituents. If water quality suggests impacts from deicing materials, MassDOT will implement one or more remedial actions which may include:

- Connection to a public water supply.

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[3] Salt Remediation Program details are available through the MassDOT website at: <www.mhd.state.ma.us/default.asp?pgid=content/environ/salt_rem&sid=about>

- Well replacement.
- Rehabilitation of the existing well.
- Water treatment installation (point-of-use (POU) or point-of-entry (POE) treatment). POU treatment such as reverse osmosis (RO) is installed if sodium and chloride concentrations are at or slightly above the respective ORSG or SMCL. At the written request of the resident, MassDOT will also consider the potential for corrosion of plumbing fixtures if groundwater chloride concentrations exceed 250 mg/L. In situations where chloride concentrations greatly exceed 250 mg/L, MassDOT may suggest a POE "whole house" treatment as a remedial action.
- Highway drainage modification.
- Implementation of a RSZ.
- Improved salt storage, handling, and housekeeping practices.

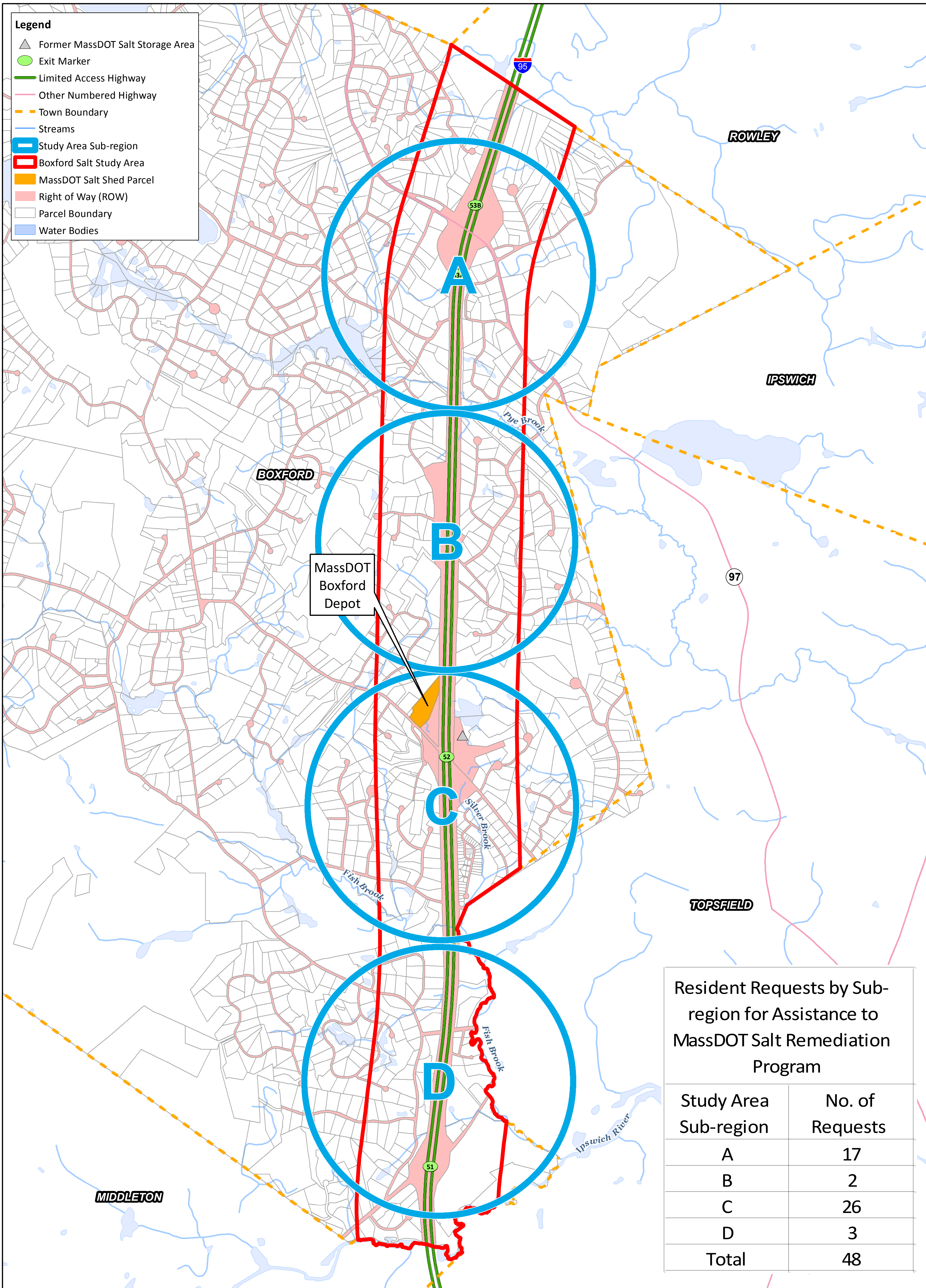
A Salt Remediation Program entry request is denied by MassDOT if it is determined that:

1. Non-MassDOT related activities are a significant cause of salt impacted groundwater (such as the use of a sodium based water softening system in the home).
2. Poor well construction allows surface contamination to enter the well, based on inspection or review of available well construction log.
3. The septic system is within the prohibited limits (50 feet) of the drinking water supply well as outlined in 310 CMR 15.0, The State Environmental Code, Title V (MassDEP, 2014).
4. The well water is otherwise non-potable.

2.4.1.2 Implementation of the MassDOT Salt Remediation Program in Boxford

Some Boxford residents within the Study Area have expressed concern regarding the presence of sodium and chloride in their domestic wells. The first resident request for entrance into the Salt Remediation Program was in 1989 with the most recent entry request received in 2012. Most residents entered the program between 2003 and 2007. In general, these homes pre-date the 1974 expansion of I-95. For the purpose of presentation, the Study Area has been subdivided into four Sub-regions (A-D) as shown on **Figure 2-6**. **Table 2-6** summarizes the history of the Salt Remediation Program within the Study Area by sub-region. Specific addresses are not listed to ensure anonymity.

Areas with the highest occurrence of entries into the program are located in Sub-regions A and C. Salt Remediation Program participants in Sub-region A are primarily located east of Exit 53 in areas north of Killam Hill Road and Rowley Road, and southeast of Exit 53 between I-95 and Killam Hill Road south to Pye Brook. Salt Remediation Program applicants in Sub-regions C are located southwest of Exit 52 in the Titus Lane neighborhood, near the Boxford Depot, and southeast of Exit 52 along Silverbrook Road. Silver Brook receives runoff from Exit 52, the Depot property, and local roads. There were relatively few entries to the program in Sub-region B northwest of the depot and Sub-region D located near Exit 51 along Fish Brook.



Resident Requests by Sub-region for Assistance to MassDOT Salt Remediation Program

Study Area Sub-region	No. of Requests
A	17
B	2
C	26
D	3
Total	48

CDM Smith

MassDOT Boxford Salt Study

Figure 2-6

Resident Requests for Assistance to MassDOT Salt Remediation Program

Source: MassGIS, CDM Smith

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Table 2-6
Summary of MassDOT Salt Remediation Program Resident Applications and Status in the Study Area

Study Area Sub-region	Remediation Program Entry Date Range	Number of Homes Approached by MassDOT to Enter Program[1,7]	Number of Homes Applied to Program[2]	Number of Homes Accepted[3]	Number of Homes that did not Qualify[4]	Remediation Program Monitoring[5]		Number of Homes that Received Replacement Well(s)	Number of Homes that Received Treatment[6]	Other Remedial Action Taken	Number of Homes Where No Action Taken[8]
						Ongoing	Closed				
A	Aug. 2004 to Nov. 2012	0	17	15	2	1	16	8	0	-	9
B	Dec. 2004 to Oct. 2011	0	2	1	1	0	2	0	0	-	2
C	Jun. 1989 to Dec. 2006	17	9	17	9	0	26	9	4	Scavenger Well #1 installation (2 homes)	11
D	Apr. 2005 to Jun. 2009	0	3	3	0	0	3	2	0	Well seal installed (1 home)	0
Total	**Jun. 1989 to Nov. 2012**	**17**	**31**	**36**	**12**	**1**	**47**	**19**	**4**	**3**	**22**
Comments		**10 Accepted 7 DNQ**	**26 Accepted 5 DNQ**	**48 Properties Assessed**		**48 Properties Assessed**		**36 Accepted 26 Remediated**			**12 DNQ 10 No Action**
								48 Properties Assessed			

Notes:
DNQ = Did Not Qualify
[1]Number of homeowners approached by MassDOT Salt Remediation Program for testing of potential salt impacts.
[2]Number of homeowners that applied to the Salt Remediation Program.
[3]Total number of homeowners accepted into the Salt Remediation Program due to high sodium and/or chloride concentrations in well samples.
[4]Number of homeowners who did not qualify for entrance into the Salt Remediation Program
[5]Number of homes currently being monitored under the Salt Remediation Program (ongoing) and number of homes that have been resolved (closed).
[6]Number of homes that received Point-of-use or Point-of-entry treatment.
[7] In the late 1980s and early 1990s MassDOT approached 17 homeowners for entrance into the Salt Remediation Program. Of these original 17 homeowners, 10 were accepted into the Salt Remediation Program.
[8] No action is taken at homes that did not qualify for acceptance into the Salt Remediation Program. Some homeowners who were accepted into the Salt Remediation Program were later denied from the program for various reasons, or did not respond to MassDOT offers of remediation.

To date, 36 residences from within the Study Area have participated in the Salt Remediation Program. In the early 1990s MassDOT reached out and collected water samples from 17 properties in an effort to investigate the extent of possible salt impacts. Of those, seven did not show elevated salt concentrations and 10 were accepted into the Program. An additional 31 residents within the Study Area requested admittance into the Salt Remediation Program of which, MassDOT accepted 26 applicants.

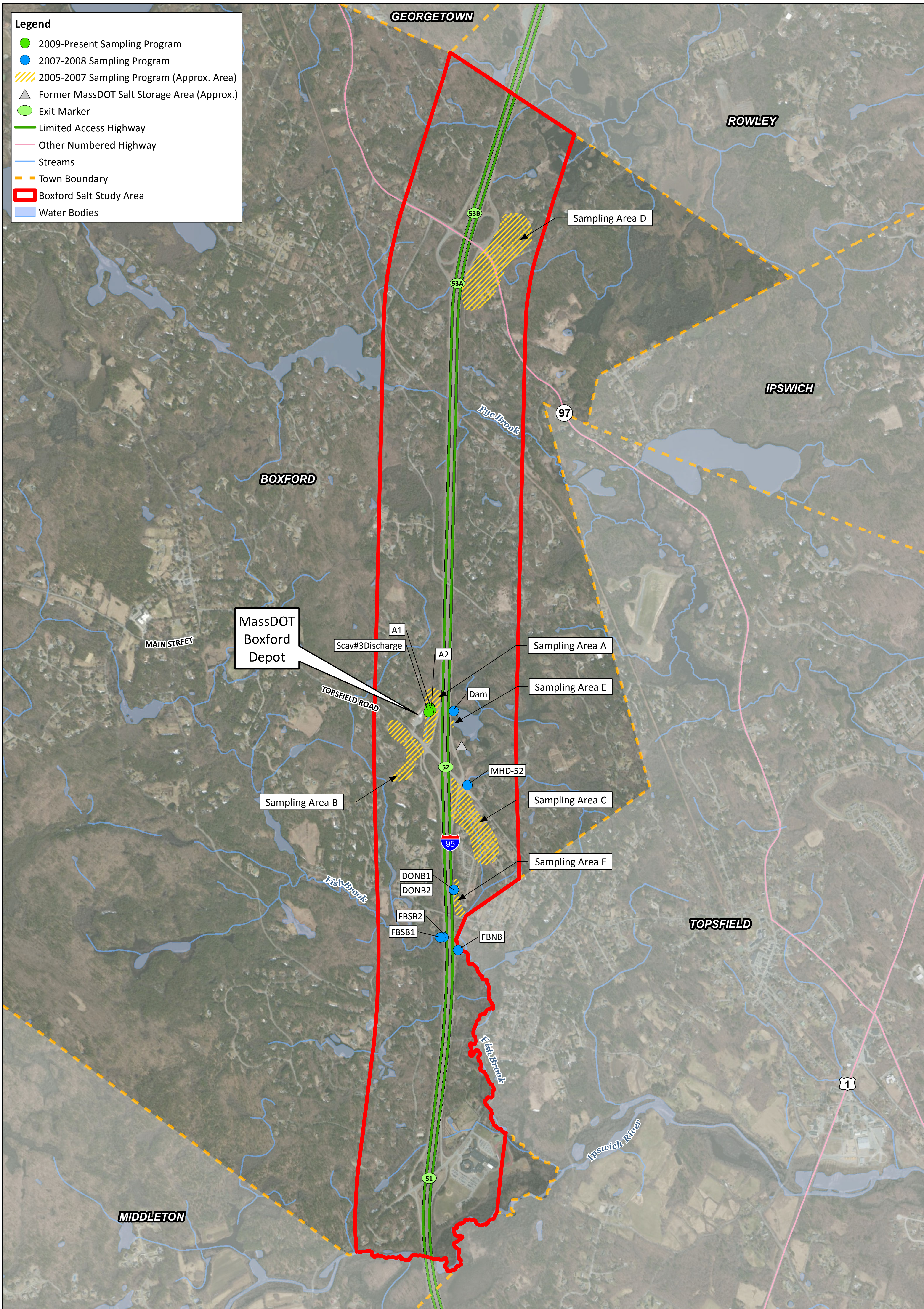
MassDOT's response has resulted in the construction of a new well and/or installation of a water treatment system at 23 locations. Three locations were remedied by other means such as rehabilitation of the existing well and/or installation of scavenger wells to pump and discharge salt impacted groundwater into the local drainage system (see **Section 2.4.1.4**). Ten residents were initially entered into the program, but were either denied during investigation or were unresponsive to MassDOT attempts to perform further investigation and remediation.

2.4.1.3 Surface Water Quality Monitoring Programs

In 2004, MassDOT enlisted the UMass Environmental Engineering Department through its Interagency Service Agreement to assist in site investigations and hydrogeological studies necessary to help address the issue of salt impacted groundwater in Boxford (MassDOT, February 2012).

From the period 2005-present, UMass performed monitoring of surface water and stormwater discharges at certain locations within the Study Area. Included in **Appendix D** are documents received from UMass presenting information on the monitoring program. Formal reporting or documented analysis of the data was not produced.

From 2005-2007, UMass monitored 52 surface water and storm water discharge locations throughout the Study Area. Surface water sampling locations were chosen based on their proximity to Salt Remediation Program residences having wells with high groundwater concentrations of salt. Surface water sampling was conducted along Pye Brook, Silver Brook, Fish Brook, and wetlands in close proximity to major highway drainage outfalls. For the period 2007 to late 2009, the monitoring program was reduced to ten locations in proximity to areas of reported salt impacted groundwater adjacent to the salt shed at the Boxford Depot and along Fish Brook and Silver Brook. From 2009 to the present, the monitoring locations were reduced to just three locations (A1, A2, and SCAV 3 located at the Boxford Depot on Map Panel #7 in **Appendix B**) which are sampled monthly. **Figure 2-7** shows the sample point locations for the UMass program, with only general areas known for the 2005-2007 period. Samples collected throughout the duration of the sampling program (2005-present) were analyzed for indications of deicing material impacts. Available water quality data from this program have been used in development of the conceptual hydrogeological model presented in **Section 4**.



CDM Smith

Source: MassGIS, CDM Smith

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

0 1,000 2,000 3,000 4,000 Feet

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MassDOT Boxford Salt Study
Figure 2-7
MassDOT Surface Water Sampling
General Locations
(2005 to Present)

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2.4.1.4 Scavenger Wells

Scavenger Well #3

As part of the remediation efforts to address groundwater impacts by deicing materials, MassDOT installed and operated three Scavenger Wells in the vicinity of Exit 52. These wells were intended to remove groundwater with high sodium and chloride concentrations and direct the pumping discharge to drainage systems or perennial streams that would carry the water away from areas of impact. No treatment was provided on the Scavenger Well discharges. A summary of the Scavenger Well operating periods, depths and MassDOT reported pumping rates is provided in **Table 2-7**. Scavenger Well and discharge locations are shown on **Figure 2-8**. Note that only Scavenger Well #3 at the Boxford Depot remains operational, discharging to a stream northeast of the salt shed.

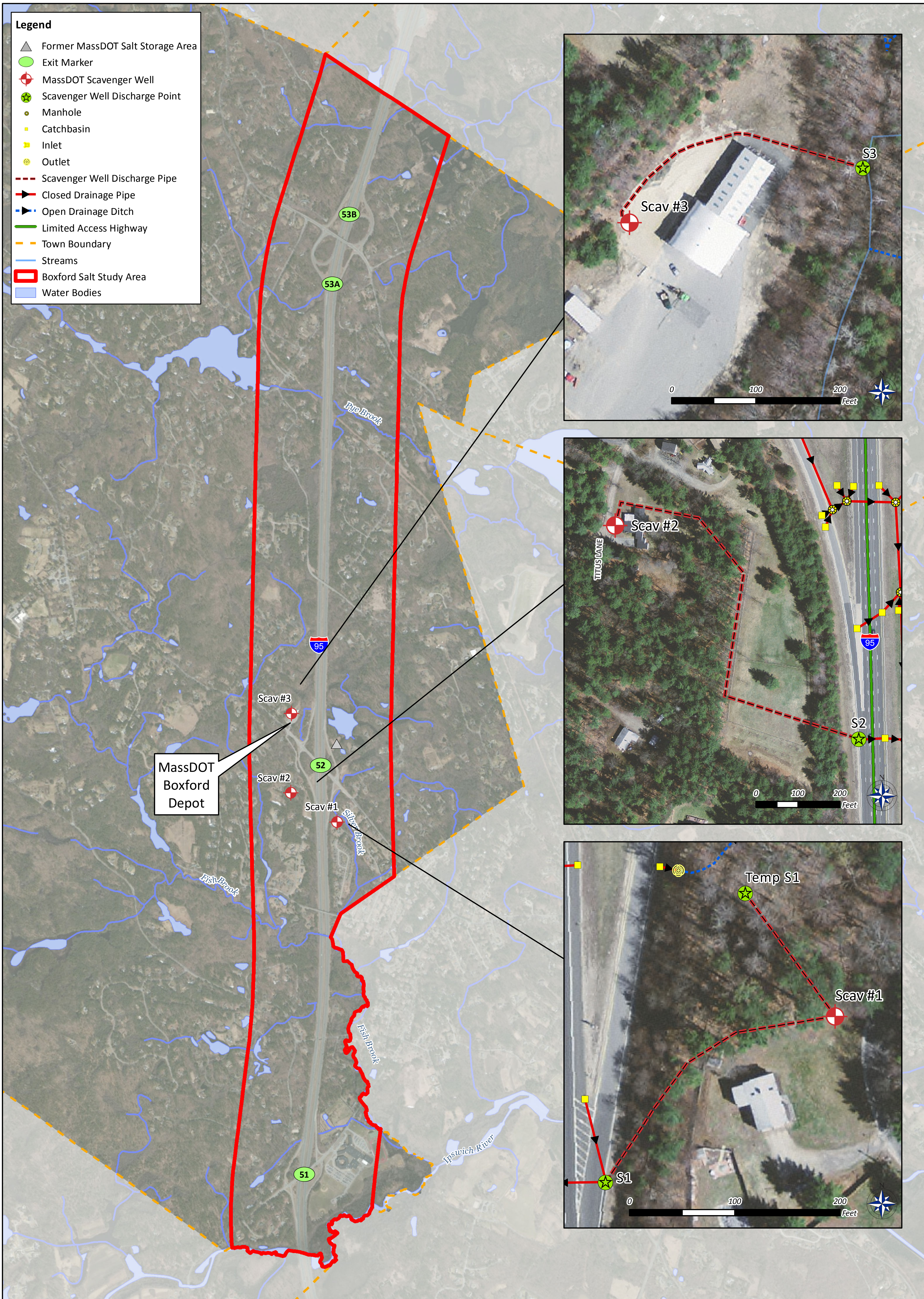
Table 2-7
Scavenger Well Summary

Scavenger Well	Location	Depth (feet)	Dates of Operation	Pumping Rate (gpm)	Discharge Location
#1	Silverbrook Road	455	6/2005 – 10/2007	35	Catch Basin (I-95 drainage)
#2	Titus Lane	900	11/2005 – 10/2007	70	Catch Basin (I-95 drainage)
#3	MassDOT Boxford Depot Property	352	12/2005 – 12/2007 3/2008 – 1/2009 4/2009 - Present	5.5	Stream

Scavenger wells were sampled in conjunction with the surface water sampling program performed by UMass personnel. Scavenger Wells #1 and #2 were sampled from 2006 to 2007. Scavenger Well #3 was first sampled in 2006 and is currently being sampled monthly. **Figure 2-9** shows well pumping history and water quality sampling results for sodium and chloride, at each scavenger well. Nine years of Scavenger Well #3 water quality pumping data clearly shows a significant decline in sodium and chloride concentrations and removal of mass over time, although concentrations still currently exceed guidelines. These trends are discussed further in Section 4.

2.4.1.5 Stormwater Drainage Improvements along I-95

As discussed in Section 2.3.1, MassDOT implemented two stormwater drainage improvements along I-95 to reroute highway drainage to faster moving streams. The areas subject to these improvements were Exit 53 south to Pye Brook and Exit 52 to Silver Brook (drainage changes are shown on Map Panels 3, 4, and 8 in **Appendix C**). In both cases, highway drainage infrastructure was modified to reroute stormwater from smaller open channels and wetlands to major streams.



CDM Smith

Source: MassGIS, CDM Smith

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

0 1,000 2,000 3,000 4,000 Feet

N

MassDOT Boxford Salt Study

Figure 2-8

Scavenger Well Locations

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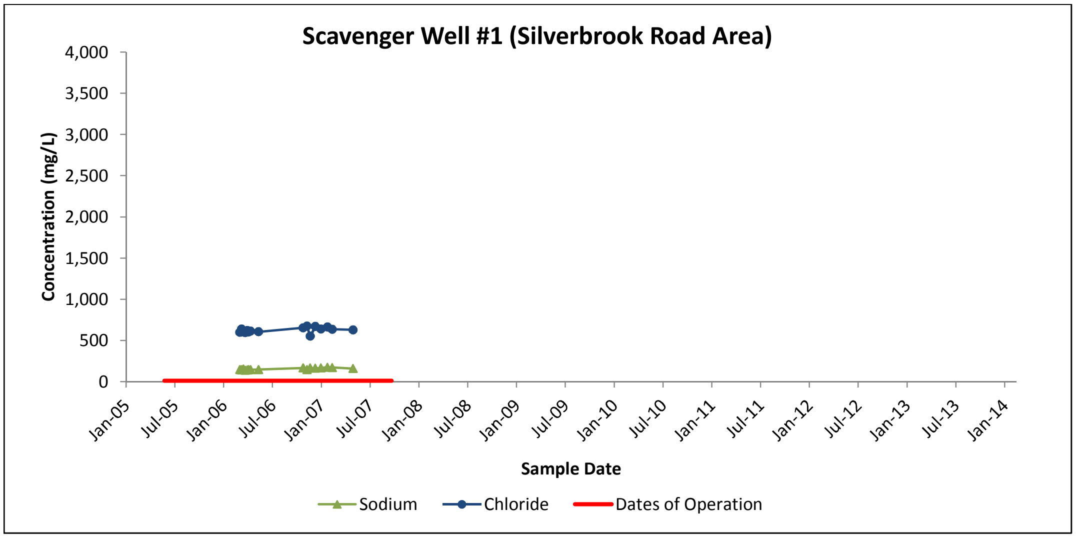

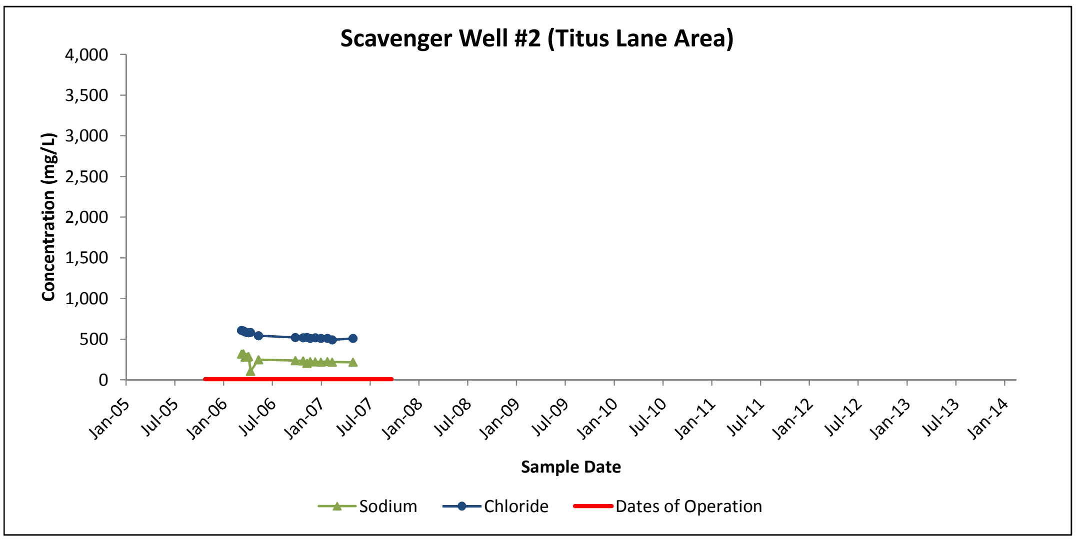

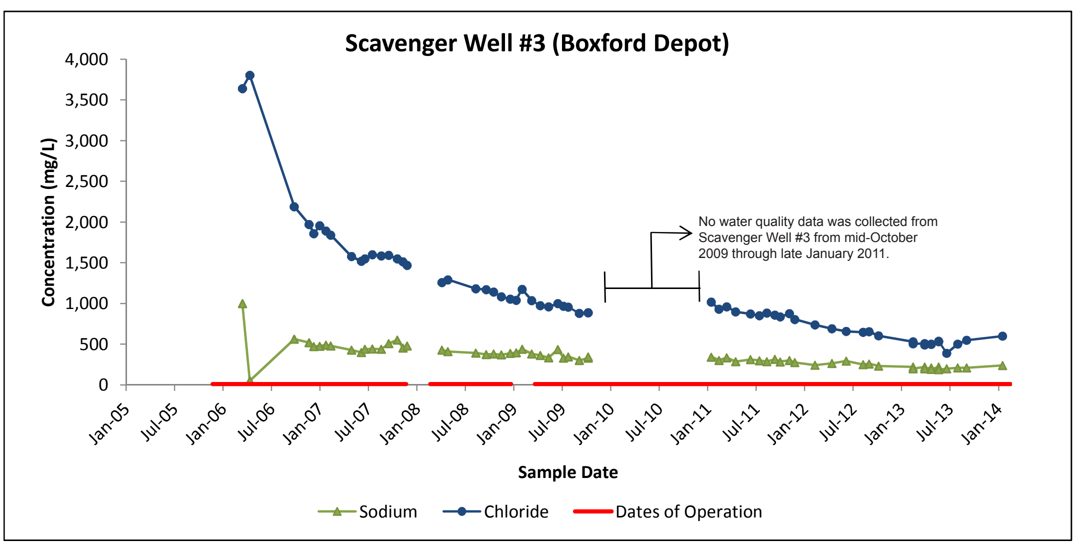

CDM Smith

MassDOT Boxford Salt Study

Figure 2-9

Scavenger Wells Historical Water Quality

Source: CDM Smith

2.4.2 Town of Boxford Efforts to Address Salt Impacts

Since the 1980s, the Town has made efforts to understand and address the impacts of deicing material on groundwater. Preserving groundwater quality is a significant concern to the Town because the residents and businesses are dependent on individual private wells for potable drinking water supply.

Over the years, Town agencies and public committees involved in the protection of groundwater quality have included the Board of Health (BOH), Board of Selectman, DPW, and the Boxford I-95 Salt Study Task Force (the Task Force). Each agency or committee has taken measures to understand and address salt impacts in the community including:

- Public outreach and education concerning salt impacts
- Recommendations of homeowner water quality testing of domestic wells
- Updating Town well regulations,
- Developing Stormwater BMPs
- Developing protocols for deicing operations and BMPs

The Task Force was established by the Legislation requiring this Study. In conjunction with MassDOT, the Task Force helped establish the Scope of Work for the Study and has been a participant throughout.

2.4.2.1 Public Outreach and Water Sampling

From 1983 to 1989, the BOH encouraged all Town residents to participate in an annual water quality testing program for private wells by offering reduced cost laboratory analysis by MassDEP certified laboratories. Water quality testing parameters typically included inorganic compounds, turbidity, synthetic organic compounds, bacteria, radionuclides, and volatile organic compounds. The BOH collected these private well testing results from homeowners. Participation in the water quality testing program was voluntary.

By early 1990, The Town was aware that residents were reporting elevated concentrations of sodium and chloride in their private wells. In 2004, the Town began notifying residents of the elevated salt levels within the Study Area via mail and publicly televised meetings.

The BOH sent a letter to residents along I-95 in March 2006 notifying them that any replacement wells installed by MassDOT as part of the Salt Remediation Program on private property in Boxford needed proper documentation and BOH approval to meet Town of Boxford regulations.

In a letter dated July 26, 2010, the BOH reached out to residents within the Study Area requesting water quality testing results from 2002 to the present. Through this voluntary program, residents were to collect water samples from their homes and submit them to a laboratory for analysis. The BOH arranged for a reduced price water quality testing package with a MassDEP certified laboratory. The program recommended that Boxford residents conduct water testing every five years. The Town was not able to collect many water quality samples as few residents participated in the program.

2.4.2.2 Well Regulation Updates

The BOH first promulgated well regulations in 1994 as Regulation 1-94. The BOH adopted Regulation 1-94 and amended it in its entirety to create the Town of Boxford Chapter 202: Private Water Supply Regulations, most recently updated on December 19, 2012. The majority of residents in the Town of Boxford rely on private wells as their source of potable water. Private wells and irrigation wells for agricultural use are not regulated under State Code, 310 CMR 22.00, and are under authority of the BOH. The BOH, acting under MGL c. 111, § 31, as amended, and with reference to MGL c. 40, § 54, in the interest of and for the protection of public health, established and adopted rules and regulations concerning private well water supplies in the Town (Town of Boxford, 2012).

As part of efforts to address salt impacts on private well water quality, the BOH updated the Chapter 202 Private Water Supply Regulations in September 2010. The purpose of this update, in regard to salt impacts, was to require well permits from the BOH before attempting to drill replacement wells at homes with elevated levels of salt in their private wells. The main updates to the well regulations included, but were not limited to:

- Well definitions distinguishing between abandoned wells, bedrock wells, monitoring wells, and test borings, etc.
- Well repair, renovation, or replacement provisions and approvals.
- Prohibition of domestic wells in overburden.
- Water quality testing requirements for new or replacement wells including at minimum pH, specific conductance, hardness, iron, manganese, sodium, nitrate nitrogen, arsenic, coliforms, organic compounds such as EPA Method 524.2, Purgeable Organic Compounds in Water, or an equivalent EPA-approved method.
- Water treatment system installation requirements.

2.4.2.3 Deicing Operations and Stormwater BMPs

The DPW is responsible for deicing operations and stormwater drainage facility O&M along the Town owned roads in Boxford. The Town operations relative to deicing and stormwater are presented in **Sections 2.3.1** and **2.3.2**.

2.4.3 Boxford Watershed Association

The Boxford Watershed Association, Inc. (BWA) was founded on May 27, 2009 by residents of the Town and is not affiliated with either the Town of Boxford or the Commonwealth of Massachusetts. As stated in the BWA's "Articles of Organization" filed with the Secretary of the Commonwealth, Corporations Division, the BWA's objectives are "… sponsoring, organizing and promoting environmental education and awareness of the health risks and impact on residential property values resulting from the infiltration of salt contaminants to the ground water aquifer …" from MassDOT road salt storage and highway deicing practices on I-95 and "… to promote a permanent resolution and remediation of the contamination of residential water supplies throughout the affected areas of

Boxford, Massachusetts …"[4]. The BWA works with state representatives and has proposed alternative water supply options for those affected such as using water from adjacent town public water systems.

CDM Smith met with the BWA on October 17, 2012 to present the purpose of the Salt Study and to request BWA's assistance in collecting information from residents in the Study Area to further the Study's objectives. CDM Smith wrote an open letter to the BWA that was published in the local newspaper shortly after the October meeting requesting well and water quality information from residents to aid in the Boxford Salt Study efforts. Copies of the letter and newspaper article are included in **Appendix A**. As a result of this request, only one resident provided water quality data which was incorporated into the database.

2.5 Summary

Data collection and review efforts were undertaken to better understand the historical operations and mitigation measures implemented by both MassDOT and the Town. The results of those efforts are summarized below.

- ***History.*** A historical timeline was constructed, beginning in 1974 when I-95 was expanded to four lanes in each direction. At that time, the Boxford Depot at 100 Topsfield Road including the salt shed, was constructed and the maintenance area east of I-95, where salt was previously stored in the open was closed. The timeline continues to the present including information on deicing operations and salt impact mitigation efforts conducted by both MassDOT and the Town related to deicing materials and storage, drainage improvements, scavenger well operations, water quality sampling, and the MassDOT Salt Remediation Program.

  Critical dates include the implementation of reduced salt application for deicing through the use of sand by both MassDOT and the Town beginning in the 1980s, Town of Boxford Board of Health activities starting in the early 1980s, implementation of the MassDOT Salt Remediation Program beginning in 1986, MassDOT stormwater drainage improvements constructed in 2005 and 2006, the addition of the fabric extension at the Boxford Depot in 2005, the MassDOT Clean Well Initiative in 2005, closure of the Boxford Depot to salt storage in 2009, and formation of the Boxford Watershed Association in 2009.

- ***MassDOT Deicing Operations and Material Storage.*** The Boxford Depot Service Area is an RSZ, meaning MassDOT uses a combination of sand and salt at a 1:1 ratio for deicing, pre-wetting the material with liquid magnesium chloride as it is applied to the roadway. These materials are applied by combination spreader/plow units, automated to drop materials at a consistent rate, while accounting for vehicle speed. When weather conditions allow, MassDOT also performs pre-treatment along the mainline of I-95 using liquid magnesium chloride. Pre-mix, containing 80% salt and 20% solid calcium chloride, is used infrequently for deicing in lieu of salt. When weather conditions dictate, straight salt is sometimes applied to maintain road conditions.

  Prior to the partial closure of the Boxford Depot, deicing of the nearly 87 lane-miles in the Boxford Depot Service Area (approximately 60 lane-miles of which are in the Study Area) was conducted out of the Boxford Depot. Salt was stored in the shed, mixed with sand, and loaded

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[4]Boxford Watershed Association. Articles of Organization; filed with the Secretary of the Commonwealth of Massachusetts. Web. May 27, 2009. <corp.sec.state.ma.us/CorpWeb/CorpSearch/CorpSummary.aspx?FEIN=001003789&SEARCH_TYPE=1>

onto spreaders. Salt handling occurred in the open until the fabric extension was constructed in 2005. Since closure of the salt shed, deicing operations for the Boxford Depot are based primarily out of the Rowley Depot, and sometimes out of the Newbury and Peabody Depots. A liquid magnesium chloride tank was installed at the Depot in 2008 and remains in operation today, with refilling of pre-treatment tankers and pre-wetting saddles still occurring.

A review of MassDOT material use records for the Boxford Depot Service Area suggests that the sand to salt ratio over the last four winter seasons has averaged 1:1.1 which is close to the 1:1 protocol for RSZs. However, there is no conclusive way to determine if the sand and salt application rates (120 lbs/lane-mile each) are as prescribed, as the number of spreader passes is unknown. Also, the pre-wetting and pre-treatment application rates for magnesium chloride appear to be less than their respective protocols. Minor discrepancies were also noted in the MassDOT record keeping.

- ***Town of Boxford Deicing Operations and Material Storage.*** The Town applies sand and salt at a 3:1 ratio using spreaders. Sand and salt are pre-wet with liquid magnesium chloride applied as the solids are dispersed from the spreader. The Town's spreaders do not have equipment needed to account for vehicle speed, resulting in varying application rates. The Town does not pre-treat its roadways. The Town services approximately 187 lane-miles of roadway, 27 of which are in the Study Area. Sand and salt are stored and loaded in the Town's salt shed at the Town's DPW yard off of Spofford Road, outside of the Study Area.

  Review of Town records suggest that over the last four winter seasons, the sand to salt ratio has been 2.9:1, which is close to the Town's prescribed ratio of 3:1. There are no records available of salt/sand application rates. Records of magnesium chloride use for pre-wetting were made available for the most recent winter season suggesting an application rate below typically accepted protocols.

- ***Stormwater Drainage Systems.*** MassDOT's drainage systems serve I-95 and the associated ramps, overpasses, and medians. The highway systems are primarily comprised of catch basins, pipes, and manholes with outfalls to larger streams or drainage ditches that flow to the larger streams and rivers. MassDOT's drainage systems vary in size, with some outfalls connected to individual catch basins and other systems discharging runoff from numerous catch basins. The Town's drainage systems are best described as "country drainage", with most outfalls discharging runoff from one or two catch basins. Runoff from many Town roads drains off the roadways to ditches or wetlands without entering catch basins. Both the Town and MassDOT perform annual inspection and cleaning of their drainage systems.

- ***MassDOT Mitigation Measures.*** MassDOT has been proactive in responding to water quality concerns in the Study Area. The MassDOT Salt Remediation Program is a state-wide program that provides residents having salt impacted domestic wells a connection to a public supply (none exist in Boxford), replacement or rehabilitation of an existing domestic well, or a residential treatment system. A total of 36 homes in the Study Area have been admitted into the program. The MassDOT Clean Well Initiative is another state-wide program aimed at protecting domestic wells through the use of new anti-icing strategies. MassDOT has also performed surface and groundwater quality sampling since 2004. Beginning in 2005, MassDOT initiated operation of three scavenger wells, pumping groundwater impacted by deicing materials to fast flowing streams. The scavenger well at the Boxford Depot remains active today, having removed substantial salt mass from the groundwater. Similarly, the I-95 drainage changes constructed in 2005 and 2006 were implemented to discharge runoff carrying deicing materials to fast moving streams.

- ***Town of Boxford Mitigation Measures.*** The Town's Board of Health began sampling residents' water quality at a reduced cost to the home owners beginning in 1983 and has remained active since, helping residents test water quality and performing outreach and education on the subject. The Board also updated domestic well regulations, requiring permits before replacement wells are installed at homes with water quality issues.
- ***Boxford Watershed Association.*** The BWA was founded in 2009 for the purpose of educating residents about water quality issues and raising awareness. Part of the BWA's stated goal is to "…promote permanent resolution and remediation of the contamination of residential water supplies". The BWA is a private organization and is not associated with the Town or the Commonwealth of Massachusetts.

Section 3

Boxford Salt Study Field Programs - Data Collection and Presentation

This section summarizes the field programs that were conducted to collect additional data and information about the hydrogeologic, surface water, and roadway drainage systems as they relate to the road salt impacts in groundwater. Data collected for each component of the field program is also presented and discussed below.

3.1 Field Program Overview

Targeted field programs were conducted to build upon existing data and to collect new information in order to better understand the salt impacts on nearby domestic wells from salt storage and handling at the Boxford Depot and roadway deicing practices within the Study Area. Field programs included:

- Stormwater drainage system reconnaissance of both I-95 and Town of Boxford (the Town) country drainage.
- Screening and focused surface water quality sampling of outfalls and streams.
- Shallow monitoring well installations.
- Sampling and analyses of soil samples along I-95 and at the Boxford Depot.
- Groundwater sampling and analysis of shallow monitoring wells and other overburden wells set in unconsolidated deposits overlying bedrock within the Study Area.
- Bedrock investigations including fracture trace analysis and borehole geophysics.
- Domestic well sampling and analysis for deicing material indicator parameters.
- A winter sampling program focused on three weather events.

Table 3-1 summarizes the field program activities in further detail and identifies the date of implementation, data needs, scope of effort and objectives. To assure data quality, a Quality Assurance Plan (QAP) was developed specific for this project, describing procedures for sample collection and data storage (see QAP in **Appendix E)**. Implementation of field activities was performed primarily by CDM Smith, with assistance from the Massachusetts Department of Transportation (MassDOT), the Town of Boxford, the University of Massachusetts (UMass) Amherst, and Hager-Richter Geoscience, Inc. (Hager-Richter).

Table 3-1
Field Program Summary

Program	Date Performed	Data Needs: Geology	Data Needs: Hydrogeology	Data Needs: Groundwater Quality	Data Needs: Surface Water Quality	Data Needs: Stormwater Drainage	Scope of Effort	Objective
Stormwater Drainage System Reconnaissance	January 2013 – June 2014				√	√	▪ Field checked select I-95 and Town stormwater drainage systems, outlets and culvert flow ▪ Identified facilities requiring repair	▪ Understand roadway drainage systems and deicing impacts ▪ Consider potential drainage modifications
Surface Water Quality Screening	January 2013 – March 2013				√	√	▪ 65 samples analyzed during surface water sampling at 72 stations ▪ Analytes: specific conductance, sodium, chloride	▪ Evaluate extent of salt impacted surface water ▪ Understand sources of roadway deicing impacts
Shallow Monitoring Well Installations	September 2013	√	√	√			▪ Installed 10 shallow monitoring wells along I-95	▪ Obtain stratigraphic data ▪ Establish overburden groundwater monitoring locations ▪ Assess impact of stormwater discharge/infiltration on groundwater quality ▪ Assess impact of snowmelt runoff and infiltration on groundwater quality
Soil Sampling	September 2013 & February 2014	√		√		√	▪ During shallow monitoring well installations, collected 13 soil samples from unsaturated zone for lab analysis ▪ Conducted six shallow borings at Boxford Depot to collect soil samples from unsaturated zone ▪ Analytes: sodium, chloride, specific conductance	▪ Assess accumulation of deicing constituents in shallow soils from infiltrated stormwater and snowmelt
Bedrock Fracture Trace Analysis	September 2013	√	√				▪ Delineated fracture trace lineaments in bedrock ▪ Confirmed bedrock outcrops & measured structural features	▪ Identify potential groundwater transport pathways in bedrock ▪ Identify potential sites for groundwater supply assessment/development

Table 3-1 (Cont'd)
Field Program Summary

Program	Date Performed	Data Needs					Scope of Effort	Objective
		Geology	Hydrogeology	Groundwater Quality	Surface Water Quality	Stormwater Drainage		
Borehole Geophysics on Bedrock Wells	October 2013 & March 2014	√	√	√			▪ Conducted borehole geophysics on three wells: – Scavenger Well #3 at Salt Shed – Existing well in Titus Lane area – New bedrock well at Exit 53 ▪ Performed groundwater sampling at specified fracture depths	▪ Confirm well depths and bedrock type ▪ Understand nature of bedrock fracture patterns ▪ Assess whether fractures provide flow into or out of the borehole ▪ Analyze groundwater quality at different fracture intervals
Groundwater Sampling	October 2013 & April 2014		√	√			▪ Performed two sample rounds on 10 new and 3 existing shallow monitoring wells along I-95 and at the Boxford Depot, respectively ▪ Sampled other available wells (MASCO irrigation well, Curtis Road test well, TW-1 bedrock well at Boxford Depot) ▪ Analytes: salt/deicing related indicators	▪ Assess deicing material impacts in overburden groundwater ▪ Assess shallow overburden groundwater quality during different seasons
Domestic Well Sampling	February 2014 – April 2014		√	√			▪ Collected / analyzed samples from 22 domestic wells ▪ Analytes: salt/deicing related indicators	▪ Evaluate nature and extent of salt impacts in bedrock groundwater
Winter Sampling Program	January 2014 – March 2014				√	√	▪ Performed three winter sampling events consisting of multiple stormwater and surface water samples at 18 stations ▪ Analytes: salt/deicing related indicators	▪ Assess runoff water quality from storm and snowmelt events ▪ Identify potential stormwater drainage system improvements to help address groundwater deicing impacts

3.2 Data Management

Initial efforts for this study included the collection of a large quantity of existing data related to wells, soil borings, surface water sample locations, water quality data, drainage facility information, and Town parcel information including those assessed by the MassDOT Salt Remediation Program. As the project progressed, field studies led to the collection of additional data.

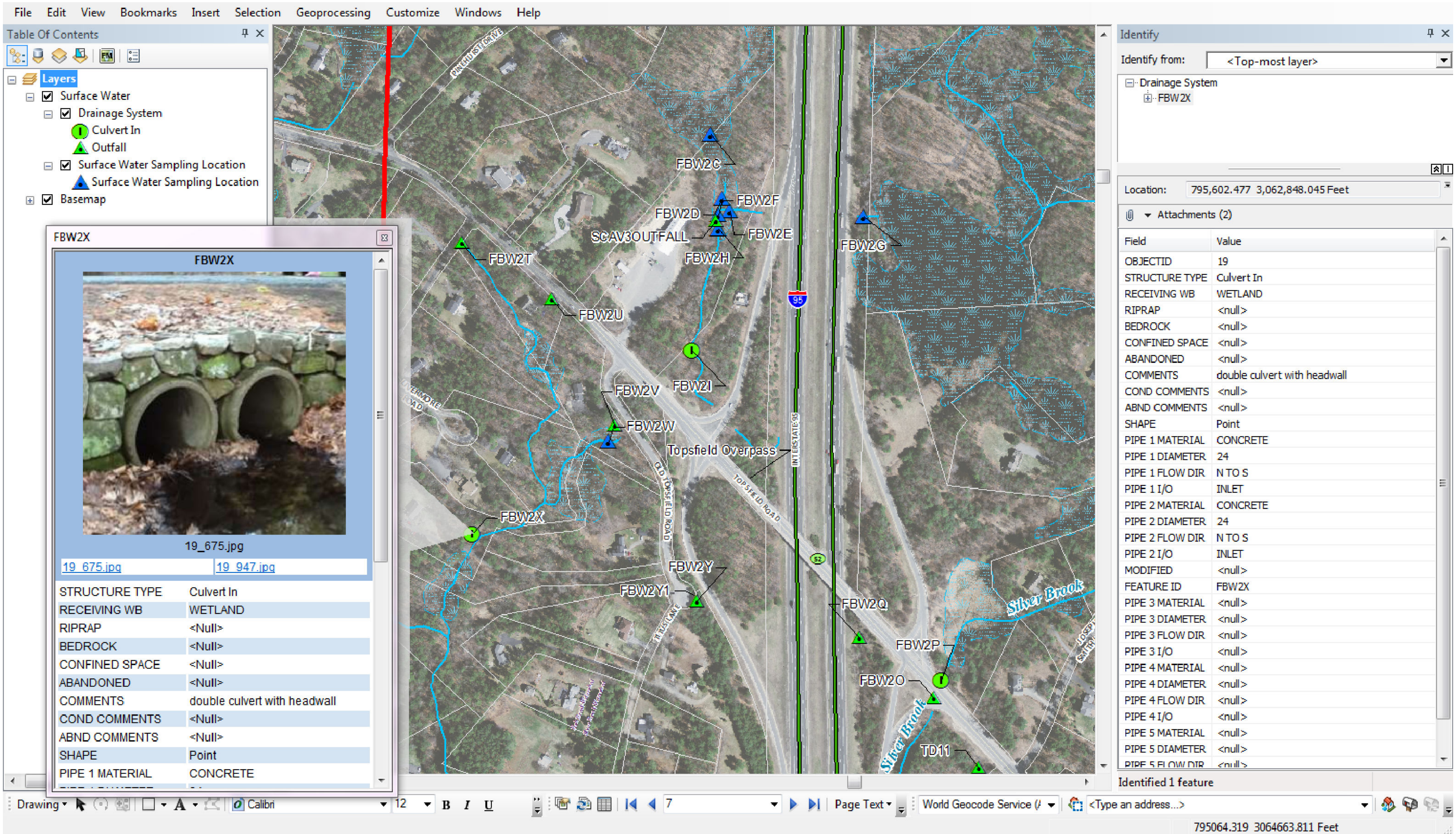
To facilitate data management and use, all data was maintained in an Environmental Systems Research Institute (ESRI) geodatabase which combines the "geo" (spatial data) and "database" (data repository) functionalities to create a central data repository for the Study. The geodatabase is accessed through ArcGIS, the software used to visualize and analyze data. **Figure 3-1** shows a screen capture of data (spatial and engineering details) and imagery (photos of sampling location) that can be accessed through the geodatabase.

This geodatabase platform was chosen because it allowed for field data, collected through an iPad or Geographic Positioning System (GPS), to be stored, managed, accessed, and visualized efficiently. In addition to the newly collected data, the historic data collected by UMass and MassDOT were imported into the geodatabase so that the database has the capacity to provide a comprehensive picture of the data collected throughout the Study Area over time. To the extent possible, historical MassDOT and UMass Amherst groundwater data were assigned to particular well locations and depths. However, for some parcels where replacement wells were installed information was insufficient to assign water quality results to a particular depth or well.

The geodatabase also includes elements of the Town and MassDOT drainage systems such as inlets, outlets, catch basins, and manholes. Having the hydrogeologic, surface water, soil, water quality, and engineering information in one place facilitated the visualization of the data spatially and allowed for efficient data analysis and interpretation. Data gaps could be effectively identified to focus field program needs. The capability to comprehensively view the large quantity of data compiled for the Study was integral to development of the conceptual model and performing the alternatives analysis.

The following locations, and associated water quality data if available, are stored in the project database:

- More than 600 hydrogeologic data points including more than 370 well and 230 soil boring locations.
- Over 100 surface water sampling locations including 41 historic MassDOT sampling locations as well as more than 70 additional sampling locations established by CDM Smith over the course of the Study.
- More than 200 data points representing inlets/outlets, catch basins, manholes, and culvert openings within the Study Area from the Town’s drainage system. Also included are 135 stormwater drainage channel segments from the Town’s system.
- Over 900 data points representing inlets/outlets, catch basins, and manholes from the I-95 stormwater drainage system. In addition, the delineation of more than 700 closed pipe segments and more than 200 open ditch segments that convey flow within the engineered drainage system of I-95.
- Over 500 Town Assessor parcel delineations within the Study Area.



MassDOT Boxford Salt Study

Figure 3-1

Example Screen Capture - Boxford Salt Study Geodatabase

Source: MassGIS, CDM Smith

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3.3 Field Program Sample Analytes

For deicing operations in the Study Area, MassDOT and the Town utilize, or have utilized in the past, road salt (sodium chloride - NaCl), as well as the liquid deicing agents calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$). As a result, calcium, magnesium, sodium, and chloride in dissolved form have been detected in water quality samples collected by MassDOT in the past. According to results from a United States Geological Survey (USGS) study of the quality of highway stormwater runoff concentrations (Smith and Granato, 2010), calcium, magnesium, sodium, and chloride concentrations in roadway runoff in Massachusetts can range from <1 to 270 milligrams per liter (mg/L) (calcium) , < 1 to 138 mg/L (magnesium), 2 to 12,700 mg/L (sodium), and 2 to 24,800 mg/L (chloride), respectively, and as such these constituents can be used as indicators of roadway runoff.

Calcium, magnesium, sodium, and chloride are ions, and have either a positive (cation) or negative (anion) charge associated with them. Specific conductance is a measurement of the ability of a substance to conduct an electric current. Solutions with increased concentrations of ions will also have increased specific conductance. As such, specific conductance is also commonly used as an indicator of roadway runoff because it is highly correlated with chloride concentrations (Hem, 1985; Smith and Granato, 2010).

The groundwater and surface water quality sampling programs conducted for the Study typically included analysis of one or more of the following parameter lists:

- Field parameters including specific conductance, pH, temperature, and dissolved oxygen. As indicated above, conductance is a good indicator of ion concentrations in a solution, such as chloride ions.

- Laboratory analysis of sodium and chloride. This reduced list of analytes was used for water quality screening purposes during the reconnaissance sampling program.

- Laboratory analysis of the following major ions: calcium, chloride, magnesium, potassium, sodium, sulfate, carbonate, and bicarbonate. This list of analytes was selected based on the major ions tested during a USGS highway runoff study (Smith and Granato, 2010).

- Laboratory analysis of bromide. Bromide was included in the list of analytes for the overburden wells and the bedrock well sampling associated with the geophysics program. Bromide was included for comparison with chloride concentrations.

The selected lab analytes for the sampling programs were based on the objectives of the individual field studies. Field parameters were typically collected at each location visited during a specific field program.

3.4 Study Area Reconnaissance

This section describes the field reconnaissance program that was conducted to map and improve the understanding of the stormwater drainage systems within the Study Area and assess how these systems might have impacted areas known to have high concentrations of road salt constituents in domestic wells. Water quality screening of drainage outfalls and surface water locations was also performed as part of this reconnaissance program.

3.4.1 Stormwater Drainage System Reconnaissance

Available drainage system information (i.e., catch basins, pipes, outfalls, inlets, and manholes) from I-95 highway design plans (U.S. DOT Federal Highway Administration, 1974) and Town drainage plans (Haley and Ward, October, 2011), supplemented by available LIDAR topography (Massachusetts Office of Geographic Information, 2011), were used to understand these engineered systems and the associated direction of stormwater flow. Through this effort, drainage structures and flow directions were incorporated onto the Map Panels presented in **Appendix C**.

Pye Brook Box Culvert under I-95

Data gaps were identified once all available drainage information was compiled and mapped. For instance drainage piping networks were not available for some sections of I-95 and in other areas flow directions needed to be identified or confirmed in the field. To address these data gaps, a field reconnaissance program was initiated which included the following:

Drainage System Inspection: Targeted locations along I-95 were visited from January to February 2013 to determine accessibility for sampling and area conditions. Based on findings, updated representations of the drainage system reflecting changes or modifications made by MassDOT were incorporated onto the Map Panels as appropriate. In addition, various pipe networks and drainage structures were inspected to ensure that the drainage systems were functioning properly. Drainage system maintenance and cleaning recommendations, as a result of these initial site visits, were reported to MassDOT for catch basins in the Exit 53 and Exit 51 areas. A revisit to these sites on June 9, 2014 determined that these catch basin maintenance issues had been addressed by MassDOT.

I-95 Drainage Outfall

Data Gap Review: I-95 drainage networks and associated flow direction information that was not available in the drainage plans collected from MassDOT and the Town were also the focus of field study. These efforts occurred during the same site visits as the drainage system inspections.

I-95 Drainage Water Quality Screening: Using both the I-95 design plans (invert elevations, flow arrows, pipe sizes) and LIDAR topography, more than 100 potential surface water and/or stormwater sample stations were identified for field screening. Water quality field readings and sampling were performed at these locations during the drainage system inspections.

Water Quality Screening Remote from I-95 (Country Drainage, or Town of Boxford Drainage): Additional water quality screening of locations that were hydraulically and hydrologically separate from the I-95 stormwater system were added to the reconnaissance effort in March 2013.

3.4.2 Water Quality Screening

Water quality screening at selected stormwater discharge points and in surface water was conducted from January through March 2013 during the stormwater drainage system reconnaissance field visits. This provided general information on water quality to further the understanding of surface water quality in the Study Area and to direct future field studies. Sampling locations included drainage ditches, swales, and unnamed streams, as well Pye Brook, Silver Brook, and Fish Brook near I-95 drainage outfalls. The water quality screening program consisted of grab sample collection at monitoring locations. Streamflow measurements were not collected.

3.4.2.1 Field Program Description

Water quality screening locations along I-95 were selected based on one or more of the following criteria:

Scavenger Well #3 Discharge to Stream Behind Boxford Depot Salt Shed

- Significant point of discharge from I-95 mainline and interchange drainage including Exits 51, 52, and 53.
- Representative points of discharge from catch basins along I-95.
- Inlets/outlets to streams crossing under I-95, some of which receive drainage from the I-95 engineered drainage systems.
- Past MassDOT sample point(s) based on water quality history or location relative to storm drainage.
- Storm drainage outlets near properties known to have wells impacted by deicing activities.
- Surface water sample points both upgradient and downgradient of the Boxford Depot.

Additional water quality screening of drainage outfall and stream culvert locations remote from I-95 (i.e., locations hydraulically and hydrologically separate from the I-95 stormwater system) was added to the reconnaissance effort. Remote locations were selected throughout the Study Area to assess potential impacts of the Town's deicing activities. Remote sampling points also provided background information for comparison to sample points along I-95.

Water quality screening field measurements included temperature, specific conductance, salinity, dissolved oxygen, pH, and oxygen reduction potential. Water samples were also collected for sodium and chloride analysis by Absolute Resource Associates (ARA). Field data was recorded using iPad Application Technology which allowed real-time documentation of all information directly into the GIS database.

From January through March 2013, more than 70 water quality screening locations were visited, of which 65 were sampled one or more times. Sites that were frozen, dry or inaccessible were not sampled. Multiple screenings typically occurred if the location was dry or frozen on the first reconnaissance attempt, if the location was spatially significant in relation to private wells that reported high concentrations of salt to the MassDOT Salt Remediation Program, or if previous screening showed high specific conductance, sodium, and/or chloride.

A summary of all screening locations and results is presented in **Table F-1** in **Appendix F**. Specific conductance, sodium, and chloride results are plotted on **Figure F-1** in **Appendix F.** Laboratory reports are also provided in **Appendix F**. All sample locations are plotted on the Map Panels in **Appendix B**.

3.4.2.2 Water Quality Screening Results Discussion

Water quality screening results are presented below, including discussion of the relationship of specific conductance to chloride based on study area data, review of weather/precipitation during dates when water quality samples were collected, and summary of sampling results.

Specific Conductance vs. Chloride

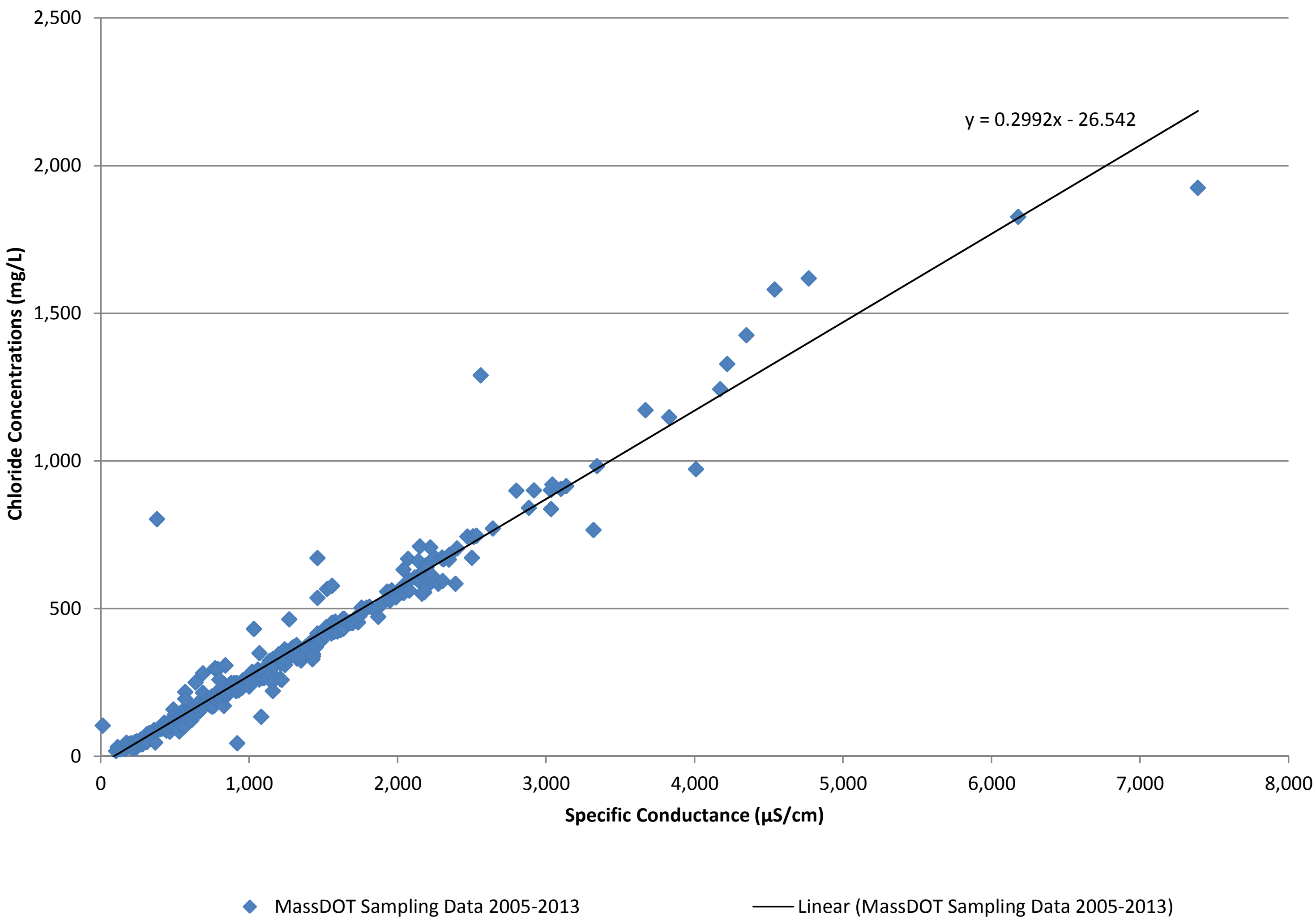
In the absence of chloride concentration data, specific conductance may be used as an indicator of relative chloride concentrations in the field. Solutions with increased concentrations of ions, such as chloride, will also have increased conductance. To illustrate this, reported chloride concentrations and measured specific conductance values for surface water samples collected in the Study Area from 2005 to 2013 are presented in **Figure 3-2.** The relationship between specific conductance and chloride is fairly linear.

Weather Conditions During Water Quality Screening

As the field screening was not conducted for specific weather events, there were some differences in meteorological conditions among the different sampling days.

Temperature, precipitation, and snow cover for the period over which the reconnaissance program was conducted are shown in **Figure 3-3**. The data presented are measurements collected at the Groveland, Massachusetts, National Weather Service Cooperative monitoring station (NWS COOP 193276). There is also a weather station in Boxford that is part of the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS). Quality control procedures are more robust for NWS COOPs, making them reliable sources of long term data. The period of record at the Groveland site is also longer than the Boxford site. Precipitation from the Groveland station is presented here and later in the report because it was also used for modeling analysis of stormwater runoff concentrations (described in Section 4). Precipitation totals at the Boxford and Groveland meteorological weather stations are very similar.

Snow depths during the reconnaissance sampling days ranged from trace amounts to 10 inches and temperatures ranged from 18 to 48 degrees Fahrenheit. There was snowfall or rain on or preceding many of the sampling days.

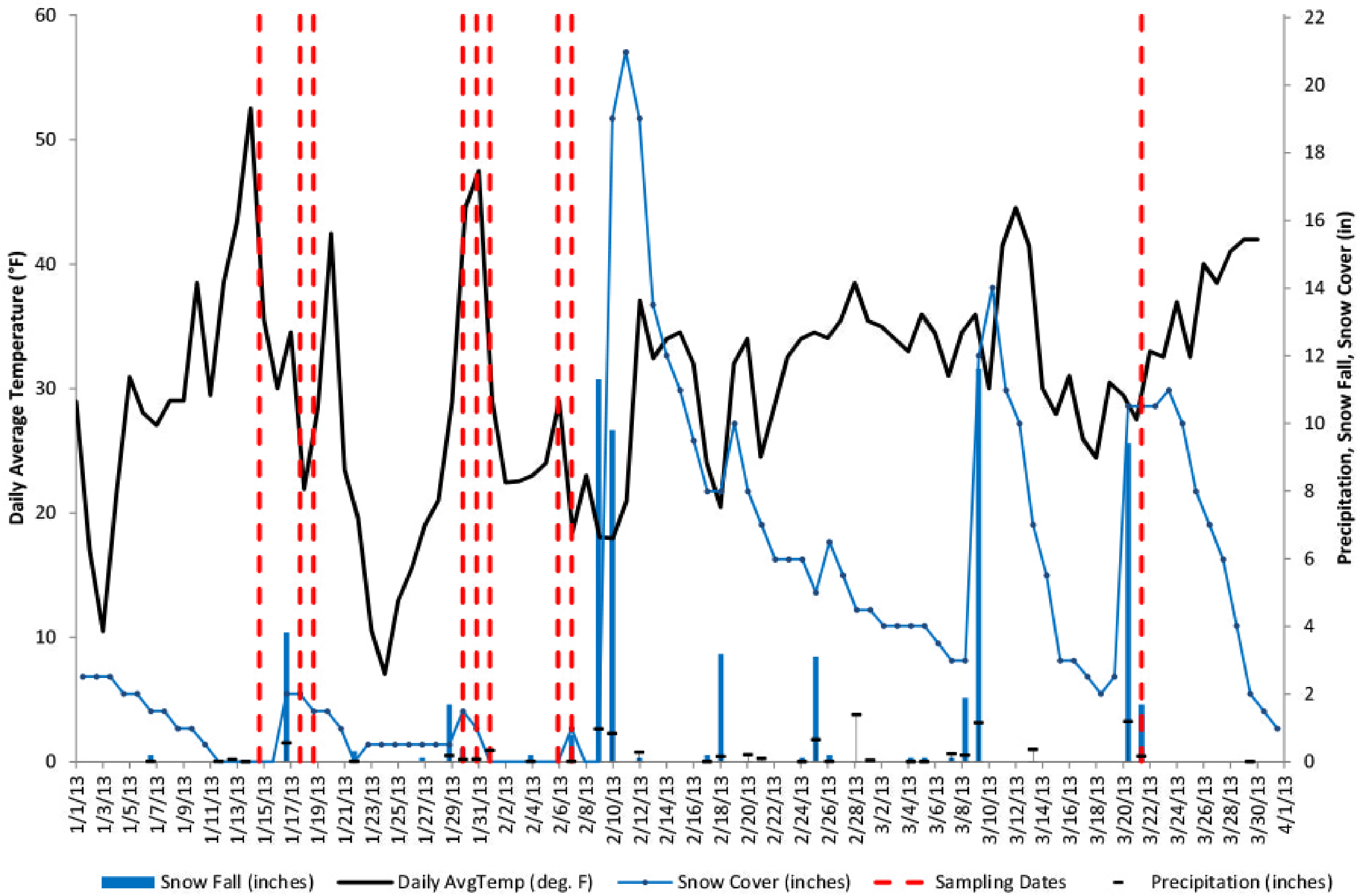


MassDOT Boxford Salt Study

Figure 3-2

Relationship between Specific Conductance and Chloride based on MassDOT Surface Water Sampling Data

Source: CDM Smith



Data Sources: Groveland NWS COOP 193276

Note: Precipitation shown on this figure is the water equivalent for various types of precipitation (i.e. snow, sleet, hail)

CDM Smith

MassDOT Boxford Salt Study

Figure 3-3

Precipitation and Climate Data for the Water Quality Screening Period January – March 2013

Source: CDM Smith

Results Summary

A summary of all screening locations and results is presented in **Appendix F** and shown on Map Panels in **Appendix B**. In general, the highest relative concentrations of sodium and chloride were found north of Exit 52 (FBW1A), downstream of the Exit 52 and Exit 53 ramp interchange discharges, and at I-95 discharges to Pye Brook. Typically, concentrations were lower at Town drainage sampling points than those at I-95 drainage locations, with the exception of Town drainage locations influenced by I-95 runoff (for example, IRW1A, IRW4E, FBW2W, and FBW2V). **Table 3-2** shows concentration ranges of sodium and chloride at locations receiving runoff from I-95 and locations remote from I-95.

Table 3-2
Water Quality Screening Results

Screening Parameter	Concentration Ranges (mg/L)	
	Locations Receiving Runoff from I-95	Locations Not Receiving Runoff from I-95
Sodium	22 - 3,200[a]	6 – 750
Chloride	32 - 5,100[b]	9 – 1,300

Notes:

[a]Three additional sites exhibited sodium concentrations up to 17,000 mg/L

[b]Three additional sites exhibited chloride concentrations up to 30,000 mg/L

The sodium and chloride concentrations at remote locations were an order of magnitude less than the lowest concentrations at locations impacted directly by I-95 runoff. The highest sodium and chloride concentrations were observed at locations receiving drainage from I-95, with three sampling points of significantly higher concentrations (FBW1A, FBW3K, and the Topsfield Road overpass). Maximum concentrations at the remote sampling locations occur at locations influenced by I-95 runoff (Fuller Lane and FBW2V). The maximum sodium and chloride concentrations at each interchange are shown in **Table 3-3**. The highest concentrations were at Exit 52 near Topsfield Road and I-95. Many of the sampling locations with higher sodium and chloride near Exits 52 and 53 are located close to areas where some residents have sought assistance from the MassDOT Salt Remediation Program due to salt impacts on domestic wells.

Table 3-3
Water Quality Screening Results - Maximum Concentrations at Interchanges

Screening Parameter	Maximum Concentrations (mg/L)		
	Exit 51	Exit 52	Exit 53
Sodium	400	6,400	1,600
Chloride	630	11,000	2,500

As previously discussed, MassDOT implemented two drainage modifications between 2005 and 2006, to help lessen salt impacts from roadway runoff to domestic wells (see **Section 2.3**). Water quality screening was conducted at the outlets of these implemented modifications. For the drainage modification that redirected additional discharge to Pye Brook (location PBW1W2), the sodium and chloride concentrations were 270 mg/L and 450 mg/L, respectively on January 29, 2013 at 12:30 pm and increased to 830 mg/L and 1,500 mg/L respectively at 3:00 pm. These increases likely reflect the snowfall and temperature rise on this date to more than 32°F. Further, the high concentrations at 3:00

pm likely reflect higher salt loading from the large catchment area of I-95 draining to this location. Nearby location PBW1W1, receiving significant drainage from a small catchment area, also had high concentrations of sodium (220 mg/L) and chloride (3,500 mg/L) on this same date. It is likely that deicing materials applied to I-95 during the snowfall event and when temperatures were above freezing, caused snowmelt and drainage flow to these sampling locations.

The MassDOT drainage modification that redirected additional stormwater discharge to a drainage swale tributary to Silver Brook (location FBW2AA) had sodium and chloride concentrations of 270 mg/L and 440 mg/L, respectively on the morning of January 29, 2013 during snowfall with temperature near 25°F. Snowmelt was not likely occurring when FBW2AA was sampled, likely yielding less flow and less salt load to the drainage system at that time.

3.5 Shallow Monitoring Well Installation and Well Sampling Program

Road salt from deicing operations is known to be present in stormwater drainage from I-95. This is evident from the historical stormwater and surface water sampling performed by MassDOT, as well as from the site reconnaissance water quality screening presented in **Section 3.4**. While much of the I-95 engineered drainage system discharges to streams, in other areas, piped discharge goes to wetlands, swales/ditches, and upland. In addition, there are areas of direct highway runoff and/or snowmelt which by-pass the I-95 engineered drainage system and discharge to surrounding areas. The result is the infiltration of stormwater discharges and runoff into the overburden soils and groundwater. As bedrock is close to the land surface in many locations in the Study Area along I-95, there is also the potential for direct infiltration into bedrock or via the shallow overburden into the underlying bedrock.

In addition to roadway runoff, salt stored and handled at the Boxford Depot likely contributed to elevated stormwater runoff concentrations from 1974 to 2005 when salt handling and loading was not performed under cover. As there is no stormwater drainage system at the Boxford Depot, runoff would have infiltrated through the pavement and surrounding grass areas into the underlying overburden. Shallow depths to bedrock likely allowed for groundwater flow into bedrock. Once the fabric extension to the salt shed was added in 2005, salt handling and loading was conducted under cover until site operations ceased in June 2009. The presence of cover likely reduced the exposure of salt spillage to precipitation during the 2005-2009 period. In addition, several Standard Operating Procedures (SOPs) and Best Management Practices (BMPs) were implemented during the 2004-2006 period which also likely helped reduce the amount of salt spillage during Boxford Depot operations through June 2009.

To better understand the highway deicing and salt storage and handling impacts on the overburden and shallow groundwater, a shallow monitoring well installation and sampling program was performed. The program included:

- ***Shallow Overburden Monitoring Well Installations:*** Ten shallow overburden monitoring wells were installed along I-95 to evaluate salt-impacted highway drainage and runoff on groundwater. Sites were selected to assess various project settings along I-95 based on differences in geology, hydrology, engineered drainage systems, highway runoff, known water quality, and areas of salt-impacted domestic wells. The wells provided an opportunity to assess salt concentrations in shallow groundwater and to better understand the relationship of groundwater quality to surface water/stormwater quality.

- ***Stratigraphy Characterization:*** Continuous soil samples were collected via direct push at each shallow monitoring well installation location to characterize overburden stratigraphy and establish depths to bedrock.

- ***Characterization of Salt Content in Overburden:*** Soil samples were collected in the shallow soil (within the top few feet) and just above the water table at each shallow monitoring well. An additional six shallow soil borings were conducted at the Boxford Depot. Laboratory analyses were performed on these samples to characterize the salt content of the soil and evaluate whether salt-impacted soil may function as an ongoing source contributing to groundwater impacts.

- ***Overburden Groundwater Sampling - Monitoring Wells:*** Groundwater samples were collected at the ten new shallow overburden monitoring wells, and up to three existing shallow wells located at the Boxford Depot. Sampling of these wells in both October 2013 and April 2014 allowed an evaluation of salt impacts to shallow groundwater and provided pre- and post-winter groundwater quality.

- ***Additional Well Sampling:*** Two other available overburden wells in the Study Area were also identified and sampled in April 2014. These included the irrigation well at the Masconomet Regional High School (MASCO) and a former Town test exploration well installed on Curtis Road.

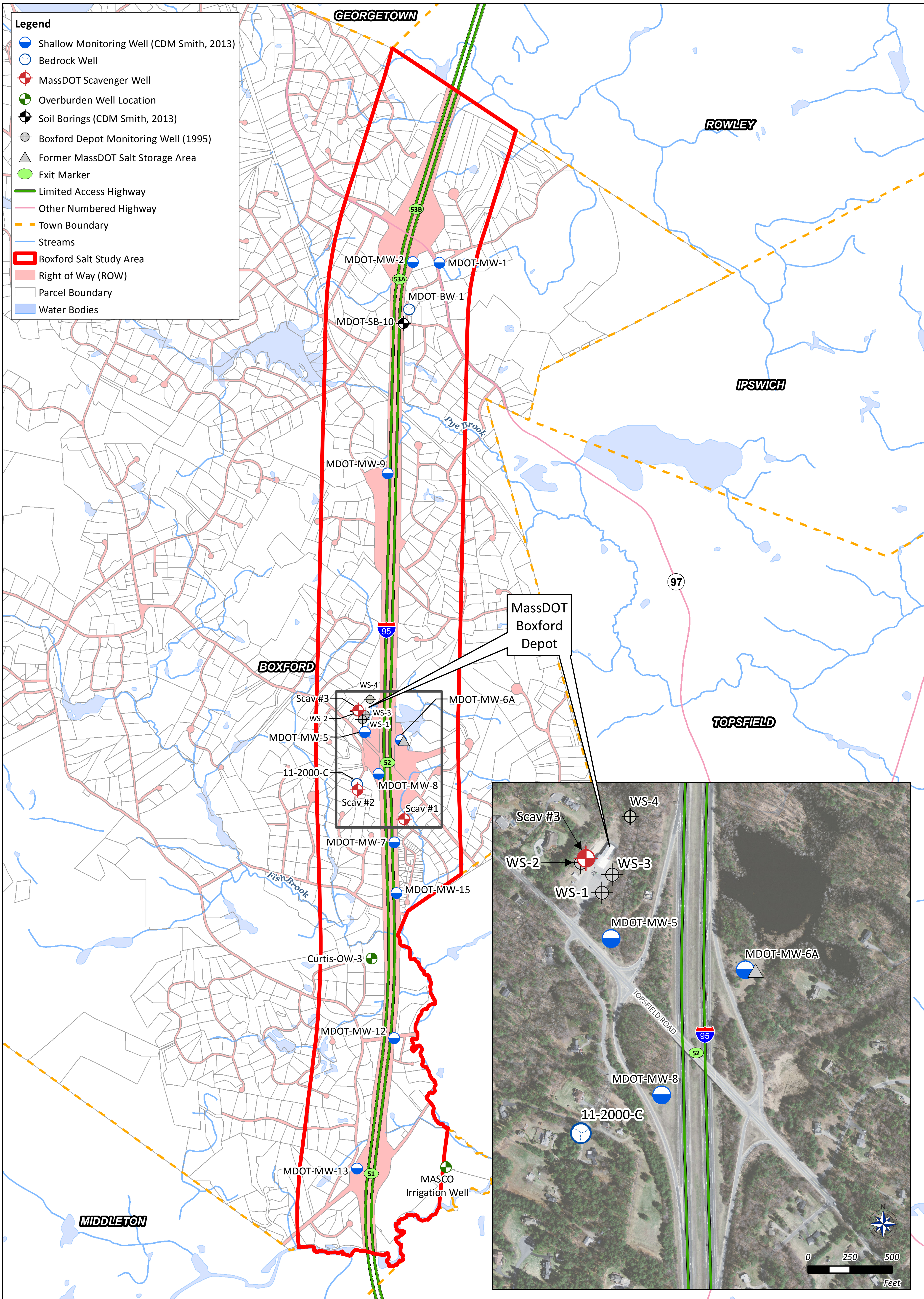
The locations of new and existing wells sampled for this program are shown on **Figure 3-4**. A summary of available well construction information for all wells sampled is presented on **Table 3-4**. Shallow monitoring well construction logs and soil boring logs for wells installed by CDM Smith are presented in **Appendix G**. A well record for the MASCO irrigation well is also included in **Appendix G.** No record is available for the Curtis Road test well.

3.5.1 Drilling Summary

During September 9-11, 2013, ten shallow overburden groundwater monitoring wells were installed by Geosearch, Inc., serving as a subcontractor to CDM Smith. Well installation oversight was performed by CDM Smith along with MassDOT personnel. MassDOT personnel also assumed responsibility for well development which was conducted on September 16-17, 2013.

The monitoring wells were installed to provide the following data/information:

- Overburden thickness
- Depth to bedrock or refusal
- Stratigraphy characterization



MassDOT Boxford Salt Study

Figure 3-4

Groundwater Sampling Locations

Shallow Monitoring Wells and Bedrock Wells

0 1,000 2,000 3,000 4,000 Feet

Source: MassGIS, CDM Smith

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Table 3-4
Summary of Overburden Shallow Monitoring Well Construction

Well ID	Property (Location)	Drilling Attempts[1, 2]	Total Depth Drilled[2] (feet-BGS)	Well Depth (feet-BGS)	Well Diameter (inches)	Well Screen			Initial Water Level (feet-BGS)
						Length (feet)	Interval (feet-BGS)	Strata	
Shallow Monitoring Wells Installed by CDM Smith – September 2013									
MDOT-MW-1	DCR	N/A	15 R	15	1.5	10	4-14	CMF SAND	6.64
MDOT-MW-2	ROW-I-95	#1 – 4.5 R #2 – 13 R #3 – 9 R	12 R	12	1	10	2-12	CF GRAVEL and CMF SAND	DRY at 12.16
MDOT-MW-5	MassDOT	#1 – 2.5 R #2 – 7 R #3 – 5.5 R #4 – 4.5 R	15.5 R	15.5	1	10	5.5-15.5	CMF SAND, some cf gravel	9.4
MDOT-MW-6A	MassDOT	#1 – 14 R #2 – 12 R #3 – 14.5 R	14 R	14	1.5	10	4-14	CF GRAVEL and CMF SAND	9
MDOT-MW-7	ROW-I-95	N/A	16.5 R	15	1.5	10	5-15	FINE SAND, little silt	7.21
MDOT-MW-8	ROW-I-95	#1 – 13 R #2 – 15 R	20 R	15	1.5	10	5-15	CMF SAND, little cf gravel	11.22
MDOT-MW-9	ROW-I-95	#1 – 5.5 R #2 – 10.5 R	15 R	15	1.5	10	5-15	CMF SAND	7.08
MDOT-SB-10[3]	ROW-I-95 or MassDOT	N/A	10.6 R	--	--	--	--	CMF SAND	DRY at 10.6
MDOT-MW-12	ROW-I-95	N/A	25	25	1.5	20	5-25	FINE SAND	10.22
MDOT-MW-13	ROW-I-95	#1 – 12 R	15 R	15	1	10	5-15	FINE SAND, little cm sand and silt	DRY at 14.55
MDOT-MW-15	ROW-I-95	N/A	20	20	1.5	10	7-17	MF SAND	8.23

Table 3-4 (Cont'd)
Summary of Overburden Shallow Monitoring Well Construction

Well ID	Property (Location)	Drilling Attempts[1, 2]	Total Depth Drilled[2] (feet-BGS)	Well Depth (feet-BGS)	Well Diameter (inches)	Well Screen			Initial Water Level (feet-BGS)
						Length (feet)	Interval (feet-BGS)	Strata	
Existing Shallow Monitoring Wells at the Boxford Depot – 1995[4]									
WS-2 (1995)	MassDOT	N/A	5.9 R	5.5	2	3	2.5-5.5	CMF SAND, some cf gravel	3.0
WS-3 (1995)	MassDOT	N/A	9.0 R	9.0	2	5	4-9	CMF GRAVEL, some cf sand and silt	7.9
WS-4 (1995	MassDOT	N/A	9.9	9.9	2	5	4.9-9.9	CMF GRAVEL AND SAND	8.5
Other Study Area Overburden Wells									
MASCO Irrigation Well (2009)	Masconomet High School	N/A	51	9.9	8	3	48-51	GRAVEL	6.40
CURTIS OW-3 (Installed 1960s)	Town - Curtis Road Test Well Site	N/A	---	34.03	2.5	---	---	---	5.88[5]

Notes:
[1]Record of multiple drilling attempts at some locations due to shallow refusal, with depth to refusal in feet-BGS.
[2]R represents refusal encountered.
[3]At MDOT-SB-10, a shallow monitoring well was not installed; only a shallow soil boring was conducted.
[4]Weston & Sampson Engineers, Inc., Facility Identification #58, Initial Investigation/Assessment Report, MassHighway, Boxford Facility, Boxford, MA, November 20, 1995.
[5]Measured by CDM Smith at the time of sampling.

Abbreviations:
BGS: below ground surface
DCR: Department of Conservation and Recreation

MASCO: Masconomet High School
MDOT: Massachusetts Department of Transportation
MW: monitoring well
N/A: Not Applicable
OW: Town observation well
R: refusal
ROW: right-of-way
SB: soil boring

Strata:
C, c: coarse
M, m: medium
F, f: fine

- Depth to water table
- Salt content in overburden soil and groundwater

Monitoring well locations were selected to allow characterization of overburden groundwater and soil in different project settings. **Table 3-5** summarizes the location and project setting of each well with regard to the rationale for site selection. Target locations for well installation are summarized as follows:

- Areas of former salt storage including the Boxford Depot and the former uncovered / unlined salt storage area east of Exit 52.
- Vicinity of salt impacted domestic wells as identified via the MassDOT Salt Remediation Program.
- I-95 interchanges and along I-95 mainline runs to evaluate highway deicing impacts in these different settings.
- Areas where stormwater discharges and/or surface water exhibited elevated salt content, as determined during the site reconnaissance water quality screening described in **Section 3.4.**
- Various stormwater drainage settings such as point source discharge locations to wetlands, streams or drainage ditches, and areas of uncontained I-95 runoff with possible overland flow.

Drilling methods used during the shallow overburden monitoring well installation program consisted of direct push technology using a 6610 track mounted Geoprobe® drill rig. During borehole advancement, five foot soil cores were extracted continuously until refusal and/or bedrock was encountered. Soil core samples were logged and soil samples for laboratory analysis were collected in accordance with QAP Section 4 (see **Appendix E**). These soil samples were collected from just a few feet below the ground surface and just above the water table at each boring/well location. Each sample was homogenized and analyzed for sodium, chloride, and specific conductance by ARA. Analytical results are provided in **Section 3.5.2**.

The overburden encountered during borehole advancement across the center to northern portions of the Study Area (I-95 Exit 52 north to Exit 53) consisted of coarse-fine gravel and sand with shallow depth to bedrock ranging from 10-16 feet-below ground surface (BGS). The overburden encountered across the center to southern portions of the Study Area consisted of thicker and finer overburden deposits with greater depth to bedrock (greater than 20 feet-BGS), with the exception of MDOT-MW-13, which was located not far from a bedrock outcrop.

All new monitoring wells were installed in the shallow overburden and screened across the water table, with the exception of two wells (MDOT-MW-2 and MDOT-MW-13) which were installed above the water table due to shallow borehole refusal. An attempt was made to install a well at proposed well location MDOT-SB-10, however, no well was installed because groundwater was not encountered at the refusal depth of 10.5 feet-BGS.

Table 3-5
Overburden Shallow Monitoring Well Objectives

Well ID	Map Panel Number	Property	Location Description	Hydrologic Setting of Shallow Monitoring Well
MDOT-MW-1	2	DCR	Exit 53: Intersection of Rowley and Killam Hill Roads	▪ Receives drainage from Killam Hill Road/Rowley Road at Exit 53 ▪ Adjacent to stormwater drainage discharge into wetland ▪ Stormwater quality screening data indicated elevated salt concentrations ▪ Salt-impacted domestic wells nearby
MDOT-MW-2	2	ROW I-95	Exit 53 Interchange southeast quadrant	▪ Potential runoff impacts from I-95 and Exit 53 NB off-ramp ▪ Potentially upgradient of salt-impacted domestic wells
MDOT-MW-5	7	MassDOT	South end of MassDOT Boxford Depot	▪ Downgradient of groundwater flow from salt shed ▪ Adjacent stream receives highway drainage, overland flow from salt shed, and Scavenger Well #3 discharge ▪ Surface water quality screening data indicated elevated salt concentrations ▪ Potential stormwater runoff from Topsfield Road ▪ Potentially upgradient of salt-impacted domestic wells
MDOT-MW-6A	7	MassDOT	Former MassDOT salt storage area (east of I-95 Exit 52)	▪ At site of MassDOT former unlined/uncovered salt storage area ▪ Potentially upgradient of salt-impacted domestic wells ▪ Receives runoff and some remote stormwater discharge from I-95 Exit 52 NB on-ramp
MDOT-MW-7	8	ROW I-95	East of I-95 NB near Silverbrook Road	▪ Area of no I-95 point source discharge (I-95 drainage modified in 2005/6) ▪ Potential of highway runoff; potential indicator of snow melt impacts ▪ Near former Scavenger Well #1 ▪ Near Silverbrook Road area of salt-impacted domestic wells
MDOT-MW-8	8	ROW I-95	Exit 52 Interchange southwest quadrant	▪ Potential runoff from Topsfield Road overpass, I-95 SB, and Exit 52 I-95 SB on-ramp ▪ Upgradient stormwater discharge from Topsfield Road ▪ Potentially upgradient of salt-impacted domestic wells in Titus Lane & Silverbrook Road areas
MDOT-MW-9	5	ROW I-95	West of I-95 SB near Bare Hill Road	▪ Area receives I-95 point source stormwater drainage ▪ Potential I-95 runoff and snowmelt impacts

Table 3-5 (Cont'd)
Overburden Shallow Monitoring Well Objectives

Well ID	Map Panel Number	Property	Location Description	Hydrologic Setting of Shallow Monitoring Well
MDOT-SB-10[1]	3	ROW I-95 or MassDOT	East of I-95 NB at Ipswich Street	▪ Area of shallow bedrock and outcrops ▪ No I-95 point source discharge; potential I-95 runoff and snowmelt impacts ▪ Near area of salt-impacted domestic wells
MDOT-MW-12	10	ROW I-95	East of I-95 SB at Fuller Lane underpass	▪ Low lying area at underpass subject to overland flow ▪ Potential runoff and snowmelt impacts from I-95 NB (at base of steep grade) ▪ Nearby surface water quality screening data indicated elevated salt concentrations ▪ Vicinity of salt-impacted domestic wells
MDOT-MW-13	12	ROW I-95	Exit 51 Interchange northeast quadrant	▪ No I-95 point source discharge ▪ Potential Exit 53 runoff and snowmelt impacts ▪ Near salt-impacted domestic well
MDOT-MW-15	9	ROW I-95	East of I-95 NB near Andrews Farm Well	▪ Area of point source stormwater discharges from I-95 to drainage swale ▪ Stormwater quality screening data indicated elevated salt concentrations ▪ Potential I-95 stormwater runoff and snowmelt impacts ▪ Assess overburden groundwater quality near Andrews Farm bedrock supply well

Abbreviations:

DCR: Division of Conservation and Recreation
MDOT: Massachusetts Department of Transportation
MW: Monitoring well
NB: Northbound lane of I-95
ROW: Right-of-way
SB: Southbound lane of I-95

Notes:

[1]At MDOT-SB-10, a shallow monitoring well was not installed; only a shallow soil boring was conducted.

Seven of the ten groundwater monitoring wells were installed with 1.5" diameter schedule-40 PVC risers and 10-20 foot long, 0.01" slot schedule-40 PVC well screens. The three remaining wells were installed with 1" PVC risers and screens due to encountering refusal when attempting to drive 3.25" temporary steel casing for well installation. Since the desired depth was not achieved when driving the 3.25" temporary steel casing, 1" wells were installed in the drilled boreholes next to the refusal location. The screens installed for the 1" wells were 10 feet long, and the top of the screens ranged in depth from 2 to 6 feet-BGS. The annular space around each overburden well was backfilled with sand to a depth of one to two feet above the screen, and one to two feet of bentonite was placed above the sand. The remaining annulus, ranging in depth from 1 to 3 feet-BGS, was sealed with concrete. Each well was furnished with a locking 4" protective steel casing having a 2 to 3 foot stickup above the ground surface.

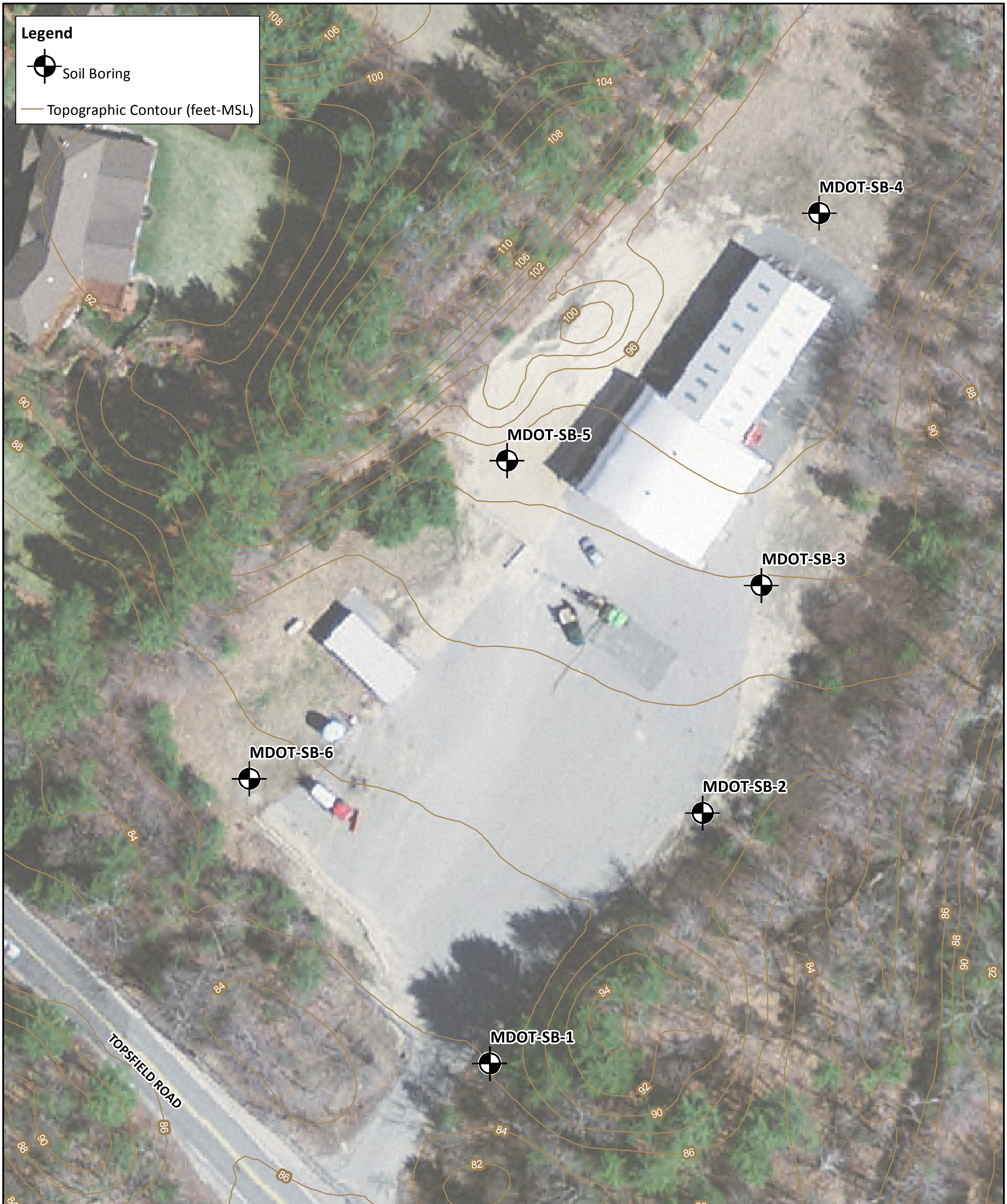
In addition to the shallow well installation program, six shallow soil borings were advanced by Geosearch Inc., via direct push at the Boxford Depot on January 24, 2014. The six borings (MDOT-SB-1 through MDOT-SB-6) were advanced outside the paved area to further assess the potential accumulation of salt in the shallow overburden around the salt shed. The shallow boring locations are shown on **Figure 3-5**. Based on location, it would be expected that all these borings would receive runoff from the paved area, except for MDOT-SB-4 which is located behind the shed. The predominant direction of runoff across the site operations area is to the east, south, and southeast, such that MDOT-SB-3 is directly downgradient of the salt shed and MDOT-SB-1 and MDOT-SB-2 are further downgradient of general site operations. The overburden encountered in the borings consisted of coarse-fine gravel and sand. Analytical soil samples were collected in the top 0-5 feet-BGS as well as just above the water table at each boring location and were analyzed for sodium, chloride, and specific conductance by ARA. All the borings were backfilled with drill cuttings and silica sand upon completion.

3.5.2 Soil Quality

Soil quality sampling was conducted by CDM Smith during both the overburden well installation program along I-95 and the shallow soil boring program conducted at the Boxford Depot, to characterize salt content in overburden. Soil samples for laboratory analysis were collected from near the ground surface and near the water table as described in **Section 3.5.1**. Soil sample composition and mineralogy were not analyzed.

I-95 Shallow Monitoring Well Soil Quality

Overburden shallow monitoring well soil quality data is presented in **Table 3-6**. Laboratory reports are provided in **Appendix H**. Sodium concentrations were, in general, substantially higher than those of chloride in those cases where both were detected. This likely reflects the fact that sodium is known to adhere to finer soils, whereas chloride tends to remain dissolved in groundwater. For the purpose of the following discussion, the results by location have been grouped relative to sodium concentrations in the categories of high, moderate, low, and none. At most locations, concentrations in deeper samples were greater than those reported for shallower samples.



MassDOT Boxford Salt Study
Figure 3-5
Boxford Depot Soil Boring Locations

0 50 100 Feet

N

Source: MassGIS, CDM Smith

billingsmc Z:\Boxford\MXD\DRAFT_Report_Figures\Section3\Fig3_5_Boring_Locations.mxd 8/26/2014

Table 3-6
Overburden Shallow Monitoring Well Soil Quality - Analytical Results

Monitoring Well ID	Map Panel Number	Depth Interval (feet-BGS)	Sodium (µg/g)	Chloride (µg/g)	Specific Conductance (µS/cm)[1]
MDOT-MW-1	2	0-2	520	52	30
		2-5	220	89	46
MDOT-MW-2	2	0-5	94	<5.5	12
		10-15	140	11	16
MDOT-MW-5	7	0-2	57	<5.3	5
		5-7	57	<5.5	<5
MDOT-MW-6A	7	0-5	94	<5.2	25
		0-5 (DUP-1)	92	<5.3	7
		5-10	130	<5.5	10
		5-10 (DUP-2)	150	<5.5	10
MDOT-MW-7	8	0-5	160	<5.3	9
		5-10	94	43	21
MDOT-MW-8	8	0-5	<50	<5.3	<5
		5-10	290	130	54
MDOT-MW-9	5	0-5	220	<27[2]	14[2]
		5-10	220	12	59
MDOT-SB-10	3	0-5	<49	<5.2	11
		5-10	<55	<5.5	14
MDOT-MW-12	10	0-5	<54	<5.6	15.0
		5-10	<60	7.2	9.0
MDOT-MW-13	12	0-2	<50	<5.2	6
		5-10	<48	<5.3	<5
MDOT-MW-15	9	0-2	340	78	24
		2-5	380	130	71

Notes:

[1]Results reported as conductivity in micromhos per centimeter at 25°C which is equivalent to specific conductance in microsiemens per centimeter.

[2]Higher detection limit due to sample dilution because of matrix interference.

Abbreviations:
DUP: Duplicate sample
feet-BGS: feet below ground surface
MDOT: Massachusetts Department of Transportation
MW: Monitoring well
SB: Soil boring
µg/g: micrograms per gram (ppm)
µS/cm: microsiemens per centimeter

- ***High Relative Concentrations:*** Sodium concentrations ranged from 220 to 520 micrograms per gram (μg/g) at MDOT-MW-1, MDOT-MW-8, MDOT-MW-9, and MDOT-MW-15, all of which are adjacent to or in the vicinity of direct point source stormwater discharges from I-95. Of these, elevated salt concentrations were present in stormwater drainage outlets adjacent to MDOT-MW-1 and MDOT-MW-15 during previous site reconnaissance water quality screening. The area of MDOT-MW-1 also likely receives runoff from Rowley and Killam Hill Roads at Exit 53. The high concentrations at MDOT-MW-8 (sodium - 290 μg/g and chloride - 130 μg/g) more likely reflect impacts of runoff at Exit 52 and Topsfield Road. This location had one of the highest concentrations of chloride which was detected in the sample collected directly above the water table. MDOT-MW-1 also had comparatively high chloride concentrations ranging from 52 to 89 μg/g.

- ***Moderate Relative Concentrations:*** MDOT-MW-2, MDOT-MW-6A, and MDOT-MW-7 had moderate concentrations of sodium on a relative basis ranging from 92 – 160 μg/g. All of these locations likely receive some direct stormwater runoff from the interchanges or I-95 mainlines. None are in the immediate vicinity of a direct stormwater discharge. It is possible that MDOT-MW-6A concentrations reflect residual salt content from the previous unlined uncovered salt storage in this area operated by MassDOT previous to 1974.

- ***Low Relative Concentrations:*** The only location with a low relative sodium concentration (57 μg/g) was at MDOT-MW-5 which is located at the Boxford Depot property, downgradient of the salt shed and related operations. There was no chloride detected at this location and low specific conductance suggesting the sodium to be representative of background conditions. Given its location north of the drainage channel, it is possible that the unsaturated soils at this location are not influenced by local runoff from Topsfield Road nor the Boxford Depot given the distance (250 feet) from the salt shed paved area.

- ***Non-Detects:*** No sodium detections were observed at MDOT-SB-10, MDOT-MW-12, and, MDOT-MW-13. The settings at these locations are all similar in that they are along the I-95 mainline or exit ramp and there is no nearby point source stormwater discharge. Results suggest that at these locations, there is no apparent effect of roadway runoff impacting the unsaturated soils.

Boxford Depot Soil Quality

Soil quality data collected during the salt shed boring program is presented in **Table 3-7**. Sodium was detected in all soil samples collected from borings at MDOT-SB-1 through MDOT-SB-6. Chloride was detected in all samples except the shallow samples from MDOT-SB-4 and MDOT-SB-5. The following observations are based on the Boxford Depot soil quality results:

- MDOT-SB-1 had high concentrations of both sodium (220-620 μg/g) and chloride (230-670 μg/g). This location may have been influenced in the past by stormwater runoff from the paved area at the Depot.

- MDOT-SB-2 had the highest concentration of sodium (1,200 μg/g) detected in the sample collected directly above the water table. The shallow soil sodium concentration (260 μg/g) and chloride concentrations (160-320 µg/g) were in the range of MDOT-SB-1 results. Again, these high concentrations likely reflect runoff from the paved area.

- MDOT-SB-3 had relatively low sodium (97 µg/g) and chloride (5.9 µg/g) concentrations in the shallow depth, but higher concentrations (370 µg/g sodium and 200 µg/g chloride) at the depth above the water table, similar in magnitude to MDOT-SB-1. The higher concentrations at this depth are consistent with those of soils impacted by runoff.
- MDOT-SB-5 located just southwest of the salt shed extension had high sodium concentrations (390-600 µg/g) and very low chloride. Although not necessarily downgradient of the shed and pavement, this area is immediately adjacent to past salt handling operations and results may reflect past practices.
- MDOT-SB-6, located at the southwest edge of the paved area was likely impacted by direct runoff from the pavement, but less likely than other areas given the lower range of sodium (51-150 µg/g) and chloride (19-160 µg/g) concentrations.
- MDOT-SB-4, located behind the shed, had moderately high (330 µg/g) and low (65 µg/g) sodium concentration in the deeper and shallow samples, respectively. Chloride concentrations were very low. The sodium likely reflects impacts of past salt storage.

Table 3-7
Soil Samples at Boxford Depot - Analytical Results

Soil Boring ID	Depth Interval (feet-BGS)	Sodium (µg/g)	Chloride (µg/g)	Specific Conductance[1] (µS/cm)
MDOT-SB-1	0-5	470	430	160
	5-10	220	230	110
	0-5 (DUP-1)	620	670	170
MDOT-SB-2	0-5	260	160	72
	5-10	1,200	320	99
MDOT-SB-3	0-5	97	5.9	9
	5-8	370	200	91
MDOT-SB-4	0-5	65	<5.7	6
	5-6	330	8	110
MDOT-SB-5	0-2	600	<6.1	27
	4-4.5	390	7.9	49
MDOT-SB-6	0-5	51	19	13
	5-10	150	160	66

Notes:

[1]Results reported as conductivity in micromhos per centimeter at 25°C which is equivalent to specific conductance in microsiemens per centimeter.

Abbreviations:

DUP: Duplicate sample
feet-BGS: feet below ground surface
MDOT: Massachusetts Department of Transportation
SB: Soil boring
µg/g: micrograms per gram (ppm)
µS/cm: microsiemens per centimeter

3.5.3 Groundwater Quality at New Shallow Wells

Groundwater quality sampling of the newly installed monitoring wells was conducted in October 2013 to establish baseline shallow overburden groundwater quality in the Study Area with respect to soluble salt concentrations, and again in April 2014 after the 2013/2014 winter season. Groundwater samples were collected from eight of the ten newly installed wells in October 2013 as MDOT-MW-2 and MDOT-MW-13 were dry at the time of sampling. All ten wells were sampled in April 2014.

Samples were collected using low flow sampling techniques in accordance with QAP Section 1 (see **Appendix E**). Field parameters including temperature, specific conductance, salinity, dissolved oxygen, pH, oxidation-reduction potential, and turbidity were recorded. Water samples were analyzed for the following major ions in dissolved form: calcium, chloride, magnesium, potassium, sodium, sulfate, bromide, and bicarbonate/carbonate alkalinity with results summarized in **Table 3-8**. Field parameter measurements are provided in **Table I-1** in **Appendix I**. Laboratory analytical reports are included in **Appendix H**.

In most but not all cases, chloride concentrations for each well sample were higher than those of sodium. While groundwater levels in the wells rose at all locations between the October 2013 and April 2014 sample events, there was no discernible consistency in water quality concentration changes between the two sampling events.

All of the monitoring well samples collected during both sampling events had sodium concentrations exceeding the MassDEP Office of Research Standards Guideline (ORSG) of 20 mg/L, with the exception of the April 2014 sample collected from MDOT-MW-5, which had a concentration equal to 20 mg/L. Many of the chloride concentrations exceeded the EPA and Massachusetts Secondary Maximum Contaminant Level (SMCL) of 250 mg/L. Specific conductance generally reflects the range of chloride concentrations, with high specific conductance measured for samples with high chloride concentrations and lower specific conductance recorded for samples having a lower concentration of chloride.

The duplicate pair collected at MDOT-MW-8 in April 2014 exhibited inconsistent results of 57 mg/L and 860 mg/L, respectively. The reason for the different results is not clear; the remaining parameters for this duplicate pair generally exhibited similar results. As the specific conductance for MDOT-MW-8 in April 2014 was 2,795 microsiemens per centimeter (µS/cm), it is likely that the 860 mg/L chloride concentration is more representative of the sample.

Chloride concentrations for the duplicate pair collected at MDOT-MW-12 in April 2014 were also inconsistent with a concentration of 1,100 mg/L and 420 mg/L for the duplicate. All other parameters for this duplicate pair were consistent. The specific conductance for this sample was 4,101 µS/cm. As this was the highest specific conductance measured at the shallow monitoring wells, it is likely that the higher chloride concentration of 1,100 mg/L is more representative of the groundwater sample.

Table 3-8
Overburden Shallow Monitoring Well Water Quality Results -
Specific Conductance and Laboratory Parameters

Well ID	Date	Field Parameter[3]	Laboratory Parameters – Dissolved [1, 2]									
		Specific Conductance (µS/cm)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium[4] (mg/L)	Bromide (mg/L)	Chloride[5] (mg/L)	Sulfate[6] (mg/L)	Alkalinity, Bicarbonate (mg/L)	Alkalinity, Carbonate (mg/L)	Alkalinity, Total (as $CaCO_3$) (mg/L)
MDOT-MW-1	10/30/13	3,528	59	11	6.9	530	<0.5	1,000	50	110	<5	110
	4/3/14	3,079	60	11	4.4	530	0.1	960	48	83	< 5	83
	4/3/14 (Dup-3)	---	59	11	4.5	920	0.2	970	48	61	<5	61
MDOT-MW-2	10/31/13	DRY										
	4/3/2014	4.32	14	1.0	1.4	66	< 0.1	110	9.5	25	< 5	25
MDOT-MW-5	10/30/13	1,317	50	12	2.1	150	<0.5	360	17	54	<5	54
	10/30/13 (DUP-1)	---	50	11	1.9	150	<0.5	360	17	50	<5	50
	4/2/14	123	4.2	1.2	0.5	20	< 0.1	30	8.8	7	< 5	7
MDOT-MW-6A	10/31/13	537	5.5	1.1	1.9	91	<0.1	88	12	120	<5	120
	10/31/13 (DUP-2)	---	5.7	1.2	2.0	95	<0.1	88	12	120	<5	120
	4/3/2014	214	3	0.5	1.1	47	< 0.1	16	7.6	81	< 5	81
MDOT-MW-7	10/31/13	563	4.5	1.7	1.4	88	<0.1	150	25	8	<5	8
	10/31/13 (DUP-3)	---	4.4	1.7	1.4	87	<0.1	150	25	8	<5	8
	4/3/2014	1,427	11	3.9	1.8	260	0.2	440	12	8	< 5	8
MDOT-MW-8	10/31/2013	3,735	76	17	7.3	570	<0.5	1,100	25	200	<5	200
	4/2/2014	2,795	60	10	2.7	470	1.1	57	18	110	< 5	110
	4/2/2014 (DUP-1)	---	57	11	2.7	450	0.6	860	18	110	< 5	110
MDOT-MW-9	10/31/2013	1,921	52	2.9	2.7	310	<0.5	470	16	260	<5	260
	4/3/2014	2,784	64	4.5	3.2	420	0.3	790	16	120	< 5	120
MDOT-MW-12	10/30/2013	3,044	53	8.2	5.6	500	<0.5	920	66	44	<5	44
	4/2/2014	4,101	74	13	14	670	< 0.5	1,100	86	140	< 5	140
	4/2/2014 (DUP-2)	---	73	13	14	680	1.4	420	85	140	< 5	140
MDOT-MW-13	10/31/2013	DRY										
	4/2/2014	420	7.4	1.2	1.2	90	< 0.1	130	16	30	< 5	30
MDOT-MW-15	10/31/2013	2,359	43	11	5.2	340	<0.5	590	38	140	<5	140
	4/3/2014	3,878	74	21	6.1	660	0.4	1,100	41	250	< 5	250
WS-2	10/30/2013	389	38	4.1	2.0	28	<0.1	2.3	3	190	<5	190
	4/2/2014	35	1.3	<0.3	<0.5	4.8	<0.1	2.0	1.4	10	<5	10
WS-3	10/30/2013	DRY										
	4/2/2014	1,383	2.8	0.5	0.6	270	<0.1	420	3.4	32	<5	32
WS-4	10/30/2013	DRY										
	4/2/2014	468	1.4	0.4	1.1	110	<0.1	19	5.6	200	<5	200
MASCO Irrigation Well	4/3/2014	2,601	190	47	7.3	260	0.1	760	38	140	< 5	140
Curtis-OW-3	4/18/2014	141	10	2.8	0.8	10	< 0.1	19	8.7	23	< 5	23

Notes:
[1]Analysis by Absolute Resource Associates in Portsmouth, New Hampshire.
[2]All samples were field filtered through 0.45 micron membrane filter before preservation.
[3]Specific conductance measured in the field using a YSI 556 Multiprobe System.
[4]Massachusetts Office of Research and Standards Guideline (ORSG) in drinking water for sodium is 20 mg/L.
[5]EPA and Massachusetts Secondary Maximum Contaminant Level (SMCL) in drinking water for chloride is 250 mg/L.
[6]EPA and Massachusetts Secondary Maximum Contaminant Level (SMCL) in drinking water for sulfate is 250 mg/L.
<# reported below method detection limit.

Abbreviations:
$CaCO_3$: Calcium Carbonate
cm: centimeter
DUP: Duplicate Sample
MASCO: Masconomet High School
MDOT: Massachusetts Department of Transportation
mg/L: milligrams/Liter
MW: Monitoring Well
OW: Town observation well
µS: microsiemens per centimeter

The following presents observations of the groundwater quality data relative to each well's hydrologic setting.

- MDOT-MW-1, MDOT-MW-8, and MDOT-MW-12 had the highest consistent concentrations during both rounds, with chloride ranging from 860 - 1,100 mg/L and sodium ranging from 450 - 920 mg/L.
- MDOT-MW-1 is adjacent to a point source stormwater drainage discharge from Exit 53 at which water quality screening also showed elevated salt concentrations as did soil quality data collected during the well's installation.
- MDOT-MW-12 is located just east of I-95 northbound near the Fuller Lane underpass. There is a steep embankment off of I-95 at this location, with the monitoring well installed at the lower elevation. High concentrations in groundwater at this location may be a result of snowmelt from the overpass infiltrating the overburden.
- High concentrations at MDOT-MW-8 within the Exit 52 interchange likely reflect infiltration of snowmelt and runoff from Topsfield Road, I-95, and the interchange.
- MDOT-MW-2 and MDOT-MW-13, each only sampled in April 2014, had comparatively low sodium and chloride concentrations relative to other monitoring wells. Located within the Exit 53 and Exit 51 interchanges, respectively, these results likely reflect some but not substantial snowmelt and runoff infiltration at these locations.
- MDOT-MW-5, located downgradient of the Boxford Depot, had moderate and low concentrations during October 2013 and April 2014 sample rounds, respectively. MDOT-MW-6A, located in the vicinity of the former salt storage area east of Exit 52, had moderately low sodium and chloride concentrations. This data suggests that the area may not be a source of salt to the groundwater.
- Concentrations at MDOT-MW-7 and MDOT-MW-15 increased from October 2013 to April 2014. MDOT-MW-7 is adjacent to the mainline of I-95 with the higher concentrations in the spring likely indicative of snowmelt and associated runoff. MDOT-MW-15 is adjacent to a stormwater point source discharge along the mainline of I-95. Concentrations of sodium and chloride are significantly higher than those of MDOT-MW-7 for the respective rounds. Therefore, it is likely that the MDOT-MW-15 results reflect the engineered drainage system discharge at this location.
- Similarly, MDOT-MW-9 had higher concentrations in April 2014 than October 2013, with a slightly higher water table elevation. This location likely receives overland runoff from I-95 and nearby point source I-95 stormwater drainage causing the observed moderately high concentrations in April 2014.

3.5.4 Groundwater Quality at the Boxford Depot

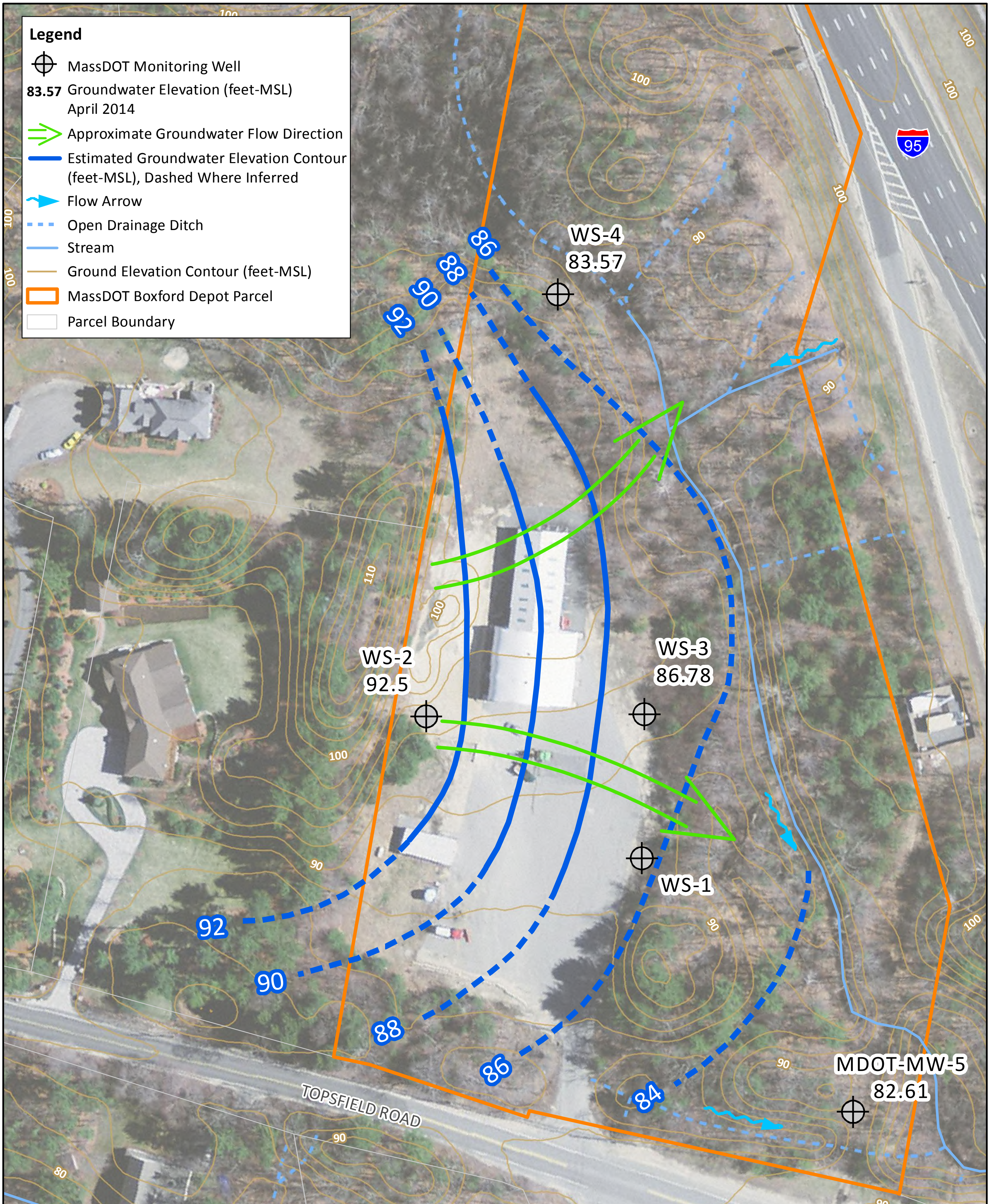
Groundwater sampling was conducted at three existing shallow monitoring wells located at the Boxford Depot in October 2013 and April 2014. The wells, referred to as WS-2, WS-3, and WS-4 were installed in 1995 as part of the MassDOT 21E Site Assessment (Weston & Sampson, 1995). They are all shallow overburden wells with depths ranging from 5.5 to 9.9 feet-BGS. A summary of their construction is included on **Table 3-4**. Their locations are shown on **Figure 3-6** along with groundwater contours and flow directions based on the April 2014 sampling event. In general, groundwater flow across the site is east toward the stream, with a component of groundwater flow to the south to southeast at the southern portion of the Boxford Depot property. Well locations are described as follows based on groundwater flow directions across the salt shed property.

- WS-2 (located upgradient of the salt shed next to Scavenger Well #3),
- WS-3 (downgradient of the salt shed), and
- WS-4 (side-gradient of the salt shed).

During the October 2013 sampling round, a groundwater sample was only collected from WS-2 as wells WS-3 and WS-4 were dry. Sodium and chloride were detected in the sample collected from WS-2 at concentrations of 28 mg/L and 2.3 mg/L, respectively.

During the April 2014 sample event, the concentration of sodium (4.8 mg/L) decreased by an order of magnitude in the sample collected from WS-2 and the concentration of chloride (2.0 mg/L) was similar when compared to the October 2013 results. The WS-3 concentrations of sodium (270 mg/L) and chloride (420 mg/L) were the highest of the Boxford Depot shallow overburden wells (including MDOT-MW-5). The concentrations of sodium and chloride in the groundwater sample collected from WS-4 are greater than WS-2 but lower than WS-3.

Prior to the Boxford Salt Study, the overburden wells at the Boxford Depot were sampled last in 1995. Limited data is available from this earlier program, however, the reported specific conductance at WS-2 in 1995 (1,940 µS /cm) was significantly greater than measured values at this well in 2013 and 2014 (35 and 389 µS /cm) suggesting a likely decrease in chloride concentrations in the overburden groundwater in this location. The condition of WS-1 did not allow for it to be sampled during the 2013-2014 program, however, 1995 results indicated specific conductance of 18,900 µS/cm. As this reading was an order of magnitude higher than any of the 2013-2014 data collected from shallow wells at the Boxford Depot, it is likely that salt concentrations in the overburden groundwater have declined over time. This may reflect Scavenger Well #3 pumping site operational improvements and the shed extension which has likely lessened the contribution of salt to the groundwater since 2005, and the salt shed's shutdown in 2009.



MassDOT Boxford Salt Study

Figure 3-6

Overburden Groundwater Flow at the Boxford Depot - April 2014

Source: MassGIS, CDM Smith

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On a relative basis, the sodium and chloride concentrations in shallow overburden groundwater at the Boxford Depot are less than those measured at many of the new shallow wells. This may reflect the facts that salt has not been stored or handled at the Boxford Depot in nearly five years, and that between 2005 and 2009 loading operations were completed under cover with BMPs and SOPs implemented to minimize materials spillage. MassDOT has not applied deicing products on the pavement at the Boxford Depot regularly since 2004 and does so currently only when safety is of concern. The highest concentrations at WS-3 likely reflect its location just off to the side and downgradient of the shed extension. This area likely received the most salt impacted runoff when handling was performed not under cover, before the addition of the extension in 2005. The lowest concentrations at WS-2 likely reflect its location as upgradient relative to groundwater flow.

3.5.5 Groundwater Quality at Other Study Area Overburden Wells

During the April 2014 water quality sampling event, the MASCO irrigation well was sampled to provide additional water quality data in the southern portion of the Study Area. The MASCO irrigation well is located within an overburden aquifer adjacent to the Ipswich River and is screened in a coarse-fine gravel deposit. The well was sampled from the well storage tank after purging approximately 50 gallons from the submersible pump. The concentrations of sodium and chloride, 260 mg/L and 760 mg/L respectively, are high in comparison with other overburden water quality data available for the Study Area. MASCO has its own small salt storage area and applies salt to the school roadways and parking areas. The irrigation well is located downgradient of some of these areas, and the water quality results may reflect impacts from salt application.

Also in April 2014, a groundwater sample was collected from an existing Town observation well at Curtis Road. In the past, groundwater exploration was performed at this site as evident by the presence of a larger diameter test well with two (2.5”) observation wells installed on the opposite sides and a third observation well approximately 100 feet to the west. The large diameter test well was sealed shut with a metal roadbox, therefore, an attempt was not made to open the well. Of the three 2.5” observation wells, only two could be opened. Depth to water and depth to bottom measurements were performed on both observation wells and it was determined that both were of similar depth, therefore, the well closest to Curtis Road was sampled (OW-3). Sampling was conducted in accordance with QAP Section 5 (see **Appendix E**). The concentrations of sodium and chloride, 10 mg/L and 19 mg/L, respectively, appear to represent background groundwater concentrations. Based on the depth of the observation wells, 36-39 feet from the top of casing, it appears likely that these wells are installed in an overburden aquifer.

3.6 Bedrock Investigation

The Study Area has a history of salt impacted domestic wells, most of which are constructed in bedrock. These wells are of varied depth, yield, and water quality. One objective of the Study was to identify the flow pathways of salt transport into and through the bedrock. Recognizing the presence of numerous bedrock outcrops and the shallow depths to bedrock in much of the Study Area, it has been conceptualized that stormwater runoff and potentially salt impacted surface water is entering bedrock directly via bedrock fractures and/or through the overlying overburden. In either case, fractures serve as the primary transport mechanism within the bedrock formations. For this reason, bedrock investigations were conducted focusing on the presence and extent of bedrock fractures and the associated groundwater quality. The bedrock investigation program included the following:

- ***Fracture Trace Analysis*** - performed to identify large scale lineaments (photolinears) that might reflect bedrock fracture zones that could influence groundwater flow.
- ***Bedrock Monitoring Well Installation*** - required in the northern portion of the Study Area, where no well suitable for down-hole monitoring purposes existed.
- ***Borehole Geophysical Logging*** - two existing bedrock wells and the new bedrock monitoring well were logged to identify specific fractures at depth, and to identify those conducting water and possibly salt constituents.
- ***Bedrock Groundwater Sampling at Discrete Depths*** - to identify fractures or fracture zones in which salt constituents may be migrating with sample collection depths based upon geophysical logging results.
- ***Conventional "Whole-Well" Sampling*** - in order to further delineate salt impacts, a sample was collected from an available bedrock well at the Boxford Depot that was not geophysically logged.

3.6.1 Fracture Trace Analysis

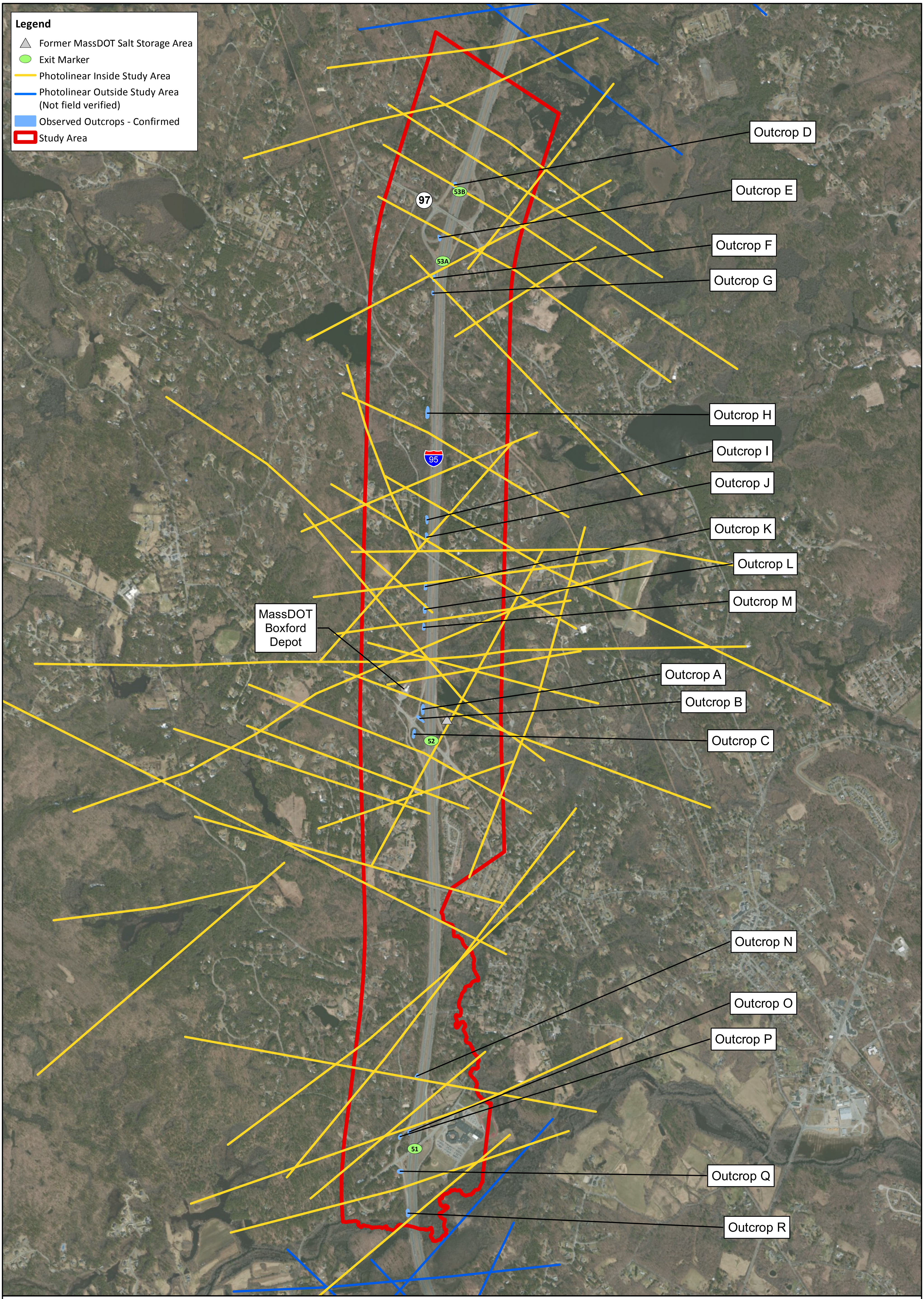
A fracture trace analysis is a desktop study using existing aerial photos to identify large scale lineaments that could be surface expressions of major bedrock fractures. Such fractures may be important conduits for groundwater flow. CDM Smith retained Hager-Richter to perform the fracture trace analysis.

After evaluating the aerial images to identify possible fracture traces, Hager-Richter performed a field verification to rule out interference by cultural features, such as stone fences that could be mistaken for a fracture lineament on the aerial photo. During the field verification, Hager-Richter also measured the orientation of planar features, such as fractures on individual outcrops. While the field verification effort was conducted mainly along the southbound edge of I-95, results are believed representative of the entire Study Area given the extent and length of fractures.

Hager-Richter's Fracture Trace Report is provided in **Appendix J**. The results of the fracture trace analysis are summarized in **Figure 3-7**. Hager-Richter identified 43 photolinears within the Study Area that were not due to cultural features. These photolinears may represent the surface expressions of large scale bedrock fracture zones which could influence groundwater flow.

Rock outcrops are also shown on **Figure 3-7**. Many were too overgrown and/or too weathered and broken up to allow measurement of planar features, however, Hager-Richter measured the orientation of planar features on seven of the outcrops.

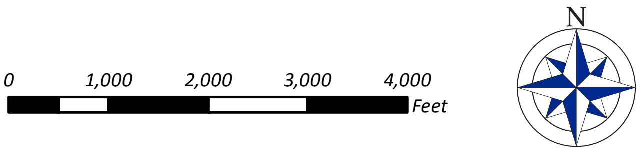
Both the photolinears and the outcrop features occurred in two dominant orientations. The dominant photolinear strike orientation is N 45° - 75° W; a secondary dominant strike orientation is N 60° - 90° E. The outcrop features exhibit similar orientations with dominant strike orientations of N 60°-75° W and N 45°-60° E. Fractures dip steeply (45° to 85° from horizontal) in either direction (i.e. northeast striking fractures dip both northwest and southeast; northwest striking fractures dip both northeast and southwest). Fractures measured in the outcrops exhibited dips ranging from 45 degrees from horizontal to nearly vertical (dip cannot be determined on photolinears as they are 2-dimensional).



CDM Smith

Source: MassGIS, CDM Smith, Hager-Richter

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



MassDOT Boxford Salt Study

Figure 3-7

Fracture Trace Analysis and Field Investigated Outcrop Locations

Source: Hager-Richter Geoscience, Inc.

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3.6.2 Bedrock Well Installation

CDM Smith contracted Skillings and Sons, Inc., to install a bedrock well in the northern portion of the Study Area, in the vicinity of salt impacted domestic wells near I-95 Exit 53. As there was no existing bedrock well available for subsurface characterization in this area, a new well (MDOT-BW-1) was installed for purposes of geophysical logging and discrete interval groundwater sampling. The location of this well is shown on **Figure 3-4**.

Well construction consisted of the installation of a 6" diameter casing grouted into bedrock, with an open hole advanced below the casing. Based upon the well depths at nearby impacted domestic well locations, a target depth of approximately 440 feet-BGS was identified. During drilling, the bedrock surface was encountered at a depth of 18 feet-BGS, and the 6" diameter steel casing was set into bedrock to 38 feet-BGS. An open borehole was advanced to a depth of 440 feet-BGS by air hammer drilling. The total well yield was about 3 gallons per minute (gpm) and water producing fracture zones were suspected at depths of approximately 195-197 feet-BGS and 230-235 feet-BGS. The boring log and well construction summary are provided in **Appendix G**.

Bedrock Well Installation (MassDOT-BW-1)

3.6.3 Borehole Geophysics

Borehole geophysical logging was conducted to characterize the bedrock subsurface at three bedrock wells – Scavenger Well #3 (central portion of the Study Area at the MassDOT Boxford Depot), Well 11-2000-C (Titus Lane area or central portion of the Study Area approximately 1,500 feet south of Scavenger Well #3), and MDOT-BW-1 (northern portion of the Study Area in the vicinity of I-95 Exit 53). The locations of these wells are shown in **Figure 3-4**; they were selected to provide the best coverage possible, based upon availability and depth, in the areas of salt impacted domestic wells.

Geophysical Borehole Logging

The geophysical logging techniques selected for use during this investigation were primarily those that provide information on fractures and potential water producing zones, as these are the most pertinent characteristics when investigating migration pathways in bedrock. Logging also included a limited number of techniques that provide information on lithology and/or water chemistry. The results of the logging were used to select depths for groundwater sampling, which allowed direct measure of the water quality flowing from fractures into the borehole. The geophysical logging techniques utilized during this investigation are described in the following text.

Methods primarily focused on fracture detection:

- ***Fluid Temperature*** - Continuous depth record of temperature. Shifts in temperature often indicate zones where groundwater is entering or leaving the borehole.

- ***Fluid Resistivity/Conductivity*** - Continuous depth record of resistivity/conductivity of the borehole fluid. Shifts often indicate zones where groundwater is entering or leaving the borehole. The fluid resistivity data would also reflect changes in groundwater salinity.

- ***Optical Televiewer (OTV)*** - Oriented “unwrapped” optical borehole image, planar features (i.e. fractures, schistosity) can be oriented. This can show lithology changes and oxidation that may be present due to water flow.

- ***Acoustic Televiewer (ATV)*** - Oriented “unwrapped” borehole image generated by acoustic waves. Borehole images are generated from both acoustic amplitude and acoustic travel time data. The amplitude images are useful for determining the depth and orientation of detected planar features (i.e., fractures, schistosity), changes in the bedrock texture due to lithology, and drilling changes. This log also helps distinguish schistosity and other minor planar features from fractures. The travel time images are useful for detecting open fractures, weathered zones, and enlarged borehole areas, which are evident based on increases in the two-way travel time of the acoustic signal. The travel time data is also converted to an acoustic caliper log, which provides a continuous depth record of borehole diameter.

- ***Heat Pulse Flow Meter (HPFM)*** - Detects the vertical rate and vertical direction of groundwater flow by deploying at a discrete depth and releasing a pulse of heat which is detected by thermistors either above or below the source depending upon flow direction. This method can also be used to determine areas where water enters or leaves the borehole for the purpose of identifying flow circuits that can be sampled with a wireline sampler. Heat pulse flow metering was performed under ambient (non-pumping) conditions, and also while pumping the well at a low rate (approximately one half gpm). The latter method helps create differential heads between fractures that may be hydraulically conductive but not actively flowing under static conditions. The HPFM was used in an iterative manner to locate zones of water entering the borehole by locating significant changes in flow magnitude/direction. For example, if a fluid temperature and/or fluid resistivity shift was observed at a large fracture located at a depth of 90 feet, the HPFM would be used just above and just below this fracture. No flow above the fracture and downward flow below the fracture would indicate that a sample should be collected below the fracture. Further, HPFM tests below this fracture would be used to determine where this water exits the borehole, say at a depth of 120 feet. Additional tests below 120 feet may find deeper flow circuits that could also be sampled.

Methods primarily focused on lithology and formation/water chemistry:

- ***Electromagnetic Induction (EM)*** - Continuous depth record of electrical resistivity/conductivity of the formation and borehole fluid, measured from an alternating electrical current transmitted into the rock. It measures rock/water properties beyond the borehole wall, and may provide insight into lithologic variation and groundwater salinity in fractures. The electrical resistivity/conductivity is affected by the porosity, permeability, and the clay content of the bedrock, and by the dissolved solids concentration of the water within the bedrock.

Methods primarily focused on lithology:

- ***Natural Gamma*** - Continuous depth record of gamma radiation. The probe records the amount of natural gamma radiation in the bedrock surrounding the borehole. Gamma radiation varies with mineralogy; in particular, bedrock with high clay or feldspar content commonly has relatively high gamma radiation. Therefore, the natural gamma data can be used to detect changes in lithology.

Hager-Richter's borehole geophysical report is provided in **Appendix K**. Due to the number of logging techniques performed on each well, two composite logs were constructed for each well and are included in Hager-Richter's report. As an example, **Figure 3-8** provides a segment of the borehole image log and geophysical log for the portion of Scavenger Well #3, from 150 to 170 feet below the top-of-casing (BTC). The logs included "tadpole" plots as a means of indicating fracture orientation. In addition, the tadpoles are shape and color coded to correspond to the fracture ranking: Rank 1 – minor (light blue); Rank 2 – intermediate (blue); Rank 3 – major (red). The example log (**Figure 3-8**) shows several fractures assigned Ranks 1 and 2 with the most pronounced between 161 feet and 164 feet-BTC.

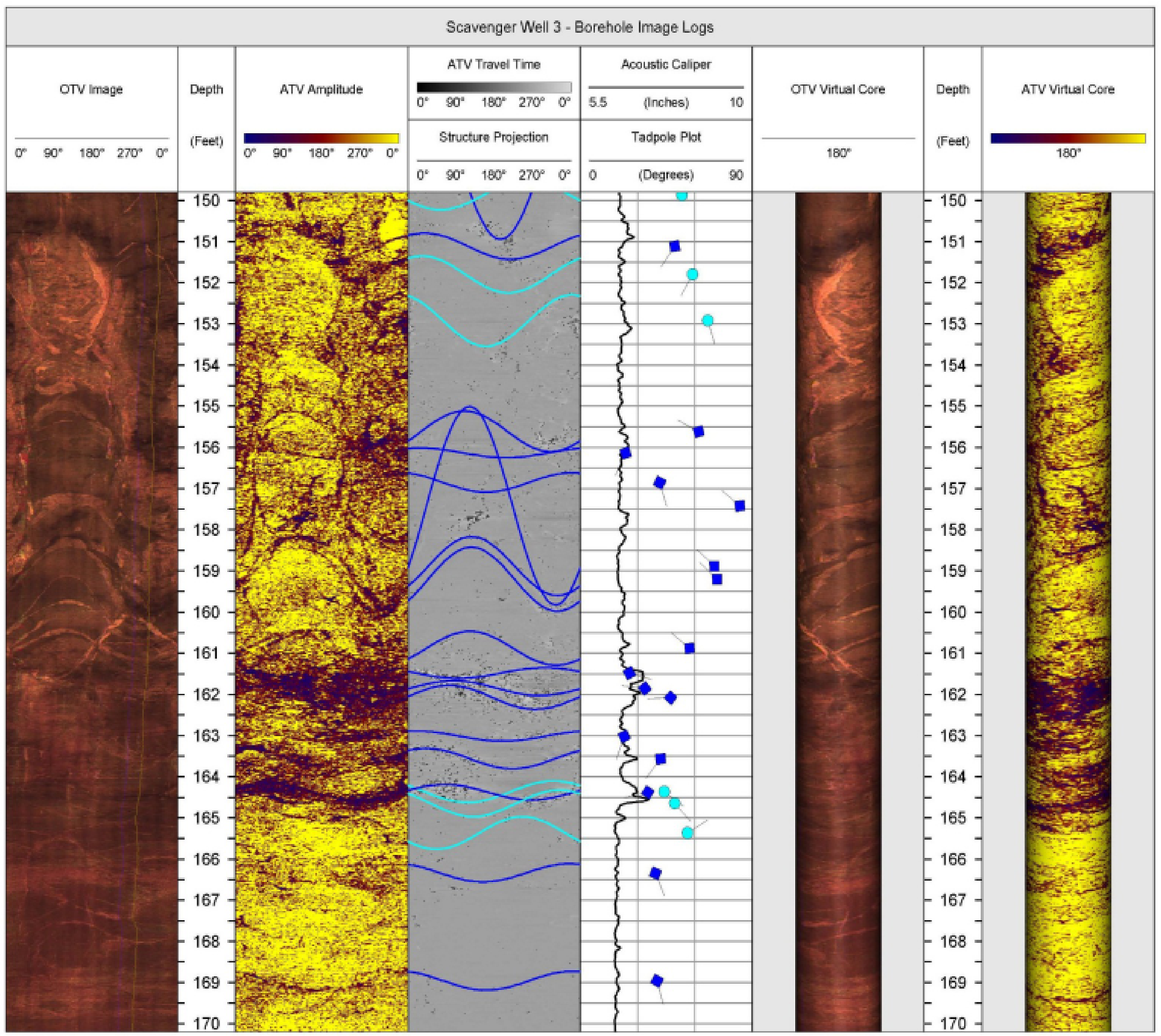
The geophysical logs were used to determine the depths at which discrete interval groundwater samples could be collected. **Figure 3-8** provides a site-specific example of this process. The fluid temperature and fluid conductivity logs on **Figure 3-8** both exhibit inflections in the vicinity of pronounced fractures at 161-164 feet-BTC. The HPFM detected downward flow under ambient conditions at 160 feet and 170 feet-BTC, with a greater flow rate at 170 feet-BTC. This suggests that under ambient conditions, water from above 160 feet-BTC is flowing down the borehole, and that additional water enters the borehole from the fractures below a depth of 160 feet, likely at the prominent fractures at 161 – 164 feet-BTC. Water continues to flow downward, to an outlet at a deeper fracture not shown on **Figure 3-8**. Under pumping conditions, HPFM tests detected upward flow, with no discernable difference in magnitude at 160 feet-BTC and 170 feet-BTC. This suggests that under pumping conditions, water entered the borehole from one or more fractures below those at 170 feet-BTC, and flowed past these fractures in this part of the borehole from below, with no discernable contribution from the fractures at 161-164 feet-BTC. Based upon these findings, a water sample was collected from a depth of 165 feet under ambient conditions as a means of sampling the water entering the borehole from the fractures at 161-164 feet-BTC. In other instances, no flow was indicated under ambient conditions, but flow from a fracture was induced under pumping conditions; in such cases samples were collected under pumping conditions. Samples were also collected in the vicinity of fractures when no indication of flow was measured but where fluid conductivity or temperature shifts were observed.

Based upon the optical televiewer logs, the wells penetrate primarily metamorphic rocks as indicated by foliations. There are also unfoliated areas of rock, which appear to be igneous. The specific geophysical log results pertaining to fracture distribution and water movement for each well are discussed below.

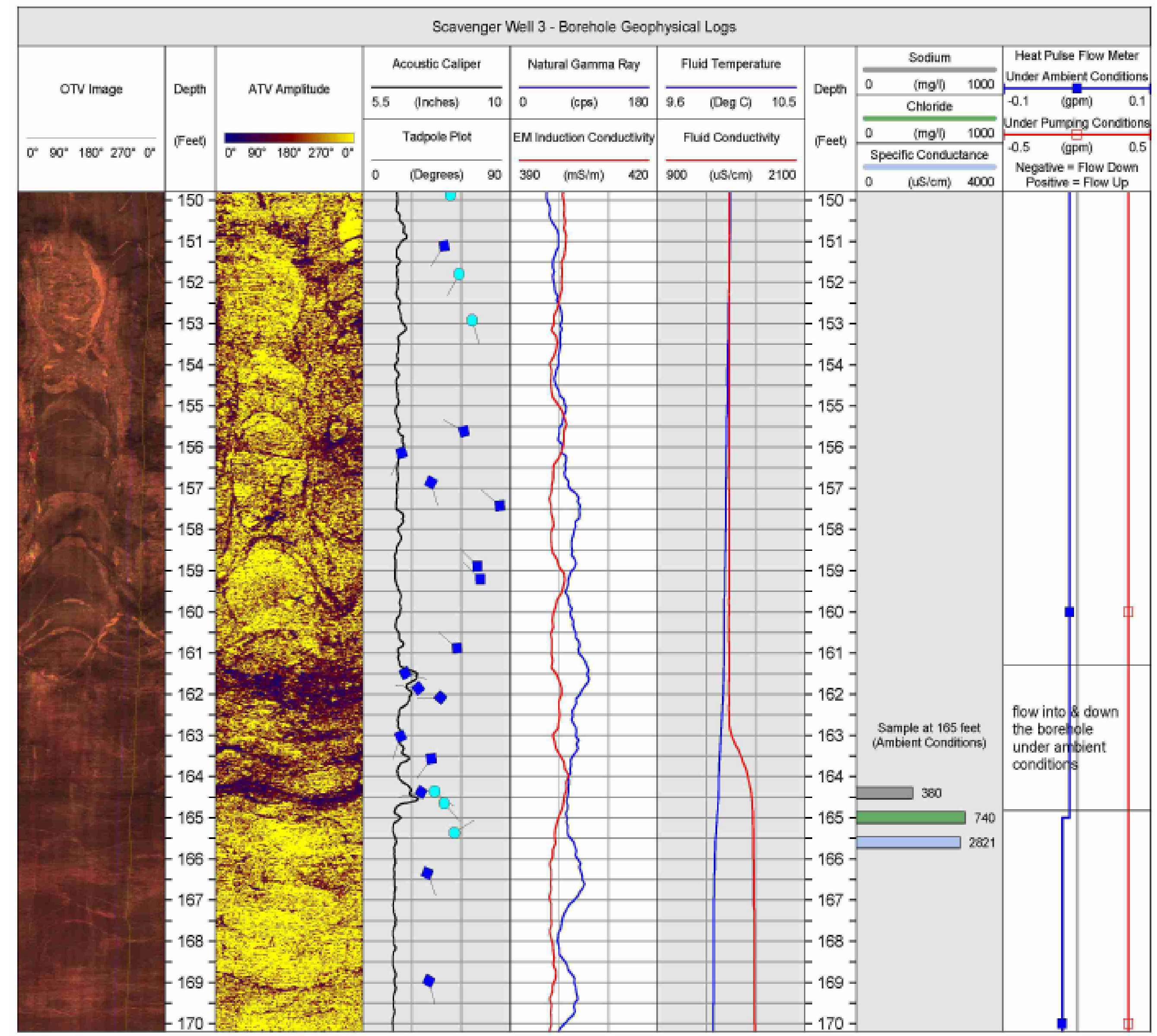
Scavenger Well #3 (Boxford Depot)

Based upon the geophysical logs, Scavenger Well #3 is cased to a depth of approximately 20 feet-BTC, and is open to a depth of 382 feet-BTC (approximately 2 feet of soft sediment was present at the bottom of the well). The static depth to water was 18.3 feet-BTC at the time of the geophysical logging.

Scavenger Well 3 (150 – 170 Feet Below Well Casing) Borehole Image Logs



Scavenger Well 3 (150 – 170 Feet Below Well Casing) Borehole Image and Geophyscial Logs



Source: Hager Richter Geosciences, Inc. May 20, 2014

CDM Smith

MassDOT Boxford Salt Study

Figure 3-8

Example Borehole Geophysical Log

Source: CDM Smith

Scavenger Well #3 at Boxford Depot

Fractures were generally well distributed throughout the borehole and were oriented in a wide variety of directions. Dip azimuths to the west-northwest, east-southeast, and northeast dominate, and dips ranged from less than 10 degrees to nearly vertical. Fractures of notable aperture were observed at depths of 60 feet, 65 feet, 78-84 feet, 142 feet, 218 feet, 254 feet, 320 feet, 344 -372 feet, and 380-382 feet-BTC. The interval 356-372 feet-BTC exhibited many interconnected open fractures and weathered bedrock.

Fluid conductivity increased downward with several discrete shifts, from approximately 900 µS/cm at the top of the water column to almost 2,000 µS/cm at a depth of 370 feet-BTC. Below a depth of 371 feet-BTC the fluid conductivity increased sharply. Based upon the depths of fractures and fluid temperature/conductivity inflections, HPFM tests to evaluate whether vertical flow was occurring within the borehole were performed at 19 depths, each under ambient and pumping conditions.

Logging results indicate that under ambient conditions, water enters the borehole through fractures at a depth of 102-107 and 161-164 feet-BTC, flows downward, and exits the borehole through fractures 352-372 feet-BTC. Additional fractures where water may enter or exit the borehole under ambient conditions are at 76-84 feet-BTC, 180-193 feet-BTC, and 213-218 feet-BTC, based on fluid conductivity/temperature data. The fluid sharp resistivity shift below 371 feet is due to saline water resting stagnant at the bottom of the well, below the deepest hydraulically active fracture. Under pumping conditions, an additional water bearing zone was observed at 342-348 feet-BTC.

Based upon an integrated interpretation of the Scavenger Well #3 geophysical logs, depths of 85 feet, 108 feet, 165 feet, 194 feet, and 220 feet-BTC were selected for wireline water samples under ambient conditions; in each case the sample depth is beneath a fracture where water may be entering the borehole under ambient (downward) flow conditions. In addition, depths of 342 and 352 feet-BTC were selected for wireline samples under pumping conditions. These samples are located above fractures that did not appear to be active during ambient conditions, but appeared to be sources of water entering the borehole and flowing upward under pumping conditions. Fractures between 352 feet and 372 feet-BTC appear to be the discharge point for the downward flow detected under ambient conditions.

Well 11-2000-C (Titus Lane Area)

Based upon the geophysical logs, well 11-2000-C is cased to a depth of 42 feet-BTC and open to a depth of 218 feet-BTC. An unknown amount of sediment has collected at the bottom of the well. The static water level was 16.1 feet-BTC at the time of the geophysical logging.

Fractures were distributed throughout the borehole and exhibited a wide variety of orientations. Dip azimuths to the northwest and easterly to southeasterly dips dominate, with several fractures dipping toward the northeast and south-southwest. Fractures or fracture zones of notable aperture are at depths of 74-77 feet, 100-105 feet, 116 feet, 136 feet, 145 feet, 147 feet, 155 feet, 187 feet, and 202 feet-BTC.

Fluid conductivity exhibited an increasing downward trend, with several discrete shifts superimposed, from approximately 1,100 µS/cm at the bottom of the casing to 1,400 µS/cm above the sediment at the bottom of the well. Based upon the depths of fractures and fluid temperature/conductivity inflections, HPFM tests were performed at 16 depths, each under ambient and pumping conditions. No flow was detected under ambient conditions. Under pumping conditions, no flow was detected below a depth of 142 feet-BTC; water entered the borehole and flowed upward from fractures at depths of 55-58 feet, 73-78 feet, 134-140 feet, and 143-149 feet-BTC.

Based upon an integrated interpretation of geophysical logs of Well 11-2000-C, depths of 55 feet, 73 feet, 134 feet, and 143 feet-BTC were selected for wireline sampling under pumping conditions. In each case, the sample depth is above a fracture believed to be a source of water entering the borehole under pumping conditions.

MDOT-BW-1 (Exit 53 Area)

Monitoring well MDOT-BW-1 is cased to a depth of 40 feet-BTC, and open to a depth of 440 feet-BTC. The static water level was 6.2 feet-BTC at the time of geophysical logging.

Fractures were generally well distributed throughout the borehole, though this borehole appears somewhat less fractured than Scavenger Well #3 and Well 11-2000-C. Fracture orientations also differed from those of Scavenger Well #3 and Well 11-2000-C, with the dominant azimuth direction south-southwest. Small displacements of up to a few inches were observed along some fractures, i.e. depths 70 feet, 336 feet, 409 feet, and 430 feet BGS. Fractures of notable aperture are present at depths of 155 feet, 197 feet, 219 feet, 235 feet, 245 - 252 feet, 350-360 feet, 369 feet, and 379 feet-BTC.

Fluid conductivity fluctuated with depth; it ranged from about 880 µS/cm to 1,180 µS/cm, exhibiting gradual changes and discrete shifts along different depth ranges. Based upon the depths of fractures and fluid temperature/conductivity inflections, HPFM tests were performed at 22 depths, each under ambient and pumping conditions. Under ambient conditions, flow entered the borehole and flowed upward from fractures at 233-236 and 196-198 feet-BTC. Flow exited the borehole at a depth of 147-156 feet-BTC. An additional possible flow zone under ambient conditions was indicated by fluid temperature and conductivity data at 304-308 feet-BTC. Under pumping conditions, an additional water bearing zone was observed at 349-361 feet-BTC, where water entered the borehole.

Based upon an integrated interpretation of the geophysical logs of MDOT-BW-1, depths of 196 feet and 233 feet-BTC were selected for wireline samples under ambient conditions. In these cases, the sample depth is above a fracture where water is believed to be entering the borehole and flowing upward. Depths of 147 feet, 304 feet, and 349 feet-BTC were selected for wireline samples under pumping conditions. The 349-foot depth was selected because HPFM indicated water entering the borehole during pumping conditions, likely from a fracture zone at 350-360 feet-BTC. The 304-foot sample depth was selected because it is above a fluid conductivity inflection that did not indicate flow differential on the HPFM, but could be a minor source. The 147-foot sample depth was selected because it was the discharge point under ambient conditions; no flow differential was observed under pumping conditions, but it could be a minor source under pumping conditions.

3.6.4 Fracture Water Quality Sampling

The geophysical logs were interpreted in an integrated manner to locate depths where samples should be collected. Specifically, caliper and imaging logs were used to locate fractures; fluid conductivity and temperature logs were used to evaluate potential water bearing zones; and the HPFM was used to identify zones of upward and downward flow. In addition, the determination of whether to sample under static or pumping conditions was based upon the geophysical logging results.

Samples were collected using a wireline grab sampler. The sampler was lowered to the desired depth and activated to collect the grab sample. The sampler was then retrieved and the water was transferred to laboratory samplers. The sampler was then decontaminated and lowered to the next desired depth for sampling. Sampling procedures were performed in accordance with the project QAP Section 3 (see **Appendix E**).

Field parameters including pH, temperature, specific conductance, salinity, dissolved oxygen, oxidation-reduction potential, and turbidity of each sample were measured. The samples were then filtered using a .045-micron filter and submitted for laboratory analysis. Water samples were analyzed for the following major ions in dissolved form: calcium, chloride, magnesium, potassium, sodium, sulfate, bromide, and bicarbonate/carbonate alkalinity.

Sample results are summarized on **Tables 3-9A and 3-9B**. In addition, sodium, chloride, and specific conductance results are shown on the geophysical logs provided in **Appendix K**. Scavenger Well #3 and well 11-2000-C are both impacted by salt. Scavenger Well #3 exhibits sodium and chloride concentrations on the order of 300 mg/L and 700 mg/L respectively. Sodium and chloride concentrations at well 11-2000-C are on the order of 100 mg/L and 400 mg/L respectively. Bedrock monitoring well, MDOT-BW-1, exhibited elevated chloride concentrations (approximately 300 to 400 mg/L), while sodium concentrations were 40 mg/L or less. All sodium concentrations exceeded the ORSG of 20 mg/L.

Calcium, magnesium, and potassium concentrations were consistent at the three wells. Bromide was detected at only one well, MDOT-BW-1. However, this was likely due to elevated bromide detection limits for samples from Scavenger Well #3 and well 11-2000C. Bromide analysis of samples from Scavenger Well #3 and well 11-2000-C required laboratory dilution due to interference from the elevated chloride concentrations, resulting in the elevated bromide detection limits. Sulfate concentrations at Scavenger Well #3 (approximately 30 mg/L) were higher than at wells 11-2000-C and MDOT-BW-1 (approximately 15-20 mg/L). Bicarbonate alkalinity was highest at Scavenger Well #3 (approximately 250 mg/L) and lowest at MDOT-BW-1 (approximately 70 mg/L), while alkalinity at well 11-2000-C was generally 160-170 mg/L. Carbonate alkalinity was below the detection limits in all samples.

In general, sodium, chloride, specific conductance, and salinity were consistent with depth at each of the three wells. One notable exception to the depth consistency of salt-related water quality parameters is the conductivity and salinity of the shallowest sample at MDOT-BW-1, which were about half the deeper values of these parameters. This is inconsistent with the chloride results, which were similar at all depths, and may be related to total dissolved solids, which was also at a lower concentration in the shallow sample.

Table 3-9A
Borehole Geophysics – Dissolved Water Quality Results
Laboratory Parameters[1,2]

Sample Depth (feet-BTC)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium[3] (mg/L)	Bromide (mg/L)	Chloride[4] (mg/L)	Sulfate[5] (mg/L)	Alkalinity, Bicarbonate (mg/L)	Alkalinity, Carbonate (mg/L)	Alkalinity, Total (mg/L)
Scavenger Well #3 at the Boxford Deport (Sampled 11/20/2013)										
85	93	36	4.4	310	<0.5	640	32	260	<5	260
108	99	38	4.6	350	<0.5	720	33	240	<5	240
165	110	42	4.6	380	<1.0	740	34	240	<5	240
194	110	45	4.6	370	<1.0	770	34	240	<5	240
220	120	49	4.8	360	<1.0	800	34	240	<5	240
342	130	56	4.4	300	<1.0	730	32	240	<5	240
352	130	58	4.1	290	<1.0	700	32	240	<5	240
352 (DUP-1)	120	56	4.0	280	<1.0	680	28	240	<5	240
Well 11-2000-C in Titus Lane Area (Sampled 11/20/2013)										
55	97	58	4.4	120	<1.0	440	17	170	<5	170
75	100	59	4.5	110	<1.0	440	16	170	<5	170
134	110	61	4.5	120	<1.0	450	16	160	<5	160
134 (DUP-2)	100	61	4.5	110	<1.0	450	17	240	<5	240
143	110	63	4.5	110	<1.0	450	16	160	<5	160
MDOT-BW-1 in Exit 53 Area (Sampled 3/12/2014)										
110	130	53	4.3	37	0.4	390	16	67	< 5	67
147	130	53	4.2	38	0.5	390	16	66	< 5	66
196	140	55	4.2	37	0.4	400	18	66	< 5	66
232	100	44	4.0	36	0.3	320	17	70	< 5	70
232 (DUP-1)	110	45	4.0	36	0.4	320	17	69	< 5	69
304	130	52	4.4	38	0.4	390	17	68	< 5	68
349	140	58	4.7	40	0.5	430	19	71	< 5	71
TW-1 at the Boxford Depot (Sampled 4/4/2014)										
--	6.3	2.6	5.4	140	<0.1	13	26	150	22	180

Notes:
[1]Analysis by Absolute Resource Associates in Portsmouth, New Hampshire.
[2]All samples were field filtered through 0.45 micron membrane filter before preservation.
[3]Massachusetts Office of Research and Standards Guideline (ORSG) in drinking water for sodium is 20 mg/L.
[4]EPA and Massachusetts Secondary Maximum Contaminant Level (SMCL) in drinking water for chloride is 250 mg/L.
[5]EPA and Massachusetts Secondary Maximum Contaminant Level (SMCL) in drinking water for sulfate is 250 mg/L.
<# Reported below detection limit.

Abbreviations:
BTC: below top of casing
BW: Bedrock well
DUP: Duplicate Sample
MDOT: Massachusetts Department of Transportation
mg/L: milligrams/liter
TW: Test well

Table 3-9B
Borehole Geophysics - Water Quality Results
Field Parameters

Sample Depth (feet BTC)	Temperature (°C)	Specific Conductance (µS/cm)	Salinity (ppt)	Dissolved Oxygen (mg/L)	pH (SU)	ORP (mv)	Turbidity (NTU)
Scavenger Well #3 at the Boxford Depot (Sampled: 11/20/2013)							
85	11.99	2,503	1.30	10.86	7.35	208.0	16.1
108	12.57	2,705	1.42	12.60	7.72	221.4	14.9
165	10.98	2,821	1.47	14.52	7.70	175.5	8.6
194	10.42	2,912	1.53	14.79	7.76	147.9	6.9
220	9.98	2,986	1.56	15.25	7.77	160.3	6.1
342	9.26	2,764	1.44	13.11	7.80	111.5	5.2
352	8.62	2,530	1.31	15.28	7.94	92.7	5.5
Well 11-2000-C in Titus Lane Area (Sampled: 11/20/2013)							
55	7.63	1,712	0.87	8.58	7.96	1.0	25.1
73	5.86	1,677	0.85	9.25	7.96	16.4	21.7
134	8.32	864	0.43	11.42	7.93	-1.9	23.6
143	5.98	1,681	0.85	14.12	7.94	29.4	14.6
MDOT-BW-1 in Exit 53 Area (Sampled: 3/12/2014)							
110	9.46	748	0.37	10.78	7.75	50.9	53.7
147	9.36	1,414	0.71	11.85	7.73	47.7	48.8
196	9.48	1,426	0.72	13.44	7.72	71.9	18.6
232	8.84	1,193	0.6	11.63	7.86	64.6	12.2
304	9.23	1,381	0.7	13.56	7.79	229.2	37.5
349	9.43	1,544	0.78	11.57	7.79	181.6	22.8
TW-1 at the Boxford Depot (Sampled: 4/4/2014)							
50-560	12.52	732	0.36	5.67	9.61	-33.3	2.0

Abbreviations:
BTC: below top of casing
BW: Bedrock Well
°C: degrees Celsius
cm: centimeter
MDOT: Massachusetts Department of Transportation
mg/L: milligrams/liter
mV: millivolts
NTU: Nephelometric Turbidity Unit
ORP: Oxygen Reduction Potential
ppt: parts per thousand
SU: standard units
TW: Test Well
µS/cm: microsiemens/centimeter

3.6.5 Whole-Well Water Quality Sampling – TW-1

Bedrock well TW-1, located at the Boxford Depot upgradient of Scavenger Well #3, was sampled to provide additional groundwater data in this area. This well was not geophysically logged, therefore it was sampled by volumetric purging in accordance with QAP Section 5 (**Appendix E**). Laboratory analysis was performed for the same parameters as the fracture samples.


TW-1 at the Boxford Depot

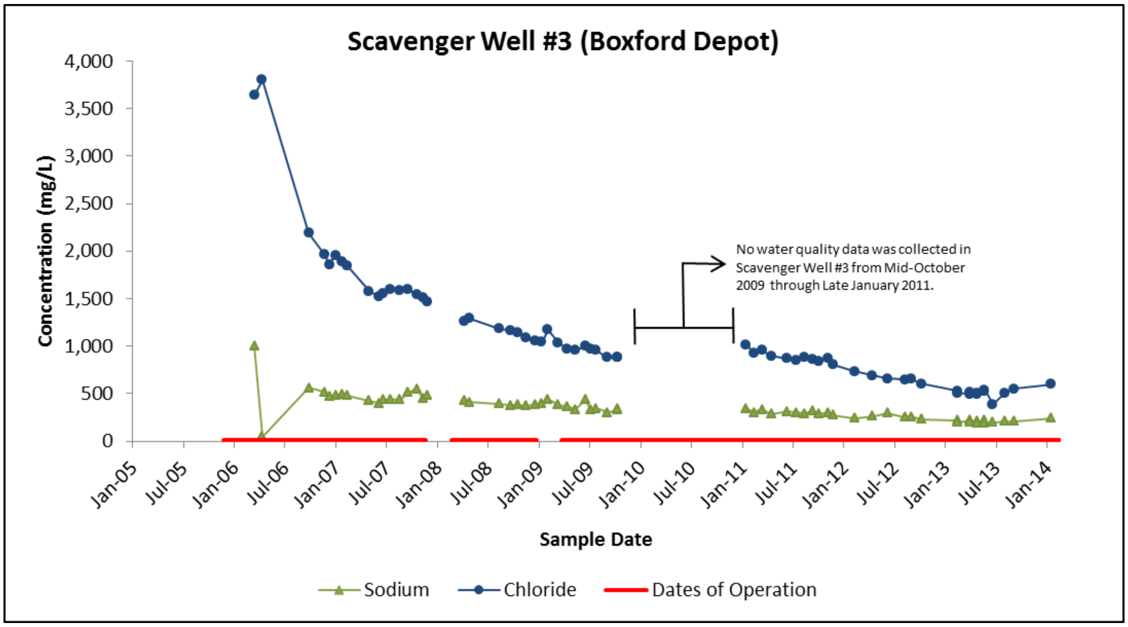
Sample results are included on **Tables 3-9A and 3-9B**. Sodium exhibited an elevated concentration (140 mg/L) in TW-1, in excess of the ORSG of 20 mg/L but lower than concentrations at nearby Scavenger Well #3. The chloride concentration (13 mg/L) in TW-1 was below the SMCL of 250 mg/L and less than any of the results from the fracture groundwater samples from Scavenger Well #3, MDOT-BW-1 and well 11-2000-C. Magnesium and calcium concentrations were an order of magnitude lower than any of the fracture groundwater samples. Potassium, sulfate, and bicarbonate alkalinity were within the range found in the fracture groundwater samples. Carbonate alkalinity was detected at a concentration of 22 mg/L, compared to the fracture groundwater samples where it was below 5 mg/L. Bromide was not detected.

The relative sodium and chloride concentrations of TW-1 and Scavenger Well #3 are notable because these wells are in close proximity to each other at the Boxford Depot. The sodium concentration at TW-1 is half that of the concentrations at Scavenger Well #3, or less. The chloride concentration at TW-1 is more than an order of magnitude lower than at Scavenger Well #3. This is consistent with the location of TW-1 upgradient of the both salt storage area and Scavenger Well #3. Comparatively, Scavenger Well #3 is adjacent to the salt shed and associated former salt handling area. Also, while TW-1 was installed as a test well and never pumped long-term, Scavenger Well #3 has a history of long-term continuous pumping for salt removal. Therefore, Scavenger Well #3 has likely drawn in salt constituents from not only the surrounding bedrock and connected fractures, but also possibly from the overburden. Finally, TW-1 is 560 feet deep whereas Scavenger Well #3 is only 382 feet deep. The extent of fracturing and associated water quality of individual fractures in TW-1 remains unknown. It is possible that deeper fractures at TW-1 could be contributing higher quality water with less salt content.

3.6.6 Bedrock Investigation Discussion

The fracture trace analysis, outcrop investigations, and geophysical logging reveal a complex fracture system in the Study Area. The fracture trace and outcrop measurements indicate fracture strike orientations primarily to the northeast and northwest (strike is the direction along which an inclined plane intersects the horizontal plane). The borehole geophysics indicated preferential fracture orientations, generally similar to those observed in the fracture trace and outcrop investigations. However, the borehole geophysical study revealed that fractures occur in all strike orientations, and fracture dips ranged from nearly horizontal to nearly vertical. The high degree of fracturing observed is believed to allow a high degree of mobility of salt constituents both horizontally and vertically through the bedrock aquifer, as well as a direct pathway from the overburden to deeper portions of the bedrock. This may explain the widespread distribution of salt within certain portions of the Study Area.

The fracture groundwater sampling results indicate that salt concentrations are well distributed vertically throughout the bedrock formations. In the case of Scavenger Well #3, and similar wells that have been in place for many years in areas of downward hydraulic head (i.e. downward flow measured by HPFM), the wells themselves may have contributed to the vertical migration of salt, because these extended open boreholes constitute migration conduits connecting water bearing zones at different depths. To some extent, the water quality in the samples collected from deeper fractures may be migrating from one fracture to another within the well over time. This is particularly true of wells with long open intervals used for long term continuous pumping (i.e., scavenger wells) or long-term daily intermittent pumping (i.e., domestic wells). Conversely, MDOT-BW-1 was installed only about one week prior to logging and is in an area of upward hydraulic head. Therefore, water quality results at this well would be less impacted by cross flow within the well. However, even this well exhibited fairly high sodium and chloride concentrations at depth, suggesting these constituents were present at depth prior to the installation of the well.



Scavenger Well #3 Historical Water Quality

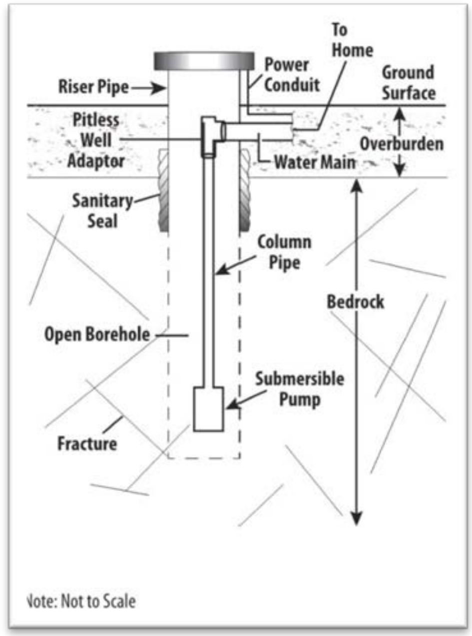
Well 11-2000-C, downgradient of the Boxford Depot, also exhibited significant sodium and chloride concentrations. While this well does not have a record of pumping, it is 6 years old, having been installed in 2008. Therefore, the borehole may have served as a conduit for salt migration between fractures over time.

TW-1 had lower salt concentrations, possibly due to its greater depth, position upgradient of the salt storage area, and because it was never pumped long-term. It is noted that a single whole-well sample was collected from TW-1; therefore, the vertical distribution of salt within the well is not known.

In summary, the data indicates that salt concentrations are widespread in the bedrock aquifer, both horizontally and vertically. The highly fractured nature of the bedrock, the varying fracture orientations, well construction (long open holes), continuous pumping of scavenger wells (past and present), and extended daily intermittent pumping of the numerous domestic wells installed at various elevations throughout the Study Area are all contributing factors.

3.7 Domestic Well Sampling Program

Domestic wells are privately owned and operated wells that provide potable water to individual residential homes. Since the Town of Boxford does not have a municipal water supply, all homes have domestic wells unless otherwise served by a small community system such as at Andrews Farm. The presence of domestic wells throughout the Study Area provided a readily available data source for geologic information and historical water quality. Relevant information from domestic wells was entered into the project data base.



Cross-Section Schematic of Typical Domestic Bedrock Well

One Study objective has been to evaluate the extent of salt impacted groundwater in bedrock. The option of installing multiple bedrock wells throughout the Study Area for assessment of water quality was considered, but deemed too expensive. Rather, it was decided to maximize the advantage of existing domestic wells within the Study Area. Specifically, a program was established for sampling domestic wells to evaluate the presence of salt impacted groundwater in bedrock. This required public outreach to Study Area residents for permission to obtain water quality samples from private domestic wells.

3.7.1 Domestic Well Program Implementation

The intent of the domestic well sampling program was to collect domestic water samples in the Study Area, focusing both on regions with historically high salt concentrations and areas where historical groundwater quality data are not available. To meet this objective, the Study Area was subdivided into Sub-regions A through D to focus sampling efforts and to evaluate localized groundwater quality patterns. These Sub-regions are shown in **Figure 3-9**.

- Sub-region A is at the northern extent of the Study Area, encompassing Exit 53 and nearby domestic wells known to have salt impacted groundwater based on residential applications to the MassDOT Salt Remediation Program.

- Sub-region B lies to the south of Sub-region A between Exits 52 and 53, an area where limited groundwater quality data are available. There are few residences enrolled in the MassDOT Salt Remediation program in this sub-region.

- Sub-region C encompasses the Boxford Depot and former MassDOT salt storage area (east of I-95) as well as the Titus Lane and Silverbrook Road neighborhoods which are areas known to have salt impacted groundwater based on records of the MassDOT Salt Remediation Program.

- Sub-region D is further south within the Study Area, encompassing Exit 53 and only several properties that filed applications with the MassDOT Salt Remediation Program.

Public Outreach

Sampling of domestic wells required permission of individual residents. A public outreach effort was therefore initiated to seek out residents who would be willing to allow domestic well sampling and analysis. To facilitate this effort, the Boxford Task Force reached out to residents personally known to them seeking permission for water sample collection. In addition, MassDOT and UMass personnel approached residents who were previously enrolled in the Salt Remediation Program.

An initial goal of the domestic well sampling program was to sample up to 30 wells. Approximately 40 residents were contacted and permission was obtained for sample collection at 22 locations. The specific location and results of domestic well sampling is being kept confidential at the request of residents. All residents who participated in the program received copies of their water quality sample results. A few of the wells sampled during the 2014 domestic well sampling program were replacement wells installed earlier by MassDOT.

Sampling Implementation

CDM Smith personnel performed all domestic well sampling to ensure consistent sample collection and testing methodology. To maintain confidentiality, domestic wells were assigned an identification code.

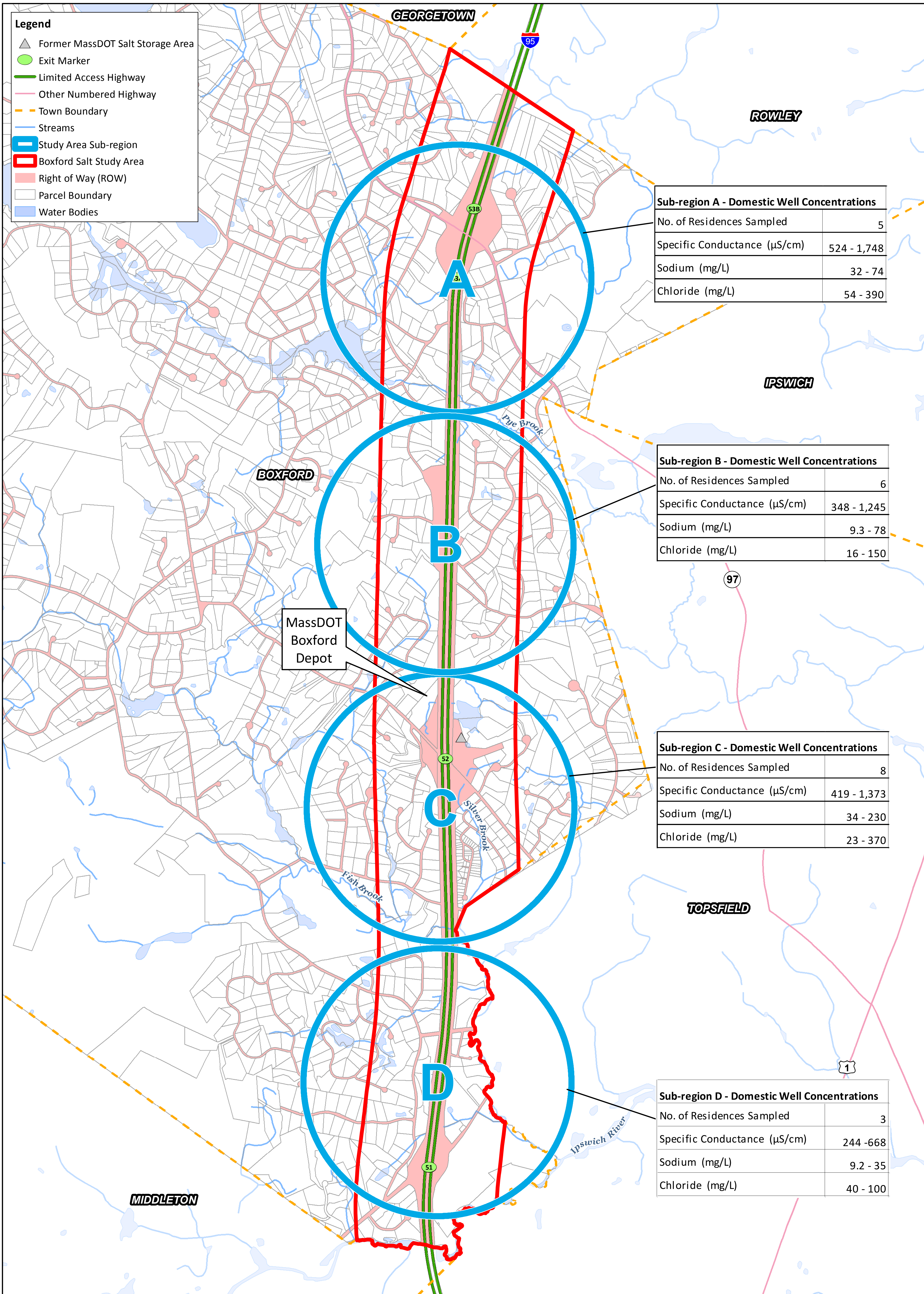
Raw (i.e., untreated) water samples were collected directly from domestic water storage tanks prior to introduction to any water treatment systems or water softeners. Water was purged for ten minutes from kitchen or bathroom faucets in the house prior to sample collection. A small amount of purge water was also collected from the water tanks prior to sampling. Further details on the sampling methods are documented in Section 2 of the QAP **(**see **Appendix E**).

Domestic well groundwater samples were sent to ARA and analyzed for the following major ions: calcium, chloride, magnesium, potassium, sodium, sulfate, and bicarbonate/carbonate alkalinity. In addition, field measurements were collected for specific conductance, salinity, dissolved oxygen, pH, and oxygen reduction potential.

3.7.2 Domestic Well Sampling Results

Figure 3-9 shows the range of specific conductance, sodium, and chloride concentrations for each sub-region, as well as the number of samples collected. **Table 3-10** lists the reported range of concentrations for each of the sampled analytes for the four Sub-regions. In general, the highest chloride concentrations were observed in Sub-region A which includes Exit 53 and Sub-region C which includes Exit 52 and the Boxford Depot. Sodium concentrations were highest in Sub-region C.

Results were compared to Massachusetts Drinking Water Guidelines for sodium, chloride, and sulfate. Twenty of the 22 wells sampled exhibited chloride concentrations in excess of the Massachusetts ORSG of 20 mg/L for sodium. Concentrations at 6 of the 22 wells sampled exceeded the SMCL of 250 mg/L for chloride. These wells were located in Sub-regions A and C. The SMCL of 250 mg/L for sulfate was only exceeded at one well located within Sub-region B.



Sub-region A - Domestic Well Concentrations	
No. of Residences Sampled	5
Specific Conductance (µS/cm)	524 - 1,748
Sodium (mg/L)	32 - 74
Chloride (mg/L)	54 - 390

Sub-region B - Domestic Well Concentrations	
No. of Residences Sampled	6
Specific Conductance (µS/cm)	348 - 1,245
Sodium (mg/L)	9.3 - 78
Chloride (mg/L)	16 - 150

Sub-region C - Domestic Well Concentrations	
No. of Residences Sampled	8
Specific Conductance (µS/cm)	419 - 1,373
Sodium (mg/L)	34 - 230
Chloride (mg/L)	23 - 370

Sub-region D - Domestic Well Concentrations	
No. of Residences Sampled	3
Specific Conductance (µS/cm)	244 -668
Sodium (mg/L)	9.2 - 35
Chloride (mg/L)	40 - 100

CDM Smith

0 1,000 2,000 3,000 4,000 Feet

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MassDOT Boxford Salt Study
Figure 3-9
Domestic Well Analytical Results
Specific Conductance, Sodium, Chloride

Source: MassGIS, CDM Smith

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Table 3-10
Domestic Well Sampling Analytical Results Summary

Sub-region	No. of Samples Collected	Field Parameter	Laboratory Analyses [1, 2]									
		Specific Conductance[3] (µS/cm)	Calcium (mg/L)	Magnesium (mg/L)	Potassium (mg/L)	Sodium[4] (mg/L)	Chloride[5] (mg/L)	Sulfate[6] (mg/L)	Alkalinity, Bicarbonate (mg/L)	Alkalinity, Carbonate (mg/L)	Alkalinity, Total (mg/L)
A	5	524 - 1,748	21 - 160	8.7 - 57	2.3 - 4.5	32 - 74	54 - 390	14 - 37	84 - 150	<5	84 - 150
B	6	348 - 1,245	12 - 190	4.9 - 45	1.2 - 3.4	9.3 - 78	16 - 150	19 - 320	76 - 340	<5	76 - 340
C	8	419 - 1,373	1.6 - 84	0.9 - 45	1.4 - 31	34 - 230	23 - 370	9.2 - 70	45 - 430	<5 - 24	45 - 450
D	3	244 - 668	11 - 72	3.7 - 14	2.1 - 3.6	9.2 - 35	40 - 100	14 - 19	31 - 150	<5	31 - 150
Total	**22**	**244 - 1,748**	**1.6 - 190**	**0.9 - 57**	**1.2 - 31**	**9.2 - 230**	**<0.5 - 390**	**9.2 - 320**	**31 - 430**	**<5 - 24**	**31 - 450**

Notes:
[1]Water quality laboratory analysis by Absolute Resources Associates (ARA) of Portsmouth, New Hampshire.
[2]Samples not filtered; results represent total.
[3]Specific conductance measured in the field using a YSI 556 Multiprobe System.
[4]Massachusetts Office of Research and Standards Guideline (ORSG) in drinking water for sodium is 20 mg/L.
[5]EPA and Massachusetts Secondary Maximum Contaminant Level (SMCL) in drinking water for chloride is 250 mg/L.
[6]EPA and Massachusetts Secondary Maximum Contaminant Level (SMCL) in drinking water for sulfate is 250 mg/L.

Abbreviations:
L: liters
mg: milligrams
µS/cm: microsiemens per centimeter

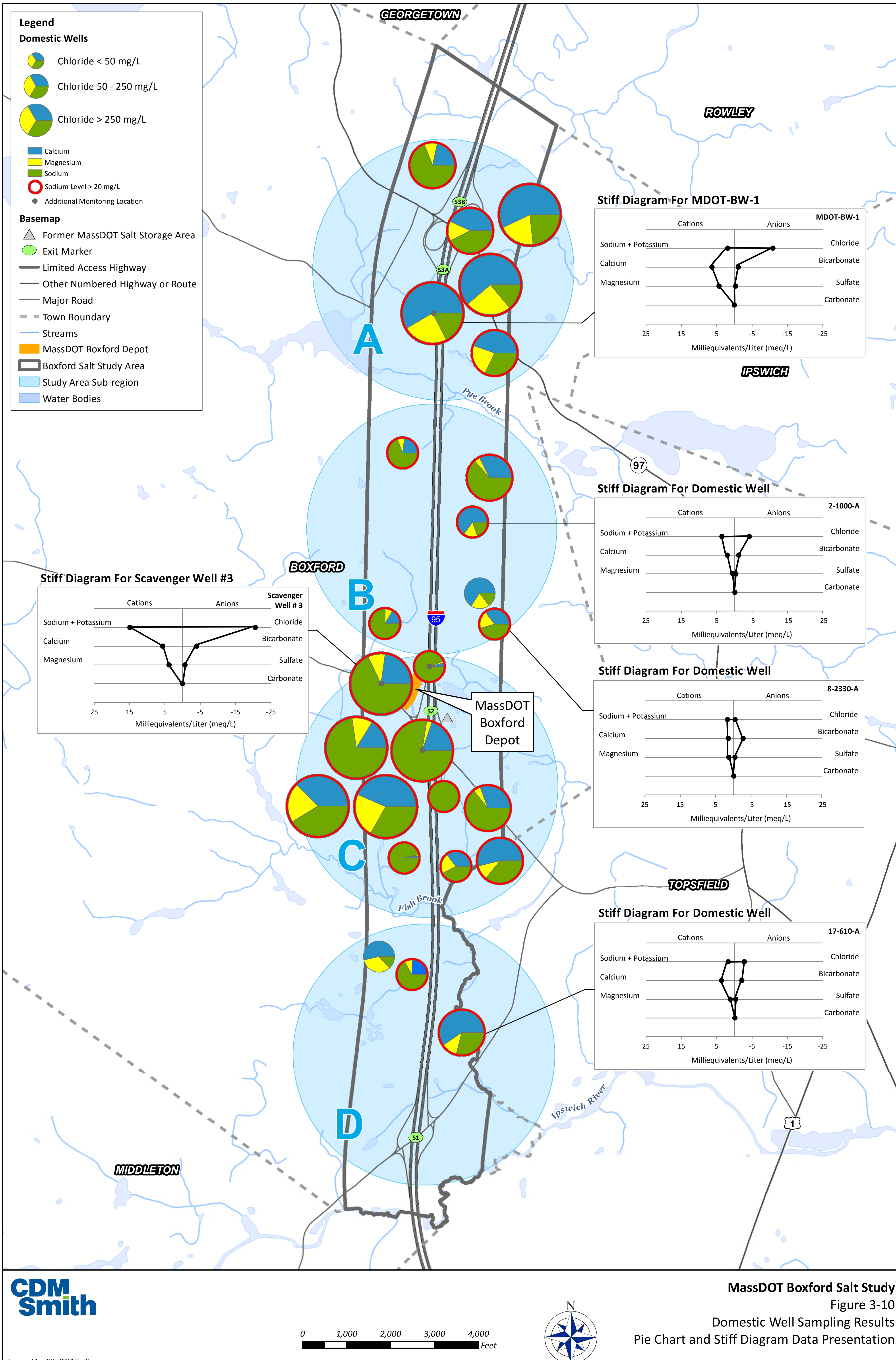
Figure 3-10 presents domestic well sodium, calcium, and magnesium concentrations in pie chart format. The pie representations do not correlate to concentrations, but rather to the composition of the water sample based on reported concentrations. The sizes of the “pies” are based on measured chloride concentrations. Locations where sodium drinking water guidelines are exceeded are outlined in red. Sampling results from the three bedrock wells monitored during the borehole geophysics program and from TW-1 are also shown in **Figure 3-10**.

Figure 3-10 also includes Stiff diagrams for some wells which is another way of representing the groundwater quality. For illustration purposes, stiff diagrams are shown for three domestic wells and two bedrock wells sampled during the geophysics program.

The Stiff plotting technique (Hem, 1985) uses four parallel horizontal axes extending on each side of a vertical zero axis. Concentrations of four cations (positive ions) can be plotted left of zero, and four anions (negative ions) concentrations can be plotted right of zero. The concentrations are in milliequivalents per liter which are based on measured concentrations in mg/L, molecular weight, and ionic charge (Hem, 1985). The resulting points are connected to give an irregular polygonal shape or pattern. The Stiff patterns are a distinctive method of showing water-composition differences and similarities. For instance, the Stiff pattern for Scavenger Well #3 is distinct from the pattern shown for the new bedrock well that was installed near Exit 53 (MDOT-BW-1), suggesting the water quality at these two locations is different in some ways. The width of the pattern is an approximate indication of total ionic content, or concentration. The cations used to develop the Stiff diagrams for the Study Area were sodium, potassium, calcium, and magnesium. The anions used for the diagrams were chloride, bicarbonate, sulfate, and carbonate. The stiff diagrams and pie charts were used to identify different bedrock water quality patterns in the Study Area.

One distinguishing characteristic in the domestic well sampling results is that at some wells, the predominant (higher concentrations) cation is calcium, while in other locations sodium is present at higher concentrations. This difference is illustrated in both the pie charts and the Stiff diagrams. For instance, domestic well locations closest to the Boxford Depot (Sub-region C) tend to exhibit sodium as the predominant cation (green portion of the pie chart), whereas well locations near Exit 53 (Sub-region A) exhibit calcium as the predominant cation (blue portion of the pie chart). This distinction may provide some information about either the potential sources of salt impacting the groundwater in the two locations, or possible geologic differences that may impact water chemistry.

Sub-regions B and D had fewer domestic well samples and generally lower concentrations, although in most cases sodium concentrations were greater than drinking water guidelines. There were fewer domestic wells assessed by the Salt Remediation Program in these areas.



CDM Smith

MassDOT Boxford Salt Study
Figure 3-10
Domestic Well Sampling Results
Pie Chart and Stiff Diagram Data Presentation

Source: MassGIS, CDM Smith

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Whereas measured surface water concentrations, described in **Section 3.4** (Study Area Reconnaissance) and in the next section, are typically closely related to storm conditions at the time of sampling, measured groundwater concentrations in the bedrock reflect contributions from earlier sources. For instance, the bedrock groundwater concentrations near Exit 53 are related to past, as well as possibly current, I-95 deicing and drainage operations. Bedrock groundwater concentrations near Exit 52 are related to past materials storage and handling at the Boxford Depot, as well as past and possibly current I-95 deicing and drainage operations. Some of the domestic wells that were sampled in 2014 were replacement wells or domestic wells also sampled earlier by MassDOT as part of the Salt Remediation Program. At nine locations where historical documentation was believed sufficient to correlate 2014 data with earlier data, reported 2014 groundwater concentrations were generally similar to earlier reported concentrations from sampling events conducted during different periods in 2006-2013. Concentration-time history graphs showing historical and 2014 groundwater quality data at the nine locations are presented in **Appendix I**. Of these nine locations, all are bedrock wells except one, which is in overburden as noted on the graph. These wells are located throughout the Study Area. More comprehensive area-wide comparisons of recent and older data could not be completed due to uncertainty in the depths of the wells sampled in the past.

3.8 Winter Sampling Program

Roadway deicing operations and previous road salt storage are contributors of deicing material impacts to groundwater in the Study Area. Recognizing that the potential flow pathways for mobilization of road salt in the environment are stormwater drainage, runoff, and snowmelt, a winter sampling program was conducted to further assess these pathways and improve understanding of road salt contributions from the three exits and mainline of I-95 within the Study Area, as well as the Town's country drainage.

The winter sampling program was conducted during the months of February and March, 2014. The scope of the program was developed based on historical surface water quality information, data from water quality screening and sampling conducted the previous year during site reconnaissance efforts, hydrogeology of the Study Area, and understanding of I-95 and Town of Boxford deicing operations. Winter sampling occurred during three separate events, aimed at providing results representative of a variety of winter conditions. Winter sampling locations and the rationale for sampling location selection are listed on **Table 3-11.**

3.8.1 Field Program Overview

In February and March 2014, CDM Smith conducted winter sampling at selected surface water and stormwater discharge locations. The sampling locations were selected based on historical data and information collected during the reconnaissance monitoring conducted in 2013. The objectives of the winter sampling program were to collect data at the following locations:

- Where roadway drainage discharges close to residences that were part of the Salt Remediation Program
- Areas where bedrock is close to the ground surface

Table 3-11
2014 Winter Sampling Locations

Watershed/ Sub-watershed	Map Panel Number	Location ID	Sample Point	Discharge Point	Location	Justification										
						Near Impacted Residential Wells	Near Residential Wells	Boxford Depot Vicinity	Stream Impacted by I-95 Drainage	I-95 Interchange	Discharges Stormwater from Large I-95 Drainage System	Affected by I-95 Stormwater Drainage Modification[1]	Country Drainage	High Sodium/Chloride/Specific Conductance from 2013 Screening[2]	Area of Shallow Bedrock	Former MassDOT Surface Water Sampling Location
Parker River	2	PRW2C	Outfall	Swale	Exit 53 Interchange	✓	✓			✓				✓	✓	
	2	PRW3K	Wetland	-	Exit 53 Interchange	✓	✓			✓				✓	✓	
Ipswich River/ Pye Brook	3	IRW3A	Outfall	Stream	Near Exit 53 (I-95 Northbound)	✓	✓		✓					✓	✓	
	3	Lined Swale to PB	Lined swale	Pye Brook	South of Exit 53 near Roberts Road (I-95 Northbound)	✓	✓		✓		✓	✓				
	3	TD03	Inlet from Stream	-	School Street near Exit 53	✓	✓						✓		✓	
	4	TD05	Outfall	Wetland	Roberts Road	✓	✓						✓	✓		
	4	PBW1W	Stream	Pye Brook	South of Exit 53 along Pye Brook	✓	✓		✓			✓		✓		
	6	TD08	Outfall	Swale	Pinehurst Drive	✓	✓						✓	✓	✓	
Ipswich River/ Silver Brook[3]	7	A5	Stream	Silver Brook	Stream downgradient of Boxford Depot	✓	✓	✓	✓						✓	✓
	7	SCAV3	Outfall	Silver Brook	Stream outfall on Boxford Depot Property	✓	✓	✓	✓						✓	✓
	7	FBW2C	Stream	-	Along Stream North of Boxford Depot	✓	✓	✓	✓						✓	

Table 3-11 (Cont'd)
2014 Winter Sampling Locations

Watershed/ Sub-watershed	Map Panel Number	Location ID	Sample Point	Discharge Point	Location	Justification: Near Impacted Residential Wells	Near Residential Wells	Boxford Depot Vicinity	Stream Impacted by I-95 Drainage	I-95 Interchange	Discharges Stormwater from Large I-95 Drainage System	Affected by I-95 Stormwater Drainage Modification[1]	Country Drainage	High Sodium/Chloride/Specific Conductance from 2013 Screening[2]	Area of Shallow Bedrock	Former MassDOT Surface Water Sampling Location
Ipswich River/ Fish Brook	7	FBW2V	Outfall	Wetland	South of Boxford Depot	✓	✓	✓					✓	✓	✓	
Ipswich River/ Silver Brook[2]	8	C5	Stream	Silver Brook	Stream upgradient of Silverbrook Road	✓	✓		✓	✓						✓
	8	FBW2Q	Outfall	Silver Brook	Exit 52 Interchange (I-95 Northbound)	✓	✓	✓	✓	✓				✓		✓
	9	FBW2BB	Stream	Silver Brook	Andrew's Farm Road Neighborhood		✓		✓		✓	✓				✓
	9	TD15	Outfall	Wetland	Lockwood Lane		✓						✓			
Ipswich River/ Fish Brook	10	TD17	Outfall	Stream	Middleton Road		✓						✓			
	10	TD18	Outfall	Wetland	Fish Brook Road	✓	✓						✓	✓		

Notes:
[1]In 2005 and 2006 drainage modifications were made to drainage pipes along the center of I-95 in the areas south of Exit 53 and Exit 52. More details on these modifications can be found in Section 2.3 and on Map Panels 3, 4, and 8 in Appendix C.
[2]See Section 3.3 for more details.
[3]Silver Brook flows into Fish Brook.

Abbreviations:
FBW: Fish Brook Sub-watershed
IRW: Ipswich River Watershed
PBW: Pye Brook Sub-watershed
PRW: Parker River Watershed
SCAV3: Scavenger Well #3 outfall
TD: Town Drainage

- Locations where MassDOT implemented drainage improvements
- Locations that were sampled by MassDOT during earlier field programs

The water quality screening and sampling efforts conducted during the reconnaissance program from January to– March, 2013 provided a water quality snap-shot across the Study Area (see **Section 3.4**). In contrast, the 2014 winter sampling program was conducted to collect multiple water quality measurements over the course of a day during different winter conditions to evaluate the temporal changes in surface water and stormwater runoff quality over the course of the monitoring event.

Field visits were conducted to select sample locations and evaluate the potential use of automatic samplers, flow monitoring devices, and/or in situ water quality sondes. However, it was determined that winter conditions would not be conducive to temporary deployment of such equipment. Deployment of more permanent equipment would have been costly as both streams and outfall conditions were not conducive for installation of this equipment, thereby requiring extensive efforts to set-up, secure and provide power to the equipment to ensure a useful dataset.

Three winter sampling events were conducted capturing each of the following conditions:

- Event #1: Snow event where deicing materials were applied to roadways (February 14, 2014)
- Event #2: A precipitation and snow melt event with no deicing materials applied (February 21, 2014)
- Event #3: A snow melt event with some rain (March 20, 2014)

A total of eighteen locations were selected for sampling, with a subset of these stations sampled during each of the three sampling events. Sampling points included stormwater drainage discharges from both I-95 and Town country drainage, as well as surface water in streams close to I-95. To the extent possible, efforts were made to sample locations during more than one winter event in order to provide data for event- to event comparison purposes.

A majority of the samples collected were analyzed for both field and laboratory parameters. Several locations, however, were sampled for field parameters only to provide supplementary information. These locations included the Scavenger Well #3 discharge, where there is already a comprehensive data set of water quality measurements. Furthermore, the Scavenger Well #3 discharge is located upstream of one of the other sampling locations (A5) and it was important to understand the potential impact of these discharges on surface water quality downstream. Additional Town drainage locations were also sampled for field parameters only, where water quality impacts from deicing could be reliably assessed based on specific conductance measurements since specific conductance is strongly correlated to chloride concentrations.

Table 3-12 provides a summary of winter event conditions and the sites that were sampled during each event. Sampling locations are shown on **Figure 3-11**. **Figures 3-12** and **3-13** show the MassDOT salt application and precipitation during the winter sampling events.

Table 3-12
Winter Sampling Event Summary

	Event #1	Event #2	Event #3
Date	February 14, 2014	February 21, 2014	March 20, 2014
Winter Event Description ▪ Weather ▪ Accumulation for day ▪ Temperature Range ▪ Deicing Operations	▪ Snow ▪ 6 inches snow ▪ 15 - 35 °F ▪ Yes	▪ Snow/Rainfall ▪ 0.79 inches rain and snow (water equivalent) ▪ 26 – 46 °F ▪ No	▪ Rainfall ▪ 0.6 inches rain ▪ 19 – 49 °F ▪ No
Focus Area	Boxford Depot & Exit 53	Boxford Depot & Exit 52 extending south	Exit 53, Pye Brook, Old Topsfield Road, Fish Brook
Number of Sample Stations	8	8	12
Water Quality Sampling Stations (Laboratory and Field Data Analysis)	A5, C5, FBW2C, FBW2Q, IRW3A, PRW2C, PRW3K	A5, C5, FBW2BB, FBW2C, FBW2Q, TD17	C5, FBW2V, IRW3A, Lined Swale to PB, PBW1W, PRW2C, PRW3K, TD18
Water Quality Stations (Field Parameters Only)	SCAV3	SCAV3, TD15	TD03, TD05, TD08, TD15

Abbreviations:

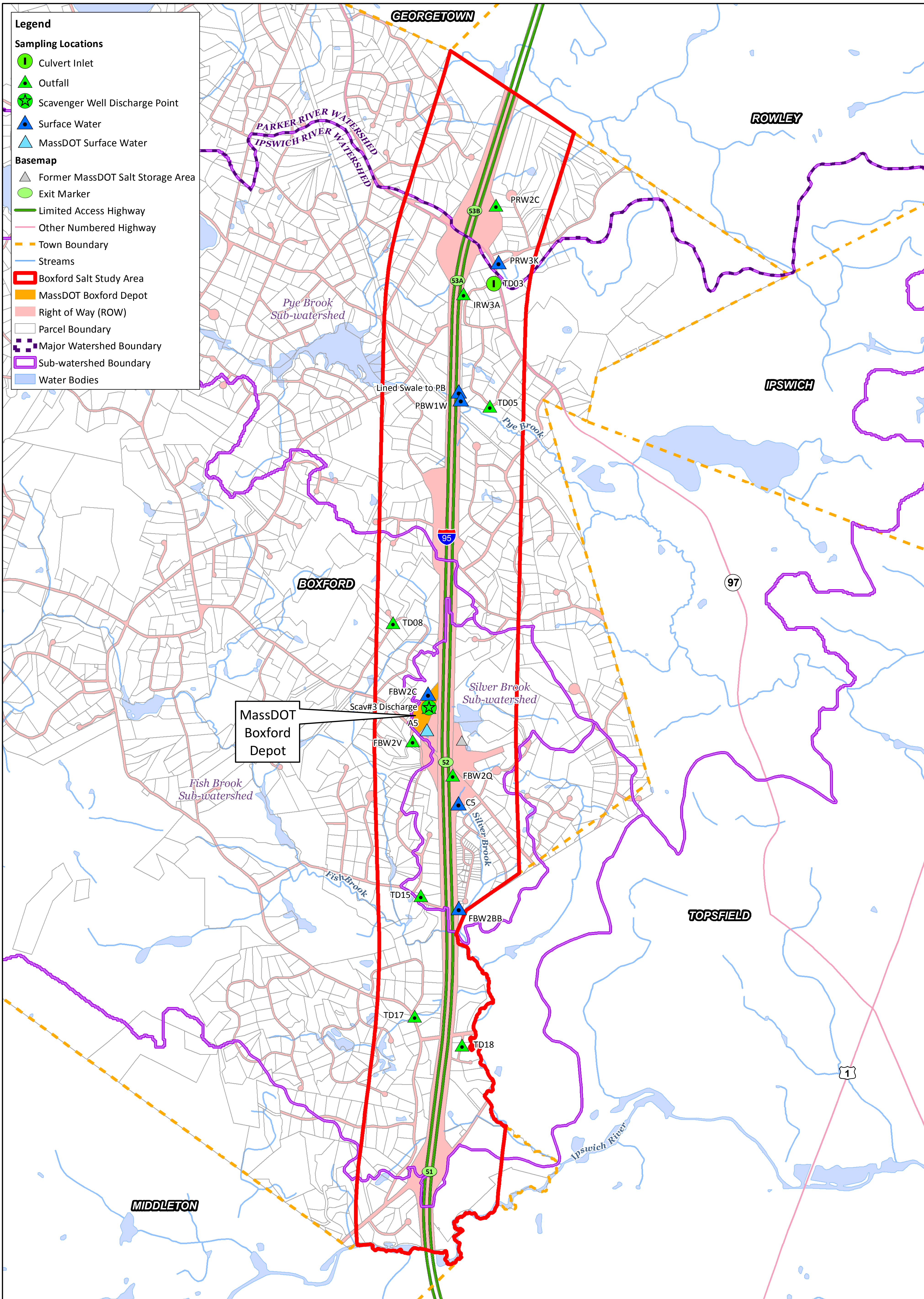
FBW: Fish Brook Sub-watershed
°F: degrees Fahrenheit
IRW: Ipswich River Watershed
PB: Pye Brook
PBW: Pye Brook Sub-watershed
PRW: Parker River Watershed
SCAV3: Scavenger Well #3 discharge
TD: Town drainage

During each event, sampling locations were generally sampled four times. The minimum interval between sample collection at a given site was 75 minutes. For a given event, the first round of sampling was collected at about the same time at all locations. Field measurements were recorded, followed by water sample collection for laboratory analysis. Flow measurements were not collected during the winter sampling events.

Winter Sample Station A5

3.8.2 Results

The winter sampling water quality results are summarized in both tabular and graphical format. A comprehensive tabulation of water quality results from the winter sampling program is presented in **Appendix I**. Of all the water quality parameters that were analyzed, sodium and chloride concentrations were greatest at all locations and during all events.



0 1,000 2,000 3,000 4,000 Feet

N

CDM Smith

MassDOT Boxford Salt Study

Figure 3-11

2014 Winter Sampling Locations

Source: MassGIS, CDM Smith

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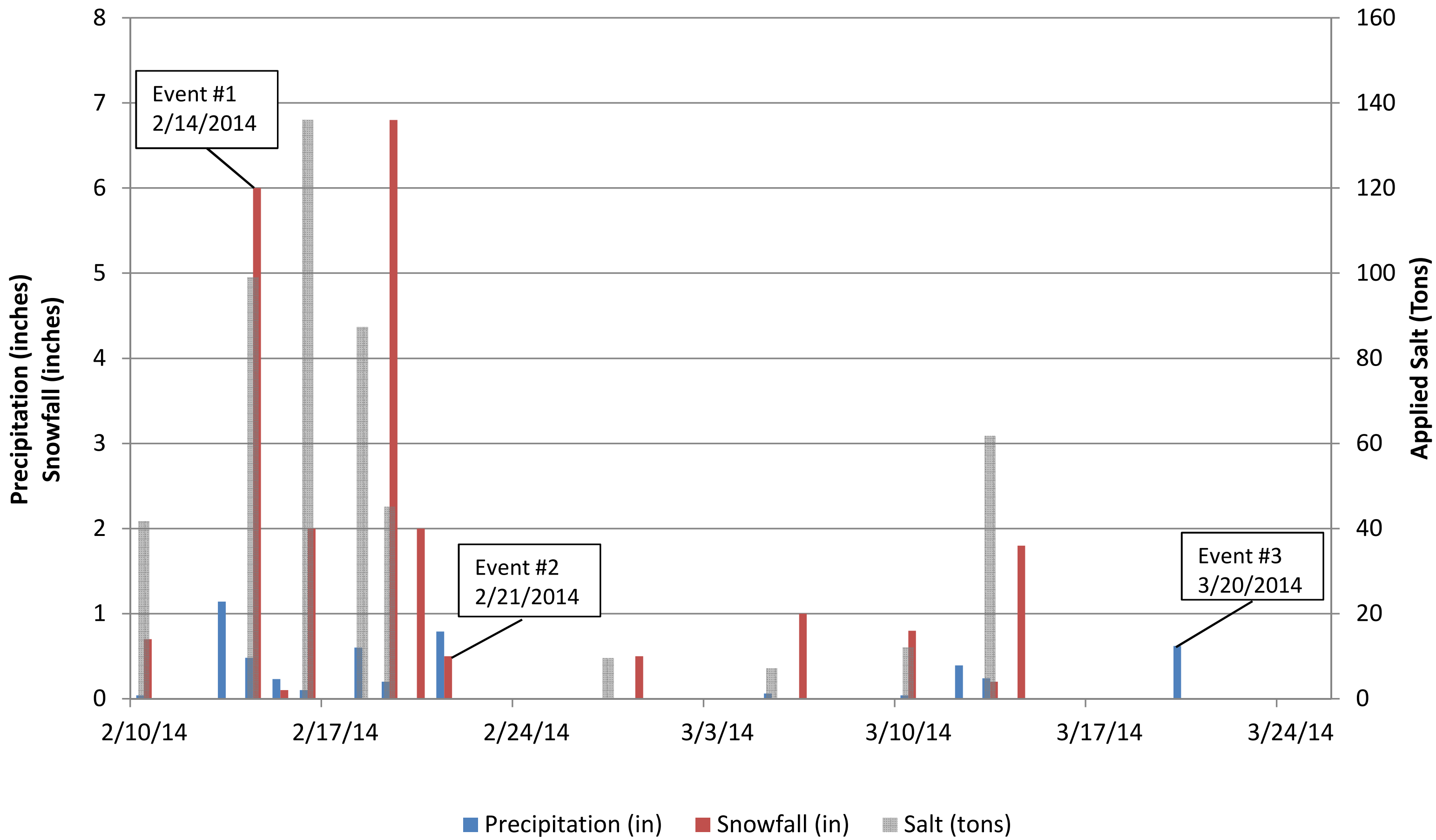


Data Sources: Groveland NWS COOP 193276

Note: Precipitation shown on this figure is the water equivalent for various types of precipitation (i.e. snow, sleet, hail)

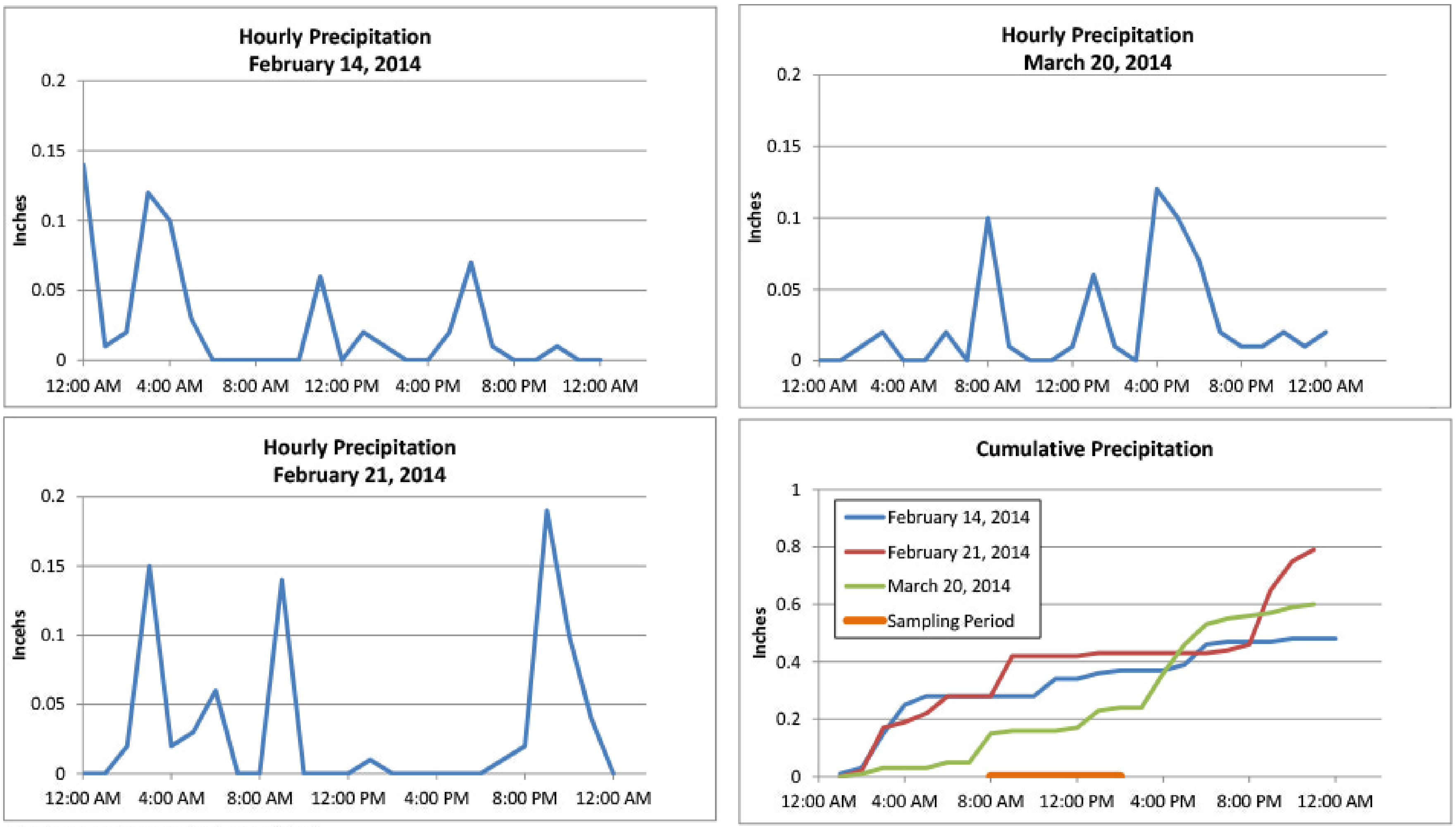
CDM Smith

MassDOT Boxford Salt Study

Figure 3-12

Record of Precipitation and MassDOT Salt Application February – March 2014

Source: CDM Smith



Data Sources: Groveland NWS COOP 193276

Note: Precipitation shown on this figure is the water equivalent for various types of precipitation (i.e. snow, sleet, hail)

CDM Smith

MassDOT Boxford Salt Study

Figure 3-13

Hourly and Cumulative Precipitation During Winter Sampling Events

Source: CDM Smith

Table 3-13 presents average sodium and chloride concentrations at each sample location for each event. **Figure 3-14** shows sodium and chloride concentration time histories from the winter sampling program. Multiple graphs are shown for locations that were sampled during more than one event. The graphs in **Figure 3-14** are presented in a north-to-south order by the location of the sampling site within the Study Area. Two graphs for IRW3A and PRW2C are outlined in orange. As concentrations at these sites were significantly greater than at other locations, their graph axes were adjusted to accommodate the different data range.

Table 3-13
Average Sodium and Chloride Concentrations During 2014 Winter Sampling

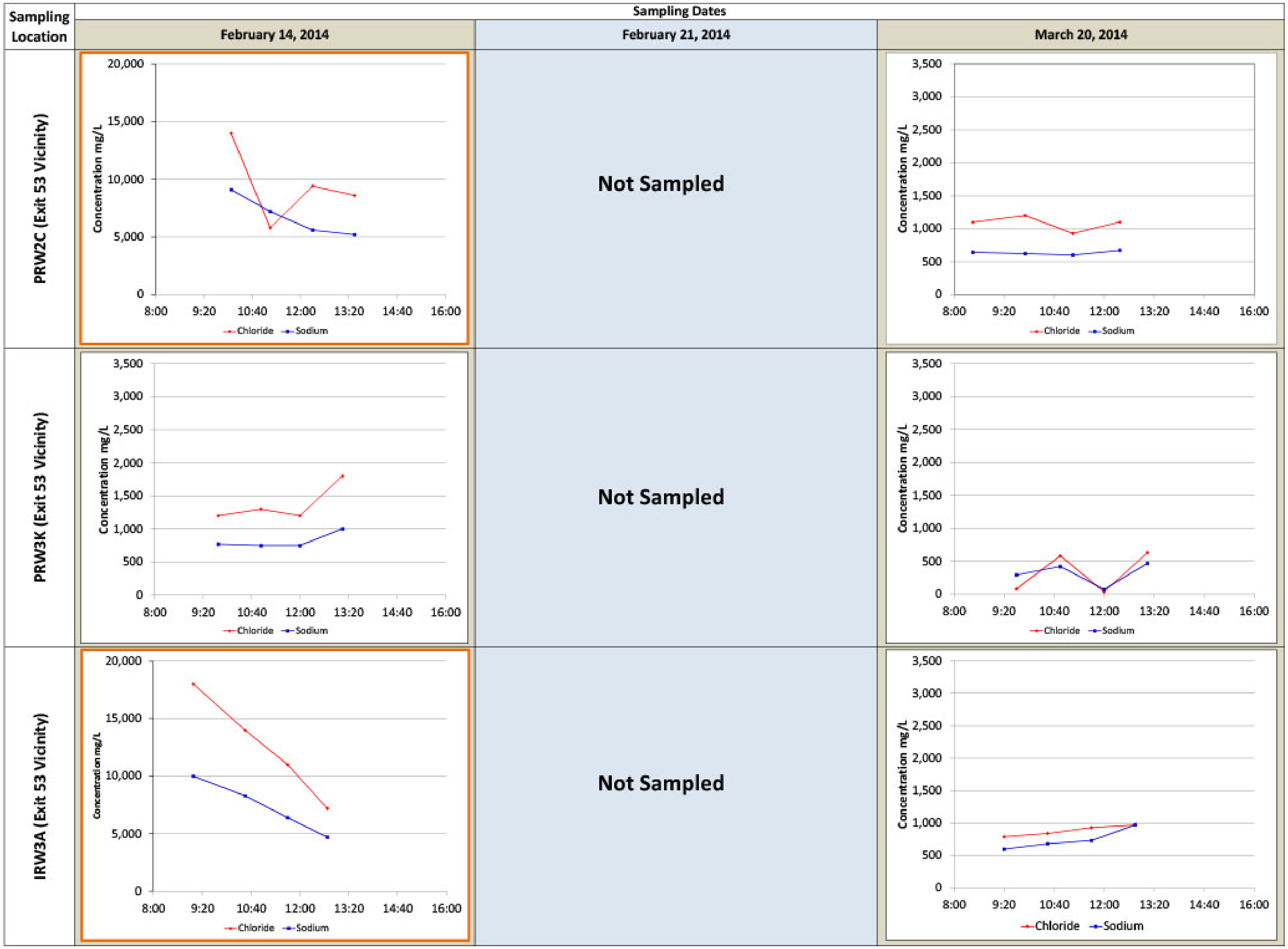
Sampling Location	Map Panel Number	Average Sodium and Chloride Concentrations[1] (mg/L)					
		February 14, 2014		February 21, 2014		March 20, 2014	
		Na	Cl	Na	Cl	Na	Cl
Exit 53 Vicinity							
PRW2C	2	6,775	9,450	NS	NS	633	1,083
PRW3K	2	818	1,375	NS	NS	313	331
IRW3A	3	7,350	12,550	NS	NS	745	883
Pye Brook							
Lined Swale to PB	3	NS	NS	NS	NS	208	64
PBW1W	4	NS	NS	NS	NS	36	56
Boxford Depot/Exit 52 Vicinity							
FBW2C	7	330	610	395	625	NS	NS
A5	7	173	343	133	233	NS	NS
FBW2V	7	NS	NS	NS	NS	613	955
FBW2Q	8	740	1,298	288	395	NS	NS
C5	8	938	1,675	195	333	103	183
Fish Brook Sub-watershed							
FBW2BB[2]	9	NS	NS	153	275	NS	NS
TD17	10	NS	NS	33	68	NS	NS
TD18	10	NS	NS	NS	NS	36	49

Abbreviations:

Cl: chloride
FBW: Fish Brook Sub-watershed
IRW: Ipswich River Watershed
mg/L: milligrams per liter
Na: sodium
NS: not sampled
PB: Pye Brook
PBW: Pye Brook Sub-watershed
PRW: Parker River Watershed
TD: Town drainage

Notes:

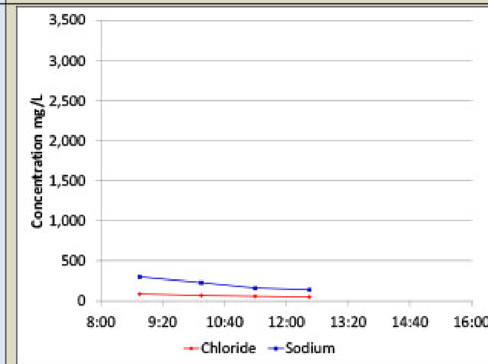
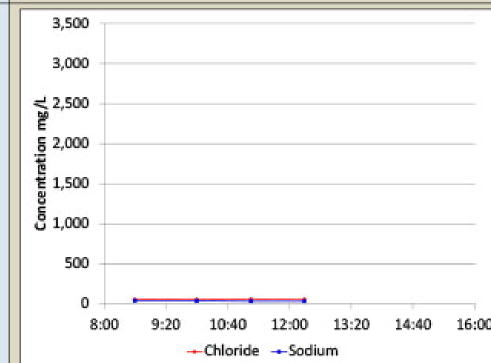
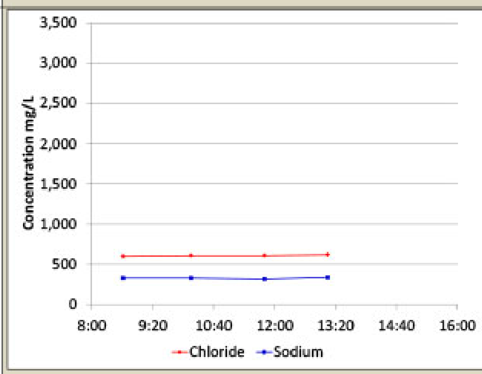
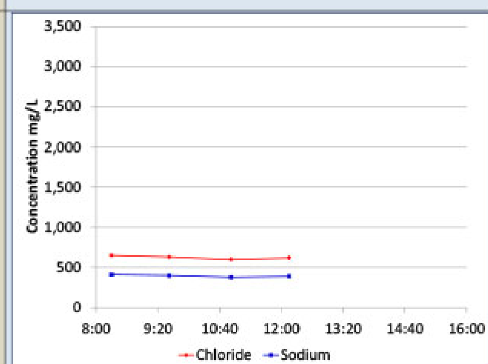
[1]Laboratory analysis by Absolute Resource Associates of Portsmouth, New Hampshire.
[2]FBW2BB in Silver Brook Sub-watershed just upgradient of confluence with Fish Brook.



Note: Plots outlined in orange are shown on a greater vertical scale.

MassDOT Boxford Salt Study
Figure 3-14
Sodium and Chloride Time Concentration Graphs of 2014 Winter Sampling Data

Source: CDM Smith

<table>
<tr><th rowspan="2">Sampling Location</th><th colspan="3">Sampling Dates</th></tr>
<tr><th>February 14, 2014</th><th>February 21, 2014</th><th>March 20, 2014</th></tr>
<tr><td>Lined Swale to Pye Brook (Pye Brook)</td><td>Not Sampled</td><td>Not Sampled</td><td>
</td></tr>
<tr><td>PBW1W (Pye Brook)</td><td>Not Sampled</td><td>Not Sampled</td><td>
</td></tr>
<tr><td>FBW2C (Boxford Depot/Exit 52 Vicinity)</td><td>
</td><td>
</td><td>Not Sampled</td></tr>
</table>

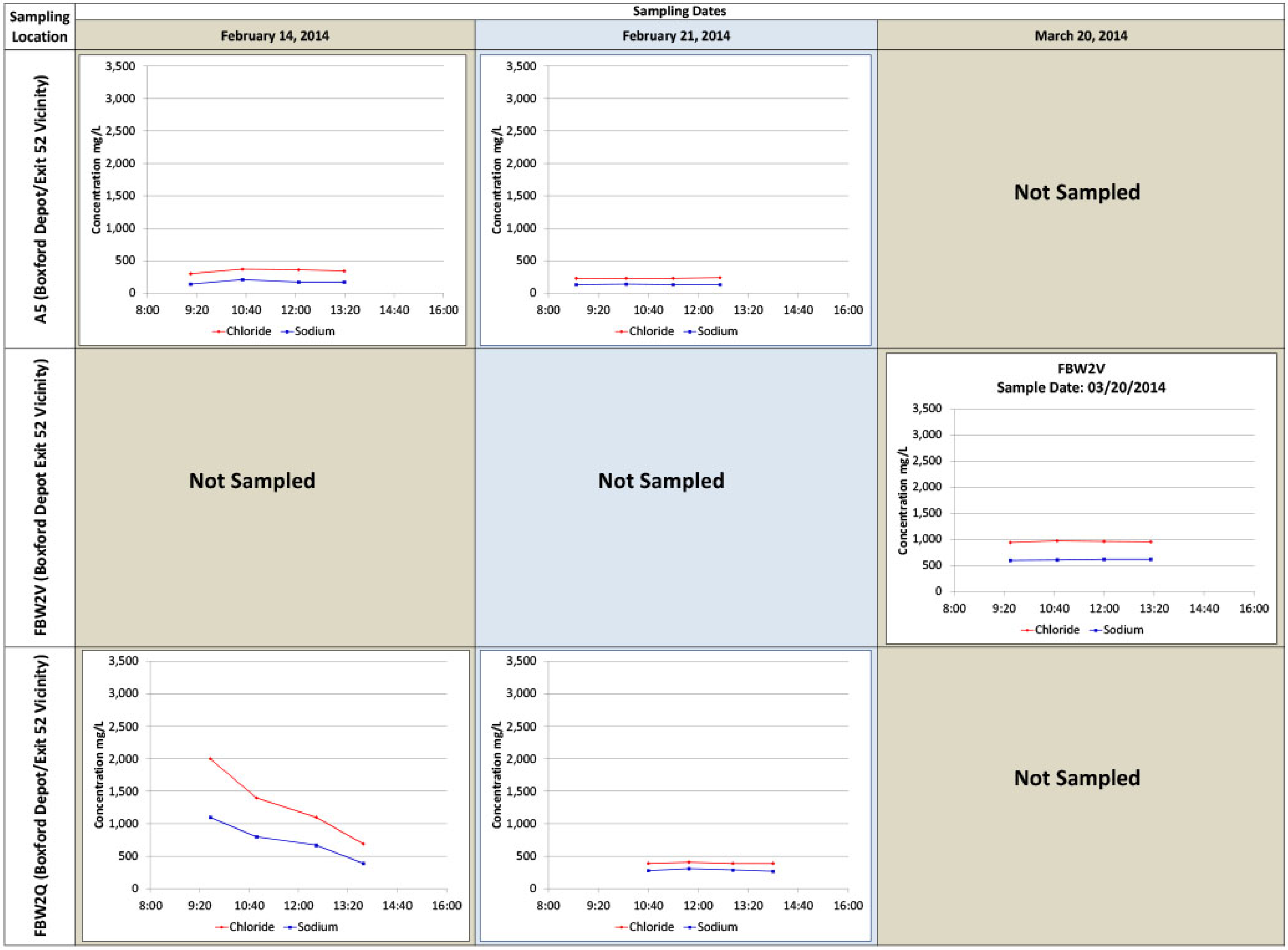
CDM Smith

Source: CDM Smith

MassDOT Boxford Salt Study

Figure 3-14

Sodium and Chloride Time Concentration Graphs of 2014 Winter Sampling Data *(continued)*



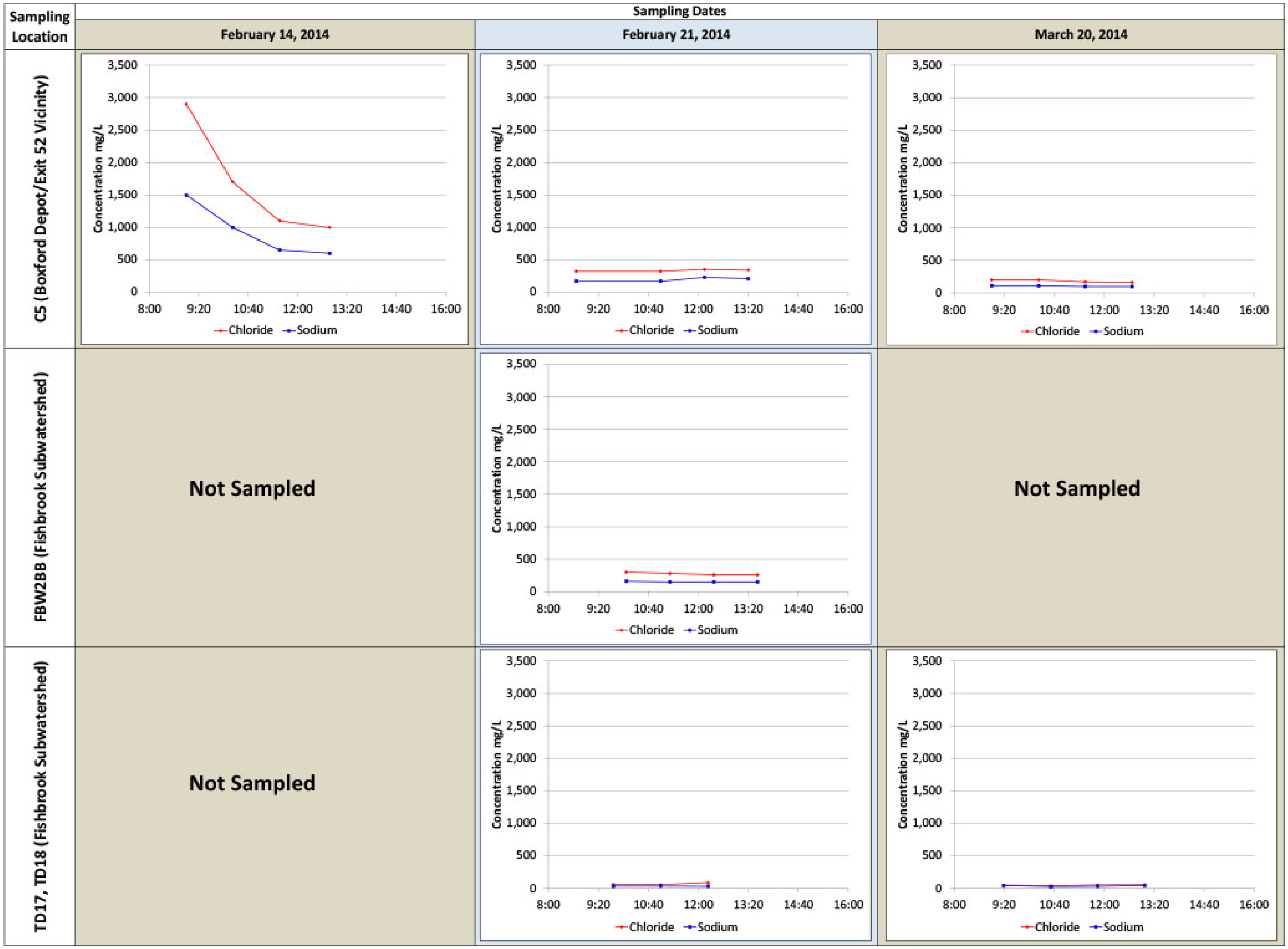
MassDOT Boxford Salt Study

Figure 3-14

Sodium and Chloride Time Concentration Graphs of 2014 Winter Sampling Data

(continued)

Source: CDM Smith



MassDOT Boxford Salt Study

Figure 3-14

Sodium and Chloride Time Concentration Graphs of 2014 Winter Sampling Data *(continued)*

Source: CDM Smith

Winter Sampling Station C5

During the February 14th sampling event, when deicing materials were applied to roadways, average surface water sodium and chloride concentrations ranged from 173 to 7,350 mg/L and 343 to 12,550 mg/L, respectively. The reported concentrations during this event were the highest measured during the three winter sampling events. At locations receiving direct runoff from I-95, concentrations at sampling locations decreased over the course of the day reflecting the loading and run off of deicing materials from the roadways (**Figure 3-14**). Towards the end of the February 14th event, measured sodium and chloride concentrations had decreased to approximately 500 mg/L or less at most locations other than those in the vicinity of Exit 53.

During the two subsequent sampling events (February 21st and March 20th), with the exception of Town drainage samples, measured surface water sodium and chloride concentrations typically ranged from 500 to 1,000 mg/L. Results did not vary much over the course of the sampling day, with the greatest variability noted at sample points in the vicinity of Exit 53. Measured sodium and chloride concentrations at Town drainage locations were generally less than 50 mg/L. Reported concentrations from the February 21st and March 20th events were consistent with concentrations measured during the 2013 reconnaissance field program. Two locations, (A5 and C5) were monitored during earlier MassDOT sampling programs. Measured 2014 concentrations at these locations were very similar to those reported by MassDOT in 2006.

Two sampling locations exhibited notably elevated sodium and chloride concentrations during the first event: PRW2C and IRW3A. Both sampling locations are located in the Exit 53 vicinity near discharge locations for highway ramp drainage. The highest chloride concentration measured was at IRW3A (18,000 mg/L). Several domestic wells impacted by salt are located near these sampling locations.

In addition to the laboratory analyses performed on the water quality samples, field measurements of specific conductance and other field parameters were also collected during the winter sampling events. Specific conductance, in particular, can be used as a measure of deicing impacts. A comprehensive tabulation of field data is presented in **Appendix I**. Average specific conductance measurements for each site and sampling event are listed in **Table 3-14**. Graphs showing specific conductance versus time are presented in **Figure 3-15**.

Specific conductance measurements at all the locations sampled during the February 14th event were generally higher than those measured during the other two events. This is because deicing materials were applied by MassDOT during this event resulting in higher chloride and corresponding specific conductance values in the stormwater runoff. It is possible that the Town also applied deicing materials to roadways during this event, however, event specific deicing operations information is not available for the Town. Specific conductance was highest at locations that receive direct stormwater runoff from I-95 roadway or ramps. These locations were PRW2C, PRW3K, IRW3A, C5, and FBW2Q. Specific conductance values at monitoring locations PRW2C and IRW3A were significantly higher than those measured elsewhere during the February 14th event.

Table 3-14
Average Specific Conductance During 2014 Winter Sampling

Sampling Location	Map Panel Number	Average Specific Conductance[1] (µS/cm)		
		February 14, 2014	February 21, 2014	March 20, 2014
Exit 53 Vicinity				
PRW2C	2	30,761	NS	3,622
PRW3K	2	3,843	NS	1,071
TD03	3	NS	NS	980
IRW3A	3	33,105	NS	4,808
Pye Brook				
Lined Swale to PB	3	NS	NS	1,171
PBW1W	4	NS	NS	283
TD05	4	NS	NS	364
Boxford Depot/Exit 53 Vicinity				
TD08	6	NS	NS	579
FBW2C	7	1,880	2,112	NS
Scavenger Well #3 Discharge	7	2,152	2,973	NS
A5	7	1,137	857	NS
FBW2V	7	NS	NS	3,150
FBW2Q	8	4,001	1,296	NS
C5	8	5,158	1,207	662
Fish Brook Sub-watershed				
FBW2BB[2]	9	NS	1,782	NS
TD15[2]	8	NS	1,836	51
TD17	10	NS	305	NS
TD18	10	NS	NS	204

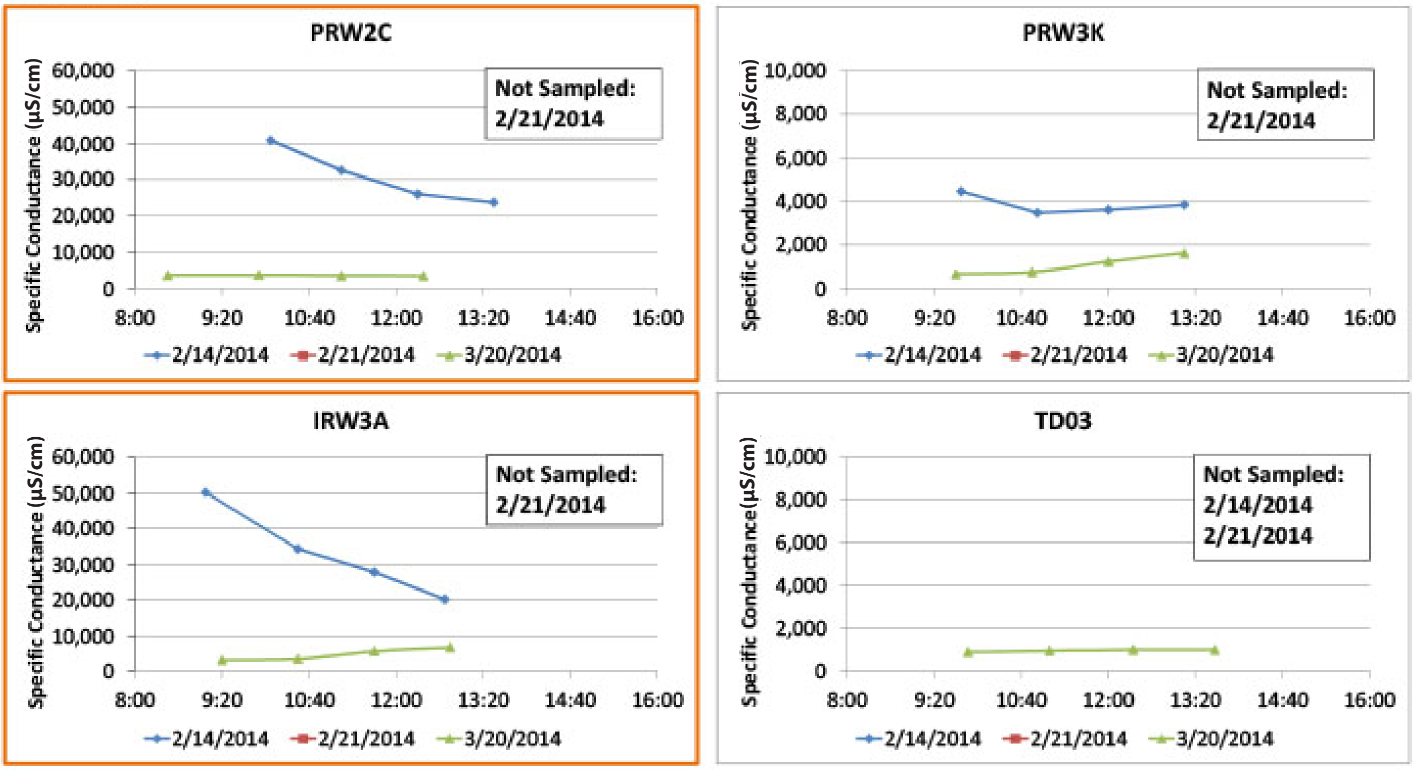
Abbreviations:

Cl: chloride
FBW: Fish Brook Sub-watershed
IRW: Ipswich River Watershed
Na: sodium
NS: not sampled
PB: Pye Brook
PBW: Pye Brook Sub-watershed
PRW: Parker River Watershed
TD: Town drainage
µS/cm: microsiemens per centimeter

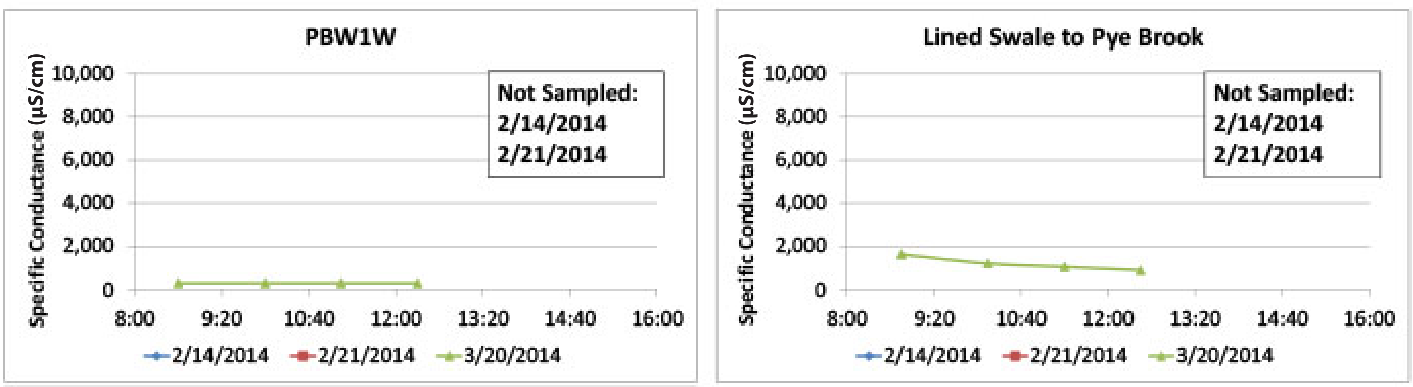
Notes:

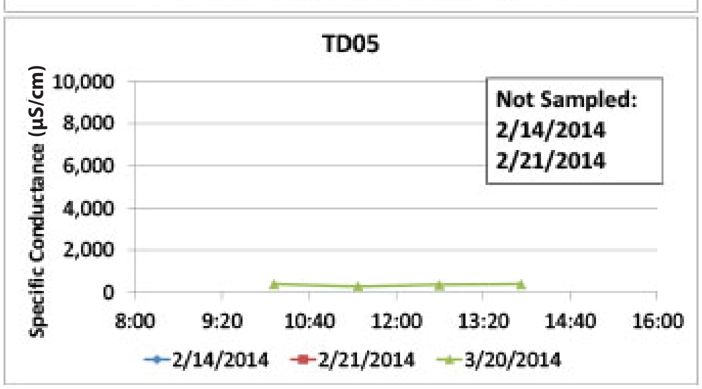
[1]Specific conductance measured in the field using a YSI556 Multiprobe System.
[2]In Silver Brook Sub-watershed which is upgradient of Fish Brook.

Exit 53 Vicinity



Pye Brook





Note: Plots outlined in orange are shown on a greater vertical scale.

CDM Smith

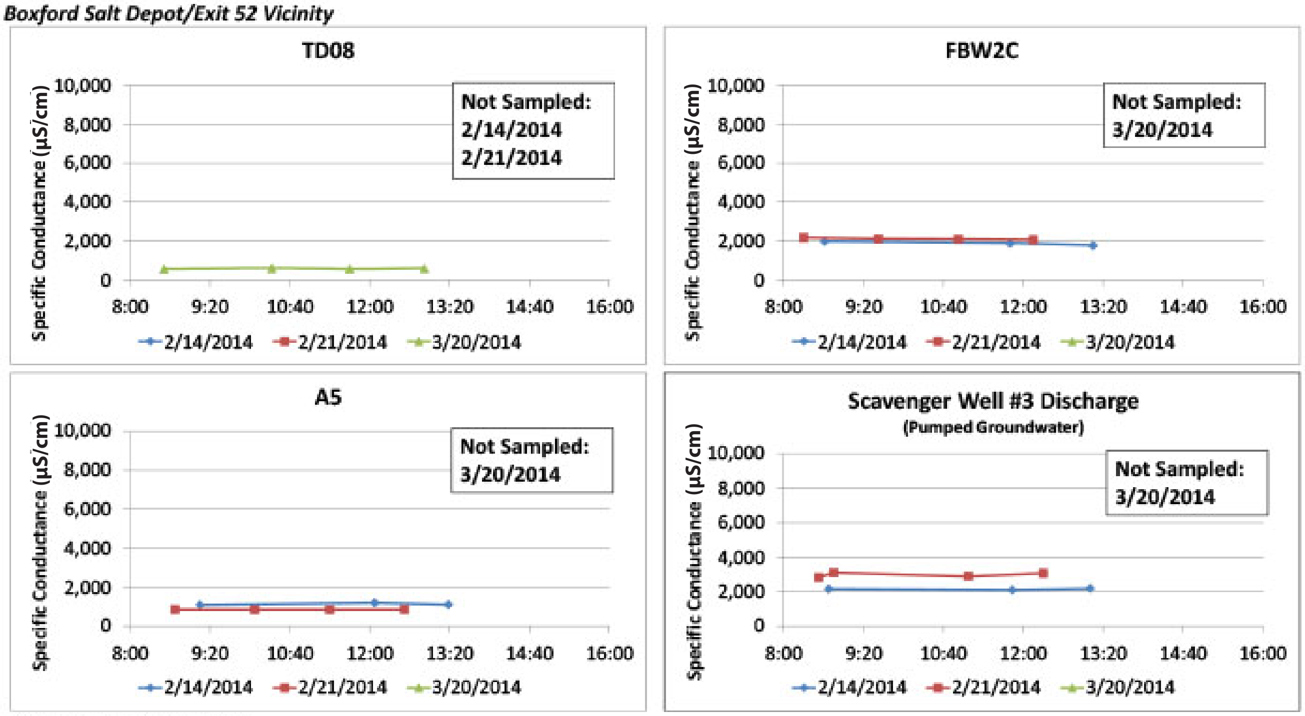
MassDOT Boxford Salt Study

Figure 3-15

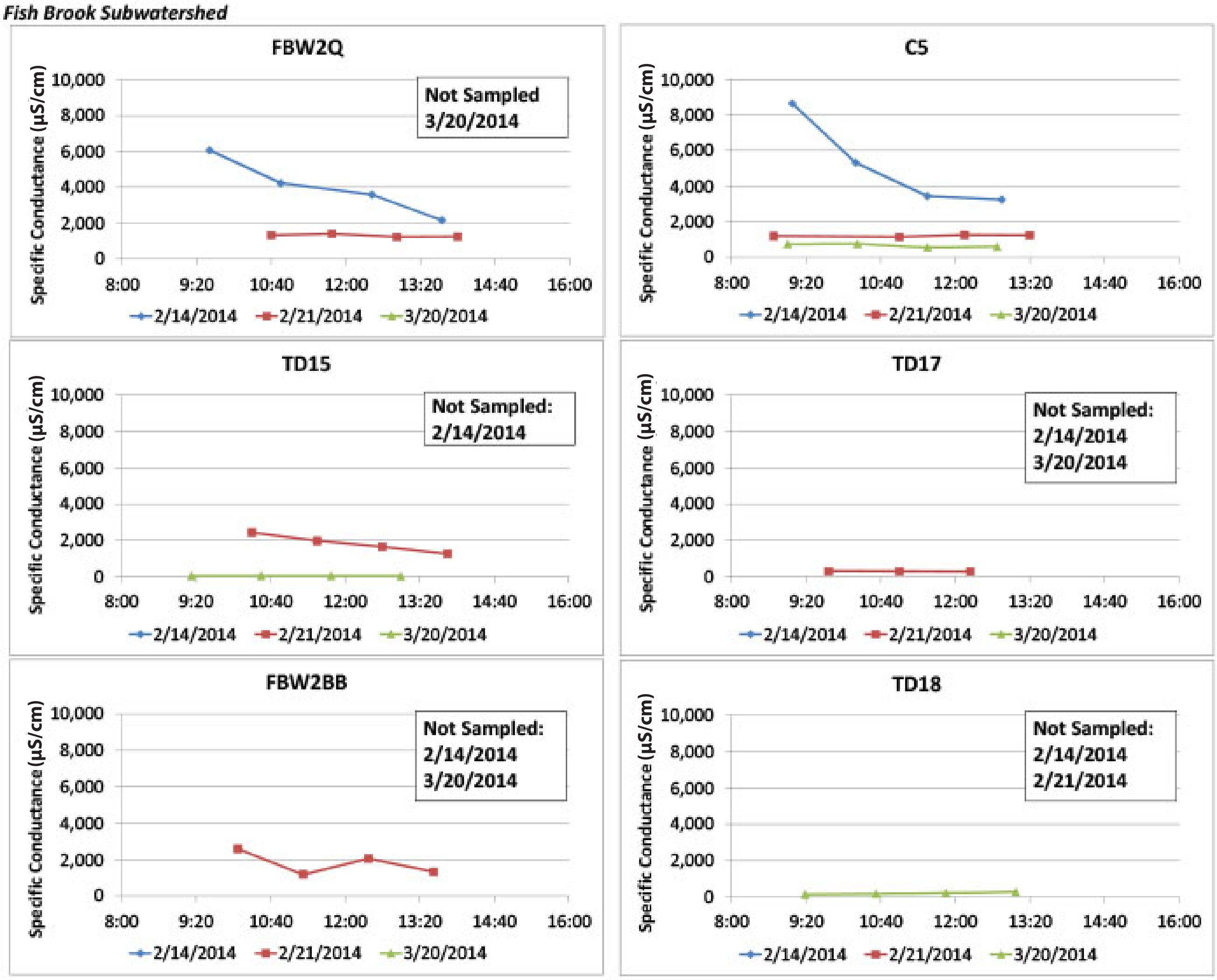
Specific Conductance Time Concentration Graphs of 2014 Winter Sampling Data

Source: CDM Smith

Boxford Salt Depot/Exit 52 Vicinity



Fish Brook Subwatershed



CDM Smith

MassDOT Boxford Salt Study

Figure 3-15

Specific Conductance Time Concentration Graphs of 2014 Winter Sampling Data

(continued)

Source: CDM Smith

Specific conductance values recorded during the February 21st and March 30th events were generally lower and varied less over the course of the sampling event. Deicing materials were not applied during the specific sampling days, however, there was deicing materials application by MassDOT several times the week before the February 21st sampling event. There was one deicing event in the week prior to the sampling event of March 20th, but the amount of material applied was less than events earlier in the winter season. At some locations, a slight increasing trend was observed in specific conductance measurements over the course of the March 20th event during which there was steady precipitation throughout the day that continued in the afternoon.

Specific conductance values measured at Town drainage locations were generally lower than those measured at I-95 discharge locations, except at TD-15 where during the February 21st event specific conductance values were similar to those measured for highway stormwater runoff.

Average specific conductance measurements collected at the Scavenger Well #3 discharge outlet for comparison with downstream locations were 2,152 to 2,973 μS/cm during the February 14th and February 21st events. Specific conductance values downstream of the Scavenger Well # 3 discharge at location A5 were 1,137 μS /cm and 857 μS /cm during the first two winter sampling events. In general, the specific conductance values recorded at the Scavenger Well #3 discharge were lower than those reported for the I-95 stormwater runoff samples.

3.9 Summary

Several field programs were conducted to help develop a better understanding of the linkage between salt impacts at domestic wells in the Study Area with past salt storage and handling at the Boxford Depot, as well as ongoing roadway deicing practices. The results of these programs are summarized below.

- ***Stormwater drainage system reconnaissance and sampling of I-95 and Town of Boxford country drainage.*** Water quality screening at selected stormwater discharge points and surface water locations was conducted from January through March 2013 during the stormwater drainage system reconnaissance field visits. Sampling locations included I-95 and Town drainage ditches, swales, and unnamed streams, as well as Pye Brook, Silver Brook, and Fish Brook near I-95 drainage outfalls. In general, the highest relative concentrations of sodium and chloride were found north of Exit 52, downstream of the Exit 52 and Exit 53 ramp interchange discharges, and at I-95 discharges to Pye Brook.

- ***Shallow monitoring well installation and groundwater sampling.*** Ten shallow overburden monitoring wells were installed along I-95 to evaluate salt impacted highway drainage and runoff on groundwater. Groundwater sampling was performed at the ten new shallow overburden monitoring wells, existing shallow wells located at the Boxford Depot, and two additional overburden wells located on Curtis Road and at MASCO. Most wells were sampled in both October 2013 and April 2014. Overburden sodium concentrations ranged from about 5 mg/L to 920 mg/L, and overburden groundwater chloride concentrations ranged from about 2 mg/L to 1,100 mg/L. There was no discernible pattern in groundwater concentration differences between the two sampling events. The highest overburden groundwater concentrations were measured at locations that receive direct runoff from I-95 drainage systems.

- ***Sampling and analyses of soil samples along I-95 and at the Boxford Depot.*** Unsaturated soil samples were collected during the installation of the overburden wells, and at six locations on the Boxford Depot site. Soil sodium and chloride concentrations at overburden monitoring well locations ranged from non-detect to 520 µg/g and non-detect to 130 µg/g, respectively. The highest soil concentrations were typically detected at locations that receive direct runoff from I-95 drainage systems. In the Boxford Depot soil samples, sodium and chloride concentrations ranged from 51 to 1,200 µg/g and non-detect to 670 µg/g, respectively. The highest soil concentrations at the Boxford Depot were measured at locations which were likely most affected by past stormwater runoff containing deicing materials.

- ***Bedrock investigations including fracture trace analysis and borehole geophysics.*** The fracture trace analysis, outcrop investigations, and geophysical logging reveal a complex fracture system in the Study Area. The extensive bedrock fracturing likely allows a high degree of mobility of salt constituents both horizontally and vertically through the bedrock aquifer, and provides a direct pathway from the overburden to deeper portions of the bedrock. Fractured groundwater sampling results conducted at Scavenger Well #3, well 11-2000-C, and MDOT-BW-1 indicate that salt concentrations are well distributed vertically throughout the depth of each borehole. The highly fractured nature of the bedrock, the varying fracture orientations, well construction (long open holes), continuous pumping of scavenger wells (past and present), and extended daily intermittent pumping of the numerous domestic wells installed at various elevations throughout the Study Area, are all potentially contributing factors to the distribution of deicing materials in bedrock groundwater within the Study Area.

- ***Domestic well sampling and analysis for deicing material indicator parameters.*** Raw groundwater samples from 22 domestic wells in the Study Area were obtained and analyzed for roadway deicing parameters. In general, the highest sodium and chloride concentrations were detected at wells near Exit 52 and Exit 53. Some of the domestic wells that were sampled in 2014 were replacement wells also sampled earlier by MassDOT as part of the Salt Remediation Program. At nine locations where historical documentation was believed sufficient to correlate 2014 data with earlier data, reported 2014 groundwater concentrations were generally similar to earlier reported concentrations from sampling events conducted during different periods in 2006-2013. More comprehensive area-wide comparisons of recent and older data could not be completed due to uncertainty in the depths of the wells sampled in the past.

  Whereas measured surface water concentrations are typically closely related to storm conditions at the time of sampling, measured groundwater concentrations in the bedrock reflect contributions from past sources. For instance, the bedrock groundwater concentrations near Exit 53 are related to past, as well as possibly current, I-95 deicing and drainage operations. Bedrock groundwater concentrations near Exit 52 are likely related to past materials storage/handling at the Boxford Depot, as well as past and possibly current I-95 deicing and drainage operations.

- ***A winter sampling program focused on three weather events.*** The 2014 winter sampling events were conducted February 14th (snow event), February 21st (snow and rain event), and March 20th (melting event with rain). For each event, a select number of grab surface water samples were collected and analyzed for deicing parameters. Flow measurements were not conducted. As roadway deicing materials were applied during the February 14th event, stormwater runoff and surface water sodium and chloride concentrations were higher during this event than during the subsequent winter sampling events when no deicing materials were applied. Stormwater runoff concentrations were highest at locations that receive direct stormwater runoff from I-95 roadways and ramps in the Exit 52 and Exit 53 vicinity. The highest concentrations were reported along the northbound Exit 53 on-ramp.

Section 4
Study Area Conceptual Model

4.1 Introduction

A conceptual model is a simplified representation or working description of a real system. It describes how a system behaves on the basis of data analysis using previous studies, mapping, field observations, and available field data. In the context of the Boxford Salt Study, the conceptual model describes linkages between potential sources of deicing materials, flow pathways associated with stormwater runoff, engineered drainage systems, and surface water, as well as groundwater migration pathways in both the overburden and bedrock. This section presents a conceptual model of the Study Area relative to sources of salt impacts to groundwater and potential salt migration pathways based on deicing practices, as well as the hydrologic and geologic setting. Considerations for alternatives analysis are also presented.

4.2 Sources of Groundwater Impacts

Groundwater in the Study Area has been impacted by deicing materials, primarily salt (sodium and chloride) but also magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$). Salt was introduced to the Study Area from several major sources. Currently, the primary source is the Massachusetts Department of Transportation (MassDOT) deicing operations along I-95 in the Study Area. The Town of Boxford's (the Town) deicing operations on local roadways represent a secondary smaller source. From 1974 until 2005, materials storage and handling operations at the Boxford Depot were sources of salt and other deicing materials to the environment. Between 2005 and 2009, contributions of salt to the environment at the Boxford Deport are expected to have been less than in previous years following the implementation of BMPs which included loading salt trucks under cover. Other potential sources, both current and past, include deicing treatment of parking lots, water softeners, domestic waste, and rock salt application to driveways and walkways by residents. Atmospheric deposition, which may be a larger contributor of sodium and chloride to the environment in coastal locations, is not believed to be a significant source of these constituents in the Study Area.

Estimates of current active loads from salt sources in the Study Area were developed based on records provided by MassDOT and the Town as well as available literature. Several reports produced by the New Hampshire Department of Environmental Services (NHDES) for chloride Total Maximum Daily Load studies (TMDLs) provided useful guidance for assessing chloride loading rates from different sources. **Figure 4-1** shows approximate relative contributions, on an annual basis, of the different active sources to the total salt load in the Study Area. Since this chart illustrates current loads, salt loads to the environment associated with past Boxford Depot operations are not represented. The loads

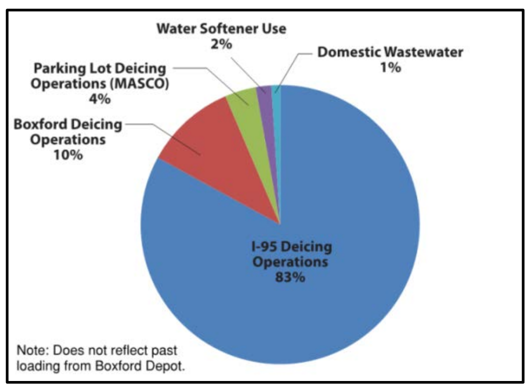


Figure 4-1
Estimated Current Active Loads from Salt Sources in the Study Area

associated with the different sources are likely to differ year-to-year depending on climate conditions and individual usage, however, the relative contributions of the individual sources to the total Study Area salt load are likely to be similar. Details on salt loading computations are provided below:

- **I-95 Deicing Operations:** The MassDOT materials usage data for highway deicing was used to calculate a salt application rate for the Boxford Depot Service Area (**Section 2.2.1.3**). The average salt application rate during the 2007/2008 through 2013/2014 winters was approximately 21.3 tons/lane-mile (**Table 2-3**) for both mainline and ramp sections of I-95. At this application rate, an average of approximately 1,270 tons of salt is applied on an annual basis to the nearly 60 lane-miles in the Study Area. This accounts for approximately 83% of the total annual salt load in the Study Area.

- **Town of Boxford Deicing Operations:** The average salt application rate for the Town based on reported materials usage during the 2007/2008 through 2013/2014 winters was 5.9 tons/lane-mile (**Table 2-5**). At this application rate, an average of approximately 159 tons of salt is applied on an annual basis to the 27 lane-miles of town and private roads within the Study Area. This is approximately 10% of the total annual loading rate from the various salt sources.

- **Parking Lots:** The only parking lot of significant size in the Study Area is the Masconomet Regional School (MASCO) parking lot, which covers approximately 8.6 acres (parking lot and roadways). Sussan and Kahl (2007) reviewed typical salt application practices in New Hampshire and other states, and estimated that on average 6.4 tons/acre/year of salt are utilized for parking lot deicing. Based on this rate, the annual loading at the MASCO parking lot is about 55 tons, which is approximately 4% of the total annual salt loading in the Study Area.

- **Water Softener Use:** Water softeners use sodium in a chemical process to remove calcium and magnesium from water, minerals which make the water hard. As a result of water softener use, additional sodium enters the domestic waste stream. Salt loading from water softener use was estimated using methodology presented by NHDES (Trowbridge, 2007). Hard water is reported in this area, and for the purposes of the calculation it was assumed that 25% of the households in the Study Area, or 110 residences, use water softeners. Assuming a typical household consists of 3.5 people, a water usage rate of 65 gallons/person/day[1], and a salt content of 0.006 pounds of salt per gallon of wastewater from water softener use, the estimated annual salt loading resulting from water softener use is 27 tons. This makes up about 2% of the total salt loading within the Study Area. Using a higher water usage rate of 110 gallons/person/day which is typically used for septic system design would result in an estimated annual loading of 46 tons from water softener use, or approximately 3% of the total salt loading. The actual salt contribution may be larger if more homes use softeners than was assumed for the calculation.

- **Domestic Wastewater:** Food waste and human sewage contain salt due to salt added to foods. Salt loading due to wastewater enters the groundwater via septic systems, as the Town is not sewered. Therefore, all homes in the Study Area are assumed to have on-site septic systems. Assuming 20 pounds of salt per person per year (Trowbridge, 2007; Metcalf & Eddy, 1991), and 3.5 people per household, an average annual loading of 15 tons of salt was calculated as the contribution from domestic wastewater, making up 1% of total salt loading in the Study Area.

[1] MassDEP. Performance Standards for Public Water Supplies - RGPCD & UAW. 2014.

- **Rock Salt Application by Residents:** In a recent study, EPA assumed that salt use on residential driveways is a minor source because snow is typically cleared by plows and shovels, not by deicing chemical application (Heath and Morse, 2011). For this calculation, rock salt application was viewed as a very minor source and was not explicitly calculated.

Although the Boxford Depot is no longer an active salt storage facility, past operations at this location likely introduced salt to the groundwater and surface water. When the Depot was active, salt handling and loading operations were not conducted under cover until 2005. Routine deicing of the pavement was also conducted at the site up until 2004 after which time deicing was performed on an as needed basis to maintain driving safety for vehicles at the Depot.

4.3 Hydrogeologic Setting

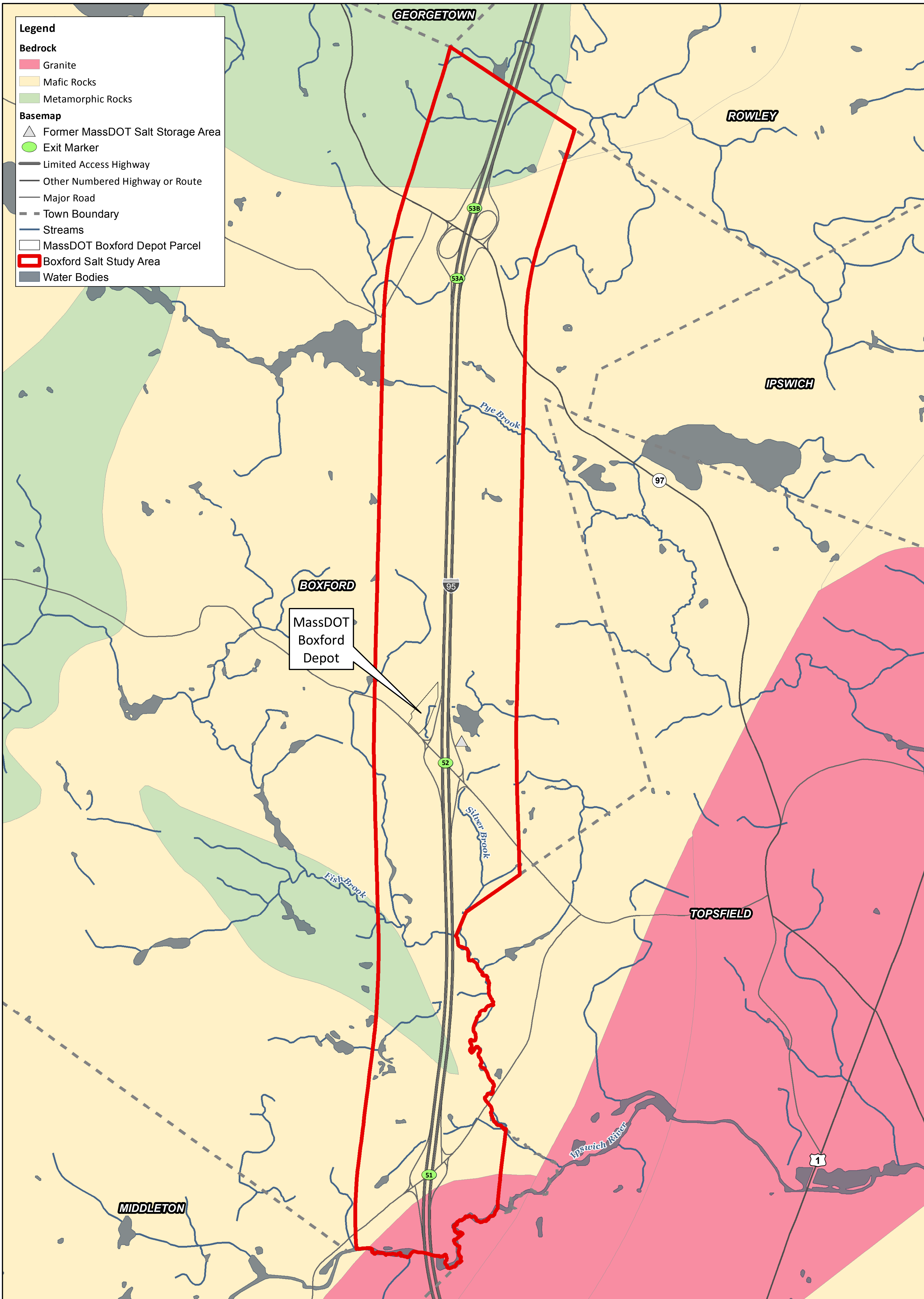
4.3.1 Bedrock Geology

The bedrock underlying the Study Area is part of the Nashoba terrane, a zone of metamorphic and intrusive rocks that is bounded by the Clinton-Newbury fault on the west and the Blood Bluff fault on the east. Bedrock types and formations that have been identified in the Study Area include Fish Brook Gneiss (metamorphic, gneiss, and schist), and Sharpners Pond Diorite (mafic, a type of igneous rock with darker minerals). Rocks of the Nashoba terrane are reportedly fractured and faulted. This is consistent with the findings of the fracture trace analysis and geophysical investigations conducted during the Study and described in Section 3. The borehole geophysics conducted for the Study indicated that the bedrock was heavily fractured with both horizontal and vertically dipping fractures throughout the length of the boreholes studied (up to depths of 440 feet). **Figure 4-2** shows the bedrock geology in the Study Area.

Figure 4-3 presents a generalized map of the elevation of the bedrock surface. The bedrock surface elevation was estimated based on land surface elevation contours and bedrock depth information provided in domestic well boring logs, I-95 highway borings, and borings advanced during the Study. In most cases, the exact location of domestic boring(s) on each residential parcel was not known. Therefore, for contouring and analysis purposes, the domestic boring was assumed to be located at the centroid of the parcel. As such, the estimates of the bedrock surface elevation (and overburden thickness presented below) are approximate for a given location, and **Figure 4-3** should be viewed as an estimated and approximate representation of bedrock surface elevations. Based on the available information used to compile the map, the elevation of the bedrock surface is estimated to range from approximately 0 to 140 feet-mean sea level (MSL) in the Study Area. In many locations in the Study Area, the top of the bedrock is close to the land surface (less than 10 feet in many areas).

4.3.2 Overburden Geology

The bedrock in the Study Area is overlain by overburden sediments comprised of glacial stratified drift deposits consisting of sand, gravel, and silt, as well as glacial till. In the Study Area, till deposits appear to be thin, and bedrock is at or near the land surface in some areas mapped as till. Numerous bedrock outcrops are shown in surficial geology mapping presented in **Figure 4-4**. Many outcrops located along I-95 were field confirmed and evaluated as part of the fracture trace analysis which indicated fracture dips ranging from 45 degrees from horizontal to nearly vertical. Lowland portions of the Study Area are generally underlain by well-sorted fluvial sands and gravels deposited from glacial meltwater streams. Overburden materials encountered during the installation of the overburden wells along I-95 for the Study generally consisted of coarse to fine sands with varying degrees of silt and/or gravel.



CDM Smith

Source: MassGIS, CDM Smith

Service Layer Credits:

0 1,000 2,000 3,000 4,000 Feet

N

MassDOT Boxford Salt Study

Figure 4-2

Bedrock Geology

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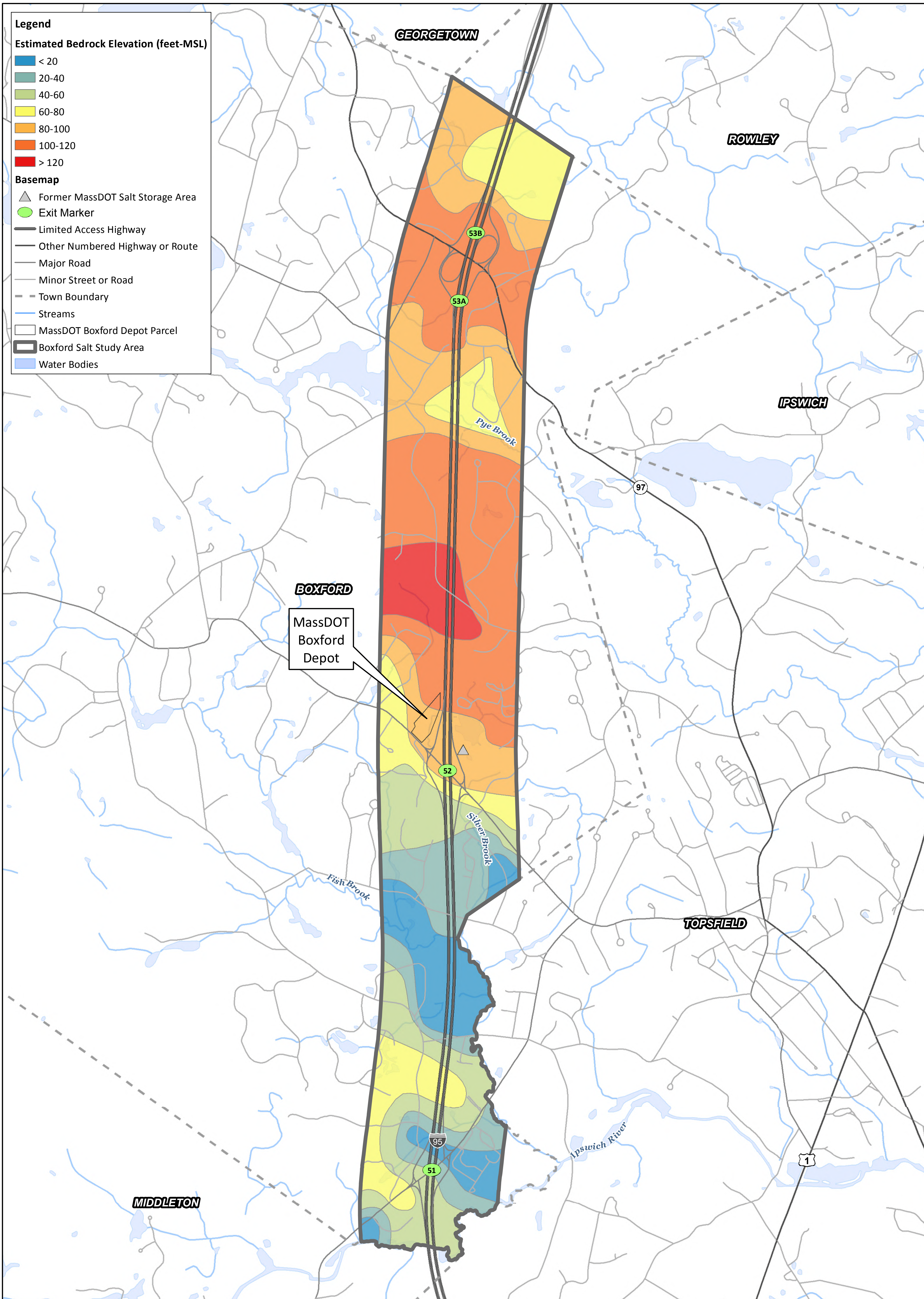

MassDOT Boxford Salt Study

Figure 4-3

Estimated Bedrock Elevations

0 1,000 2,000 3,000 4,000 Feet

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Source: MassGIS, CDM Smith

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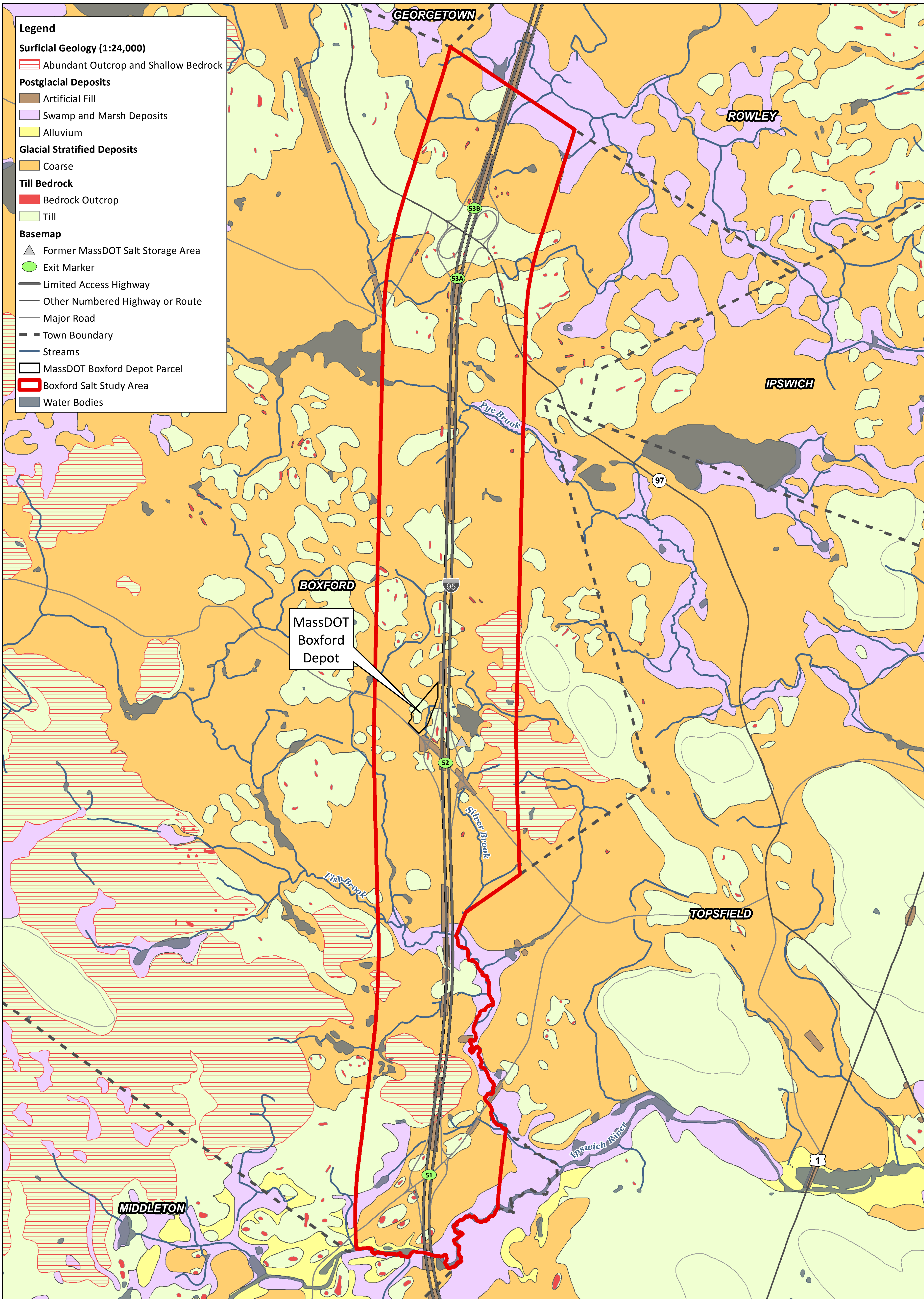

MassDOT Boxford Salt Study

Figure 4-4

Surficial Geology

Source: MassGIS, CDM Smith

Service Layer Credits:

0 1,000 2,000 3,000 4,000 Feet

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The thickness of overburden materials in the Study Area was estimated from information provided in domestic well boring logs, I-95 highway borings, and borings advanced during the Study. Similar to the bedrock surface elevation mapping presented above, the estimates of overburden thickness in the Study Area are approximate because the exact location of many of the borings was not known. **Figure 4-5** shows the estimated depth to bedrock (or overburden thickness) in the Study Area. The thickness of the overburden in the Study Area is estimated to range from 0 to more than 60 feet.

Near Exit 53 in the northern portion of the Study Area, the bedrock is close to the land surface with overburden thickness ranging from about 0 to 10 feet. The thinner overburden results in a shorter travel distance between surface water and shallow groundwater, and the deeper bedrock groundwater system. Multiple residents in this area have entered MassDOT's Salt Remediation Program.

Moving southward, the overburden thickens in the vicinity of Pye Brook, and then becomes thinner in the Boxford Depot and Exit 52 vicinity where again the estimated overburden thickness is 0 to 10 feet. South and southeast of Exit 52, the bedrock surface decreases in elevation and the overburden is much thicker. This includes the Titus Lane area (south of the Boxford Depot) and the Silver Brook area. Multiple residents in each of these areas have also entered MassDOT's Salt Remediation Program.

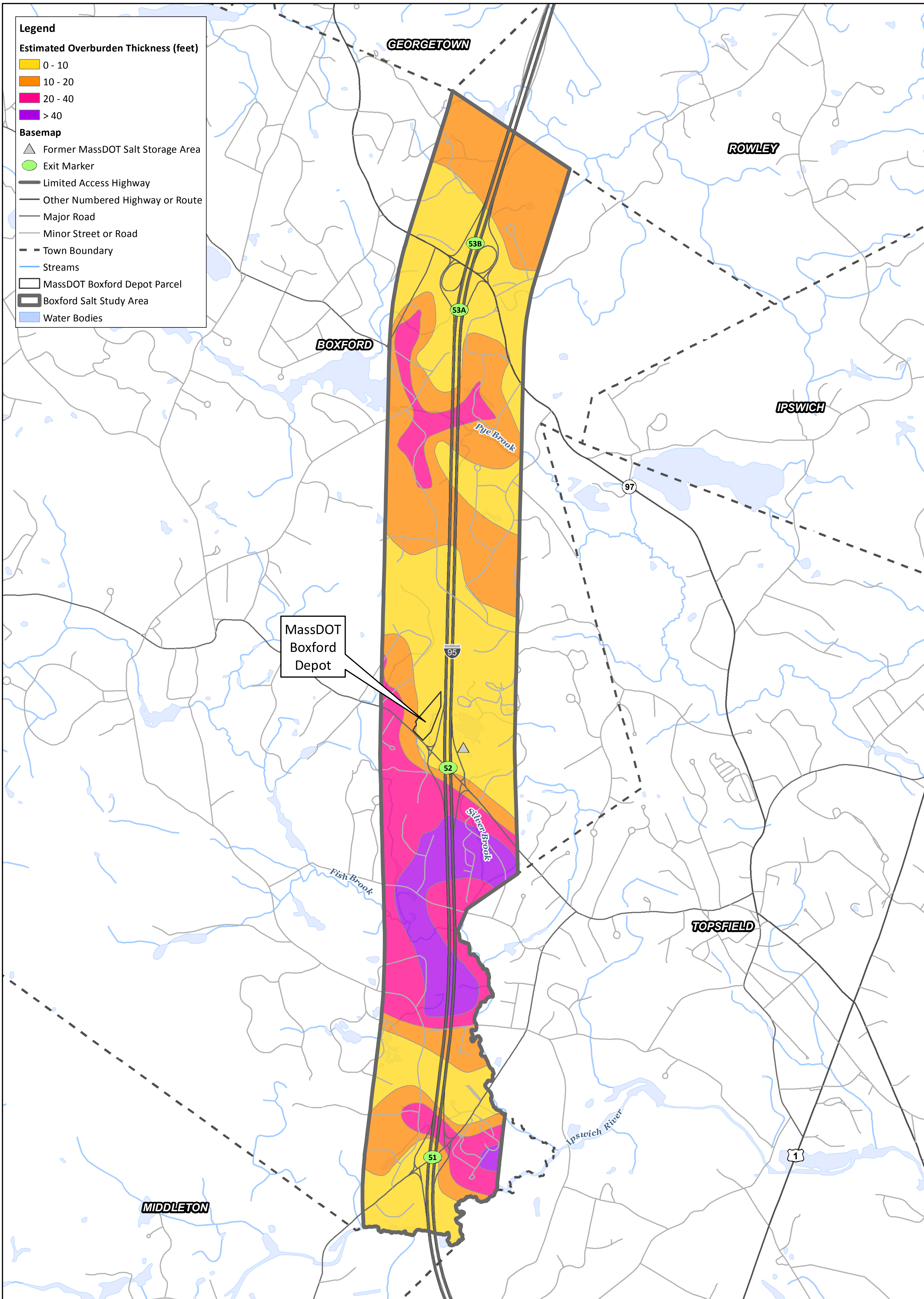
The area with greater overburden thickness is located in the vicinity of Silver Brook and Fish Brook. South of this area, the overburden becomes thinner as the bedrock surface elevation rises and even outcrops to the land surface, as confirmed by mapping and field visits. Continuing south towards the Ipswich River, the bedrock surface elevation decreases and the overburden thickness is greater. The MASCO irrigation well, which is 51 feet deep, is located in this area of greater overburden thickness. Only four residences in this area have entered into MassDOT's Salt Remediation Program.

4.3.3 Groundwater

Groundwater in the Study Area exists in both the overburden and bedrock. Subsurface exploration conducted for the Study and available drillers' logs did not indicate the presence of extensive clay, till or silt layers that would impede groundwater flow from the overburden to the bedrock. As such, in the Study Area, there is a direct hydraulic connection between the overburden and bedrock. Also, the likelihood of a hydraulic connection between surface water and bedrock increases as the overburden becomes thinner.

Groundwater flow patterns in the shallow overburden are believed to generally mimic surface topography. For example, the estimated groundwater flow direction in the overburden at the Boxford Depot (**Section 3.5**) is to the east, south, and southeast from relatively higher elevation areas towards streams and drainage ditches.

Groundwater in the bedrock flows primarily through secondary porosity: joints, faults, and fractures in otherwise relatively impermeable competent rock. The complex geometry of interconnected fractures can result in flow systems that may not follow regional or local surface water or shallow groundwater flow patterns. Steeply dipping fractures, like those observed in the Study Area, are expected to provide connections between the bedrock and overburden, as well as connections between horizontal and sub-horizontal fracture sets. Depth to water measurements in the domestic well installation records suggest that the regional bedrock groundwater flow direction in the Study Area is primarily south/southeast towards the Ipswich River, with the exception of a small portion of the Study Area in the Parker River basin where the bedrock groundwater flow direction is towards the north.



MassDOT Boxford Salt Study

Figure 4-5

Estimated Overburden Thickness

0 1,000 2,000 3,000 4,000 Feet

N

Source: MassGIS, CDM Smith

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The fracture trace analysis, described in **Section 3.6**, confirmed that the bedrock in the Study Area is heavily fractured, and that the fractures are oriented in different directions along which groundwater flow may occur. The results of the borehole geophysics field program, which are also described in Section 3.6, indicate that in the three borings studied, water transmitting fractures were encountered throughout the depth of each borehole (up to 440 feet depth). Water quality samples, collected from different fracture zones within each borehole, were similar, suggesting that the fractures were hydraulically connected. The number of fractures at the two wells tested in the vicinity of Exit 52 (Scavenger Well #3 and well 11-2000-C) was much greater than observed in the bedrock well installed near Exit 53 (MDOT-BW-1). Groundwater samples from all three wells that were tested during the geophysics study showed evidence of salt impacts throughout the depth of the borehole.

Qualitative comparisons of estimated groundwater elevations at overburden wells and estimated groundwater elevations in the bedrock suggest that a downward vertical gradient exists, indicating a tendency for groundwater in the overburden to flow into the bedrock.

4.3.4 Surface Water Hydrology

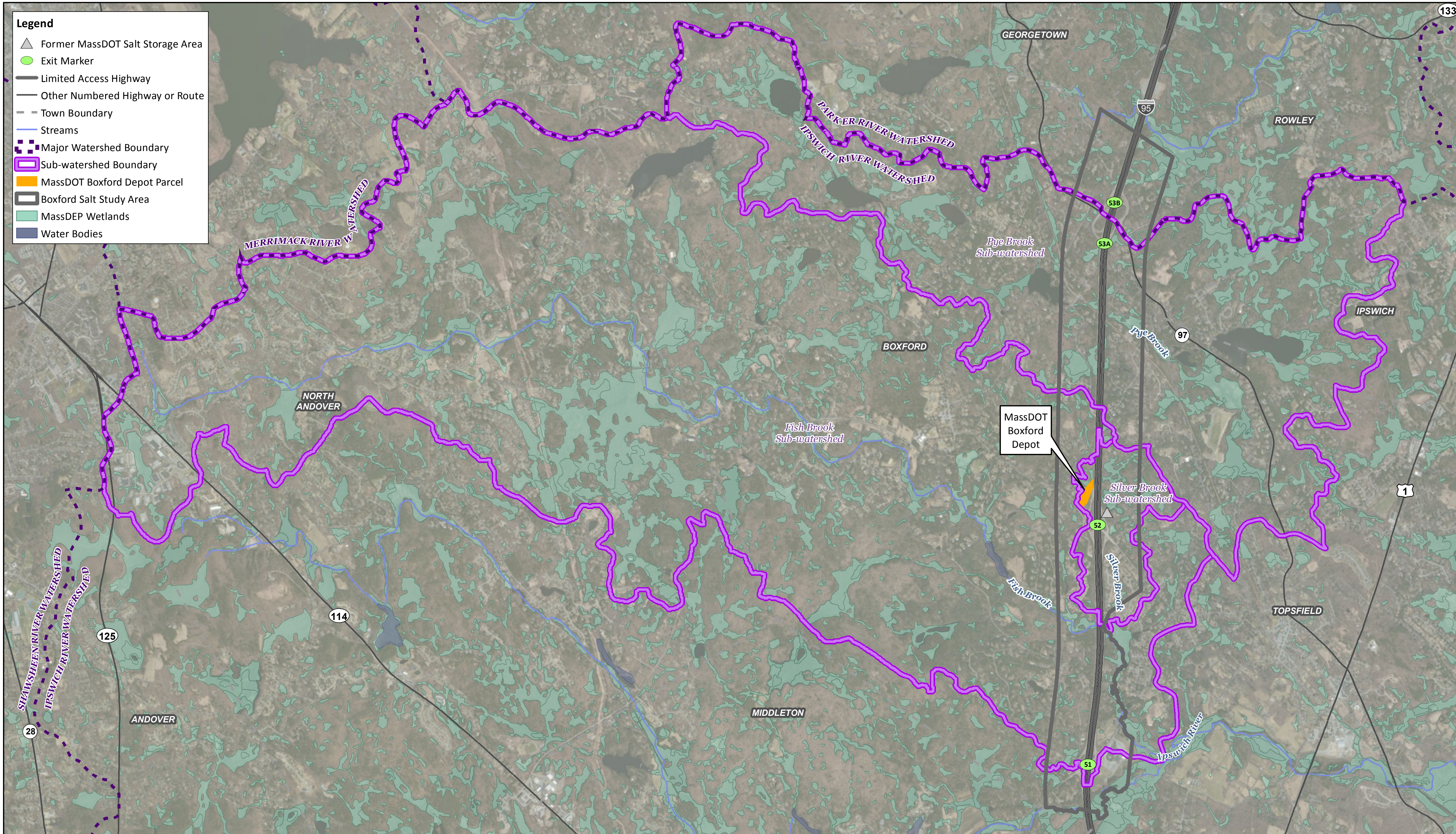
The Study Area is located within the Ipswich River and Parker River watersheds. Land surface elevations in the Study Area range from about 40 to 160 feet-MSL. The topography is generally flat, and there are many streams and wetlands that ultimately drain to either the Ipswich or Parker Rivers, which in turn flow into Plum Island Sound and Ipswich Bay.

Precipitation runoff in the study area follows natural drainage networks or highway drainage systems that ultimately discharge to natural streams. During winter precipitation events, when deicing materials are used by MassDOT and the Town, and during snowmelt events, deicing materials in the surface water runoff are transported by roadway drainage systems to local streams.

Drainage systems along Town roads tend to be unlined, dirt swales that allow for runoff to infiltrate readily into the ground. The I-95 drainage system collects runoff from larger areas and transmits the runoff via lined and unlined channels to natural stream channels or wetlands.

A more detailed discussion of the MassDOT I-95 and Town stormwater drainage systems is presented in **Section 2.3**.

Once in stream channels or wetlands, surface water transport of deicing materials is governed by watershed hydrology. The Study Area straddles two major watersheds; the area to the north of Exit 53 drains to the north towards the Parker River, while the remaining area drains to the south towards Pye Brook, Silver Brook, and Fish Brook which ultimately discharge to the Ipswich River. **Figure 4-6** shows the Pye Brook, Silver Brook, and Fish Brook sub-watersheds. Only 12% of the Pye Brook sub-watershed and 5% of the Fish Brook sub-watersheds are within the Study Area, while 76% of the Silver Brook sub-watershed is within the Study Area.



CDM Smith

Source: MassGIS, CDM Smith

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

MassDOT Boxford Salt Study
Figure 4-6
Area Watersheds

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4.4 Deicing Material Migration Pathways

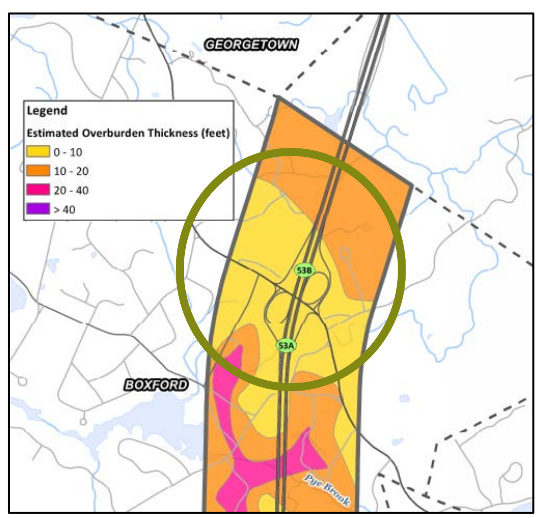
As a result of salt storage and handling operations at the Boxford Depot, particularly previous to 2005 when cover for salt loading was not available and roadway application of road salt and deicing products, sodium and chloride have been introduced to the groundwater. Additionally, the use of magnesium chloride and past use of calcium chloride by both MassDOT and the Town has, over time, introduced magnesium and calcium, as well as additional chloride, to groundwater. For the Study, groundwater quality impacts and deicing material migration pathways were evaluated based on measured groundwater, surface water, and stormwater runoff concentrations of sodium, magnesium, calcium, and chloride, as well as specific conductance.

Water quality impacts and migration pathways were evaluated by comparing data collected during the Study to estimated background, or unimpacted, concentrations. Groundwater sampling in the 1950s provided a basis for this comparison (Baker and Sammel, 1962). Based on reported groundwater concentrations for wells in the Boxford vicinity, approximate background sodium, calcium, magnesium, and chloride concentrations range from 3-32 milligrams per liter (mg/L), 6-44 mg/L, 1-13 mg/L, and 4-31 mg/L, respectively. The depths of the wells sampled for this United States Geological Survey (USGS) study ranged from 11 to 110 feet-below ground surface (BGS). Wells were installed in either the overburden or bedrock. Generally speaking, there was little difference in the reported water quality for the overburden and bedrock wells.

Sodium, chloride, and other ions are transported in groundwater. In some cases, depending on the type of subsurface geologic materials, sodium will adsorb to mineral surfaces. Calcium and magnesium may also adsorb to soil, but not as much. Chloride is considered to be a conservative ion and does not absorb to subsurface materials, and as such is believed to be a good indicator of the presence of salt and salt migration pathways. Specific conductance, which is correlated to chloride concentrations, is also a good indicator of deicing impacts.

A discussion of the conceptual understanding of the extent of deicing impacts and salt migration pathways in different portions of the Study Area is presented below. The term "deicing material" in the discussion below refers to salt and/or salt, $MgCl_2$, and $CaCl_2$.

The extent of deicing impacts was evaluated based on historical MassDOT water quality data and data collected during the Study.



Exit 53 Area

4.4.1 Exit 53

This area generally covers Exit 53 and locations south to Pye Brook. The conceptual understanding of deicing and salt migration pathways in the Exit 53 vicinity is summarized below:

Sources

- Bedrock groundwater impacts in this area are associated with roadway deicing operations, and not with materials storage and handling.

Salt Migration Pathways

- Stormwater drainage and runoff from I-95 and the Exit 53 interchange discharge to grassy swales alongside the highway mainline and interchange, respectively. In addition, snowbank melting beyond the drainage system along the exit ramp may infiltrate directly into the overburden. Bedrock is within ten feet of land surface where these discharges occur, and several bedrock outcrops have been identified in this area, resulting in a short pathway from surface water and overburden groundwater to bedrock. Because the bedrock is heavily fractured, horizontal and vertical pathways exist for transport of deicing materials in bedrock groundwater. Domestic well pumping may further contribute to migration in the bedrock.

Extent of Impact

- Based on historical data, a majority of the wells impacted in this area are in locations where bedrock is within about 10 feet of land surface. Bedrock groundwater quality impacts associated with deicing have been observed at parcels up to and more than 1,500 feet east of I-95, and approximately 1,000 feet west of I-95. In general, there appears to be a larger number of impacted wells east of I-95 than to the west. Wells of up to 440 feet-BGS have shown evidence of deicing impacts, however, because of the variability of the fractures in the bedrock, there may be zones at shallower depths that are not impacted by deicing materials.

Discussion

- Measured concentrations in surface water and highway stormwater runoff locations near Exit 53 were the highest measured in the Study Area during the 2013 Reconnaissance Field Program and the 2014 Winter Sampling Program (sampling locations PRW2C at northbound onramp and IRW3A along I-95 northbound; see Figure 3-11). Field visits to these stormwater drainage locations indicate that these outfalls convey runoff from highway catchments that are almost entirely impervious, as opposed to drainage swales and pervious median strips, resulting in high deicing material loads and runoff concentrations.

- Overburden groundwater concentrations from wells installed near surface water and stormwater runoff locations in this vicinity are also among the highest measured in the overburden in the Study Area.

- Anecdotal reports by MassDOT staff have suggested that in the past the Exit 53 interchange may have been treated by two spreader crews and as a result received twice the amount of deicing treatment. This double treatment is no longer the case.

- The bedrock in this area is fractured. Groundwater quality samples collected from newly installed bedrock well MDOT-BW-1 indicated salt impacts the full length of the borehole down to 440 feet-BGS. Domestic wells tested in the area during the 2014 Domestic Well Sampling Program range in depth from 70 to 600 feet-BGS. With sodium concentrations ranging from 32 to 74 mg/L and chloride concentrations ranging from 54 to 390 mg/L, all wells showed salt impacts with concentrations at several locations exceeding recommended drinking water guidelines (MassDEP Office of Research Standards Guideline (ORSG) of 20 mg/L for sodium and EPA Secondary Maximum Contaminant Level of 250 mg/L for chloride).

- Several domestic wells sampled during the Study were also sampled in the past by MassDOT. Groundwater quality from the earlier period and the current study was generally similar indicating neither improvement nor degradation.

- At most of the domestic wells sampled in 2014 in this area, the predominant constituents in bedrock groundwater samples were calcium and chloride. This differs from other locations in the Study Area where ions measured at the highest concentrations are sodium and chloride. This difference may be related to deicing materials applied at Exit 53 in the past, or possibly a difference in the chemical characteristics of bedrock groundwater in this area.

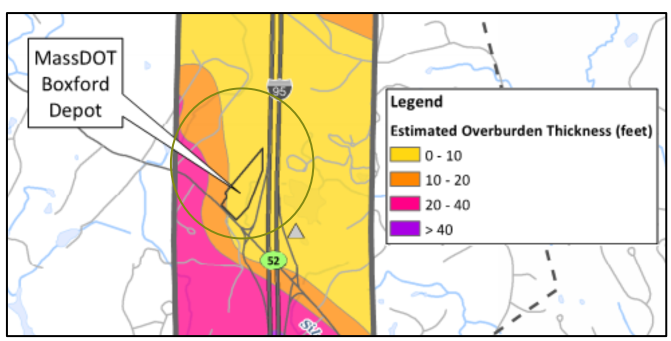
Summary

Bedrock groundwater in this area appears to have been impacted by deicing operations. Data collected during the 2014 winter sampling program indicated high stormwater runoff concentrations at several highway (for instance, IRW3A) and ramp runoff discharge locations (for instance, PRW2C). Stormwater concentrations up to 10,000 mg/L sodium and 18,000 mg/L chloride were reported for monitoring location IRW3A, and concentrations up to 9,100 mg/L sodium and 14,000 mg/L chloride were reported for monitoring location PRW2C. Stormwater runoff follows topographic drainage pathways and enters shallow groundwater. Snowmelt likely follows similar pathways. The bedrock is close to land surface in this area, resulting in a relatively short migration pathway from the overburden and surface water to bedrock groundwater. Because the bedrock is heavily fractured, horizontal and vertical pathways exist for transport of deicing materials in bedrock groundwater. Domestic well pumping may further contribute to migration in the bedrock.

MassDOT did implement a drainage modification south of Exit 53 in 2005 where stormwater runoff was redirected from a drainage swale alongside I-95 to faster moving water in Pye Brook, an area where the depth to bedrock is also greater. This drainage modification likely reduced the amount of stormwater runoff entering shallow groundwater and bedrock; however, the impact of the drainage modification on groundwater concentrations could not be ascertained. In most locations, comparisons of recent and older groundwater concentration data could not be made due to uncertainty in the depths of the wells sampled in the past.

4.4.2 Boxford Depot

The conceptual understanding of deicing and salt migration pathways at the MassDOT Boxford Depot, when it was active, in the Exit 52 vicinity is summarized below:



MassDOT Boxford Depot West of Exit 52

Sources

- Bedrock groundwater impacts at the Boxford Depot are likely associated with both pavement deicing operations, and materials storage and handling. Salt was always stored under covered conditions at the Boxford Depot. However, truck loading and salt handling occurred in the open from 1974 through early 2005, which would have resulted in salt exposure and materials spillage being mobilized with stormwater runoff. Salt spillage during handling operations was likely reduced during 2005-2009 due to the covered extension and implementation of BMPs.

- Pavement at the Boxford Depot was routinely plowed and deiced to maintain safe driving conditions for MassDOT staff and plowing contractors up until 2004. Since then, deicing is infrequently performed at the Boxford Depot and only when needed to improve safety.

Salt Migration Pathways

- Drainage at the Boxford Depot is governed by the topography at the site. Surface water and stormwater runs off the paved areas to the south and east towards unpaved areas and ultimately to a small stream or drainage ditch. The Boxford Depot does not have a stormwater collection system. Currently and in the past, there have been no stormwater runoff controls in operation at the Boxford Depot that would collect and redirect salt impacted stormwater runoff. As a result, runoff from the paved area of the facility entered shallow groundwater and surface water onsite. The onsite stream flows south and east where it ultimately discharges to Silver Brook.

- The pavement at the Boxford Depot is deteriorated with many cracks. While the length of time over which these conditions have existed is not known, the cracks in the pavement can serve as a conduit for stormwater runoff to enter the subsurface and groundwater.

- Based on the information collected during monitoring well installation at the Boxford Depot, bedrock is within ten feet of land surface, resulting in a short pathway from surface water and overburden groundwater to bedrock.

- Study results indicate that the bedrock is heavily fractured, and many horizontal and vertical pathways exist for transport of deicing materials in bedrock groundwater. Domestic well pumping may further contribute to migration in the bedrock, as may Scavenger Well #3 pumping on the Boxford Depot parcel.

Extent of Impact

- Based on water quality sampling results at Scavenger Well #3, deicing groundwater impacts are observed in the bedrock to a depth of 380 feet-BGS just west of the salt shed. Well TW-1, located northwest of the Boxford Depot salt shed, is 560 feet deep. The measured chloride concentration at this well was within the range of background concentrations. Sodium concentrations were elevated and specific conductance values were higher than background but not as high as those measured at Scavenger Well #3.

Groundwater Travel Time Estimates

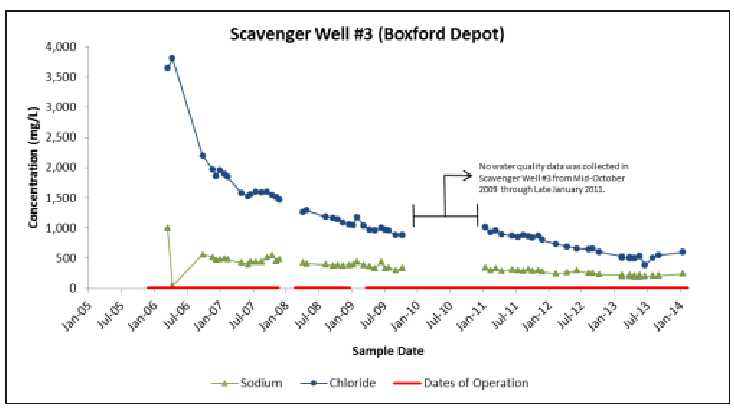
The Boxford Depot was operational from 1974 until 2009. There are no records of materials spillage during this period, but it is reasonable to believe that deicing materials were introduced to the subsurface during the course of operations, especially prior to 2005. After 2005, materials handling was conducted under cover and BMPs were implemented by MassDOT to reduce and minimize spillage. In the vicinity of the Boxford Depot, groundwater in the bedrock is estimated to flow in a south/southeastward direction towards the Ipswich River. As such, the Titus Lane and Silverbrook Road neighborhoods are located downgradient of the Boxford Depot.

The historical water quality data compiled for the Study shows that the earliest reported groundwater quality results indicating salt impacts at domestic bedrock groundwater wells were reported in 1985 for a residence on Titus Lane (11 years following the construction of the Boxford Depot), and in 1994-1998 for residences on Silverbrook Road (20-24 years following the construction of the Boxford Depot). For the purpose of estimating groundwater velocity, it was assumed that the source of bedrock groundwater impacts at these locations was infiltration of salt-laden stormwater into the bedrock at the Boxford Depot. Using the distances between the residences and the Depot, the estimated bedrock groundwater flow velocity in this area is approximately 100-200 feet per year. This value is consistent with groundwater velocities estimated in other fractured bedrock settings studied by CDM Smith. If salt was introduced to the bedrock groundwater later than 1974, the groundwater velocity may be greater than the estimated values presented above. The groundwater velocity calculation presented above does not consider potential contributions of I-95 roadway deicing to groundwater impacts at the referenced wells.

The earliest detections at the Titus Lane and Silverbrook Road wells suggest that the groundwater travel time from the Boxford Depot to the wells could be approximately 11 years and 20-24 years, respectively. As such, monitoring locations near Titus Lane and Silverbrook Road may not yet register changes in groundwater quality associated with operational changes at the Boxford Depot from 2005 to the present. Similarly, in locations where I-95 drainage modifications were constructed, bedrock groundwater quality improvements may not become apparent for many years.

Discussion

- Salt impacts on bedrock groundwater were detected in 1995, during the 21E study (Weston and Sampson Engineers, 1995) conducted at the Boxford Depot, when a groundwater sample from Scavenger Well #3 (a water supply well for the Boxford Depot) indicated a specific conductance of 18,080 microsiemens per centimeter (µS/cm). A laboratory analysis for chloride was not performed, but this specific conductance value approximately corresponds to a chloride concentration of 5,000-6,000 mg/L.
- In late 2005, MassDOT started operating Scavenger Well #3 as a remediation well which remains in operation today. MassDOT reports that this well pumps approximately 5 gallons per minute (gpm). The pumped water is discharged without treatment to the stream located on the Boxford Depot parcel where it can potentially enter shallow groundwater or be transported downstream with surface water flow



Scavenger Well #3 Historical Water Quality

towards Silver Brook. The overburden thickness beneath the stream is less than 10 feet, so some downward vertical flow to the bedrock is also possible.

- Scavenger Well #3 sodium and chloride concentrations have decreased from about 1,000 mg/L and 3,800 mg/L, respectively, in 2006 to 240 mg/L and 600 mg/L, respectively, in 2013. Calcium and magnesium concentrations have decreased from 635 mg/L and 276 mg/L, respectively, in 2006 to 120 mg/L and 50 mg/L, respectively, in 2013. A relatively large decrease in pumped chloride concentrations was observed from 2006 to 2009, a period of time when salt handling was completed under cover, and measures to reduce salt spillage were implemented by MassDOT. The change in concentrations is consistent with reduced loading due to improved salt handling practices, but other factors such as the location of the pumping well relative to the limits of the groundwater plume may also result in a rapid decline of pumped groundwater concentrations over time.

  Current pumped groundwater concentrations at Scavenger Well #3 are generally higher than reported concentrations at domestic wells sampled in 2014, although they are currently not as high as early measurements at some domestic wells that entered MassDOT's remediation program. Based on observed concentration trends, future concentrations at this well are expected to decrease slowly over time with possibly small seasonal variations (increases and decreases). Assuming pumping at this well has remained relatively constant, and based on the measured chloride concentrations at this well, Scavenger Well #3 has extracted approximately 90 tons of chloride during its period of operation. This is approximately equivalent to 120-150 tons of deicing materials (NaCl, $CaCl_2$, or $MgCl_2$). This mass, once extracted by the well, was then reintroduced to the environment via discharge to the onsite stream where it flowed towards Silver Brook and could have potentially entered shallow groundwater.

- Based on the borehole geophysics conducted at Scavenger Well #3, the bedrock in the Boxford Depot vicinity is heavily fractured particularly in a zone between 343 to 372 feet-BGS where many interconnected fractures and weathered bedrock were observed. The fractures observed in the borehole are oriented west-northwest to east-southeast and dip vertically towards the east and southeast. Groundwater quality samples collected from Scavenger Well #3 indicate salt impacts the full length of the borehole (382 feet-BGS). Groundwater concentrations from different fracture zones and depths are similar suggesting that the fractures are hydraulically connected and that groundwater moves readily from shallow to deep zones because of vertical fractures.

- Pumping Scavenger Well #3 continuously has likely contributed to the vertical distribution of salt impacted groundwater, as has pumping of domestic wells in the area. The open boreholes of the domestic wells are conduits to vertical groundwater flow between horizontal fracture zones.

- The predominant deicing constituents observed in the water quality samples from Scavenger Well #3 are sodium and chloride, although calcium and magnesium were also detected at concentrations above background.

- Comparisons of 2014 overburden groundwater concentrations reported at Boxford Depot monitoring wells (2014 specific conductance: 35 – 1,383 µs/cm) with historical measurements (1995 specific conductance: 1,940 – 18,900 µs/cm) suggest that overburden groundwater chloride concentrations have decreased, likely due to operational improvements and the shed extension in 2005, as well as eliminating salt storage at the Depot after 2009.

Summary

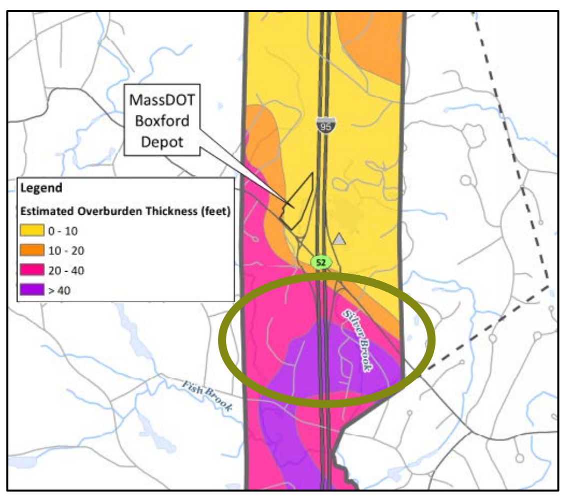
From 1974 until 2005, materials storage and handling operations at the Boxford Depot were sources of salt and other deicing materials to the environment. Between 2005 and 2009, contributions of salt to the environment at the Boxford Deport are expected to have been less than in previous years following the implementation of BMPs which included loading salt trucks under cover. Both groundwater and surface water pathways have been identified as transport mechanisms for stormwater runoff at the Boxford Depot delivering dissolved deicing materials to the bedrock beneath the site and to the onsite stream. These in turn have likely contributed to impacted domestic wells in the downgradient Silver Brook and Titus Lane areas.

It is likely that stormwater runoff impacts to groundwater and surface water commenced with the start of operations at the Boxford Depot in 1974. The earliest reported chloride concentrations exceeding background levels in the MassDOT database were in 1985 at a Titus Lane residence and in 1990-1994 at a Silverbrook Road residence. Because of the estimated bedrock groundwater velocity in this area, monitoring locations near Titus Lane and Silverbrook Road may not yet register changes in groundwater quality associated with operational changes at the Boxford Depot from 2005 to the present. Similarly, in locations where I-95 drainage modifications were constructed, bedrock groundwater quality improvements may not become apparent for many years.

MassDOT also maintained an unlined salt pile east of I-95 prior to the construction of the Boxford Depot. Aerial photos of the area suggest that salt storage occurred in this area as early as the 1950s. Early groundwater quality data in the Study Area are limited, and impacts from the former salt storage pile versus the Boxford Depot cannot be distinguished.

4.4.3 Exit 52 Including Titus Lane and Silverbrook Road Areas

This section presents the conceptual understanding of groundwater and surface water deicing material migration pathways in the vicinity of Exit 52, outside the limits of the Boxford Depot. For the purpose of discussion, this area generally extends from Topsfield Road to Lockwood Lane and includes the Titus Lane and Silverbrook Road areas. The conceptual model for this area is summarized as follows:



Exit 52 Area (Including Titus Lane and Silverbrook Road

Sources

- The main sources of bedrock groundwater impacts in the Exit 52 vicinity are likely associated with I-95 deicing operations as well as groundwater transport of deicing materials originating from the Boxford Depot.

Salt Migration Pathways

- Stormwater runoff from I-95 and the Exit 52 interchange discharges to grassy swales alongside the roadway. In areas where bedrock is close to the land surface, there is a potential for stormwater runoff to impact the groundwater as well.

- Groundwater containing deicing materials in the bedrock that were introduced to the subsurface at the Boxford Depot has migrated away from the Depot and towards the Exit 52 vicinity. Domestic well and scavenger well pumping may have also influenced transport of salt-impacted groundwater in this area.

Extent of Impact

- Based on historical data compiled by MassDOT, deicing impacts have been observed in the Titus Lane neighborhood up to 5,000 feet south of Topsfield Road and about 1,500 feet west of I-95. In the Silverbrook Road neighborhood within the Study Area, deicing impacts have been observed in the bedrock up to about 1,000 feet south of Topsfield Road and approximately 1,500 feet east of I-95. Deicing impacts have been observed at a well 900 feet-BGS (Scavenger Well #2), however, because of the variability of the fractures in the bedrock there may be zones at shallower depths that are not impacted by deicing materials.

Discussion

- Borehole geophysics conducted at a bedrock well on Titus Lane indicated fractures oriented in many directions, with the predominant fracture orientation being northwest-southeast. The predominance of the Salt Remediation Program participants in the Exit 52 vicinity south and southeast of the Boxford Depot and the I-95 interchange likely reflects the predominant groundwater flow direction to the south and southeast in the bedrock in this area. These localized flow directions are also consistent with regional bedrock groundwater flow patterns and with the orientation and dip of the fractures observed during the borehole geophysics at Scavenger Well #3 and well 11-2000-C (Titus Lane). The groundwater quality measured at the Titus Lane bedrock well during the geophysics field program indicated similar water quality throughout the depth of the well suggesting vertical groundwater connections between different bedrock fractures.

- It is not clear how much, or if any, of the groundwater impacts in this area are associated with the former salt storage pile which was located east of I-95 and north of Topsfield Road prior to construction of the Boxford Depot. Depending on the surface drainage patterns at the time, there may have been some surface water flow to the north away from Silverbrook Road. Old topographic maps of the area indicate that the area of the former salt pile was flat and possibly marshy in the past.

- South of Topsfield Road, the overburden thickness increases considerably where a depression in the bedrock surface is observed, generally coincident with the course of Fish Brook. As the overburden becomes thicker, the pathway from shallow groundwater and surface water to the bedrock is longer. Groundwater in the overburden flows horizontally towards natural discharge locations, Fish Brook, and the Ipswich River, and does not flow as readily, vertically towards the bedrock.

- Surface water samples collected during both the 2013 Reconnaissance Field Program and the 2014 Winter Sampling Program indicated elevated surface water and stormwater runoff concentrations of deicing materials east and west of I-95 near Exit 52. West of I-95, sampling location FBW2V (see Figure 3-11) located near a discharge outlet of an area receiving runoff from both Town and I-95 ramp drainage, exhibited sodium and chloride concentrations of 740 mg/L and 1,300 mg/L, respectively. East of I-95 near Exit 52, stormwater runoff discharges to surface water or drainage swales that flow towards Silver Brook and Fish Brook. In general, stormwater runoff concentrations were not as high in the Exit 52 vicinity as those measured at I-95 outfalls in the Exit 53 vicinity.

- While surface water and stormwater runoff concentrations at Town drainage locations are generally lower than those measured at I-95 outlets, reported concentrations at Town drainage location TD-15 (see Figure 3-11) were comparable to concentrations measured at some other I-95 discharge locations during a 2014 winter sampling event. TD-15 is located near Lockwood Lane, and does not receive any runoff from I-95.

- From 2005 to 2007, MassDOT operated Scavenger Well #1 on Silverbrook Road and Scavenger Well #2 on Titus Lane. Both wells pumped water from the bedrock, and the pumped water was discharged without treatment to I-95 catch basins that ultimately discharge to Fish Brook.

- Groundwater samples from overburden wells located near stormwater runoff discharge locations in this area (MDOT-MW-7, MDOT-MW-8, and MDOT-MW-15) generally exhibit higher concentrations of deicing materials, primarily salt, than overburden wells in other portions of the Exit 52 vicinity. Downward vertical groundwater flow from the overburden to the bedrock likely occurs, based on vertical head gradients estimated from data. However, migration pathways at depth from the overburden to the bedrock will also be influenced by local overburden and bedrock conditions.

- At most of the domestic wells sampled in the Exit 52 vicinity in 2014, the predominant constituents in the bedrock groundwater samples are sodium and chloride. Magnesium and calcium concentrations, associated with use of $MgCl_2$ and $CaCl_2$, at the domestic wells sampled in the Exit 52 vicinity were lower than those reported for domestic wells sampled in the Exit 53 vicinity.

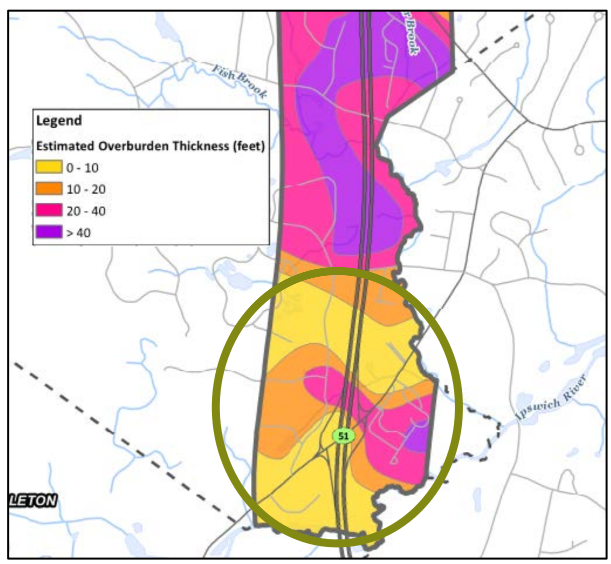
- Several domestic wells on Silverbrook Road and Titus Lane sampled during the Study were also sampled in the past by MassDOT; groundwater quality from the earlier period (2006-2013) and the current study were generally similar indicating neither improvement nor degradation (see Appendix I, Figure I-1).

- The Andrew's Farm community supply well is located south of Silverbrook Road. This bedrock well is 1,160 feet-BGS and pumps approximately 45 gpm serving about 140 residents. There is no evidence that water quality at this well is impacted by deicing materials. Sodium concentrations at this well, and at another well close by that is also more than 1,000 feet-BGS, are higher than background levels (53 mg/L and 230 mg/L) but chloride concentrations are low and within the range of background values (not detected and 23 mg/L). The high sodium concentrations may be associated with bedrock groundwater chemistry at greater depths in this area where some boring logs also indicate a change in bedrock characteristics. In other locations in the Study Area where deicing impacts have been observed, both sodium and chloride are typically both present at concentrations above background.

Summary

Deicing material impacts to bedrock groundwater wells in this area are likely associated with MassDOT roadway deicing operations. Additionally, salt introduced to the groundwater at the Boxford Depot has likely impacted groundwater in this area which is hydraulically downgradient of the Boxford Depot. Groundwater transport as well as stormwater runoff and drainage from these sources have introduced deicing materials to the bedrock in this area. The fractured rock conditions identified at both Scavenger Well #3 and well 11-2000-C located on Titus Lane indicate numerous bedrock fractures with depth, which then likely serve as groundwater migration pathways to the south and southeast from both the Boxford Depot and Exit 52. The predominant orientation of these fractures is primarily northwest to southeast, and the observed water quality impacts in the bedrock are generally consistent with this fracture orientation and the estimated groundwater flow direction. The overburden thickness increases south of Topsfield Road, and as a result there is a less direct pathway from surface water and shallow groundwater to the bedrock. Some vertical groundwater flow from the overburden to the bedrock is expected based on the estimated vertical groundwater flow gradients, however, migration pathways at depth from the overburden to the bedrock will also be influenced by bedrock conditions. Groundwater flow in the overburden is believed to be predominantly horizontal towards discharge boundaries.

Stormwater runoff concentrations near I-95 and Town drainage outlets during the Study sampling programs were elevated, but not as high as those observed near Exit 53. One reason for this could be that the stormwater runoff at the sampling locations is mixed with surface water and non-highway drainage and as a result stormwater runoff concentrations are diluted. Stormwater runoff enters surface water and shallow groundwater, but since the overburden is deeper in this area there is a less direct pathway from surface water to bedrock. While there may be some flow from the overburden vertically down to the bedrock, groundwater in the overburden is more likely to flow horizontally towards discharge boundaries like the Ipswich River.



Exit 51 Area

4.4.4 South of Lockwood Lane and Exit 51

A discussion of deicing material migration pathways in the southern portion of the Study Area is presented below. This area generally extends from Lockwood Lane to the southern limits of the Study Area. The conceptual model for this area is summarized as follows:

Sources

- Bedrock groundwater impacts in this area are associated with roadway deicing operations, and not with materials storage and handling.

Salt Migration Pathways

- Stormwater runoff from I-95 discharges to grassy swales alongside the highway. Bedrock is within ten feet of land surface in the areas where bedrock groundwater impacts were reported, resulting in a short pathway from surface water and overburden groundwater to bedrock. Because the bedrock is likely fractured, horizontal and vertical pathways exist for transport of deicing materials in bedrock groundwater. Domestic well pumping may further contribute to migration in the bedrock.

Extent of Impact

- Based on historical data, a majority of the wells impacted in this area are in locations where bedrock is within about 10 feet of land surface. Bedrock groundwater quality impacts associated with deicing have been observed at parcels up to 1,000 feet east of I-95. There are limited data to evaluate bedrock groundwater quality impacts west of I-95 except at one of the Salt Remediation Program participants. Wells up to 755 feet-BGS have shown evidence of deicing impacts, however, because of the variability of the fractures in the bedrock, there may be zones at shallower depths that are not impacted by deicing materials.

Discussion

- Measured concentrations in surface water and highway stormwater runoff locations near Fuller Lane during the 2013 Reconnaissance Field Program indicated salt impacts (750 mg/L sodium, 1,300 mg/L chloride). Field visits to nearby drainage locations indicate I-95 is elevated and that snow melt and runoff containing deicing materials likely flows over the roadway edge and down a relatively steep slope towards homes adjacent to I-95. This is the only location within the Study Area where I-95 is elevated and where there may be a tendency for runoff to flow in such a manner. Fuller Lane passes under I-95, and Town drainage may receive runoff from the elevated portion of I-95 at this location.

- Overburden monitoring well MDOT-MW-12 was installed at the base of the steep slope near Fuller Lane. The average sodium and chloride overburden groundwater concentrations at MDOT-MW-12 were 580 mg/L and 1,010 mg/L, respectively. These concentrations are similar to those measured at other overburden wells located near I-95 drainage outfalls, and may be representative of snowmelt and runoff down the steep embankment.

- Field visits conducted during the fracture trace analysis identified a fractured bedrock outcrop nearby, indicating that bedrock is fractured in this portion of the Study Area as well. As in other portions of the Study Area, the bedrock fractures provide pathways for deicing material transport in bedrock groundwater.

- One domestic well was sampled near Fuller Lane. The predominant deicing constituents in the bedrock groundwater sample were calcium and chloride, similar to domestic well samples near Exit 53 where stormwater runoff is also believed to be the source of deicing material impacts in bedrock groundwater quality. Only sodium concentrations at this well were greater than the recommended MassDEP ORSG guideline.

- The overburden thickness is generally greater than 10 feet in the portion of the Study Area south of Lockwood Lane, with the exception of the general locations where bedrock groundwater impacts were studied and addressed by MassDOT's Salt Remediation Program. For instance, on Curtis Road where the Town conducted a water supply investigation, the estimated overburden thickness is approximately 40 feet. There is no evidence of salt impacts in the overburden groundwater sample collected from this location.

- The MASCO property, further south, contains an irrigation well that is 51 feet-BGS and screened in sand and gravel. This well reportedly pumps approximately 45 gpm to meet irrigation supply needs for the property. Overburden groundwater concentrations reported for the MASCO irrigation well were elevated (sodium: 260 mg/L; chloride: 760 mg/L) which likely reflects impacts of MASCO's deicing operations. Overburden groundwater in this portion of the Study Area is believed to flow towards the Ipswich River, therefore not likely impacting any nearby homes.

Summary

Deicing material impacts to bedrock groundwater wells in the Study Area south of Lockwood Lane are likely associated with I-95 deicing operations. The locations where bedrock appears to be impacted are areas where the bedrock is close to the land surface. In the case of the impacted wells near Fuller Lane, stormwater runoff from I-95 flows overland towards nearby homes and areas where bedrock is shallow. Both surface water concentrations and overburden groundwater concentrations show evidence of deicing impacts.

4.5 Summary

Groundwater in the Study Area has been impacted by deicing materials, primarily salt (sodium and chloride) but also $MgCl_2$ and $CaCl_2$. Salt was introduced to the Study Area from several major sources. Currently, the largest source is MassDOT deicing operations on I-95 highway and ramps. Town deicing operations on local roadways represent a secondary smaller source. Town drainage might have an impact on surface water in localized areas but in general, study data did not indicate stormwater runoff and surface water concentrations at Town drainage locations that were as high as those measured at I-95 outlets. From 1974 until 2005, materials storage and handling operations at the Boxford Depot were sources of salt and other deicing materials to the environment. Between 2005 and 2009, contributions of salt to the environment at the Boxford Deport are expected to have been less than in previous years following the implementation of BMPs which included loading salt trucks under cover. Other potential sources of deicing materials to the environment in the Study Area, though notable, are less significant.

Locations in the Study Area which are most sensitive to deicing material impacts in bedrock are locations where the top of the bedrock is close to the land surface. The fracture trace analysis and borehole geophysics conducted for the Study indicated that the bedrock in the Study Area is heavily fractured with both horizontal and vertically dipping fractures throughout the length of the boreholes studied (up to depths of 440 feet-BGS). The fractures provide ready pathways for salt transport both laterally and vertically in the bedrock. In addition to the fractures, the numerous domestic water supply wells pumping in the Study Area also may influence the migration of impacted groundwater in the bedrock. The number and orientation of the bedrock fractures can vary with location and depth. Locations where I-95 stormwater runoff is directed, either by overland flow or via outfalls, to areas where the bedrock is close to land surface, are particularly sensitive to salt impacts.

Measured groundwater concentrations in the bedrock likely reflect contributions from past sources, such as deicing materials storage and handling at the Boxford Depot, as well as current sources. For instance, the bedrock groundwater concentrations near Exit 53 are related to past, as well as possibly current I-95 deicing and drainage operations. Bedrock groundwater concentrations near Exit 52 are related to past materials storage and handling at the Boxford Depot, as well as past and possibly current I-95 deicing and drainage operations. Because of the lateral and vertical extent of groundwater impacts, and because of relatively low groundwater flow velocities and travel times, groundwater monitoring conducted to date may not yet register changes in groundwater quality associated with operational changes at the Boxford Depot from 2005 to the present, or from I-95 drainage modifications constructed in 2005-2006. The observation that bedrock groundwater concentrations measured in 2014 are similar to those reported for different periods in 2006-2013 confirms that perhaps changes in groundwater quality that may have resulted from drainage modifications or changes in Boxford Depot operations have not yet been detected. Nonetheless, continued routine monitoring of groundwater quality is recommended not only to track water quality changes over time, but also to understand groundwater quality and surface water quality conditions before any mitigation measures are implemented.

Section 5

Analysis of Alternatives

5.1 Objectives of Analysis

The Legislation establishing this project, *Chapter 199 of the Acts of 2010*, identified a number of specific project goals regarding mitigation of the effects of storage and handling of salt, and application of deicing materials on roadways within the I-95 corridor in the Town of Boxford (the Town). The goals identified were as follows:

- To determine "what measures need to be taken to prevent [infiltration of deicing chemicals to groundwater aquifers and bedrock fissures] from occurring in the future."
- To develop recommendations for "short-term and long-term remedial actions necessary to restore groundwater quality to a safe drinking water standard within the I-95 corridor".
- To develop "a plan to modify highway drainage systems to prevent stormwater run-off and highway drainage from adversely impacting aquifers, bedrock and adjacent wetland resource areas".
- To develop "an alternative means to provide a reliable and adequate safe drinking water supply to the residents located within the I-95 corridor meeting all state and local requirements."

For the purpose of this project, "safe drinking water" is defined by the Legislation as being "water meeting or exceeding all primary and secondary standards and recommended guidelines for drinking water as defined by the department of environmental protection".

These legislative requirements are the foundation of the analysis of alternatives for the Study. To address them, CDM Smith's scope of work formulated six broad categories which encompass all technologies and mitigation approaches being considered. The six categories are as follows:

- ***Methods and Materials for the Deicing of Massachusetts Department of Transportation (MassDOT) and Town Roadways.*** This first category includes such items as alternative deicing methods and materials, mechanical application methods, equipment calibration, instrumentation to provide increased monitoring of deicing materials applied, improved training, modified deicing/plow routes, and geofencing.
- ***Improvements to MassDOT Salt Storage and Associated Operations and Maintenance (O&M) Procedures.*** Deicing of the MassDOT Boxford Depot Service Area requires the use of salt as well as deicing/anti-icing agents. Such operations require a consistent and assured location for spreaders to obtain salt during a storm event. Therefore, this second category focuses on salt storage options to serve the Boxford Depot Service Area, including alternatives for the Boxford Depot itself such as the salt storage building (e.g., cover, extension, or replacement), site grading to minimize infiltration and redirect runoff, stormwater management, paving, deicing chemical storage, and materials handling.

- ***Stormwater Drainage System Improvements.*** For both MassDOT and Town stormwater drainage systems, this third category includes such options as drainage collection and conveyance system modifications to reroute stormwater runoff, grading modifications to redirect runoff, use of snow berms to redirect meltwater runoff, and changes to drainage system O&M procedures.

- ***Community Water Supply Options.*** This fourth category includes the delineation of potential service areas for one or more public water systems to serve affected property owners, and water supply options for those service areas, including bedrock wells, overburden (sand-and-gravel) wells, or water purchase from an adjacent community such as the Town of Topsfield.

- ***Residential Water Supply Options.*** This fifth category includes options for homeowners to continue using private wells for water supply instead of a potential public water system. It includes options such as individual residential treatment systems (reverse osmosis), and replacement well options (bedrock or overburden). Also included are the impact of local regulations regarding well installation and the value of public education on aquifer protection.

- ***Remediation.*** This sixth category includes remediation alternatives such as pump and treat systems, the removal and treatment of soils, and the use of scavenger wells on both an area-wide and localized scale.

5.2 General Approach to Analysis

The following four-fold approach was utilized during the analysis of alternatives:

1. ***Technology Listing.*** For each of the six categories, lists were first developed of potential technologies, corrective actions, and other mitigation measures. The lists are discussed in **Section 5.3**.

2. ***Screening.*** It was not envisioned in the scope of work that detailed evaluations would be performed on each item on the list for each of the six categories. Instead, a screening approach was developed and utilized to narrow down the lists to a more manageable size. The screening procedure is presented in **Section 5.3**.

3. ***Evaluation.*** Each item that passed the screening criteria in each category was then evaluated for potential implementation. The evaluations for the six categories are presented in **Sections 5.4 through 5.9**, identifying the items which had greater or lesser potential for contributing to an overall implementation plan.

4. ***Summary.*** A summary of the evaluation results are presented in **Section 5.10** focusing on action items to be considered for both MassDOT and the Town.

5. ***Development of Alternative Implementation Plans.*** Given the breadth of issues in the six categories, there are many ways in which items can be combined to arrive at ultimate implementation plans. Accordingly, CDM Smith developed three possible implementation plans, for each of the following areas: Exit 53; the Boxford Depot; Exit 52/Titus Lane and Silverbrook Road areas; and south of Lockwood Lane and Exit 51. The three alternative plans for each area represent a lesser, moderate, and greater number of items for implementation, and are presented in **Section 6**.

Table 5-1
Summary of Applicable Technologies and Mitigation Approaches
Alternative Analysis Screening

Alternative	Description	Current Practices: MassDOT	Current Practices: Town of Boxford
Deicing Materials, Technologies, and Procedures			
Sodium Chloride ($NaCl$)	Liquid Phase (Salt Brine) - Pre-treatment of roadways (anti-icing) alone or with other materials (e.g., $MgCl_2$ or $CaCl_2$) - Pre-wetting of NaCl/sand - Pre-treatment of NaCl stockpiles		
	Solid Phase (Road Salt) - Solid deicing material - Paired with sand in Reduced Salt Zones (RSZ)s - Often needs to be treated with a liquid product to enhance performance (pre-wetting)	X	X
Calcium Chloride ($CaCl_2$) Based Products	Liquid Phase - Pre-treatment of roadways alone or with salt brine - Pre-wetting of NaCl/sand - Pre-treatment of NaCl stockpiles - "treated salts" pre-packaged and enhanced with liquid $CaCl_2$		
	Solid Phase - Can be used in coordination with, or in place of, NaCl as a solid deicing material - Can be used to create liquid $CaCl_2$ - Used in Pre-Mix by MassDOT (80% NaCl, 20% $CaCl_2$)	X	
Magnesium Chloride ($MgCl_2$) Based Products	Liquid Phase - Pre-treatment of roadways alone or with salt brine - Pre-wetting of NaCl/sand - Pre-treatment of NaCl stockpiles - "treated salts" pre-packaged and enhanced with liquid magnesium chloride	X	X
Magnesium Chloride ($MgCl_2$) Based Products	Solid Phase - Can be used in coordination with, or in place of NaCl as a solid deicing material - Can be used to create liquid $MgCl_2$		
Agricultural (organic) Based Products (Non-Chloride)	Liquid Phase - Pre-treatment of roadways alone or with salt brine - Pre-wetting of NaCl/sand - Pre-treatment of NaCl stockpiles		
Acetate Based Products (e.g., Potassium Acetate (KAc), Calcium Magnesium Acetate (CMA), etc.)	Liquid Phase - Liquid standalone product for either pre-treatment of roadway or deicing - Available as packaged product of acetate treated NaCl		
	Solid Phase - Can be used in coordination with, or in place of, NaCl as a solid deicing material		
Airport Quality Liquid Deicers (e.g., Ethylene Glycol, Sodium Formate, Methyl Alcohol, etc.)	Liquid Phase - Deicing material, direct liquid application - Almost exclusively used at airports - Used in areas where chlorides cannot be tolerated (elevated walkways or airports)		
Urea Based Products	Solid Phase - Solid deicing material - Not often used for deicing (primary use is in fertilizers) - Used where chlorides cannot be tolerated (elevated walkways or airports)		

Retained for further analysis

Table 5-1 (Cont'd)
Summary of Applicable Technologies and Mitigation Approaches
Alternative Analysis Screening

Alternative		Description	Current Practices: MassDOT	Current Practices: Town of Boxford
Deicing Materials, Technologies, and Procedures			*MassDOT*	*Town of Boxford*
ENHANCED ROADWAYS				
Fixed Automated Spray Technology (F.A.S.T.) Systems		In-situ spray system installed in the roadway for pre-treatment application, particularly on bridges, ramps, and high traffic areas.		
Road Weather Information Systems (RWIS)		Roadside stations which collect and transmit pertinent weather data (e.g., air temperature, humidity, wind speed/direction, precipitation rate, etc.) and pavement data (e.g., pavement temperature, condition, freezing point) via the internet using a variety of meteorological and pavement sensors to better characterize conditions and determine the best course of treatment.	X	
Solar Power and Roads		Solar panels to heat roads and/or water in pipes beneath roads, keeping surface temperature higher and reducing/preventing snow and ice accumulation.		
Alternative Pavements		Alternative asphalt products produced to aid in the deicing process via the incorporation of additives during the paving process. These may help to prevent re-freezing or prevent ice formation.		
"SMART" VEHICLES				
Mobile Friction Meters		Apparatus attached to vehicles to assess road conditions and help identify when treatments should be applied. Skid resistance readings are obtained by attaching an additional wheel to the truck or trailer. Readings indicate road friction conditions to evaluate effectiveness of applications and/or make adjustments.	X	
Geofencing		Hardware installed on spreader vehicles allow for both remote and onboard control of material application, inclusive of such parameters as application rate, vehicle speed, and direction of travel which are continuously recorded. Controls can be set by an administrator based on pre-determined values, locations, or weather conditions. Depending on level of sophistication, control adjustments can be uploaded to vehicles remotely or when they arrive at the Depot.		
Closed Loop Controllers		Spreader automatically adjusts application rates during a storm based on onboard sensor outputs that monitor truck speed and speed of the feed-belt or auger. Allows for more consistent and uniform applications. Proper use can result in a 20-30% savings in solid materials.	X	
Ground Speed Controllers/ Electronic Controllers		Spreader automatically adjusts application of material in proportion to the speed at which the truck is traveling to help prevent uneven application/waste of material.	X	
Zero Velocity Spreaders		Spreader is automated to drop material at a rate matching the truck's velocity and opposite to direction of travel, theoretically applying the materials so they hit the pavement with horizontal speed of 0 mph, thereby reducing bounce and scatter of material.		
EQUIPMENT ENHANCEMENT				
Alternative Plow Blades	Flexible/ Segmented Blades	Flexible/segmented blades that contour to road better, increasing precipitation removed by plows and reducing chemical deicing demands.		
Alternative Plow Blades	Tow Plows	Tow plows have a deicing unit with plow on a trailer towed behind a plow truck to provide more efficient plowing, thereby reducing the need for secondary plowing, deicing materials, material loss, and costs.	X	

Retained for further analysis

Zero velocity spreaders retained for evaluation for the Town of Boxford only. MassDOT currently uses equipment more advanced than zero velocity spreaders.

Table 5-1 (Cont'd)
Summary of Applicable Technologies and Mitigation Approaches
Alternative Analysis Screening

Alternative		Description	Current Practices: *MassDOT*	Current Practices: *Town of Boxford*
Deicing Materials, Technologies, and Procedures				
QUALITY ASSURANCE PROCEDURES/PROGRAMS				
Equipment Calibration Program		- Improved or more frequent spreader equipment calibration procedures - Goal of annual equipment calibration - Calibration teams perform periodic field calibration over the course of each winter season	X	X
Enhanced Record Keeping Program		- Total facility material usage - Track usage quantities per truck for optimal program management - Track material usage by storm event - Improve measurements of materials during loading - Record and track application rates - Periodic meetings to discuss performance, areas of improvement - Annual benchmarking	X	
Staff Training Program		- Annual new staff/contractor and refresher training on proper material handling, usage, equipment operation, calibration, and environmental impacts/best management practices	X	X
Good Practices		- Program management practices to review data and adapt practices accordingly - Storm tracking to maximize advantage of pre-treatment - Work to meet protocols - Properly cover product to mitigate loss/exposure to the elements - Handling salt materials under cover - Truck routes to avoid overlap	X	X
SNOW/ICE MANAGEMENT STRATEGIES				
Policies	**"Open Road" Policy**	A policy of snow removal and deicing such that roads are "passable with a reasonable amount of inconvenience and still provide safe driving conditions". Generally, smaller roads and side streets are addressed using open road policies.		
	"Bare Pavement" Policy	A policy of snow/ice removal with "mechanical and chemical techniques until no snow remains on the road". Generally, major thoroughfares and highways are cleared using bare pavement (i.e., high traffic, high speeds).		
Reduced Salt Zones (RSZ)		Implemented in areas of environmental sensitivity (i.e., water supply protection) to maintain road conditions with less salt usage per application. Typically salt is mixed with an abrasive (usually sand) at sand/salt and sand/pre-mix ratios of around 1:1 to 3:1.	X	X
Roadway Pre-treatment (Anti-Icing)		Liquid deicing materials applied to roadways prior to a storm event to prevent initial bonding of snow/ice to the roadways. Application is weather condition specific, typically between 15° F and 30° F.	X	
Pre-wetting		On-board spreader application of liquid deicing agents to solid material as it is applied onto the roadway. Usually effective at/below 30° F. Results in a quicker reaction time and less loss of material due to bounce, scatter and wind, reducing material loss by up to 30%.	X	X
Material Pre-treatment		Application of deicing liquids or additives to stored salt instead of on-board pre-wetting.		
OTHER				
Snow Fences		Man-made barriers or trees, shrubs, etc., which prevent snow accumulation and serve as wind blockers, preventing drifts from degrading road conditions.		
Snow-melting Machines		Stationary equipment for the melting of snow, typically used in urban areas and municipalities where there is limited space to pile plowed snow.		

Retained for further analysis (shaded rows: Equipment Calibration Program, Enhanced Record Keeping Program, Staff Training Program, Good Practices, Reduced Salt Zones, Roadway Pre-treatment, Pre-wetting)

Table 5-1 (Cont'd)
Summary of Applicable Technologies and Mitigation Approaches
Alternative Analysis Screening

Alternative	Description
Improvements to MassDOT Salt Storage and Associated Operations and Maintenance (O&M) Procedures	
SALT STORAGE ALTERNATIVES	
Modifications to Existing Structure at Boxford Depot	Modify the existing facility to expand cover, change flooring, create new point(s) of ingress and egress, replace roof.
MassDOT Boxford Depot Remains Partially Closed (Status Quo)	Maintain operations as they are presently conducted such that deicing operations for the Boxford Depot Service Area continue out of the Rowley Depot with materials support from the Newbury and Peabody Depots. Storage of $MgCl_2$ would continue at the Boxford Depot.
Replace Existing Structure at Current Location	Demolish and replace existing structure with more modern facility that incorporates best practices and technologies.
New Salt Shed Location to Treat Boxford Service Area	Construct new salt shed to serve Boxford Depot Service Area at location other than existing facility.
SITE/OPERATIONS AND MAINTENANCE ALTERNATIVES SPECIFIC TO EXISTING MASSDOT BOXFORD DEPOT	
Site Stormwater Improvements and Management	Regrade site to capture runoff from storage and handling areas in new drainage infrastructure, redirect to perennial streams to minimize infiltration.
Specialized Pavement	Install new pavement including buried impermeable geotextile or rubberized asphalt to mitigate infiltration.
Capture Runoff and Treat or Reuse as Brine	Capture runoff from salt storage and handling area to a tank for treatment or reuse as brine.
Deicing Material Handling	Improve handling processes to mitigate exposure of deicing materials to the environment.
Containment for Liquid Deicing Storage and Loading	Provide spill containment for permanent storage and transfer of liquid deicing agents.
Stormwater Drainage Improvements on I-95 and Town Roads	
NON-STRUCTURAL IMPROVEMENTS	
O&M Procedures	Increase frequency of structure and pipe cleaning, including catch basins and pipe outlets.
Closed Circuit Television Investigations	Identify where disjointing/structural issues in stormwater pipes may be allowing flows with high deicing constituent concentrations to infiltrate soils.
STRUCTURAL IMPROVEMENTS	
Reroute Drainage Piping	Change piping conveyance arrangements to discharge runoff captured from roadways to perennial streams to reduce the potential for infiltration.
Snow Berms	Paved areas outside of guardrails sloped to drainage systems in gutter. Allows melt from snow banks/piles to drain to collection system instead of to area adjacent to highway.
Swales	Collect drainage running from area adjacent to highways (snowmelt) and redirect to drainage system.
Community Water Supply Options	
WELL SUPPLY OPTIONS	
Bedrock Wells	Large yielding bedrock wells for community use, complete with treatment and distribution system.
Sand-and-Gravel Wells	Large yielding wells set in unconsolidated sand and gravel deposits for community use complete with treatment and distribution system.
WATER SYSTEM MANAGEMENT OPTIONS	
Town of Boxford Supply	Establish Town Water Department to own and operate water supply, treatment, and distribution system for local community.
Water Supply District	Establish local Water Supply District to own and operate water supply, treatment, and distribution system.
Private or Home Owner Association System	Water supply, treatment, and distribution system owned and operated by private entity or home owner association.
ADJACENT COMMUNITY SUPPLY	
Adjacent Community Supply	Provide potable water to neighborhoods by extending distribution system from adjacent town, dependent on availability of supply.

Retained for further analysis

Table 5-1 (Cont'd)
Summary of Applicable Technologies and Mitigation Approaches
Alternative Analysis Screening

Alternative	Description
Residential Water Supply Options	
APPROACH TO INDIVIDUAL HOMES	
Point-of-Entry (POE) Treatment	Whole house treatment system for salt constituents and other drinking water parameters.
Point-of-Use (POU) Treatment	At point of use (typically kitchen faucet), install treatment systems at individual homes, for salt constituents.
Combined Point-of-Entry (POE) and Point-of-Use (POU) Treatment	Treats water entering home (softener & neutralizing pH) with additional treatment to meet drinking water standards at locations where water is used for consumption.
Replacement Wells	Replace existing domestic well when water quality declines due to salt concentrations; such replacement wells could be in bedrock or overburden depending on geology, yield, bylaw status, water quality and surrounding land uses.
COMMUNITY APPROACH	
"District" or Homeowner Association for Operations and Maintenance of POE/POU Treatment Systems	Establish a District or Homeowner Association solely devoted to the operation and maintenance of residential POE/POU devices.
POLICY/PROGRAM	
Revise Local Regulations	Implement revisions to the Town of Boxford Board of Health Private Water Supply Regulations to provide homeowners greater flexibility in type of domestic well.
Public Education	Provide public education regarding aquifer protection, well head protection, domestic well operations and water quality.
Remediation Options	
Soil Treatment (ex-situ) at Boxford Depot	Remove soils underlying Boxford Depot and pavement; treat for contaminants.
Soil Treatment (ex-situ) along Highway	Remove soils along I-95 and treat for contaminants.
Pump and Treat (in-situ)	Pump and treat existing groundwater; reintroduce into groundwater after treatment.
Expand Scavenger Well Operation throughout Study Area	Increase the Scavenger Well capacity in the Study Area to remove contaminated groundwater and introduce it into perennial streams.
Scavenger Well #3 (at Boxford Deport)	Continue operation of Scavenger Well #3 at Boxford Depot with discharge to stream (status quo - no treatment).
	Continue operation of Scavenger Well #3 at Boxford Depot with treatment.

Retained for further analysis

Abbreviations:

$CaCl_2$: Calcium Chloride
Cl: Chloride
$MgCl_2$: Magnesium Chloride
NaCl: Sodium Chloride
RSZ: Reduced Salt Zone

5.3 Technology Listing and Screening Analysis

Table 5-1 summarizes the list of technologies and mitigation measures considered for each of the six categories, and indicates whether or not the measure was retained for evaluation based on the screening analysis.

The screening analysis was performed in tabular form, with each of the six categories having its own table. The screening tables, **Tables L-1** through **L-6**, are included in **Appendix L**. Note that the first category was divided into two sub-tables for clarity.

- **Table L-1a**: Alternative Deicing Materials
- **Table L-1b**: Alternative Deicing Procedures
- **Table L-2**: Improvements to MassDOT Salt Storage and Associated O&M Procedures
- **Table L-3**: Stormwater Drainage System Improvements on I-95 and Town Roads
- **Table L-4**: Community Water Supply Options
- **Table L-5**: Residential Water Supply Options
- **Table L-6**: Remediation

Each screening table presents a list of items, seven screening criteria, and the results of the screening analysis. The seven screening criteria are defined as follows:

- ***Relative Costs*** - a qualitative, comparative, order-of-magnitude assessment of capital costs for implementation and future operations/maintenance costs.
- ***Overall Effectiveness*** - a qualitative assessment of the anticipated improvement resulting from implementation of the technology or approach.
- ***Difficulty of Implementation*** - assessment as to the constructability and/or feasibility of the alternative.
- ***Prevention and/or Mitigation of Impacts*** - a qualitative assessment as to whether the action undertaken would be conducted to prevent future impacts or mitigate existing impacts.
- ***Degree of Benefit*** - an assessment as to the degree of favorable benefits provided by implementation of the alternative relative to the magnitude of impact (i.e., large-scale or individual benefit).
- ***Reliability*** - an assessment as to the short-term and/or long-term nature of the alternative, consistent with the legislative requirements that short-term and long-term remedial actions be considered.
- ***Regulatory/Institutional Feasibility*** - a qualitative assessment of the institutional concerns and ease with which regulatory approval can be achieved, and regulatory compliance maintained.

The seven criteria described above appear as columns in each of the tables for the six categories found in **Appendix L**. The criteria definitions cited above are repeated at the bottom of each table for the convenience of the viewer. Each item has its own row, with a brief description of factors affecting the choice of a ranking score for each criterion. The scores were established on a scale of one to five, with one being the lowest or worst score, and five being the highest or best score.

The total score for each item is listed in the right-hand column on each of the screening tables. Score results on each screening table were compared qualitatively to one another to select a breaking point relative to higher and lower values. Those measures with the higher values were advanced to the evaluation phase, while those with lower scores were determined to not rank high enough to be retained for evaluation. The items selected for advancement are shown with color highlighting in the right-hand column.

Sections 5.4 through 5.9 present the evaluations for each of the six categories, discussing all the items that were retained as a result of the screening analysis.

5.4 Evaluation of Alternative Deicing Materials, Technologies and Procedures

Current snow and ice management operations for both MassDOT and the Town have been reviewed, with a summary presented in **Section 2.2**. The goal of this alternatives analysis is to identify alternatives for consideration and possible future implementation that will provide an overall decrease in the net quantity of salt used per typical storm event relative to current practices and operations. Based on this goal, an evaluation of alternative deicing materials, technologies, and procedures has been performed. In addition to deicing, this analysis included materials, technologies, and procedures for pre-treatment, also referred to as anti-icing. This section summarizes the alternatives retained from the screening effort for further evaluation. It was recognized that the retained deicing materials and procedures cannot be effectively evaluated independently, as they work in combination to achieve desired outcomes. Therefore for MassDOT, three operations scenarios were developed for evaluation, each of which consist of solid and liquid deicing materials coupled with supporting technologies and procedures. For the Town, a phased approach to implementing an improved deicing program is recommended. Additionally, there are stand-alone technologies/procedures evaluated independently.

5.4.1 Deicing Materials Retained for Evaluation

Based on the screening procedure described in **Section 5.3**, **Table 5-2** presents the deicing materials retained for evaluation. These materials offer a variety of deicing, environmental, and/or cost benefits to consider. Each deicing material is discussed further below.

Salt (NaCl): Solid salt, commonly known as rock salt, is the most common solid deicing material. It is currently used as the primary deicing material by MassDOT. Salt lowers the freezing point of water and prevents ice/snow from bonding to pavement. However, its usefulness is limited by pavement temperature, as it becomes less effective below 15^{o} F. Liquid salt (salt brine) can be used for roadway pre-treatment or solid material pre-wetting. MassDOT presently uses brine for pre-treatment in parts of the Commonwealth (Districts 1 and 2). Brine is mixed with liquid magnesium chloride to lower the potential for freezing. The brine is produced and mixed with magnesium chloride at MassDOT's facility in Sagamore, trucked to areas where it is used for pre-treatment, and stored until needed. A new salt brine production and mixing facility has significant capital and O&M costs. Should brine be used in the Boxford Depot it, is likely to be trucked in from the Sagamore facility and stored in District 4. It must be recognized that salt (solid and salt brine) can contribute sodium (Na) and chloride (Cl) to the surrounding environment, where it can impact water quality and result in impacts to the environment and surrounding drinking water sources.

Table 5-2
Retained Alternatives: Deicing Materials

Alternative		Current Practices	
Material	**Uses**	**MassDOT**	**Town of Boxford**
Sodium Chloride ($NaCl$)	**Liquid phase (Salt Brine)** ▪ Pre-treatment of roadways (anti-icing) alone or with other materials (e.g., $MgCl_2$ or $CaCl_2$) ▪ Pre-wetting of NaCl/sand ▪ Pre-treatment of NaCl stockpiles		
	Solid phase (Road Salt) ▪ Solid deicing material ▪ Paired with sand in RSZs ▪ Needs to be treated with a liquid product to enhance performance (pre- wetting)	X	X
Magnesium Chloride ($MgCl_2$) Based Products	**Liquid phase** ▪ Pre-treatment of roadways (anti-icing) alone or with salt brine ▪ Pre-wetting of NaCl/sand ▪ Pre-treatment of NaCl stockpiles ▪ "treated salts" pre-packaged and enhanced with liquid magnesium chloride	X	X
Agricultural (organic) Based Products (Non-Chloride)	**Liquid phase** ▪ Pre-treatment of roadways (anti-icing) alone or with salt brine ▪ Pre-wetting of NaCl/sand ▪ Pre-treatment of NaCl stockpiles		

Notes:

$CaCl_2$: Calcium chloride
$MgCl_2$: Magnesium chloride

Sand: Although not a deicing product, sand is used by MassDOT in RSZs such as the Boxford Depot Service Area and by the Town as part of their respective snow and ice management operations. Sand is the most common abrasive paired with solid deicing materials. As sand is highly abrasive, it provides good traction especially at low speeds. This abrasiveness also causes damage to any surface it contacts, including vehicles, roadway infrastructure, and roadway markings/stripping. Typically, sand is mixed with salt (or pre-mix) in order to increase traction on the roadway and decrease the amount of salt that must be applied to the road in a single pass. Sand can be harmful to vegetation and equipment and requires clean-up efforts in the spring to remove residual sand, as well as inspection and maintenance of impacted stormwater drainage systems. As traffic travels through the applied sand, the sand is further crushed and loses its angularity, reducing its traction effectiveness. Sand remaining on the roadway may be transported to drainage structures via runoff. Therefore, sand which accumulates on roads and within drainage structures must be removed for proper drainage at a significant expense. Sand can also cause environmental issues with air and water quality, as fines from the sand can become an airborne particulate, and sand can contribute to suspended solids and sedimentation issues within waterways, as well as carry other pollutants.

Liquid Magnesium Chloride ($MgCl_2$): Liquid $MgCl_2$ is commonly used for pre-treatment of roads and pre-wetting of solid deicing materials, and is currently used by MassDOT and the Town. When used for pre-treatment, $MgCl_2$ may prevent the formation of "hard pack" before deicing operations can begin. This is critical because once hard pack forms it is difficult to remove both mechanically and chemically.

When used for pre-wetting, liquid $MgCl_2$ can reduce salt use by 20-30%[1, 2] compared to dry solids application. Additionally, pre-wetting solid salt with $MgCl_2$ extends the useful temperature range of the salt, as the treated salt can be effective at lower pavement temperatures. The use of $MgCl_2$ reduces the amount of NaCl being introduced to the environment through a reduction in solid salt use, and reduces the amount of sodium. $MgCl_2$ may be enhanced with an anti-corrosion inhibitor or used in a blend with other deicing/anti-icing chemicals.

Liquid Agricultural Byproduct: Agricultural byproducts (ABP) have been researched and used for roadway pre-treatment and deicing for over 20 years. Liquid agricultural byproducts are most commonly used for pre-treatment of roads and pre-wetting of solid deicing material. The products are often comprised of byproducts including corn, wheat, rice, and sugar beet molasses. When applied as pre-treatment to a road prior to a storm event, these products may prevent the formation of "hard pack" before deicing operations can begin. Once the hard pack forms, it is more difficult to clear the roads and requires more passes and deicing material use than if the road was treated before the hard pack formed. Per gallon, ABPs are generally more expensive than the liquid $MgCl_2$ currently used by both MassDOT and the Town. Unlike other pre-treatment liquids which have a narrower effective temperature range (20-32^o F), some ABPs can be used at higher temperatures (up to 40^o F [3]) without the adverse side effects of slick roadways or "greasy" buildup which can be observed with other liquid pre-treatment products. When used as a pre-wetting material, an average 30%[4] reduction in solid material application can be achieved. ABPs provide an added benefit towards mitigating environmental impacts due to salt use as there are multiple non-chloride products available which utilize molasses, beet juice, and materials other than chlorides (i.e. BIOMELT® AG64, Apogee ™, GEOMELT® 55). Agricultural byproducts and other organic materials however, have the potential to adversely affect water quality due to noted high biological oxygen demand (BOD) of individual products. High BOD can lead to low dissolved oxygen (DO) levels in surface water bodies which can contribute to nutrient impairment and degradation of water quality. Impacts to waterways would be lessened due to dilution of these high BOD products associated with precipitation, snow melt, and mixing in the surface water bodies. Further dilution and reduced threat of a BOD and resulting DO issue can be achieved through the use of blends, mixing agricultural byproducts with $MgCl_2$ and/or salt brine. Regardless of the final product, if a watershed is impaired for sodium and chloride, and/or DO and nutrients, then pilot testing and monitoring should be conducted in order to assess the impacts, and determine the environmental priority.

5.4.2 Deicing Technologies and Procedures Retained for Evaluation

Based on the screening procedure in **Section 5.3**, **Table 5-3** presents the deicing technologies and procedures retained for evaluation.

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[1]Lemon, Harold. Michigan Department of Transportation; 1974-1975 Pre-wetted Salt Report. June 1, 1975.

[2]Nixon ,Dr. Wilfrid A. Asset Insight Technologies, LLC; Review of Two Documents Pertaining to Chloride Reduction and Cost Savings Resulting from the Use of Pre-wetting in Winter Highway Maintenance. March 24, 2003.

[3]Freeman, Dan. SNI Solutions, Vendor Correspondence. July 2, 2014. Telephone interview.

[4]SNI Solutions. Product Data Sheet; Biomelt® AG64 Anti-icing/Deicing Fluid. November 2, 2011. Web.

Table 5-3
Retained Alternatives: Deicing Technologies and Procedures

Alternative	Description	Current Practices	
		MassDOT	*Town of Boxford*
ENHANCED ROADWAYS			
RWIS (Road Weather Information Systems)	▪ Roadside stations which collect and transmit data via the internet to better characterize conditions and determine best course of treatment. ▪ Stations collect pertinent weather data and pavement data using a variety of meteorological and pavement sensors.	X	
"SMART" VEHICLES			
Mobile Friction Meters	▪ Skid resistance readings are obtained by attaching an additional wheel to the truck, or a trailer behind it. ▪ Readings indicate road friction conditions to evaluate timing and effectiveness of applications and/or make adjustments.	X	
Geofencing	▪ Hardware installed on vehicles allows for both remote and onboard control of material application. Application rate, vehicle speed, and heading are continuously recorded. ▪ Control level can be set by administrator, and can be based on pre-determined values, locations, or weather conditions.		
Closed Loop Controllers	▪ Automatically adjusts application rates based on truck's speed and speed of the feed-belt or auger. ▪ Continuous feedback from the sensors allows application rates to adjust throughout a storm event for more consistent/uniform applications. ▪ As of 2014, required on all MassDOT contracted vehicles.	X	
Ground Speed Controllers/ Electronic Controllers	▪ Automatically adjusts application of material in proportion to the speed at which the truck is traveling. ▪ Helps prevent uneven application/waste of material. ▪ Subset of closed-loop controllers, only considers vehicle speed, not feed-belt or auger speed.	X	
Zero Velocity Spreaders	▪ Spreader is automated to drop material at a rate matching the truck's velocity, opposite to direction of travel. Reduces bounce and scatter of material.		
Portable Pavement Temperature Sensors	▪ Small units attached to the vehicle's bumper that transmit road surface temperature to readout in cab. ▪ Reflects more accurate road conditions than air temperatures (which can vary significantly). ▪ Helps determine if and when pre-treatment and deicing should be applied.	X	
EQUIPMENT ENHANCEMENT			
Alternative Plow Blades: Flexible/ Segmented Blades	▪ Flexible/segmented blades that contour to road better or wing blades are proving more effective. ▪ Several states have seen success with JOMA blades. JOMA blades have tungsten carbide inserts strategically located on the plow's base and encased in rubber. Found to perform better and last up to 4 times as long for only 2-3 times the cost of current carbide blades.		
QUALITY ASSURANCE PROCEDURES/PROGRAMS			
Equipment Calibration Program	▪ Improved or more frequent spreader equipment calibration procedures ▪ Goal of annual equipment calibration. ▪ Calibration teams perform periodic field calibration over the course of each winter season.	X	X
Enhanced Record Keeping Program	▪ Total facility material usage. ▪ Track usage quantities per truck for optimal program management. ▪ Track material usage by storm event. ▪ Improve measurements of materials during loading. ▪ Record and track application rates. ▪ Annual benchmarking.	X	

Table 5-3 (Cont'd)
Retained Alternatives: Deicing Technologies and Procedures

Alternative	Description	Current Practices	
		MassDOT	*Town of Boxford*
Staff Training Program	▪ Annual new staff/contractor and refresher training on proper material handling, usage, equipment operation and calibration, and environmental impacts/best management practices.	X	X
Good Practices	▪ Program management practices to review data and adapt practices accordingly. ▪ Storm tracking to maximize advantage of pre-treatment. ▪ Work to meet protocols. ▪ Properly cover product to mitigate loss/exposure to the elements. ▪ Handling salt materials under cover. ▪ Truck routes to avoid overlap.	X	X
SNOW/ICE MANAGEMENT STRATEGIES			
Reduced Salt Zones (RSZ)	▪ Serves to maintain road conditions with less salt usage per application. ▪ Salt is mixed with an abrasive (usually sand). ▪ Sand/salt and sand/pre-mix ratios are around 1:1 to 3:1.	X	X
DEICING METHODS AND PROCEDURES			
Roadway Pre-treatment/Anti-Icing	▪ Liquid materials applied to roadways prior to a storm event. ▪ Prevents initial bonding of snow/ice to the roadways. ▪ Pretreat roads on a regular basis (e.g., twice/month is an option). ▪ Apply salt brine (or equivalent material) to roads in anticipation of an event (before precipitation). ▪ Can only be used when conditions are right, typically between 15° F and 30° F. ▪ Creates overall reduction in material use and cost.	X	
DEICING METHODS AND PROCEDURES (Cont'd)			
Pre-wetting	▪ Apply liquid to solid material onboard spreaders as it is applied onto the road. ▪ Pre-wetting usually effective at/below 30° F. ▪ Results in a quicker reaction time and less loss of material due to bounce, scatter, and wind. ▪ Pre-wetting reduces material loss by up to 30%.	X	X

Abbreviations:
mph: miles per hour
RSZ: Reduced Salt Zone
RWIS: Road Weather Information Sensor

References:

[1] Rall, Jaime. The National Conference of State Legislature. The Forum of America's Ideas, Weather or Not; State Liability and Road Weather Information Systems (RWIS). 2010.

[2] Massachusetts Department of Transportation. MassDOT Snow & Ice Control Program 2012 Environmental Status and Planning Report, EOEA# 11202. February, 2012.

Enhanced Roadways: Enhanced roadways is a category of technologies focused on physical modification to and/or along the roadway to improve deicing operations. The retained technology in this category is a Road Weather Information System (RWIS), which when installed provides real-time conditions data. RWIS systems can be used to gather and transmit weather and roadway conditions, sending a customized report back to the Depots for review and assessment. Deicing operations and the deployment of vehicles can be based in large part on RWIS outputs.

Typical Roadway Weather Information System (RWIS)

"Smart" Vehicles: "Smart" vehicles is a term used to identify equipment and technologies that can be installed in, or attached to vehicles to aid in the decision making process regarding mobilization for pre-treatment and deicing.

- ***Mobile friction meters*** provide real-time feedback of roadway conditions and can aid in decisions regarding when to begin deicing activities, when to re-apply, and when activities can be stopped. MassDOT's Real Time Traction Tool (RT3) Team has piloted the use of friction meters in the Cambridge Reservoir Watershed and demonstrated how the equipment's functionality and communications have improved, providing real-time roadway condition information to the Depot for improved deicing operations. New models and features are now available which include digital dashboard units from which outputs can be reviewed in real-time by the driver and/or synched to a website and uploaded. Readings can be stored electronically and managed for review and future use.

Available Mobile Friction Meter Features and Onboard Outputs (Source: Halliday Technologies)

- ***Geofencing*** utilizes global positioning system (GPS) enabled vehicles for tracking of routes, material usage, and jurisdictional boundaries. These systems track a specified number of deicing operations parameters during a storm event. A predetermined program can be loaded onto the geofencing systems, or new directions can be pushed remotely as conditions change.

- To monitor and maintain applications rates (in order of increasing sophistication) ***zero velocity spreaders, ground speed controllers, and closed-loop controllers*** all serve to control the application rate of solid material and assist with providing the most efficient and effective application of deicing material. Closed loop controllers can be used in conjunction with geofencing equipment to monitor and record application rates remotely.

- ***Portable pavement temperature sensors*** are a vital part of a snow and ice management program, especially when roadway pre-treatment is part of the operation, as pavement temperature and air temperature can vary significantly. Knowledge of temperature can help determine when anti-icing and deicing operations should be initiated relative to a storm event.

Equipment Enhancement: Of the identified technologies that may enhance a vehicle's performance during deicing operations, flexible/segmented plow blades were retained for evaluation. Flexible/segmented blades contour to the road better, proving more effective at clearing snow/ice down to the pavement. More efficient and effective plowing would mean that more snow and ice can be removed from the roadways by mechanical means, resulting in the need for less chemical treatment. These blades are more expensive, but can last up to four times longer than conventional blades.

Quality Assurance Procedures and Programs: The implementation of quality assurance procedures and programs is a low capital cost element of a snow and ice management program that can have high yield results. Quality assurance procedures and thorough record keeping can lead to substantial savings in materials and labor, and a reduction in environmental impact. Calibration programs and enhanced record keeping can be used to identify effective or ineffective implementation of established operational policy, material usage rates, program deficiencies, and inconsistencies in operations and application. Methods for checking that protocols are being followed should be developed, ranging from simple measures like visual markers on spreader calibration settings, to more intensive operational evaluations. MassDOT, contractor, and Town staff training is vital to optimal program implementation, and an emphasis on mandatory training for MassDOT personnel and contracted employees should be made. Personnel need to be aware of and understand protocol as well as be properly trained on all equipment. Good practices include program management and review as well as implementation and enforcement of best management practices (BMPs). Monitoring and review of deicing operations enables a program to adjust as necessary to ensure success.

Snow/Ice Management Strategies: Of the alternative snow and ice management strategies identified, only Reduced Salt Zones (RSZs) were retained for evaluation. A RSZ serves to maintain safe driving conditions during a winter storm event with less salt usage per application. In order to achieve less salt usage while still maintaining adequate traction on the roadways, rock salt (NaCl) is mixed with an abrasive, generally sand. The use of sand presents its own set of both operational and environmental problems, and the benefit of sand needs to be evaluated and considered. Based on these facts, MassDOT is currently piloting programs in three Districts to evaluate modifications to sand application rates and/or elimination of sand from their overall snow and ice management program in RSZs. Under current operations, the Boxford Depot Service Area is a RSZ, and MassDOT operates under a reduced salt policy, applying pre-wetted sand and salt at a 1:1 ratio for a total of 240 pounds per lane-mile. Within their jurisdiction, the Town applies pre-wetted sand and salt at a 3:1 ratio.

Deicing Methods and Procedures: Roadway pre-treatment and pre-wetting of solid deicing material have become widely accepted as the best and most efficient way to decrease solid salt use. During roadway pre-treatment, the road surface is treated with a liquid deicing material in advance of a storm event. Pre-treatment along with the right weather conditions has been shown to eliminate the need for solid deicing materials during specific events. An aggressive liquids program can yield the greatest benefit in terms of decreasing total salt usage during typical storm events. Material pre-treatment is pre-treating solid deicing materials with a liquid, then stockpiled for later use. As both MassDOT and the Town currently have on-board pre-wetting equipment, material pre-treatment was not evaluated further. Pre-wetting is an on-board process whereby the solid deicing material is sprayed with liquid deicing materials as the solids are applied to the roadway.

5.4.3 Evaluation of Alternative Deicing Program Scenarios for MassDOT

5.4.3.1 Overview of MassDOT's Current Deicing Materials and Procedures

MassDOT is responsible for snow removal and deicing operations along the mainline stretch of I-95 and associated ramps and overpasses within the Study Area. MassDOT personnel based out of the Boxford Depot are responsible for all decisions relative to the initiation of snow removal and deicing activities. Within the Study Area, MassDOT adheres to the prescribed standard operating procedures (SOP) for a RSZ, as defined in MassDOT SOP number HMD-01-01-1-000 (**Appendix D**), and applies solid deicing materials (NaCl or pre-mix) at a ratio of 1:1 with sand from the Rowley Depot. All solid deicing material is pre-wetted with liquid magnesium chloride as it is applied to the roadway. Over the course of a winter storm season, liquid magnesium chloride is also used by MassDOT to pre-treat roadways prior to storm events. Overall, MassDOT employs various equipment and controls to help ensure implementation of an effective snow and ice management program.

CDM Smith reviewed and evaluated MassDOT's current operating procedures. Variances from protocol are noted, as are areas for improvement to MassDOT's snow and ice management program.

- Between winter seasons 2007/2008 through 2013/2014 the prescribed 1:1 sand to salt ratio was not consistently achieved in the Boxford Depot Service Area (the average sand to salt ratio was 1:1.4). Over the past four winters (2010/2011 through 2013/2014) the ratio has been 1:1.1, closer to the prescribed 1:1. Note that these calculations did not account for "extreme" weather events when the SOP allows for straight salt use in order to maintain safe driving conditions and also do not account for instances when spreaders from remote depots made undocumented deicing material applications in the Boxford Depot Service Area.

- 1:1 ratio is difficult to maintain when responding to extreme events.

- During the time period pertaining to the available records (winter seasons 2007/2008 through 2013/2014), on average the applied application rates for liquid $MgCl_2$ were significantly below protocol for pre-wetting and roadway pre-treatment.

- Minor discrepancies and inconsistencies were noted between material usage data and records provided by MassDOT. Material use is recorded and reported to different departments within MassDOT. Data provided from those different departments was not always consistent. These observations were also noted in an independent report conducted by an engineering firm not associated with this study (Geosphere and VHB, 2012).

- MassDOT does not currently pre-treat ramps and overpasses, as pre-treatment using liquid $MgCl_2$ is only performed on the I-95 mainline. MassDOT does not pre-treat the mainline at every available opportunity, but instead is limited by an inadequate number of dedicated tanker trucks to perform this activity.

These observations were used as the basis for developing three alternative scenarios relative to deicing program modifications for consideration by MassDOT.

5.4.3.2 Identification of Scenarios for MassDOT

Three alternative scenarios have been developed and evaluated as potential modifications to MassDOT's current deicing operations at the Boxford Depot Service Area. As presented in **Table 5-4**, each scenario is comprised of certain retained alternatives, suggested materials and application rates, paired technologies, and quality assurance procedures. The scenarios were developed based upon the retained materials and technologies that resulted from the screening process, supplemental research and vendor provided information, and information requested from MassDOT. Each scenario was developed with the objectives of addressing the discrepancies and/or areas for improvement summarized above and, with the intent of achieving the ultimate goal of decreasing total salt usage per typical storm event relative to current practices and operations. Each scenario takes a different approach towards reaching this ultimate goal; incorporating alternative materials, adjustments to application rates, new equipment, and for all, an increased emphasis on record keeping, material usage tracking and most importantly, MassDOT personnel and contractor training.

Three categories of alternatives were included as a component of all three scenarios.

Increased Roadway Pre-Treatment: Includes the addition of pre-treating ramps and over passes, and pre-treating at every available opportunity. Based on the interchange designations per the American Association of State Highway and Transportation Officials (AASHTO), Exits 51 and 52 are Diamond Style interchanges and Exit 53 is a Partial Cloverleaf interchange. The interchange layouts, including slope and merging lanes, should be able to accommodate the application of roadway pre-treatment without endangering motorists. This may not be the case throughout the Commonwealth as not all ramps meet the requirements of layouts conducive to accept pre-treatment. The greatest concerns arise in roadway pre-treatment when liquids are mismanaged. A SOP for roadway pre-treatment is a valuable program element for a winter maintenance program. Development of such an SOP is recommended as it would allow for management level direction regarding the goals of the overall program; the proper equipment, materials, and settings to employ; and consistency in how pre-treatment is being performed across varying event conditions and MassDOT service areas.

Improved and/or New Quality Assurance Procedures and Programs: Includes the addition of new quality assurance procedures and protocols, as well as improvements to procedures already in place. Procedures and programs include, but are not limited to, staff training, enhanced record keeping, increased equipment calibration, and establishment and execution of good practices. Staff and operator training is essential for ensuring that current protocols, and any future changes in protocol made as a result of policy decisions or pilot testing results, are properly and consistently implemented. Staff needs to be regularly trained to implement all new and existing SOPs inclusive of their respective protocols. Training on overall program goals and the importance of following proper procedures should be included, as well as detailed training on proper material use and application, storage and handling practices, equipment calibration, maintenance procedures, and the importance of thorough reporting and record keeping.

Table 5-4
Alternative Scenarios – MassDOT Deicing Materials and Methods for the Boxford Depot Service Area

Retained Alternative	Current Practices	Alternative Deicing Program Scenarios		
		Scenario #1	**Scenario #2**	**Scenario #3**
	- Sand/salt at 1:1 ratio - Pre-wetting of materials for the mainlines, ramps, overpasses - Pre-treatment of mainlines only	- Maintain sand/salt at a 1:1 ratio - Maintain pre-wetting operations - Increase pre-treatment (additional storms; ramps and overpasses)	- Eliminate sand - Increase salt application rate - Maintain pre-wetting operations - Increase pre-treatment (additional storms; ramps and overpasses) - Pilot study to assess performance of a range of liquid blends for pre-treatment[1]	- Decrease sand application rate - Decrease salt application rate - Maintain pre-wetting operations - Increase pre-treatment (additional storms; ramps and overpasses) - Pilot study to assess performance of a range of liquid blends for pre-treatment and pre-wetting[1]
Solids Application				
- Sodium Chloride (NaCl)	Yes Application Rate: 120 lbs/L-M	✓ Application Rate: 120 lbs/L-M	✓ Application Rate: 180 -200 lbs/L-M	✓ Application Rate: Varies. Dependent on pilot testing
- Sand			N/A	
Pre-wetting *(application rate: 8-10 gal/ton of applied solid material)*				
- Magnesium Chloride ($MgCl_2$)*	Yes	✓	N/A	✓[3]
- $MgCl_2$, Agricultural byproducts, Salt Brine [1]	No	N/A	✓	
Roadway Pre-treatment/Anti-icing *(current application rate: 20-30 gal/L-M)*				
- $MgCl_2$*	Yes	✓	✓[2]	✓[3]
- $MgCl_2$, Agricultural Byproducts, Salt Brine [1]	No	N/A		
"Smart" Vehicles				
- Mobile Friction Meters	No	N/A	✓	✓
- Closed Loop Controllers	Yes	✓	✓	✓
- Portable Pavement Temperature Sensors	Yes	✓	✓	✓
Equipment Enhancement				
- Alternative Plow Blades[4]	No	N/A	✓	✓
Enhanced Roadways				
- Road Weather Information Systems (RWIS)	Yes	✓	✓	✓
Quality Assurance Procedures/Programs				
- Equipment Calibration Program	Yes	✓	✓	✓
- Enhanced Record Keeping Program	Yes	✓	✓	✓
- Staff Training Program	Yes	✓	✓	✓
- Good Practices[5]	Yes	✓	✓	✓

Notes:
*: Current $MgCl_2$ product in use by MassDOT is a $MgCl_2$ liquid with a corrosion inhibitor.
[1]Materials can be considered on their own, or as part of a blend with one another
[2]Scenario #2 pilot program to assess performance of different liquid products for pre-treatment
[3]Scenario #3 pilot program to assess liquid products for both pre-wetting and pre-treatment
[4]Assumes Flexible/Segmented Blades
[5]Good practices include: protection of materials during storage, route optimization

Abbreviations:
gal: gallon
lbs: pounds
L-M: Lane mile
N/A: Not Applicable

Operations out of the Boxford Depot Service Area are conducted by MassDOT personnel, however, all plowing, solid material application, and liquid material applications are conducted by contracted staff. The success of any program depends on the individuals applying these materials to the roadways. It is important that all contracted staff are fully trained in MassDOT protocol, material application policy, and their equipment. Proper and frequent training of all contracted staff is a recommendation to be implemented regardless of the scenario selected to pursue. A training certification program could be developed to help ensure contractors are operating in a manner consistent with MassDOT's program protocols.

Ensuring proper training is only one of the challenges facing operations in the snow and ice management program, others include:

- Rotation of different contractors to ensure even distribution of work, changing of shifts
- Equipment breakdown
- Rerouting of equipment and personnel based on need
- During "extreme" weather events, vehicles servicing roads in the Study Area may be from neighboring Peabody, Rowley, or Newburyport Depots based on need, adding to logistical and material tracking challenges

In order to address some of these challenges, MassDOT might consider conducting post-storm meetings in order to discuss the event relative to execution of their operations. Practices such as this should be implemented to identify opportunities for improvement. Contracted staff should be included and/or made aware of the results of the meetings prior to the next storm event.

Enhanced record keeping in terms of facility usage, truck usage, and storm usage can be used for benchmarking in order to confirm protocol relative to material usage and application rate, and identify any areas for improvement. A template, uniform tracking form, or spreadsheet can be developed for consistency among areas, vehicles, and operators for comparable information. The records should be examined regularly to confirm that the target salt application rates are being maintained and significant discrepancies should be corrected by training or equipment maintenance, as appropriate. Specific record keeping for optimum program management include:

- Purchase/storage quantities (solid and liquid) by facility
- Quantities used on each route
- Quantities used during each storm (including unique storm/weather information)
- Quantities used by each vehicle, each operator
- Calibration records
- Contractor certification programs

Dashboard Mounted Portable Temperature Sensor on a MassDOT Vehicle (CDM Smith)

Continued Use of Technology: Includes the continued use and emphasis on technologies and equipment currently employed by MassDOT. MassDOT currently uses RWISs, closed-loop controllers, and portable pavement sensors in their snow and ice management program in the Boxford Depot Service Area. Together, these technologies and equipment help MassDOT track and monitor weather, aid in the decision making process, and enforce protocol through more effective application rates of materials. While consideration of a locally installed RWIS is evaluated separately, MassDOT should at a minimum continue use of a remote RWIS as a component of enhanced roadways. The use of a RWIS in a region is beneficial to a snow and ice management program; the closer a RWIS is to the service area location that is utilizing their data, the greater the benefit will be.

Scenario #1

Objective: *Increase roadway pre-treatment and quality assurance procedures/programs in order to create a more efficient model of current operations. Increased pre-treatment would result in the need for less solid deicing material per storm event. Proper training, material tracking, and records will identify instances of excess material usage and provide opportunities for correction, resulting in more accurate and efficient solids applications.*

Building upon MassDOT's current operations, this scenario aims to address the observation that current practices only include roadway pre-treatment of the mainline, and does not include pre-treating of ramps and overpasses. Scenario #1 also calls for increased roadway pre-treatment throughout the entire Study Area during more storm events. Depending on the pre-treatment liquid, temperature constraints limit the number of times roadway pre-treatment can be performed during a winter storm season, therefore diligent weather and temperature tracking will need to be implemented in order to ensure no opportunity is missed. Based on historic weather data, six additional storms were identified where pre-treatment could have been conducted during the 2012-2013 winter storm season. Post-storm event discussions involving both MassDOT personnel and contracted staff should be expanded upon in order to discuss what is working, what is not working, and actions to remedy identified issues.

Scenario #2

Objective: *Determine through pilot testing if sand can be removed from the snow and ice management program. Through pilot testing of alternative application rates and anti-icing materials, as well as the introduction of new technologies and equipment, this scenario would evaluate the impacts of removing sand from the program while still maintaining safe roads and working towards the ultimate goal of decreasing net salt usage.*

Under Scenario #2, the possibility of eliminating sand use in the Study Area would be investigated. Eliminating sand will reduce impacts to slow-moving waterways, adjacent drainage systems, and spring clean-up of residual sand. As sand only provides traction at low speeds, its use in conjunction with salt is meant to reduce the amount of salt necessary. However, in addition to negative environmental and operational maintenance impacts, there are some significant disadvantages regarding sand use for snow and ice management. When salt and sand is applied at a 1:1 ratio, only 50% of the material being applied to the roadways has melting capabilities. This requires more frequent passes and applications of solid materials in order to maintain enough salt on the roads to effectively melt the snow and ice and prevent hard pack. As a result, crews are likely instructed to reapply more often, resulting in an overall increase in material spread. With each additional pass, a full application of sand and salt is reapplied to the road, further increasing the amount of salt used. Also, as discussed in **Section 2.2.1**, straight salt is sometimes needed to provide safe driving conditions. Pilot testing of a movement towards straight salt application is a consideration under this scenario. Across the Commonwealth, MassDOT is piloting programs looking at the impact of sand on snow and ice management programs to assess alternative solids applications in RSZs. In cooperation with the City of Cambridge Water Department (CWD) – Watershed Operations, MassDOT has completed two years of piloting straight salt application in the RSZ along Route 128 in Lexington, Waltham, and Weston. The results and data from this pilot program could lay the framework for a similar program in the Boxford Study Area to evaluate straight salt applications.

In association with piloting the elimination of sand, pilot testing of alternative liquid materials for roadway pre-treatment and pre-wetting, increased pre-treatment, and enhanced quality assurance procedures are also included within this scenario. All are intended to help reach the ultimate goal of a reduction in total salt usage per typical storm event, and therefore contribute to lessening impacts to groundwater due to the application of anti-icing/deicing materials. With the elimination of sand, this scenario relies on an increased use of technology and new equipment to maintain safe driving conditions. Friction meters would be used to monitor roadway condition and ensure sufficient traction is maintained, as well as flexible/segmented plow blades for better road surface clearing. By maintaining a clean clear road through the use of mechanical methods the need for chemical deicing, whether it be from solids or liquids, is decreased. As each scenario includes increased pre-treatment and implementation of the quality assurance programs and procedures, this scenario would address the noted issues of incomplete roadway pre-treatment, record keeping, and tracking of applied application rates.

Scenario #3:

Objective: *Perform pilot testing of sand/salt ratios and anti-icing materials to determine if deviations from the prescribed 1:1 ratio may result in an overall more effective deicing program.*

Scenario #3 involves maintaining the current RSZ status of the Study Area, but adjusting the application rates and ratios of sand and salt in order to determine a more optimal combination. As noted under Scenario #2, sand does not contribute to melting snow and ice on the roadways. With half of the applied materials not contributing to the active deicing of the roadways, additional passes are needed to maintain the road surfaces, contributing to another full application of materials (and additional 120 pounds of salt that may not be fully needed). One option to pursue during piloting is to adjust the solids ratio to be greater parts salt than sand, which in turn would make each application more effective, as more active deicing materials rather than inert traction materials, are applied with each pass. The rationale for this approach is that more efficient applications will result in more time between applications, and overall less passes per storm event. This is the approach MassDOT is considering in pilot programs in Districts 3 and 5. The expectation of these piloting programs is that material usage data and tracking records will indicate that with each storm, less passes and less salt were needed to maintain safe driving conditions.

Another option to consider is to decrease the quantity of salt per application in order to determine if application rates less than current practices can be used for deicing operations. In order to decrease the quantity of salt used per application, alternative pre-treatment and pre-wetting materials and technologies should be considered. An aggressive and diligent anti-icing program will have the highest return in terms of reducing solid material application. Increased roadway pretreatment is a vital part of this scenario, as with the other two. This scenario also relies on the implementation of new technologies (mobile friction meters) to better monitor road conditions, and alternative plow blades in order to optimize the benefits of mechanical snow clearing in order to balance out a dependence on chemical methods.

MassDOT has had success with its current salt application rates, however pilot testing this scenario may highlight room for improvement. Reduction to the rates analyzed as part of the pilot study recommendations may not be feasible, i.e. 100 pounds per lane mile (assumed during the analysis performed with the Stormwater Management Model, or SWMM), but piloting the alternative methods and materials proposed could provide results that support some level of reduced salt application. Any reduction in the amount of salt used in the snow and ice management program would get MassDOT one step closer towards their goal of reducing total salt usage per typical storm event, relative to current operations.

5.4.3.3 Evaluation of Scenarios

Literature research, professional and technical experience, vendor information, and solicited input from MassDOT were all considered during the evaluation of the alternative scenarios. Components of the evaluation included, technical feasibility, estimated reductions in salt use, and costs. Quantifying improvements to deicing procedures and programs is empirical requiring field observation of implementation experience. Therefore, experience of other snow and ice management programs was critical to understanding expected reductions in solid material use due to pre-wetting (20-30% reduction), the added benefit of pre-treating the roadway prior to storms (the prevention of hard pack, reduction of solid material use), and the advantages of onboard controls and equipment. Ultimately, pilot testing will be required to assess the viability of each scenario relative to achieving a decrease in net salt use per typical storm event, as compared to current operations.

Scenario Modeling and Analysis

To aid in the evaluation of these scenarios, a runoff and water quality model of the MassDOT-owned drainage network along I-95 was developed using EPA's SWMM. For modeling purposes, current deicing material application rates by event were obtained from MassDOT for the 2013/2014 winter season and used to establish a baseline. The three scenarios were modeled by changing deicing material application policy and procedures with results compared against the baseline run of the model presented in **Table 5-5**. For each scenario, a 5% salt reduction was assumed due to optimization of operating procedures based on professional experience with other snow and ice management programs. The model also assumed for each scenario a 30% reduction in salt usage associated with additional pretreatment. This was based on a review of literature and reports from other programs identifying a range in usage reductions. A summary of the findings are listed below. A detailed discussion of the model development and analysis is provided in **Appendix M**. The model is also discussed in **Section 5.6**.

Model observations:

1. Sodium is reduced by reducing salt, both through additional pre-treatment and through scenarios involving a reduced salt application rate.

2. Elimination of sand in the Reduced Salt Zone (Scenario #2) is expected to increase sodium and chloride loads significantly in the Study Area.

3. Magnesium loads increase significantly on the ramp catchments, and also increase relative to the baseline due to additional pre-treatment.

4. Chloride generally decreases with decreasing salt load but not as uniformly as sodium, as chloride is also contained in the alternative pre-wetting and pre-treatment liquids.

Table 5-5
Modeled Chloride, Sodium, and Magnesium Loads

Parameter	Model Run	Scenario #1	Scenario #2	Scenario #3
Chloride (Cl)	Baseline Computation (lbs)	490,194		
	Alternative Results (lbs)	470,210	717,846	458,265
	% Difference	**-4%**	**46%**	**-7%**
Sodium (Na)	Baseline Computation (lbs)	301,851		
	Alternative Results (lbs)	284,139	449,887	236,782
	% Difference	**-6%**	**49%**	**-22%**
Magnesium (Mg)	Baseline Computation (lbs)	8,192		
	Alternative Results (lbs)	10,711	7,862	6,648
	% Difference	**31%**	**-4%**	**-19%**

Note:
lbs: pounds
Baseline computations based on 2013/2014 MassDOT data.
Analysis assumes pre-wetting and anti-icing using $MgCl_2$

While additional chloride is applied in Scenario 1 due to additional pre-treatment, the accompanying salt reduction modeled as a result of pre-treatment causes a much larger overall reduction in chloride load. Therefore, overall highway chloride load decreases due to reduced salt application rates for each of the existing and proposed pre-treatment dates despite the additional pre-treatment applications.

Based on the model results, Scenario #2 is shown to increase overall sodium and chloride levels introduced into the environment. However, not reflected in the results for the SWMM model, the elimination of sand could reduce the level of effort related to spring clean-up, decrease labor/costs associated with measuring and maintaining a 1:1 ratio, and decrease impacts to equipment and the environment due to sand. By pilot testing alternative pre-wetting and pre-treatment materials under

Scenarios #2 and #3, a greater reduction in chlorides may be seen if a product containing more ABP is used over one containing a higher percentage of $MgCl_2$.

While the model is a useful tool to aid in the understanding of the overall drainage of runoff and associated deicing chemicals within the Study Area, a number of assumptions were made in terms of deicing materials and loading. As such, the results of the modeling analysis provide useful information for evaluating and comparing the scenarios, but do not provide definitive conclusions.

Pilot Testing

Changes to a snow and ice management program are best developed based on field testing and tracking of conditions during implementation of each new alternative. For this reason, pilot testing is strongly recommended to evaluate alternative pre-wetting and pre-treatment materials under Scenarios #2 and #3. Road conditions, weather conditions, timing of storms, and traffic patterns factor into the effectiveness of deicing procedures. As conditions can vary significantly per location, pilot testing aims to ensure the right mix of snow and ice fighting tools are utilized. Alternative liquid materials on the market carry with them benefits that can contribute to a decrease in salt use, and a decrease in chloride addition to the environment. Pilot testing of new materials may result in the selection of one that can allow for a further increase in roadway pre-treatment, as some ABP products are not limited by the warm temperatures as are $MgCl_2$ and $CaCl_2$, however, each new product may have its own set of side effects or limiting factors. Pilot testing would allow assessment of alternative materials relative to weather and roadway conditions, pairing with other materials, and application rates and procedures.

General elements for pilot testing new materials include:

- Selecting the material or materials to pilot test, and determining the equipment and staff resources necessary. Testing one new material or one material change at a time is preferred to be able to discern which change causes resulting effects.

- Determining a single winter season for testing across a representative sampling of winter storm events (light snow, heavy snow, long duration freezing rain, etc.). Testing during 10 events should be adequate for meaningful results, weather dependent. More than one season could be necessary.

- Selecting a specific roadway segment or segments with acceptable characteristics, and any necessary signage or notifications.

- Developing pilot test forms that will be used to collect consistent data and information, including staff training for the testing procedures and data collection.

- Collecting and assessing the pilot study results, and determining any material usage or program modifications.

Pilot testing provides site specific results for material and protocol changes for more confident program management decisions, and can allow for further testing of different combinations of materials or procedures to optimize program performance. This is normally a multi-winter season process as optimal mixtures and operational measures are dialed in. Once operational modifications are made as a result of these efforts, all winter operations staff must be trained to implement the new and advanced practices. Some agencies are piloting different combinations of liquids (ratios of $CaCl_2$, $MgCl_2$, and beet juice) to optimize liquid pre-treatment performance during different types of storm events. Using different liquid mixtures for different anticipated storm events is an industry leading philosophy for roadway pretreatment, requiring an advanced level of weather forecasting, an investment in additional mixing tankage and equipment, and a commitment of time and resources to diligently test options and fine tune results into protocol. Additional liquid storage tanks and blending apparatus will be necessary for producing different liquid mixes for piloting, including any special mixing or storage equipment necessary for individual liquids. In addition to differing liquid mixtures based on storms, varying application rates based on storm events can be piloted as well. More sophisticated and logistically challenging than an exchange of liquid materials, varying application rates should be tied to geofencing or other tools that can help manage and adjust application rates automatically based on a desired set of conditions. MassDOT piloting of modifications to RSZ protocol is ongoing, and the results and conclusions of such programs could yield valuable information for the development of a program to pilot modified application rates in the Study Area.

An important component to be associated with any pilot testing conducted within the Study Area is a monitoring program to sample and evaluate water quality. As application rates and alternative materials are piloted along I-95, monitoring should be conducted in the Study Area. At locations throughout the Study Area, and for the duration of the pilot testing program, water quality samples should be collected and evaluated to determine what, if any, impacts due to the alternative materials are observed. If ABPs are piloted, due to potential BOD concerns, dissolved oxygen concentrations should be monitored in adjacent downstream waters.

Costs

Due to the qualitative, rather than quantitative nature of the development and evaluation of alternatives, a full cost analysis was not performed. Rather, the following tables present estimated costs for individual items retained and evaluated as part of the scenarios.

Table 5-6 presents current and proposed materials costs associated with solid deicing materials and liquid roadway pre-treatment and pre-wetting materials. Scenario #1 proposed continued use of solid salt and sand, and continued use of $MgCl_2$ for all liquid activities. In Scenarios #2 and #3, pilot testing would be implemented in order to determine the most appropriate and effective combination of solid and liquid materials, as well as the optimal application rates. The items listed in the below table provide representative prices for the materials proposed as part of each scenario. An estimated annual material cost associated with the 2013/2014 season for the Study Area is included as well. As noted, prices vary between the proposed liquid materials, however material costs are just one component of a larger alternative scenario, the potential benefits of each have already been discussed.

Table 5-6
Summary of Roadway Pre-treatment and Deicing Material Costs

Item	Unit	Unit Cost	2013/2014 Annual Cost[6]	Source
Solid Deicing Materials[1]				
Sodium Chloride (NaCl)[2]	ton	$53.26	$80,000	MassDOT operations data, Winter 2013/2014
Sand	ton	$16.71	$22,000[7]	MassDOT operations data, Winter 2013/2014
Liquid Roadway Pre-treatment and/or Pre-wetting Materials				
Magnesium Chloride ($MgCl_2$)[3]	gal	$0.89	$10,000	MassDOT operations data, Winter 2013/2014
Magic Minus Zero (MMZ)[4]	gal	$1.26	N/A	Quote from vendor, Innovative Surface Solutions
BIOMELT® AG 64[5]	gal	$1.75	N/A	Quote from vendor, SNI Solutions

Notes:
[1]Current protocol calls for 120 pounds salt and 120 pounds sand per lane-mile (240 pounds total per lane-mile)
[2]The common name for Sodium Chloride (NaCl) is road/rock salt.
[3]Current protocol is 20-30 gallons of $MgCl_2$ per lane-mile for roadway pre-treatment. 8-10 gallon of $MgCl_2$ per ton of solid material for pre-wetting.
[4]Magic Minus Zero is a $MgCl_2$/Molasses product. Application rates of new materials unknown.
[5]BIOMELT® AG 64 represents an agricultural byproduct (non-chloride) available on the market. Application rates of new materials unknown.
[6]Costs are approximate and calculated based on material usage quantities provided by MassDOT for the 2013/2014 winter season for the Boxford Depot Service Area.
[7] In addition, cleanup costs associated with sand for the 2013/2014 winter season were approximately $21,000. These costs include police details, cleaning, and supervisor costs.
N/A: Not Applicable

Considered in each alternative scenario, are alternative equipment and technologies which support modification in materials, policy, and application rates. **Table 5-7** presents the costs associated with equipment and technologies that have been retained and included for consideration in at least one of the three scenarios proposed for MassDOT. The majority of costs presented in the below table represent capital costs if MassDOT was to purchase new equipment. Requiring contractors to have this equipment installed on their trucks would likely result in increased hourly rates and operational costs. As the scenarios increase in sophistication, in terms of materials used or application rates, additional equipment is considered in order to support the overall objective of providing safe public driving conditions. An aggressive approach to new snow and ice management such as the reduction or elimination of sand would require more thorough monitoring of roadway conditions (provided by friction meters), tracking of storm conditions over the course of an event (RWIS, pavement sensors), and perhaps consideration of alternative plows that can achieve a cleaner roadway surface with less effort. The table below details the associated capital costs of each technology, as well as the scenarios for which it would apply, and recommended quantities or requirements.

Table 5-7
Summary of Costs – Equipment and Technologies

Item[1]	Unit	Unit Cost	Comments	Source
Equipment				
Mobile friction meters*	EA	$20,000 - $30,000[2]	A minimum of 1 unit required	MassDOT
Retrofit existing spreader with closed loop controllers	EA	$8,500	1 unit needed per truck	MassDOT, Vendor (Cirus Controls)
Zero Velocity Spreader**	EA	$4,500	1 unit needed per truck	Vendor provided information, (Monroe Truck Equipment, Inc.)
Portable pavement temperature sensors	EA	$1,200	A minimum of 1 unit required	MassDOT
Alternative Material (Flexible/Segmented) Plow Blades***	EA	$9,000	1 unit initially. Final quantity following pilot testing	Vendor provided information, (Monroe Truck Equipment, Inc.)
Liquid Storage Tank (5,000 gal)	EA	$20,000 [3]	Minimum of 1 additional tank. Final quantity following the demands noted during pilot testing	Vendor provided information, (SNI Solutions, GVM Inc.)
Tanker truck for pre-treatment	EA	$133,000	1-2 additional trucks needed. Final quantity following demand noted during pilot testing.	Vendor provided information, (Monroe Truck Equipment, Inc.)
New spreader truck with closed loop controller/Cirus controls	EA	$150,000	Additional trucks purchased as needed based on demand and/or age of current trucks. Would need total of four for Boxford Depot.	Vendor provided information, (Monroe Truck Equipment, Inc.)
Road Weather Information Systems (RWIS)				
Road Weather Information System[4]	EA	$21,000	1 unit. More complex units with additional capabilities are available at higher costs.	MassDOT
Geofencing-Related Equipment (Cirus Controls Used)				
Base Station	EA	$500.00	1 unit. (1 unit required per depot, additional units if used beyond Boxford Depot)	Vendor provided information, (Cirus Controls)
License for truck to use host website	EA	$120.00	1 unit needed per truck	Vendor provided information, (Cirus Controls)
Mobile hot spot	EA	TBD[5]	1 unit per truck	Vendor provided, (Cirus-Controls)

Notes:

[1]Listed items are associated with all scenarios for MassDOT and proposed improvements for the Town of Boxford, unless otherwise noted.
[2]Price is dependent on the model, and level of sophistication desired in the unit.
[3]Price assumes a new, double-walled polyethylene tank. Includes price of unloading, install and testing of each tank.
[4]Price assumes a Vaisala Guardia System, price includes installation.
[5]Vendor unable to provide associated costs until geofencing program and contractor vehicle specifics determined.
*Applicable to only MassDOT Scenario #2 and #3 and Town of Boxford
**Applicable to the Town of Boxford only
***Applicable to MassDOT Scenario #2 only
TBD: To be determined

Comparison and Evaluation of Scenarios

The development and evaluation of alternatives is a qualitative rather than quantitative process. The tools for evaluation consist of the previously discussed research and technical experience with deicing BMPs, the results and interpretation of the SWMM model, the understanding and awareness of the importance of pilot testing, and the overall objective of the Study. **Table 5-8** compares each scenario to current operations. Arrows indicate if each scenario would result in an improvement compared to current operations, a decrease compared to current operations, or no significant change.

Table 5-8
Comparison and Evaluation of Alternative Scenarios to Current Operations

	Scenario #1	Scenario #2	Scenario #3
Improvement Relative to Current Operations			
Solid material application rates are inconsistent with protocol	↑	↑	↑
RSZ/deicing policy rates are not met consistently	↑	↑	↑
Liquid material application rates are inconsistent with protocol	↑	↑	↑
Inconsistent and/or incomplete record keeping	↑	↑	↑
More opportunity for roadway pre-treatment (including pre-treatment of ramps/overpasses)	↑	↑	↑
Impact to Groundwater and Drinking Water			
Impact due to chlorides	↑	↓	↑
Impact due to sodium	↑	↓	↑
Impact due to sand	↔	↑	↑
Relative Costs			
Solid deicing materials[1]	↔	↑	↑
Liquid deicing materials[2]	↔	↓	↓
Equipment[3]	↔	↓	↓
Labor/time[4]	↓	↓	↓

Notes:
↑ : Indicates an improvement compared to current operations
↓ : Indicates alternative is worse in comparison to current operations
↔ : Indicates little to no change as compared to current operations
Note, arrows indicate how a component of a proposed scenario compares to current operations. E.g., implementation of any scenario would require increased labor and time, therefore for all three scenarios, relative to current operation, would be "worse" or require more labor/time associated costs
NaCl: Sodium chloride
$MgCl_2$: Magnesium chloride
[1]Solid materials include NaCl and sand
[2]Liquid materials retained for consideration include liquid $MgCl_2$, liquid agricultural byproducts, and salt brine
[3]Equipment includes mobile friction meters, closed loop controllers, ground speed controllers, portable pavement temperature sensors, and alternative plow blades
[4]Increased labor/time due to such items as increased pre-treatment, record keeping and improved QA/QC protocols.

5.4.4 Supplemental Evaluations

As shown in **Table 5-9**, additional alternatives that could be applied to one or more of the scenarios were retained for evaluation. Geofencing, the elimination of RSZs, and a new RWIS within the Boxford Depot Service Area are supplemental alternatives retained during the screening process. These are unique in that they may require a policy change or change in the way MassDOT operates and makes decisions regarding deicing operations. Each of these alternatives could be applied to or incorporated into any or all of the scenarios above, therefore they are evaluated separately.

Table 5-9
Supplemental Alternatives Retained for Evaluation for MassDOT Deicing Operations

Item	Description	Application	Requirements
Geofencing	Provides remote and onboard control of material application and monitoring of application rate, vehicle speed, and direction.	▪ All scenarios	▪ Onboard vehicle software and hardware controls ▪ Method of downloading/ uploading (e.g., Drive-by stations for Wi-Fi data download, "hot spot" vehicles)
Modifying protocol in Reduced Salt Zones (RSZ)	Adjustment of sand use. Investigating reducing and/or eliminating sand.	▪ Scenario #2 and #3 only	▪ Pilot testing ▪ Policy change
New Road Weather Information System (RWIS) in Boxford	Roadside stations which collect and transmit weather and pavement data via the internet to better characterize conditions and determine best course of treatment	▪ All scenarios	▪ Install new RWIS in Boxford

Geofencing

From a snow and ice program perspective, a geofencing system's main objective would be to improve the efficiency of plow, pre-treatment, and deicing routes, eliminate overlapping applications, and optimize material application. Plow and spreader equipment would be equipped with GPS devices, mobile data terminals, and sensors to detect plowing status as well as salt, sand, and liquid application rates. Data is stored and can be transferred back to a computer system for mapping and analysis. Data can be downloaded from the vehicles via hardware connections or by wireless networks with hubs at depots or designated hot spots along the road. Various reports can be produced that assist in optimizing route and application rate performance. Information can also be uploaded to the vehicles, controlling the feed rates of various materials based on weather and road conditions. Operators are provided real-time navigation and data transmitters to communicate with supervisors. Systems can provide a web-based mapping interface and display real-time location information, status and vehicle activity and maintenance progress.

The use of geofencing technologies could result in material savings and labor cost savings. Due to the number of interchanges in the study area, multiple spreaders pass through the same interchange with the potential for overlapping applications. It can be difficult for operators to know if a section of road has already been treated. Currently all new MassDOT fleet vehicles purchased are equipped with the necessary onboard software to implement geofencing; however, the plows and spreaders that service the Boxford Depot Service Area are all contractor vehicles that do not have the necessary equipment. State bid laws do not allow for the requirement of equipment by specific manufacturers used by contractors and installed upon their equipment. While it is feasible for geofencing equipment to be required, vehicles could potentially have products from different manufacturers, resulting in non-uniform controls and data formatting. To implement geofencing technology, MassDOT operators, vehicles, and equipment would have to be utilized for deicing activities, requiring additional staff hires or reallocation of staff resources. This could affect the overall cost of implementing the technology.

Modifying Protocol in Reduced Salt Zones (RSZs)

Modifications to protocol to reduce sand use in RSZs and move towards the elimination of sand use in the Boxford Depot Service Area would require a change in operations and procedures. MassDOT has expressed interest in such a change throughout the Commonwealth citing not only the fact that sand does not possess any snow/ice melting properties, but also the significant effort associated with sand clean-up, drainage maintenance resulting from sand use, and the environmental impacts associated with sand.

Currently MassDOT is piloting protocol changes in three different Districts. In cooperation with the City of Cambridge Water Department (CWD) – Watershed Operations, MassDOT has implemented a pilot testing program in District 4 moving away from a 1:1 sand to salt mix, to a straight salt on Route 128 in Lexington, Waltham, and Weston in an effort to optimize the efficiency of the materials being applied. MassDOT completed a second year of pilot testing with CWD during the 2013/2014 winter season. In District 3 and District 5, MassDOT is piloting a change in the RSZ ratio of 1:1 (sand to salt), having completed a second winter season where a 1:3 ratio of sand to salt was applied for deicing. Pilot testing along Route 128, and Districts 3 and 5 indicates an interest and commitment by MassDOT to assess current policy with the objective being to provide the most efficient and effective deicing services while maintaining safe driving conditions and environmental consciousness.

These three pilot programs will yield results and data that could help guide operations in the Study Area. Specifically, Scenarios #2 and #3 were developed recognizing that these ongoing pilot programs could form the framework for pilot testing less or no sand in the Study Area. The current sand to salt ratio of 1:1 in the Study Area means that each pass a spreader makes is half as efficient in terms of snow melting abilities as a straight salt pass. Therefore, more passes are needed to ensure sufficient salt is delivered to the roadways in order to maintain safe driving conditions. This can mean that more passes are made in an RSZ than a non-RSZ, in some cases negating the intended effect of reducing the salt use in that zone. Piloting of alternate sand to salt ratio and possibly no sand will help determine if the overall salt usage on I-95 may be reduced.

CDM Smith reviewed findings presented in the 2012 Geosphere/VHB report which suggests that RSZ areas receive equal amounts of salt, if not more, as compared to nearby non-RSZs. As a part of the evaluation of this alternative, CDM Smith reviewed previous winter material usage data for the Boxford Depot Service Area (a RSZ) and for nearby Newbury Depot Service Area and Peabody Depot Service Area (both non-RSZ). Material usage was compared for dates when both depots performed deicing operations to determine if the RSZ did in fact result in less salt use, or if the findings in the Geosphere/VHB report were substantiated. For winter 2013/2014, the Newbury Depot Service Area used 60% more salt per lane-mile and the Peabody Depot Service Area used 20% more salt per lane-mile compared with the Boxford Depot Service Area's average application rate across the season. This evidence suggests that in the case of the Boxford Depot Service Area, substantially less salt is being used in the RSZ. However, this does not take into account all variations in storms or extreme weather events when current protocol allows for the use of straight salt in order to keep up with the roads.

In addition to our review of 2013/2014 salt usage for the Boxford, Peabody, and Newbury salt depots, CDM Smith compared historic salt use reported for winter 2010/2011 for each salt depot in District 4. Reported salt usage for each depot was normalized by the total number of lane-miles for each depot's service area. The median salt application rate throughout District 4 was 33.9 tons of salt per lane-mile per year. The Boxford Depot used 18.9 tons per lane-mile per year, which compares favorably with nearby Newbury, Peabody, and Rowley's usage of 37.2, 38.8, and 49.5 tons per lane-mile per year, respectively. **Figure 5-1** shows the salt application rate for each of the salt depots within District 4 arranged from lowest to highest salt usage. While some of the salt depots presented in **Figure 5-1** service RSZs, the Boxford salt usage is significantly below the median for District 4. Recognizing that the data does not account for storm variations or extreme weather events, the information in this figure may demonstrate that the reduced salt policy employed for the Study Area is resulting in less salt use when compared to nearby non-RSZs within District 4. There are occasional undocumented applications of salt in the Boxford Depot Service Area by spreaders from remote Depots. Spreaders not assigned to the Boxford Depot Service Area may pass through the area and apply deicing materials to help maintain roadway conditions. These materials, when applied, are not differentiated, as all materials are accounted for by each spreader's assigned service area. Such applications would serve to reduce the reported total for Boxford and increase the totals for the spreader's Depot of origin.

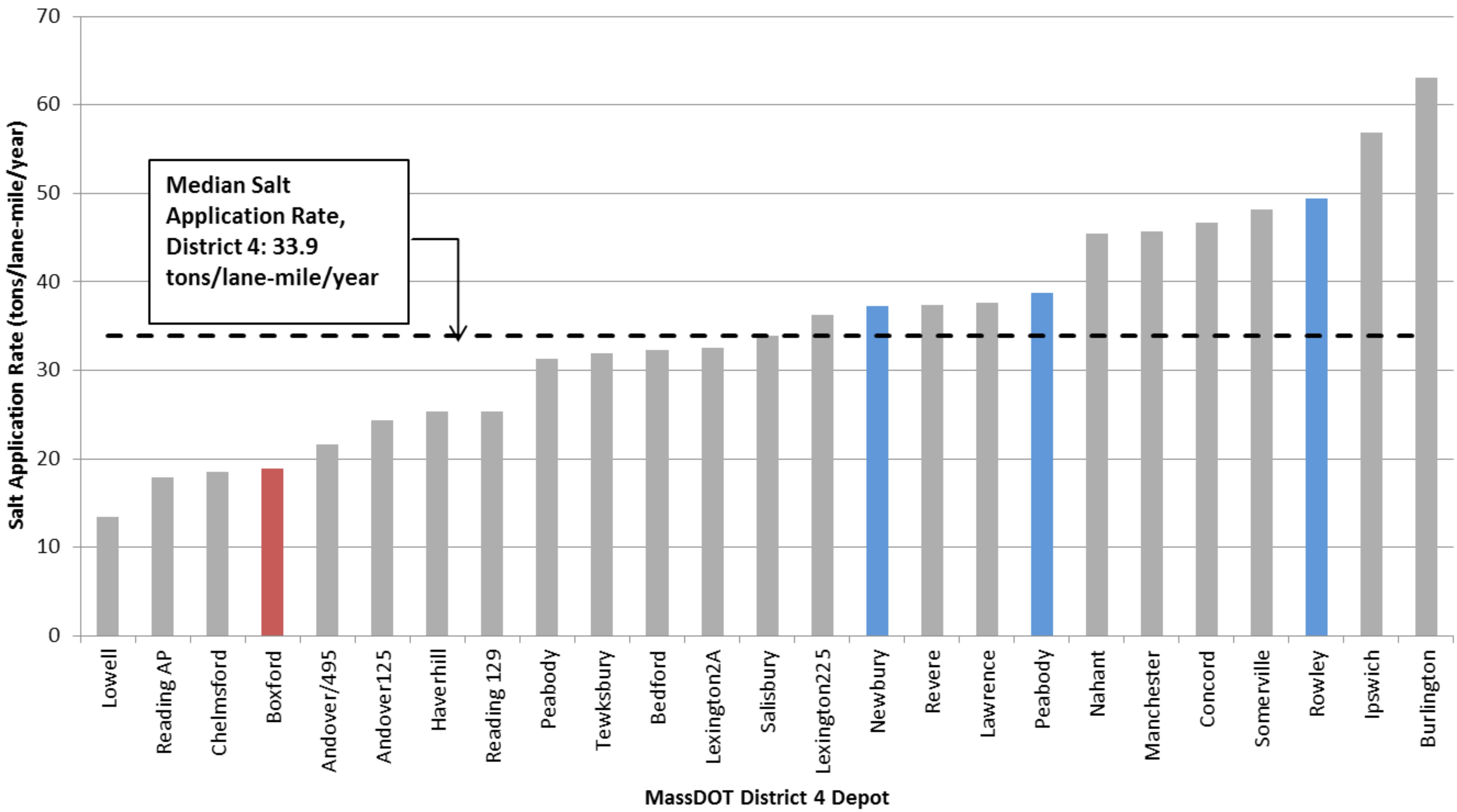
A final conclusion cannot be drawn regarding the effectiveness and need for the current RSZ protocols without pilot testing and field observations. The goal of the pilot testing would be to determine if the RSZ can be modified in the Boxford Depot Service Area without increasing the total net salt usage per typical storm, compared to current operations. As previously discussed, multiple factors must be considered when developing or changing a snow and ice management program, and each service area and jurisdiction operates under different conditions and protocols. The pilot programs currently underway can act as models and guides for implementing such a program, and can be expanded upon to suit the specific needs and conditions of the Boxford Depot Service Area.

New RWIS in the Boxford Depot Service Area

A new RWIS in the Boxford Service Area would provide more accurate and relevant weather data for the use of storm tracking and deicing event scheduling. Currently, MassDOT operates twenty-six RWIS's throughout the Commonwealth, with interest in purchasing and siting up to 15 more in the near future. MassDOT operates RWIS stations in the surrounding communities of Peabody, Salisbury, Andover, and Tyngsboro, but there are currently no plans to site a RWIS within the Boxford Depot Service Area. Currently, data from the three surrounding locations, ranging from 4 to 30+ miles away, is used for making decisions regarding roadway pre-treatment and deicing operations in Boxford.

Typical Roadway Weather Information System (RWIS) (MassDOT)

The accuracy of the data received and benefit of using such data is based on the proximity of the RWIS station to the area for which the data will be reviewed and applied. Thus, the closer a RWIS station is to a depot, the better quality and more accurate the data received will be. Localized weather patterns, coupled with the sensitive nature of some snow and ice management operations, including the specific range at which roadway pre-treatment can occur, lend support towards siting a new RWIS in Boxford.



Notes:

1. Deicing material usage data provided by MassDOT District 4 and assuming 86.56 lane-miles for the Boxford Depot Service Area.
2. Boxford Depot Service Area is identified in red; nearby Depot Service Areas (Rowley, Newbury, and Peabody) are in blue.
3. Salt Application Rate shown for the Boxford Depot Service Area may be low, as it does not account for undocumented salt applications by spreaders from remote Depots.

CDM Smith

MassDOT Boxford Salt Study

Figure 5-1

Comparison of Normalized Salt Load Rates for MassDOT District 4 Depot Service Areas, Winter 2010-2011

Source: CDM Smith

The location for a new RWIS can be selected based upon both environmental and logistical considerations. Ideal locations take advantage of existing infrastructure by locating the stations where they can take advantage of already established utilities and access areas, thus minimizing both installation expenses and continued O&M and utility costs. In the past, MassDOT has determined locations for their RWIS based on thermal mapping. Pavement temperatures can vary across a service area, and thermal mapping looks at the spatial fluctuations in the minimum night-time temperature across an area. Truck-mounted infrared thermometers measure road surface temperatures, and this data is analyzed to determine the patterns in temperature variation and a suitable location for a new RWIS.

A new RWIS can be tailored specifically for a location in Boxford, including only the environmental sensor stations (ESS) desired at the time of installation, while allowing for the addition of more sensors in the future. ESS include, but are not limited to weather data (e.g., air temperature, humidity, wind speed/direction, precipitation rate, etc.) and pavement data (e.g., pavement temperature, condition, freezing point) using a variety of meteorological and pavement sensors. Customized reports can be generated and analyzed by staff to make decisions based on findings. Customized software can be purchased to gather and manage the data for supervisors and foremen, and data can be reviewed and accessed remotely through password protected web sites as needed. A RWIS located in Boxford is a tool that could be utilized by the Town as well once their deicing operations progress to that level, and earlier phases of the proposed improvements have been implemented. The closer a RWIS is to a service area, the greater the benefit to a snow and ice management program and deicing operations.

5.4.5 Proposed Improvements to the Town of Boxford Deicing Operations

Although the Town's winter season salt usage within the Study Area and salt concentrations in Town outfalls are in general less than those associated with I-95, improvements can be made to the Town's deicing operations. In **Section 2**, CDM Smith reviewed the Town's current operating procedures, resulting in the following potential improvements for the Town's snow and ice management program:

- ***Improved Record Keeping*** - The Town does not keep records pertaining to solid material usage, application rates, accurate ratios, or records associated with liquid deicing material usage.
- ***Rate Control*** - Based on quantities purchased, it was determined that the Town does not pre-wet material with liquid $MgCl_2$ at the recommended application rate. Furthermore, the Town does not utilize equipment and technologies to monitor and maintain a prescribed application rate of solid deicing material.
- ***Implementation of Roadway Pre-treatment*** - The Town does not conduct roadway pre-treatment.

A phased implementation of program improvements is recommended for the Town, focusing on quality assurance/quality control (QA/QC) practices, technologies, methods, and alternative materials. **Table 5-10** identifies the improvements with specific objectives. Alternative deicing materials and methods could be considered immediately. It is expected that the addition of pre-treatment and alternative liquid deicing products could reduce the need for sand and perhaps lower salt use. Piloting would be required to assess the success of such applications. The Town should consider future investments in technology, which would require certain equipment purchases to be acquired over time.

Table 5-10
Proposed Improvements to the Town of Boxford Deicing Operations

Item	Description	Comments
Current Operations		
Sand/Salt Solids Application	- Application of sand/salt at a 3:1 ratio	- Application rate of sand/salt is unknown beyond the 3:1 ratio
Pre-wetting	- Pre-wetting of sand/salt material with $MgCl_2$	- No established record keeping program to track usage and application rates
Immediate Improvements		
Objective - Obtain a better understanding of salt use/application in order to determine improvements		
Calibration	- Manual equipment calibration of spreaders	- Builds upon current operations - Low implementation cost
Record Keeping	- Track quantity of sand and salt purchased - Track usage quantities per truck for optimal program management - Record and track application rates of material - Record calibrations per vehicle	
Training	- Train drivers on equipment, record keeping, and established application rates - Annual training, new hire training, and new procedure training	
Good Practices	- Route optimization - Proper covered storage and handling	
Future Investment in Technology		
Objective - Use of technology to reduce salt use through proper application		
Zero Velocity Spreaders	- Drops material on roads in manner that reduces bouncing, allowing for more efficient and precise placement of materials	- Capital purchase of trucks/equipment - Can prioritize needs, and purchase equipment over time
Closed Loop Controllers	- Automatically adjusts solids application rate based on vehicle and material feeder speed	
Friction Meters (mobile)	- Collects friction measurements to monitor traction on the road - Identifies need for additional deicing applications - Attaches to rear of a vehicle or new vehicle purchase	
Alternative Deicing Materials and Methods		
Objective - Improve deicing operations through the use of alternative deicing materials and methods		
Modified Sand/Salt Ratio	- Potential reduction in total sand and/or total salt per application - Better understanding of current rates of sand/salt is needed - Pilot program required	- Requires education of drivers - Requires potential purchase of new materials - Requires purchase of tanker trucks for pre-treatment - Requires new or expanded chemical storage for liquid deicing material - Requires pilot program to assess liquid chemical options
Alternative Pre-wetting Materials	- Salt brine or agricultural byproduct as alternatives to or mixed with $MgCl_2$ - Potential increased deicing effectiveness and reduced salt use - Pilot program required	
Addition of Pre-treatment	- Pre-treat roadways prior to certain storm events - Means of anti-icing - $MgCl_2$ or mix with salt and brine or agricultural byproduct - Requires tanker trucks and increased liquid storage - Pilot program to determine materials/rates	

Notes:

$MgCl_2$: Magnesium Chloride

5.4.6 Summary

Based on the evaluation of the retained alternatives, along with a review of both MassDOT's and the Town's current deicing operations, the following areas for improvement and recommendations for consideration have been identified. Overall areas of improvement for both MassDOT and the Town include the implementation of quality assurance programs to ensure established protocol is being met. It should be recognized that the effectiveness of such improvements relative to observed improvements in groundwater quality may not be realized for a long period of time.

5.4.6.1 MassDOT's Snow and Ice Management Program

Overall Areas for Program Improvement

- Improved and more frequent equipment calibration.
- Improved measurements of materials during loading.
- Recording and tracking of material usage and application rates.
- Annual benchmarking to identify deficiencies and/or further areas of improvements.
- New staff/contractor training on proper material handling, usage, equipment operation, and calibration, as well as environmental impacts/BMPs.
- Establish a vendor certification program.
- Implementation of program management practices to review data and adapt practices accordingly.
- Commitment to an enhanced roadway pre-treatment program, and consideration towards purchasing sufficient equipment to service the Boxford Depot Service Area to meet that commitment.

Meeting the established operational protocols should take priority over the additional program enhancements recommended in this Study.

Recommendations for Consideration

The three scenarios presented provide alternative approaches for MassDOT's snow and ice management program. Piloting would be required to assess whether each scenario can meet MassDOT's objective of a net reduction in salt use per typical storm by adjusting application rates, using alternative anti-icing/deicing materials, and implementing alternative technologies. The following items can be considered by MassDOT to enhance and improve current operations:

- ***Increased Roadway Pre-treatment.*** This would require a renewed commitment to roadway pre-treatment, including a change in procedures and emphasis on pre-treatment liquids pilot testing and implementation.
- ***Pilot Testing.*** Three alternative scenarios have been presented, two of which propose changes to operations. Any changes in operations in terms of new materials (such as agricultural byproducts for pre-wetting and roadway pre-treatment), or modified material ratios and/or

changes in policy such as eliminating RSZs, must be conducted with a thoughtful and thorough pilot testing process before any changes are implemented, inclusive of monitoring.

- ***Introduction of New Equipment and Technologies.*** In order to compensate for modified application rates of sand and salt (Scenario #3), or the elimination of sand (Scenario #2), tools such as friction meters to monitor roadway traction, and/or flexible/segmented plow blades used to get a "cleaner" plow will need to be considered in order to maintain the necessary level of safety on the roads.

- ***Geofencing.*** As a new technology, Geofencing offers the best means currently available of controlling and monitoring material application rates. A geofencing system can improve the efficiency of plow, pre-treatment, and deicing routes; eliminate duplicate or over applications; and optimize material application. Newer MassDOT vehicles are equipped with geofencing capabilities, however contractor vehicles are not. A means of addressing this issue would be required for successful geofencing implementation.

- ***RWIS.*** While the data currently pulled from the Peabody, Salisbury, and Tyngsboro RWIS provides valuable weather tracking information and aids the Boxford Depot in decision making, a new local RWIS in Boxford would enhance the usefulness of the data received, further improving decision making capability and MassDOT operations in the area.

5.4.6.2 Town of Boxford Snow and Ice Management Program

Considerations for the Town of Boxford for snow and ice management improvements are provided below.

Obtain a better understanding of current protocol, and implementing protocol:

- Recording and tracking of material usage and application rates.

- Improved measurement and recording of materials during loading.

- Recording and tracking liquid pre-wetting material usage to ensure application rates fall within the industry accepted 8-10 gal/ton.

- Annual new staff refresher training on proper material handling, usage, equipment operation, and environmental impacts/BMPs.

- Implementation of program management practices to review data and adapt practices accordingly.

- Annual benchmarking to identify deficiencies and/or further areas of improvements.

Future Investments in Technology and Alternative Investigations:

- Following a more thorough understanding of current protocol, new equipment and technologies can be integrated into operating procedures by the Town to monitor and maintain application rates, roadway conditions, and weather tracking.

- Resources and equipment already a part of current operations for MassDOT could prove valuable to the Town. A sharing of knowledge and/or resources between the Town and MassDOT's Boxford Depot Service Area could prove to be mutually beneficial.

- As the Town phases in improvements within their operating procedures, supplemental alternatives such as geofencing and RWIS can begin to be considered, whether it be for small scale pilot testing, in conjunction with MassDOT or neighboring communities, or their own efforts.

5.5 Evaluation of Salt Storage Facility Options and Associated O&M

This section presents an evaluation of alternatives related to the storage and handling of salt for the MassDOT Boxford Depot Service Area. As presented in **Figure 2-3**, the service area consists of 86.56 lane-miles, with 59.42 lane-miles located within the Study Area limits. Prior to its partial closure in June 2009, the Boxford Depot stored salt and sand, and also served as a loading and operations center for vehicles associated with deicing and snow removal in the Boxford Depot Service Area. According to MassDOT, having such a facility is important for their operations during winter storm events in order to "…*maintain a roadway surface condition that allows motorists to maintain vehicle control and mobility at reduced vehicle speeds*." (MassDOT, 2012). The development and evaluation of salt storage options considered this objective as well as mitigation measures that would reduce potential impacts of salt storage on the environment, including groundwater.

To address these objectives, there were two categories of alternatives considered during the screening process outlined in **Section 5.3**.

- ***Salt Shed Facility Alternatives:*** These included: (1) modification or replacement of the existing salt shed structure at the Boxford Depot; (2) finding a new location for the Depot and associated salt shed facility; or, (3) continuation of present-day operations (i.e., continued partial closure of the Boxford Depot to salt storage).

- ***Site and Operations Improvement Alternatives:*** For the scenario where the existing Boxford Depot is reactivated for salt storage, several site and operations improvements were considered, such as: the addition of new drainage infrastructure, capturing and storing stormwater runoff having elevated salt concentrations for reuse as salt brine or treatment prior to discharge, specialized pavement to mitigate infiltration of runoff, and improved materials handling.

Alternatives retained during the screening analysis are presented in **Table 5-11**. As shown, there are two retained alternatives related to salt storage facility location and several related to site and material handling improvements. The approach to evaluating these alternatives is presented in **Section 5.5.1**.

Table 5-11
Retained Alternatives: Salt Shed Facility and Associated O&M Procedures

Alternative	Description
SALT STORAGE ALTERNATIVES	
MassDOT Boxford Depot Remains Partially Closed (Status Quo)	▪ Maintain operations as they are presently conducted: Deicing of Boxford Depot Service Area out of Rowley Depot with materials support from the Newbury and Peabody Depots; storage of $MgCl_2$ at Boxford Depot.
Replace Existing Structure at Current Location	▪ Demolish and replace existing salt shed structure with modern facility that incorporates best practices and technologies.
SITE/OPERATIONS AND MAINTENANCE ALTERNATIVES SPECIFIC TO EXISTING MASSDOT BOXFORD DEPOT	
Site Stormwater Improvements and Management	▪ Regrade site to capture runoff from storage and handling areas in new drainage infrastructure; redirect to perennial streams to minimize infiltration.
Specialized Pavement	▪ Install new pavement including buried impermeable geotextile or rubberized asphalt to mitigate infiltration.
Capture Runoff and Treat or Reuse as Brine	▪ Capture runoff from salt storage & handling area to a tank for treatment or reuse as brine.
Deicing Material Handling	▪ Improve handling processes to mitigate exposure of deicing materials to the environment.
Containment for Liquid Deicing Storage and Loading	▪ Provide spill containment for permanent storage and transfer of liquid deicing agents.

Modification of the existing salt shed facility at the Boxford Depot was not an alternative retained for further evaluation. The shed itself is 40 years old, with a covered extension added in 2005. While building modifications would prove less expensive in the short-term, there remains a future cost for eventual shed replacement. Furthermore, any short-term building modifications would need to ensure that potential salt impacts to the groundwater are limited. The existing structure has full-length wooden walls which do a poor job of keeping salt in the shed structure. Salt would potentially exit the shed through the existing structure's wooden walls, even if refurbished. Wooden walls are susceptible to swelling, shrinking, and other deformations and may have gaps at joints and at the interface with the ground. Modern designs are far better at significantly mitigating the potential for salt to enter the environment through the implementation of solid, seamless concrete buttress walls that provide a continuous, gap-free barrier. Consequently, this option was determined to be ineffective given the short-term and long-term associated costs.

Relocation of the salt shed elsewhere within the Boxford Depot Service Area was also not retained for further evaluation. MassDOT has identified the following criteria as relevant to the siting of salt storage facilities: available property, land area (typically 2 acres), presence of watersheds, proximity to wetlands and surface waters, proximity to water supplies, proximity to residents, operations requirements, distance to spreader routes, and safety/access. It would not be practical to relocate the facility in Boxford given the added cost for site selection, development, and access. The Rowley portion of the Boxford Depot Service Area is a Zone II wellhead protection area for the Town of Rowley's municipal wells; therefore, this area may not be feasible for siting of a salt shed. Other areas in Rowley or Topsfield near Exits 53 or 51, respectively, could be considered but would also increase drive times for material loading during storm events. In consideration of these siting issues, unknown feasibility and associated costs of a new facility, relocation of the salt shed was not retained as an alternative for evaluation.

5.5.1 Approach to Salt Shed Storage Facility Evaluation

Table 5-12 identifies the components comprising each of the two salt storage facility options retained for evaluation.

Table 5-12
Approach to Salt Storage Facility Alternative Evaluation

Alternative Evaluated	Salt Storage Facility Options	
	Boxford Depot Remains Partially Closed (no salt storage)	Boxford Depot Salt Storage Reactivated with State-of-the-Art Facility
Material Storage at the Boxford Depot (100 Topsfield Road)		
▪ Salt	---[1]	√
▪ Sand	√	√
▪ Liquid Deicing Agent (i.e., $MgCl_2$)	√	√
Site Improvements		
▪ Addition of Drainage Infrastructure	√	√
▪ Capture and Store Stormwater Runoff		√
▪ Replace Pavement to Mitigate Infiltration	√	√
Operational Improvements		
▪ Solid Deicing Material Handling	√	√
▪ Liquid Deicing Material Storage and Handling	√	√
▪ Expansion of Office Space at the Rowley Depot	√	

Notes:
[1]Salt would be obtained from the Rowley Depot, with the Newbury and Peabody Depots as backup.

Based on **Table 5-12**, general assumptions in the evaluation include the following:

- The Boxford Depot stores liquid magnesium chloride for use as a deicing pre-treatment and pre-wetting agent. It has been assumed that liquids storage will continue at the Boxford Depot site in the future, irrespective of whether or not salt storage will resume. Therefore, the liquid deicing material and handling improvements identified in **Table 5-12** are evaluated specific to the Boxford Depot for each of the salt storage facility options.

- Recognizing the continued use of the Boxford Depot for magnesium chloride and equipment storage, there are site improvements worthy of consideration, even if salt storage is not reactivated at the site. These include: additional drainage infrastructure and specialized pavement to mitigate infiltration of runoff.

- Improvements to salt material handling are evaluated whether or not salt storage resumes at the Boxford Depot. These improvements would be the same whether at the Boxford or Rowley Depots.

- If salt storage does not resume at the Boxford Depot site, the Rowley Depot is assumed as the primary site for salt storage, with the Peabody and Newbury Depots as backup facilities.

Each of the salt facility options are presented below (**Sections 5.5.2** and **5.5.3**), followed by a discussion of the site and operational improvements (**Sections 5.5.4** and **5.5.5**) applicable to each. In

Section 5.5.2, a cost analysis based upon net present value (NPV) has been developed to compare operational costs out of the Boxford versus the Rowley Depot over a 30-year period. Facilities are summarized in **Section 5.5.6** for each of the Salt Storage Facility Options along with the associated capital costs and present value costs.

5.5.2 Boxford Depot Remains Partially Closed (Status Quo)

As discussed in **Section 2**, salt has not been stored at the Boxford Depot since June 2009. Currently, salt and sand used for the Boxford Depot Service Area is stored and loaded primarily at the Rowley Depot, and at times the Newbury and Peabody Depots. Liquid magnesium chloride is still stored and loaded at the Boxford Depot, and is also loaded from the Rowley, Newbury, and Peabody Depots as necessary, prior to and during storm events. During winter storm events, the Rowley, Newbury, and Peabody Depots are all between a 15-30 minute drive from the Boxford Depot Service Area, depending on traffic and weather conditions. Combination units (vehicles with plows and spreaders) load at the various depots based on a variety of conditions including their location when their payload is exhausted, material availability, and truck queuing at the different depots. Combination units will often load at different depots during a given storm event.

While salt is not currently stored at the Boxford Depot, the facility continues to serve as the operations center for the Boxford Depot Service Area, in addition to the continued storage and loading of liquid magnesium chloride. MassDOT personnel at the Boxford Depot track weather as well as contractor operating time, material use, and loading. The Boxford Depot also has sand stores, but combination units do not load sand there, as the sand is not mixed with salt.

MassDOT has recognized the need to maintain the level of service in the Boxford Depot Service Area since the partial closure of the Boxford Depot. The primary concern is travel time between the service area and various depots. To account for this, MassDOT deploys a fifth combination unit during numerous storm events to ensure continuous deicing as vehicles travel back and forth between the Boxford Depot Service Area and the Rowley, Newbury, and/or Peabody Depots. Prior to partial closure of the Boxford Depot, four combination units were needed.

While the need for an additional combination unit has not necessarily changed the amount of sand and deicing materials needed to treat the service area, it carries with it an additional cost. MassDOT pays subcontractors on an hourly basis. Consequently, during storm events requiring a fifth spreader, the cost of deicing operations excluding materials is increased by 25%, plus the increased time all five units spend traveling to the various depots. The increased travel time means that the decision to begin deicing must be made sooner and more aggressively, as there is less time to monitor conditions.

Beyond the added travel time concerns, having five additional vehicles entering, queuing, loading, and exiting the Rowley, Newbury, and Peabody Depots creates added stress at those locations. Material stores and deliveries must be increased at those facilities and must include sand as the Boxford Depot Service Area is a RSZ. Of the three depots, only Peabody services a separate RSZ, meaning Rowley and Newbury must store sand specifically for the Boxford Depot Service Area. Conducting deicing operations out of different depots also makes record keeping more difficult, as material quantities loaded into trucks bound for the Boxford Depot Service Area must be recorded and compiled separately.

The operations of pre-treatment tankers and plows have not changed as a result of the Boxford Depot being prohibited from storing salt. Fifteen contracted plows and one contracted tanker perform mechanical snow removal and pre-treatment, respectively. Time for front end loaders, used to move snow and materials at depots, and in some instances along highway embankments, is also not impacted.

5.5.2.1 Operations Cost Analysis Comparison

CDM Smith performed an analysis to estimate the difference in operations costs, both in terms of present day (annual) costs and the NPV of costs over a 30-year operating period, associated with the following conditions:

- ***Remote Operations:*** Cost of deicing operations in the Boxford Depot Service Area when being conducted out of the Rowley, Newbury, and Peabody Depots, based on winter 2013/2014 conditions.

- ***Operations Out of the Boxford Depot:*** A hypothetical condition under which deicing operations, including salt storage and loading, were conducted out of the Boxford Depot during winter 2013/2014.

Under remote operations, the actual hours and equipment deployments for winter 2013/2014 were available from a Depot Cost Summary Report provided by MassDOT[5]. There were a total of 25 deicing events during winter 2013/2014. The following adjustments were made to the actual costs of deicing operations during winter 2013/2014 to develop an estimated cost of operations for the same time period if the Boxford Depot were open for salt storage:

- The number of actual 2013/2014 spreader deployments during remote operations was reduced by 10%. This assumes that remote operations required an additional spreader for half of the storm events. Similarly, the number of actual 2013/2014 remote operations hours was also reduced by 10%, which assumes that the average number of hours per deployment is consistent between those events requiring an additional spreader and those that do not.

- The remaining actual 2013/2014 remote operating hours were reduced by one hour per remaining deployment to reflect the additional travel and queuing time when operating out of Rowley, Newbury, or Peabody. This assumes that remote operations require one hour of additional travel time per spreader during each deployment.

Time for plows and tankers was not adjusted as their usage would not change. A small reduction for front-end loader operating time could be expected if operations were to occur at the Boxford Depot. This change was not included as the impact on the overall operations cost would be minimal. Material costs and state personnel costs were also not changed as they theoretically are not affected by remote operations, though it is possible that both would slightly increase.

For each operating condition, **Table 5-13** shows the spreader deployments and hours, computed operating costs for winter 2013/2014, and the calculated NPV for a 30-year operating period. The

[5]MassDOT. Depot Cost Summary Report, from: 07/01/2013 00:00 to: 04/29/2014 15:11, Fiscal Year 2014, 4728 – Boxford. Provided by S. Bassam. April, 2014.

resulting differences between the two operating conditions are shown in the last column. Costs for the winter 2013/2014 operations are in today's dollars, while NPV of costs for operations over a 30-year period assume an interest/inflation rate of 3% per year, compounded annually.

Table 5-13
Boxford Depot Service Area – Operating Costs Comparison

Item	Remote Operations[1] (actual)[2]	Operations Out of Boxford Depot[3] (estimated)[4]	Difference[5]
Spreader Deployments	120	108	12
Spreader Hours	1,393	1,145	248
Total Spreader Operations Costs	$280,000	$230,000	$50,000
Additional Operations Costs (other contracted equipment, MassDOT personnel, materials)	$390,000		$0
Total Operations Costs, Winter 2013/2014	$670,000	$620,00	$50,000
Net Present Value Cost of 30-year Period	$13,100,000	$12,100,000	$1,000,000

Notes:
[1]Remote salt storage and deicing operations out of the Rowely, Peabody, and Newbury Depots.
[2]Data based on actual remote operations during the 2013/2014 winter season.
[3]Assumes salt storage and deicing operations resume at the Boxford Depot.
[4]Estimates developed based on the 2013/2014 winter season.
[5]Represents difference between actual remote operations and estimated operations out of the Boxford Depot.

The results show the higher cost impact of conducting deicing operations for the Boxford Depot Service Area out of remote locations. Based on winter 2013/2014 data, it would cost MassDOT an additional $1.0 million over a 30-year period (in NPV). A more severe winter would likely yield an increase in the difference between costs and conversely a less severe winter would likely yield a decrease. The future cost difference over a period of 30 years assumes that the materials, equipment, and manpower used during the winter 2013/2014 are typical.

5.5.2.2 Other Considerations

According to the MassDOT Road Inventory Map and available traffic count data, this segment of I-95 is functionally classified as an urban interstate facility, carrying an average daily traffic volume of 71,000 to 73,000 vehicles per day. MassDOT provided vehicle crash data for the Boxford Deport Service Area for the period 2003 to 2014 along I-95. Over the course of a six year period prior to the partial closure of the Boxford Depot (2003 to 2008), the average number of crashes was 4.67. In the six years since the partial closure of the Boxford Depot, the average number of crashes per year increased slightly to 6.67. The 2012 average cash rates per million vehicle miles traveled (mvmt) by Federal Functional Classification for an urban Interstate in Massachusetts is 0.54. Crash rate calculations indicate that the rate per mvmt in the time period prior to partial closure of the Boxford Depot along this segment of I-95 is 0.02. The crash rate per mvmt in the time period following partial closure of the Boxford Depot is 0.03. It is not known if these statistics reflect the impact of the Boxford Depot's closure to salt storage, as the statistics are likely influenced by the severity and timing of storm events, and only represent those incidents that were reported.

Whether operations continue remotely or return to the Boxford Depot, a timekeeper is needed to monitor spreaders servicing the Boxford Depot Service Area. At present, the timekeeper position is located at existing facilities within the Rowley Depot. If the Boxford Depot were to remain partially closed, new office space at the Rowley Depot would permanently be required for the Boxford timekeeper. A capital cost for additional office space at the Rowley Depot is included in the **Section 5.5.6** capital cost summary.

5.5.3 New Salt Shed Structure at the Boxford Depot

The existing salt shed at the Boxford Depot is a wood-walled, metal-gabled roofed structure constructed in 1974. A fabric extension on concrete buttresses was added at the open end of the salt shed in 2005 to allow for under-cover loading. The best option for renewed salt storage at the Boxford Depot is the demolition of the existing salt shed, removal of the existing fabric extension, and construction of a new salt shed. CDM Smith considered various styles of salt sheds, including:

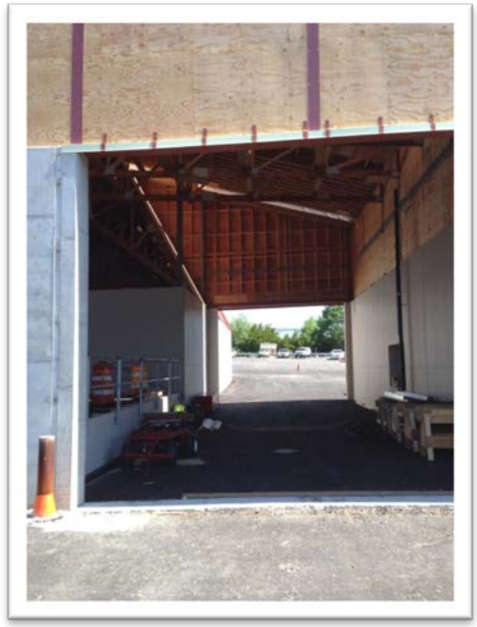
- Arched fabric
- Timber, with metal or shingle gable roofing
- Timber high-arched gambrel, with metal or shingle roofing
- Timber, metal, or fabric geodesic dome
- Timber or metal, round or hexagonal shape with gazebo-style roof

These styles can have full height walls or concrete buttresses. Another variable to consider when designing salt sheds is the material loading location. There are three primary under-cover loading options for salt shed facilities:

- **End-Loading -** Shed opening is on short side of structure, with material loaded at that end of the shed and material stored in the middle and opposite end of the shed. This is the simplest style of building.
- **Center-Loading** - Shed opening is on longer side of structure, with material loaded at entrance and stored on either end of the shed. Center-load facilities have similar storage efficiency as end-load, but a more complicated structure is required to accommodate an entrance on the longer side of the structure.
- **Drive-Thru-Loading** - Material is brought into the shed from either an end or side entrance, but loaded in a drive-through configuration typically using separate, smaller openings. These facilities require a larger site to accommodate entrance and exit drives, and also require a larger overall structure. Risk of material loss through the entrance and exit is dependent on the length of loading area. Drive-thru-loading facilities allow faster loading operations, as a continuous stream of vehicles can move through the shed in one direction.

Under-cover loading operations are dependent on the shed size and type. Large square or rectangular structures with high sidewalls allow for the greatest flexibility in terms of loading options. Outdoor material loading was not considered as such an approach considerably increases the likelihood of salt being introduced to the environment.

MassDOT provided information on recently constructed salt sheds. Data provided, shown in **Table 5-14**, included location, construction cost, and type, loading type, size, materials stored, service area information, and site-specific features. CDM Smith visited ongoing salt shed construction projects at two of the listed locations, Braintree and Andover, in May 2014.



Drive-thru Style Salt Shed Under Construction in Braintree

As shown on **Table 5-14,** MassDOT's recently constructed salt sheds have all been timber, high-arched gambrel as the durability and operational flexibility afforded is greater than that of other, less-expensive styles. All of the sheds have under-cover loading. The Braintree Depot parcel is significantly larger than the others, as it serves the most lane-miles, affording room for a drive-thru-loading area. All of the facilities serve more lane-miles than the Boxford Depot Service Area and all store sand, with all but Braintree serving RSZs. The Chelmsford, Lexington, and Andover facilities were all constructed in salt sensitive areas.

End-load Style Salt Shed with Concrete Buttress Walls under Construction in Andover

Based on investigations and recent shed construction, a new salt shed at the Boxford Depot should be a timber, high-arched gambrel with concrete buttresses and metal roofing. For evaluation purposes an 85-foot-wide by 105-foot-long shed (8,925 square feet) was considered. This would provide more space than the existing 40-foot-wide by 80-foot-long shed and 65-foot-wide by 60-foot-long fabric extension, combined (7,100 square feet). In addition, to increased room for sand and salt storage, the new shed would allow for a center-load arrangement and concrete buttress walls, significantly mitigating the potential for salt loss through the walls. The parcel's size and shape are not conducive to a drive-thru loading arrangement.

The new shed would be located south of the existing structure, removing it from the wetland buffer zone. The location of a potential new salt shed is shown on **Figure 5-2A**. To accommodate the new salt shed structure, the existing office structure would be demolished and a new office space would need to be provided, either as part of the new shed structure or as a trailer, similar in size to the existing one. For the purposes of this evaluation it has been assumed a new trailer would be constructed. The other features shown on the figure, such as drainage infrastructure and pavement improvements were evaluated independently from a new salt shed structure and are discussed later in this section.

Table 5-14
Recent MassDOT Salt Shed Construction Information[1]

Location	Date Completed (or Expected)	Construction Cost	Construction Type	Additional Features	Vehicle Loading Type	Material Stored	Service Area		Facility Size		Miscellaneous. Information/Comments
							Lane-Miles Served	RSZ (Y/N)	Shed sq feet (Salt Storage sq feet)	Property (sq feet)	
Andover (District 4)	June 2014	$5,795,000	High-arch Gambrel	Two Bay Garage, two 5,000 gallon anti-icing tanks with pumps, and detached Offices with Kitchen and Rest Rooms	End-Load	NaCl, Sand, $MgCl_2$	181	Y	9,600	NA	Pre- and Post-Construction runoff monitoring program to track water quality changes (LEED Certification underway)
Braintree (District 6)	Under construction	$3,921,500	High-arch Gambrel, Concrete Buttress Walls	Drive-thru operation/indoor loading, attached offices	Drive-thru	NaCl, Sand, $MgCl_2$	275.7	N	12,800 (7,107)	398,574	Two separate areas are serviced out of this depot, with separate crews operating out of this facility
Chelmsford (District 4)	November 2011	$2,144,000	High-arch Gambrel, Concrete Buttress Walls	None	Center-Load	Pre-Mix, NaCl, Sand, $MgCl_2$	202	Y	9,800	NA	Salt Sensitive Area (Public Water Supply)
Lexington (District 4)	December 1995	$954,000	High-arch Gambrel, Wood Buttress Walls	None	Center-Load	NaCl, Sand, $MgCl_2$	149.5	Y	10,240	NA	Salt Sensitive Area (Public Water Supply)

Notes:

[1]All information provided by MassDOT.

Abbreviations:

$MgCl_2$: magnesium chloride
NA: not available
NaCl: sodium chloride
sq feet: square feet
Y/N: Yes/No

In summary, construction of a new state-of-the-art salt shed can significantly reduce the potential for salt to be introduced to the environment. It should be recognized however, that reopening the Boxford Depot to salt storage and loading would also increase the number of recently loaded spreaders in the vicinity of the site, increasing the potential for salt spillage as trucks with full payloads maneuver in the area.

5.5.4 Site Improvements

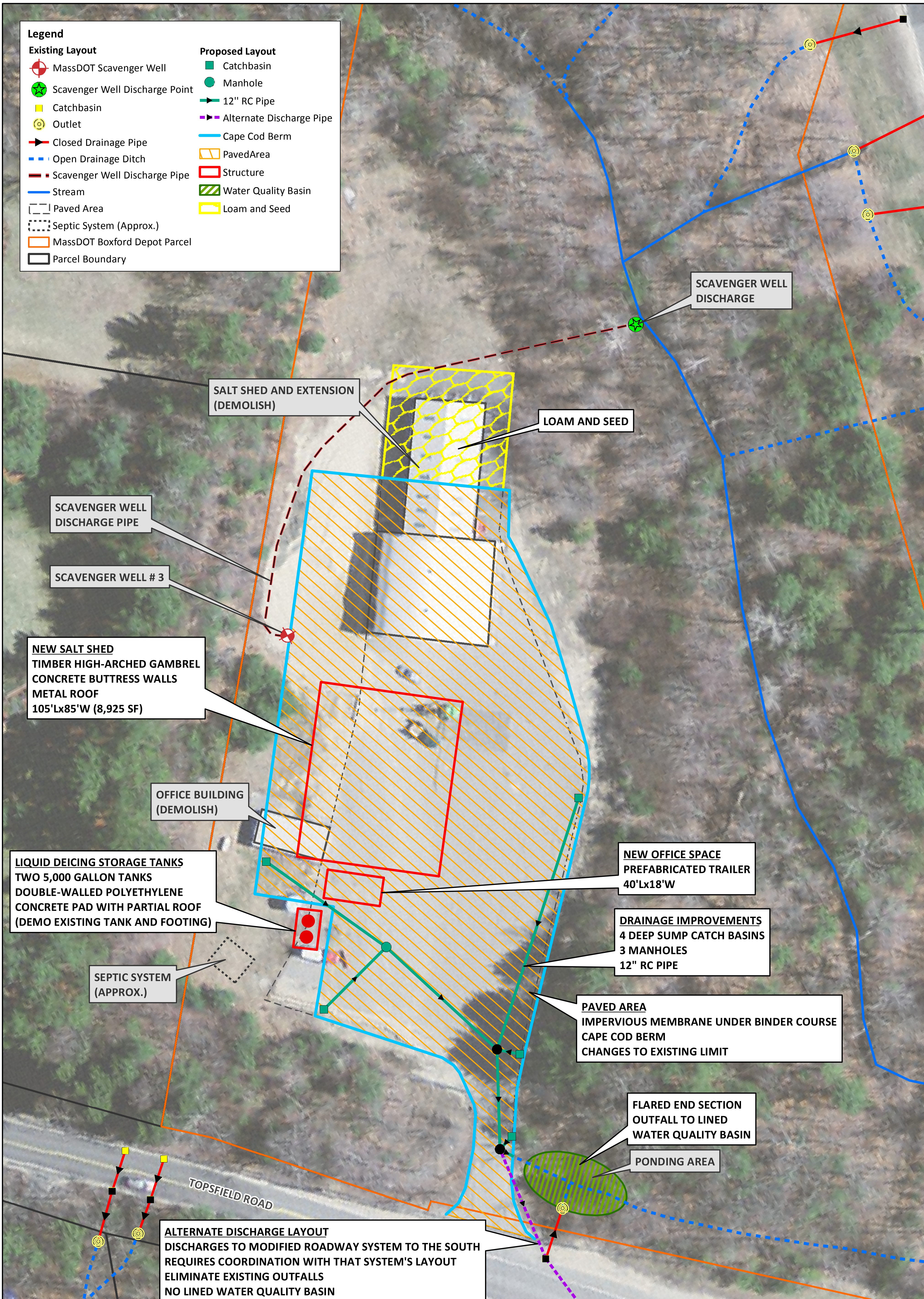
Potential site improvement options and related costs were developed independently of one another and separate from any potential modifications or replacement of the salt shed structure. However, improvements may be implemented in combination to increase overall cost effectiveness. Potential site improvements accommodating a new salt shed are shown on **Figure 5-2A** and improvements considering no changes to the existing salt shed are shown on **Figure 5-2B**.

5.5.4.1 Stormwater Management

There is presently no stormwater infrastructure at the Boxford Depot. However, a stormwater drainage system is recommended for implementation whether or not salt storage is reactivated at the Boxford Depot site, for the following reasons:

- If salt storage resumes at the parcel, it would be important to collect and convey stormwater runoff in a drainage system, thereby limiting the potential for elevated salt concentrations in runoff to infiltrate and further impact groundwater.
- The large paved area at the Boxford Depot is deiced on occasion, when safety is of concern. Reactivation of salt storage at the Boxford Depot could increase the need for periodic deicing of the pavement depending on the storm event. In either case, a stormwater drainage system would collect and convey runoff impacted by the use of salt and deicing agents at the site.
- Even without resumption of salt storage, the Boxford Depot will continue to see heavy equipment for deicing related operations (i.e., magnesium chloride storage and supply), operations related to on-site sand storage, and vehicle and heavy equipment storage. Spreaders carrying salt still visit the Boxford Depot to refill liquid magnesium chloride. Given the presence of nearby domestic wells, implementation of a stormwater drainage system and related BMPs is a recommended action to provide increased protection of the surrounding areas.

The existing salt shed structure is situated on the high point of the site, with the majority of the site sloping to the south and east. Runoff from the salt shed roof and fabric extension drains directly onto the paved area around the structure without gutters or downspouts. Approximately half of the shed runoff flows east to the stream on the Depot parcel while the remaining half flows south onto the pavement south of the structure. Runoff from the pavement drains via sheet flow from the northern corner to the south, towards a low spot on the east side of the facility entrance. This runoff enters a ponding area east of the driveway, which then discharges via a drainage ditch to the stream running through the property. That stream receives runoff from the remainder of the site north of the shed. The ponding area has potential to allow infiltration of salt laden runoff. The addition of a series of catch basins and manholes would enable the control of stormwater discharges.



CDM Smith

0 25 50 75 100 Feet

N

MassDOT Boxford Salt Study

Figure 5-2A

MassDOT Boxford Depot Improvements with Salt Shed Replacement

Source: MassGIS, CDM Smith

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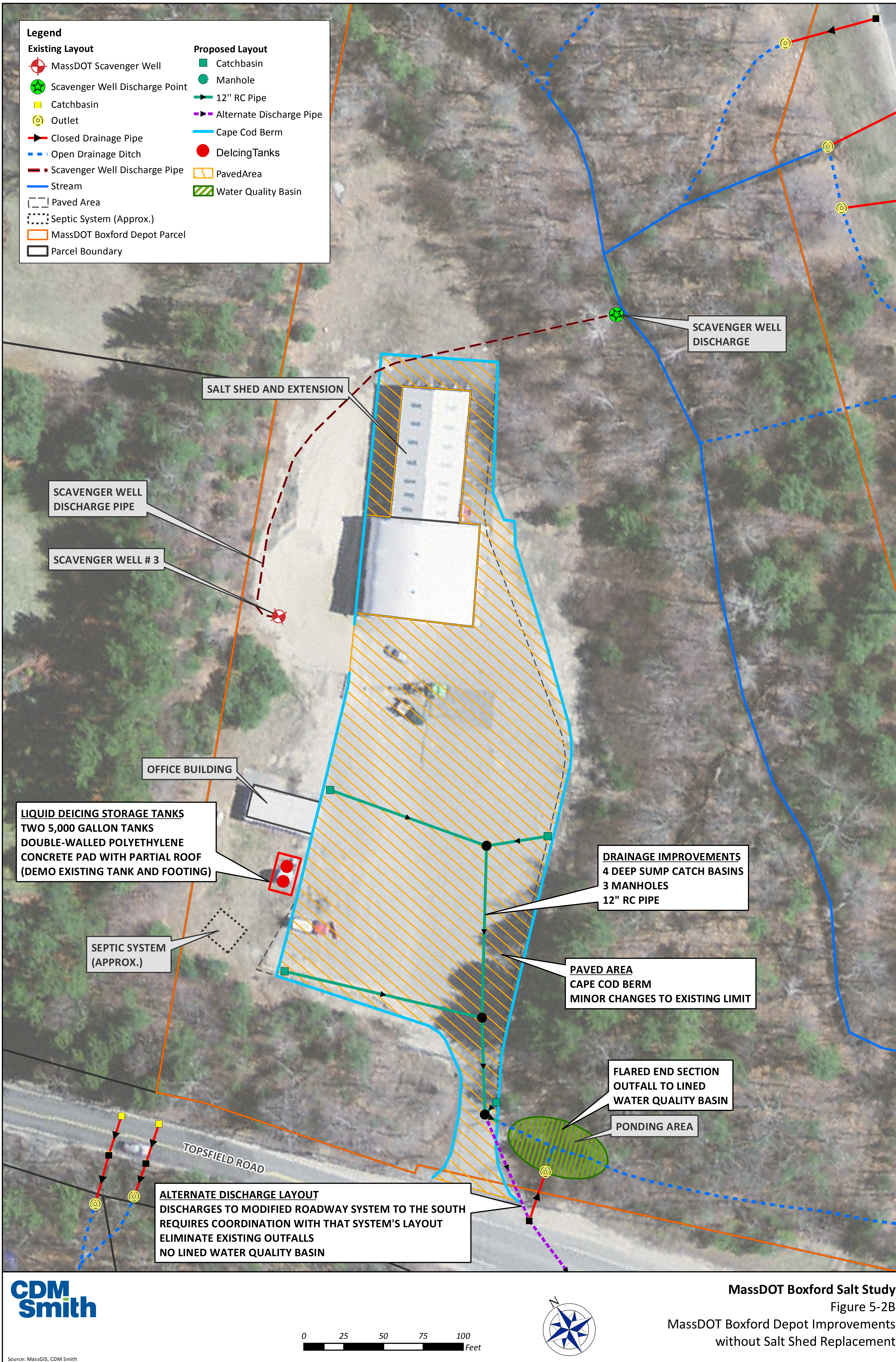

CDM Smith

MassDOT Boxford Salt Study

Figure 5-2B

MassDOT Boxford Depot Improvements without Salt Shed Replacement

Source: MassGIS, CDM Smith

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CDM Smith developed two conceptual drainage layouts for the Boxford Depot, one accommodating a new shed location (see **Figure 5-2A**) and one for the existing shed location (see **Figure 5-2B**). Each of the two layouts consist of four catch basins, three manholes, and one outfall, all connected by 12-inch reinforced concrete pipe. The outfall would discharge to the present-day ponding area, which would be converted to a lined water quality basin. The lined BMP would promote the settling of total suspended solids (TSS) from the sand stored on site, while preventing infiltration of stormwater that may have elevated concentrations of sodium and chloride. TSS removal would also be achieved by installing catch basins with deep sumps.

As part of the stormwater improvements the paved area at the Boxford Depot would need to be regraded to direct runoff toward catch basins located on the edge of pavement. A bituminous concrete, Cape Cod style berm would be installed around the paved area to create gutters in which flow could accumulate and be collected by the catch basins.

The stormwater improvements at the Boxford Depot were also laid out to enable a connection improvement to the I-95 drainage infrastructure along Topsfield Road (discussed later in **Section 5.6**). If such a connection is made, runoff from the Depot's paved area would ultimately discharge to Silver Brook near Andrews Farm Road. This discharge point is located in a less environmentally sensitive area than the present discharge point, which is over shallow bedrock and potentially upgradient of several homes known to have salt impacted domestic wells.

Stormwater drainage systems are not typical at salt shed depots throughout the Commonwealth. However, the newly constructed facility at River Road in Andover, another facility built in an environmentally sensitive area, includes catch basins, an oil/grit separator, and a series of small retention/treatment areas. Having similar controls at the Boxford Depot would help mitigate water quality issues in the Study Area.

5.5.4.2 Specialized Pavement

The paved area at the Boxford Depot has excessive cracking, in many cases 2 to 3 inches wide. This increases the potential for infiltration of runoff with higher concentrations of salt, whether from salt shed reactivation or on-going deicing related operations. Specialized pavement applications would help mitigate infiltration through the pavement.

Pavement can mitigate infiltration through the use of rubberized asphalt, impervious membrane liners, or high density, low pore space pavement, as was installed along I-95 in Boxford. High density, low pore space pavement is created by using asphaltic concrete mixes with increased fine aggregates. The increased use of fines reduces porosity resulting in fewer openings on the surface and throughout the depth of application through which runoff can infiltrate. High density, low pore space pavement is typically only applied in the top course or a portion of the top course as the material is less flexible than regular asphalts.

Rubberized asphalt includes ground up rubber tires (crumb rubber) that also reduce the openings on the surface and throughout the depth of the application by serving a similar function as fine aggregates. Rubberized asphalts can be applied as a top coat or can be installed below a normal top coat. Rubberized asphalts typically perform well in heavy-duty situations like depots where vehicles such as combination units and front end loaders frequently operate.

The greatest degree of protection against infiltration is an impervious membrane, such as Petromat®, placed either between the top course and binder course or under the binder course. When installed correctly, the membrane prevents all infiltration through the pavement and into the groundwater. Since a goal at the Boxford Depot is to minimize infiltration, the use of an impervious membrane is the best approach. It is possible to use an impervious membrane in combination with low pore space or rubberized asphalt, though these materials would be redundant when considering a properly installed membrane.

If the Boxford Depot is reopened to salt storage, it is recommended that the site be repaved with the following pavement section to meet the demands of the heavy duty vehicles at the Depot and mitigate the potential for infiltration:

- 2-inch-thick top course
- 2.5-inch-thick binder course
- Impervious membrane
- 4-inch-thick asphalt base
- 12-inch thick gravel sub-base

Should the Boxford Depot remain closed to salt storage it is recommended that the site be repaved as detailed above, but without the impervious layer. Although lack of salt makes groundwater impacts less of a threat, the site may still be periodically deiced and frequented by heavy duty vehicles.

5.5.4.3 Capture Runoff for Treatment or Reuse as Salt Brine

If salt storage at the Boxford Depot were to resume, the stormwater collection system could be designed to capture site runoff for treatment or reuse as salt brine for pre-treatment and pre-wetting applications.

As typical practice is to only deice pavement at the Boxford Depot when safety is a concern, runoff from the paved area will not have particularly high salt concentrations. Therefore, the best approach to mitigating the release of salt to the environment via runoff is to target the area nearest the salt shed, where salt would be stored and loaded. Although storage and loading would occur under-cover, there is the potential for loose material to spill as recently filled spreaders exit the extension. MassDOT has BMPs in place to minimize spillage; however, if such BMPs are not followed or if trucks are overloaded then spillage may occur. Wet equipment can also track moisture into the shed, leading to runoff from the building.

Alternatives screening suggested the possibility of an on-site treatment system to treat and release captured runoff for salt removal. The available treatment method for this purpose is reverse osmosis (RO) which is rather expensive and generates a brine waste requiring storage and disposal (RO is discussed further in **Section 5.8** as it relates to water treatment systems). Any treatment method that generates further salt brine negates its value, therefore, treatment is not considered further.

If used as salt brine in deicing operations, captured runoff would require the addition of solid sodium chloride to raise the salt content. Captured runoff would likely have salt concentrations well below the eutectic level of 23% and would require additional salt to be added. Additional facilities would also be required to mix the brine with liquid magnesium chloride before it could be used for pre-treatment and pre-wetting.

Neither the runoff captured nor the salt concentration can be accurately predicted. These unknowns could greatly affect the efficiency and adequacy of the salt brine supply. High variability of concentration and quantity, coupled with the high capital and O&M costs of magnesium chloride mixing facilities, prevent salt brine reuse from being cost effective. For these reasons, establishing a salt brine facility using stormwater is not recommended. With proper materials handling and stormwater controls previously discussed, the amount of salt in runoff from the site can be minimized.

5.5.5 Operational Improvements

The following operational improvements concerning materials handling were developed for the Boxford Depot and could also be applied to the Rowley, Newbury, and Peabody Depots, as well as other depots throughout the Commonwealth. These improvements are recommended for Boxford Depot operations, irrespective of resumed salt storage at the site.

5.5.5.1 Solid Deicing Material Handling

Salt (and sand at locations servicing RSZs) at MassDOT Depots is typically loaded into spreaders using the buckets of front-end loaders. For an RSZ such as Boxford, alternating buckets filled with salt and sand are either dumped directly into the bed of spreaders or mixed together on the floor of the salt shed prior to being loaded into trucks. The weight of materials being loaded into spreaders is based on an assumed volume of material in the spreader and that volume's calculated weight. Consequently, the volume loaded into each bucket can vary, resulting in incorrect values being reported. Also, sand and salt have different densities, so alternating buckets does not result in a true 1:1 mix as presently prescribed for RSZs.

Scales could be used to more accurately measure the weight of salt and sand being loaded onto spreaders. Scales could be placed where front-end loaders are normally stationed to load spreaders, with the payload weight determined by recording the weight of the loader, operator, and material in the bucket and subtracting the weight of the operator and loader when the bucket is empty. Several manufacturers make scales for heavy duty equipment that would serve this purpose. Such scales are available in portable configurations, allowing for flexibility of operations. Specialized hydraulics systems that can provide the weight of payloads are also available for front-end loaders.

Portable Truck Scales (Cardinal Scale Mfg. Co.)

Continued training for front-end loader operators and contracted spreader drivers would help to ensure efficient loading, helping to minimize material spilling from front-end loaders and spreaders. Temporary berms could be used to prevent spilled materials from exiting the loading area. Temporary berms are sold by numerous manufacturers and can include moveable ramps that close after a vehicle has driven over it, or removable sections that can be taken out and put in place as necessary to allow vehicles entry into the designated area.

5.5.5.2 Liquid Deicing Material Storage and Handling

At present, liquid magnesium chloride (30% concentration by weight) is stored in an outdoor 5,000 gallon tank adjacent to the office building at the Boxford Depot. The tank was installed in 2008 and is constructed of single-wall polyethylene, resting on a crushed stone base with wood plank sidewalls. Magnesium chloride is pumped from the tank into the saddles on combination unit trucks as needed.

Secondary Containment Considerations

The existing set up does not provide any means of secondary containment or spill prevention for liquid magnesium chloride storage or loading. The nature of the chemical is such that secondary containment and spill prevention is not required. However, in an environmentally sensitive area such as Boxford, a significant spill and release of magnesium chloride into the environment could further degrade existing water quality. While the chemical is normally intended to be distributed in small quantities over a large area, a point source release could have the potential to elevate chloride levels in surface and groundwater around the Boxford Depot area.

There are several options to help prevent a point source release of magnesium chloride to the environment. With respect to storage, potential secondary containment measures to prevent discharge from the tank include either berms, a wall around the tank, or a double-walled tank with appropriate fittings. Because the tank is located outside with no cover, berms or walls are not ideal as the volume intended for leak storage would fill with precipitation requiring operation and maintenance time after each storm event. An enclosure could be built on the walls around the tank, but would be costly. The best option for an outdoor application such as the one at the Boxford Depot is a double-walled tank. The likely material for a new tank would be fiberglass or cross-linked polyethylene. Specialized fittings are required so that in the event that the inner tank should leak, liquid magnesium chloride would not leave the annular space between tank walls via piping penetrations.

Chemical Transfer Containment and Considerations

In addition to storage failure, another means of point source discharge would be a loading mishap where liquid magnesium chloride might be accidently pumped from the tank into the environment. There are two options for providing spill containment in an outdoor setting during loading operations. The first would be to have a controlled, depressed area with a drain to collect spills and prevent material from leaving the area, and the second would be a temporary berm.

Each of these options was considered, but they are not recommended as they both present similar issues. First, there will be occasions when vehicles will be loading during periods of precipitation. By nature, any spill control measure will collect the precipitation, requiring frequent removal. A depressed area would require a drain that would have to be closed while loading is occurring, adding to the precipitation collection problem. A temporary berm would require frequent operation of an entrance/exit section, slowing operations.

The issues of frequency of operation and trapping precipitation, combined with the controllable nature of loading spills, result in minimal overall benefit to spill collection measures. Unlike a storage failure where there is a risk of all the contents of the tank entering the environment, loading spills can be minimized by discontinuing pumping operations and/or closing valves.

Liquid Chemical Usage

Liquid magnesium chloride loading is presently measured by the volume of the saddles being loaded. This means that spreaders must empty their saddles in order for an accurate measurement to occur. This is problematic for deicing operations as it may encourage operators to let their saddles run out before refilling, resulting in solid material being applied without pre-wetting. A magnetic flow meter could be used to accurately measure the quantity of liquid deicing agents being loaded into saddles.

Example of MassDOT Liquid Deicing Material Storage with Canopy under Construction in Andover

Storage Tank Recommendations

For the purposes of this evaluation, two 5,000 gallon polyethylene, double-walled tanks were considered. Sizing was based on a review of the greatest sand and salt use for a single storm event during winter 2013/2014. The total 10,000 gallons of storage represents three times the greatest use. Additionally, potential changes to pre-treatment and pre-wetting discussed in **Section 5.4** may necessitate the storage of two different liquids, such as magnesium chloride and an agricultural byproduct. Though not considered as part of this evaluation, it is possible that based on expanded liquids pilot programs, additional storage may be needed in the form of a third tank.

As has been done at newer facilities, the two new tanks should be placed on a concrete slab with a canopy. Any new tanks at the Boxford Depot should be located in the vicinity of the existing tank, as shown on **Figures 5-2A and 5-2B**. The existing pump can remain in use with a magnetic flow meter installed to help track quantities.

5.5.6 Facility Summary and Capital Cost

Two salt storage facility options have been considered:

1) ***Boxford Depot Remains Partially Closed:*** Under this option, salt storage would not resume at the Boxford Depot. Instead, salt would be obtained at the Rowley Depot with the Newbury and Peabody Depots as backup. Sand and deicing agent storage (magnesium chloride) would continue at the Boxford Depot, as would vehicle and equipment storage.

2) ***Boxford Depot Salt Storage Reactivated with State-of-the-Art Facility:*** For this option a new salt shed and office space would be constructed at the Boxford Depot with salt storage and handling reactivated. Sand and deicing agent storage (magnesium chloride) would continue at the Boxford Depot, as would vehicle and equipment storage.

Facility and site improvements to accommodate each of these options are summarized below and serve as the basis of a capital cost estimate:

- If the Boxford Depot is to remain partially closed (i.e., no resumption of salt storage), then increased office space at the Rowley Depot is required for the Boxford timekeeper. A furnished trailer is assumed of about 720 square feet inclusive of water and electrical services, similar to the existing structure at the Boxford Depot.

- Reactivation of salt storage and handling at the Boxford Depot would require demolition of the existing shed and office structure. A new center-load facility is assumed of 8,925 square feet, constructed of timber, high-arched gambrel with concrete buttresses, and metal roofing. A new, furnished trailer would also be provided. New pavement is required within the structure matching the design of the specialized pavement described in **Section 5.5.4.2**. Other miscellaneous appurtenances such as lighting would be included.

- Pavement, drainage infrastructure, and improved magnesium chloride storage at the Boxford Depot are recommended whether or not salt storage resumes at that location.

  - Repavement of the Boxford Depot site is recommended due to excessive cracking. If salt storage resumes at the facility, an impervious membrane is recommended for inclusion in the pavement design to limit the potential of downward migration of salt constituents.

  - The drainage system layout, inclusive of a lined basin BMP and discharge to the drainage swale, is assumed as shown on **Figures 5-2A** and **5-2B. Section 5.5.4.1** identifies potential stormwater improvements in Topsfield Road adjacent to the Boxford Depot site. If those improvements are implemented, the drainage system infrastructure at the Boxford Depot could also be connected.

  - New magnesium chloride storage tanks would include two double-walled, polyethylene 5,000 gallon storage tanks on a concrete slab, located outdoors, with a canopy, and a new magnetic flow meter to measure use. If MassDOT chooses to pilot and/or select alternative deicing agents described in **Section 5.4**, then associated storage tanks could also be housed at the Boxford Depot, with the size and type of tank to be determined.

- Costs presented do not include temporary berms for either salt handling or liquid deicing agent containment as the usefulness of these items is dependent on the final site layout and the berms are comparatively low in cost.

- Should salt storage be reactivated at the Boxford Depot, capture of runoff for reuse as salt brine is not recommended, given the high cost of implementation. Furthermore, neither the runoff captured nor the salt concentration can be accurately predicted.

- It is recommended that scales for heavy duty equipment be employed to provide improved accuracy of material measurement (i.e., weighing front-end loaders with and without payload). For the purposes of this evaluation, portable floor scales were considered. The scales would be located at the Boxford Depot if salt storage were to resume at this location or otherwise located at the Rowley Depot.

Based on these assumptions, an opinion of probable project costs for each salt storage facility option is presented in **Table 5-15**.

Table 5-15
Salt Storage Facility Options – Opinion of Probable Project Costs

Improvement	Boxford Depot Remains Partially Closed (no salt storage)	Boxford Depot Salt Storage Reactivated with State-of-the-Art Facility
New Office Space	$350,000	$350,000
New Salt Shed – Boxford Depot (Including demo of existing shed and office)	NA	$2,730,000
New Liquid Deicing Material Storage Tanks – Boxford Depot	$240,000	$240,000
Repave Boxford Depot	$500,000	$670,000
Drainage System – Boxford Depot	$130,000	$130,000
Portable scale for Improved Accuracy of Material Measurement – Boxford or Rowley Depot	$80,000	$80,000
TOTAL	**$1,300,000**	**$4,200,000**

The costs above include construction of the facilities noted in the text; an allowance for permitting, engineering, and implementation; and contingencies. As the work identified is expected to be conducted above bedrock, which is at a depth of 5-10 feet below ground surface (BGS) at the Boxford Depot, no additional allowances were included. The cost estimates are based on June 2014 prices, and do not include inflation to future time periods. The Engineering News Record (ENR) Construction Cost Index for June 2014 is 9800[6].

The capital costs (from **Table 5-15**) and NPV operations costs (from **Table 5-13**) for the two salt storage facility options are summarized in **Table 5-16**. The estimated total NPV of $16.3 million for resumption of salt storage at the Boxford Depot is higher than the estimated $14.4 million with the Boxford Depot remaining partially closed. In selecting an option, MassDOT must consider this cost differential in relation to such other factors as level of service to the Study Area, public driving safety, and water supply protection.

Table 5-16
Salt Storage Facility Options – Summary of Present Value Costs

Improvement	Boxford Depot Remains Partially Closed (no salt storage)	Boxford Depot Salt Storage Reactivated with State-of-the-Art Facility
NPV of Operations Costs[1]	$13,100,000	$12,100,000
Capital Cost	$1,300,000	$4,200,000
Total NPV	**$14,400,000**	**$16,300,000**

Notes:
[1]NPV refers to Net Present Value, and is based on costs for 30 years of operation; with 3% annual inflation.

[6] The ENR Construction Cost Index represents 200 hours of common labor at the 20-city average of common labor rates.

Regardless of the option selected, establishment of a groundwater monitoring program is recommended at the Boxford Depot. Should salt storage not be reactivated at the site, a groundwater monitoring program will allow ongoing assessment of the expected decrease in salt concentrations, as well as provide monitoring relative to ongoing site operations. Should salt storage be reactivated, then a monitoring program will be necessary to ensure that BMPs are being met so as to minimize the potential for runoff with salt constituents to infiltrate the groundwater.

5.6 Evaluation of Stormwater Management Alternatives

Stormwater management alternatives were considered as a means to mitigate infiltration of stormwater runoff containing deicing agents (NaCl, $MgCl_2$). Immediately after deicing activities have occurred, runoff from MassDOT and Town roads may carry significant concentrations of sodium, chloride, and other deicing chemicals. Long after such events have occurred, residual quantities of deicing chemicals can contribute to slightly elevated concentrations in runoff. Managing this runoff and preventing it from infiltrating will reduce the impacts resulting from deicing operations to groundwater quality.

When applied, the deicing materials lower the freezing point of water, turning solid precipitation such as ice and snow into a liquid, which may then flow off the roadway to drainage systems, carrying along with it the deicing materials. As a result of plowing operations, deicing materials may also accumulate in snowbanks along the side of the road. As the snowbanks melt, runoff carrying deicing agents may either enter drainage systems, runoff via overland flow to wetland and watercourses, or infiltrate directly into the groundwater. Managing this runoff and preventing it from entering the groundwater is an important step towards reducing stormwater impacts to bedrock groundwater quality.

The alternatives identified to reduce stormwater infiltration fall into two categories:

- ***Non-Structural Improvements:*** These include stormwater system O&M and closed circuit television inspections of existing closed drainage systems including catch basins, manholes, and pipe networks. These are considered non-structural as their execution would not require physical changes to existing grading or stormwater infrastructure in the Study Area.
- ***Structural Improvements:*** These include modifications to existing drainage systems and lined swales in addition to implementation of snow berms. The implementation of these alternatives would by nature require physical changes to either existing grading, stormwater infrastructure, or both.

Potential mitigation approaches and technologies retained from the alternatives screening analysis are presented in **Table 5-17**.

Table 5-17
Retained Alternatives: Stormwater Drainage Improvements on I-95 and Town Roads

Alternative	Description
Non-Structural Improvement	
O&M Procedures	▪ Increase frequency of structure and pipe cleaning, including catch basins and pipe outlets.
Structural Improvement	
Reroute Drainage Piping	▪ Change piping conveyance arrangements to discharge runoff captured from roadways to perennial streams to reduce the potential for infiltration.
Snow Berms	▪ Paved areas outside of guardrails sloped to drainage systems in gutter. Allows melt from snowbanks/piles to drain to collection system instead of to area adjacent to highway.
Swales	▪ Collect drainage runoff from areas adjacent to highways (snowmelt) and redirect to drainage system.

As shown, all three structural improvement alternatives were retained along with the non-structural O&M measure. The retained alternatives are described and evaluated below.

5.6.1 Non-Structural Improvements

O&M of stormwater infrastructure is critical to the performance of drainage systems. The removal of sediment and debris from catch basins, manholes, pipes, and open channels is required to prevent system malfunction resulting in potential flooding and water quality impacts. O&M measures within the Study Area have added importance as sediment removed from structures, pipes, and open channels, as well as sand removed during street sweeping operations, may contain traces of deicing materials that could potentially contribute to water quality impacts after the winter season.

Ongoing O&M procedures conducted by the Town and MassDOT are described in **Section 2.3**. Each performs annual street sweeping and inspection of their drainage systems. Sediment is typically removed from the drainage systems as determined necessary through inspection.

The existing O&M procedures of the Town and MassDOT meet their respective National Pollutant Discharge Elimination System Phase II - Small Municipal Separate Storm Sewer Systems General Permits. As was noted during the alternatives identification and screening process, increased O&M would not likely have a significant impact on the surface and groundwater quality in the Study Area. CDM Smith recommends continued adherence to the existing drainage system O&M plans and procedures of the Town and MassDOT, with annual street sweeping and drainage inspections in April, soon after the winter ends. This would help maximize removal of sand and sediments containing salt constituents prior to their mobilization to the environment.

5.6.2 Structural Improvements

Structural improvements retained during screening for further evaluation include modifications to existing drainage systems, implementation of snow berms, the construction of new lined drainage swales, and the lining of presently unlined drainage swales. The goal of these changes would be to prevent infiltration of runoff having elevated concentrations of deicing materials. The following describes how this goal would be met by the different alternatives.

5.6.2.1 Modifications to Existing Drainage Systems

In the Study Area, locations where I-95 stormwater runoff is directed either by overland flow or via outfalls to areas where the bedrock is close to land surface are particularly sensitive to salt impacts. Modifications can be made to existing drainage systems to redirect flow currently discharging to such sensitive areas either to faster moving streams or to locations where the overburden thickness is greater.

The majority of runoff from I-95 and the associated ramps and overpasses is collected by MassDOT's closed drainage systems. These drainage systems range in complexity from single catch basins discharging via small outfalls to systems with dozens of catch basins and manholes, all discharging via a single, large outfall. The Town's drainage infrastructure is best classified as country-drainage, with small clusters of catch basins and manholes. The layouts of MassDOT and Town drainage systems are shown in **Appendix C**.

An effective way to reduce stormwater runoff infiltration in sensitive areas is to combine systems and redirect discharge to less sensitive locations. To accomplish this, new pipes and manholes may be necessary, and existing infrastructure may require replacement or modification to accommodate the connection of existing systems and properly convey increased flow. Modifications such as this were previously made to MassDOT systems in 2005 and 2006 (see **Section 2.3.1.2**).

The smaller disconnected nature of the Town's drainage system, combined with its distance to larger surface water bodies, make it difficult to implement changes that would result in a reduction in stormwater infiltration. Furthermore, as previously presented in **Section 3**, stormwater runoff and surface water concentrations at Town outfalls were generally much lower than those recorded at I-95 discharge locations.

5.6.2.2 Snow Berms

As snowbanks melt, runoff carrying deicing agents may enter drainage systems, runoff via overland flow to wetland and watercourses, or infiltrate directly into the groundwater. One method for controlling snowbank melt runoff is through the implementation of snow berms. Snow berms are comprised of paved areas located beyond the highway breakdown lane and shoulder where snow can be piled. Snow berms can be graded in a number of configurations that direct snowmelt runoff to drainage systems. To maximize use of the existing drainage systems in the Study Area, snow berms should be slope toward the roadway so that when the snowbanks melt, the runoff collects in the gutter and is conveyed to the highway drainage system.

By controlling snowmelt runoff, snow berms prevent infiltration of meltwater runoff carrying deicing constituents. Snow berms may be cost effective as they can utilize existing drainage infrastructure and therefore only require regrading and paving. To accommodate snow berms, areas must have the proper combination of sufficient open space and appropriate grades adjacent to the highway. The available area for regrading is dependent on the distance between the highway edge and the limit of the right-of-way. When only a narrow area is available, the existing grades must be sloped more sharply back towards the highway to be favorable for snow berm implementation. If there is a wider area of available land, there is more opportunity to manipulate existing grades to accommodate a snow berm.

Snow berms are not intended to serve as a travel way for vehicles and should have guardrails or other means of access restriction separating them from the breakdown lanes and shoulders.

5.6.2.3 Lined Swales

The primary function of lined swales is to convey runoff in an open channel while preventing infiltration. Lined swales also typically have less friction than natural swales and can therefore convey more flow than a similarly sized natural channel. For the purpose of this study, lined swales were considered to capture and convey snowbank melt where snow berms could not be implemented due to grading and spatial constraints and as a replacement for existing natural channels where infiltration may be occurring.

Lined swales can be constructed using either concrete or asphalt paving. The latter is preferred when addressing salt laden runoff as concrete is more rigid than asphalt and therefore more prone to cracking. Lined swales can discharge to a catch basin located at the downstream end of the swale, or the swale can be tapered to discharge to a gutter or water body. There are several lined swales in the Study Area. In some instances, the swale is intended to capture runoff from the I-95 median strips, as is the case with the swale along the I-95 northbound Exit 53B off-ramp. There is also a lined swale adjacent to I-95 northbound between Exits 52 and 53, near School Street, intended to convey flow from several outfalls (some of which were abandoned as part of the MassDOT drainage modifications implemented in 2005) to Pye Brook.

5.6.3 Selection of Potential Areas for Structural Modifications

CDM Smith used various data to identify locations in the Study Area where the structural stormwater management modifications described above could potentially be implemented. Stormwater runoff modeling using SWMM was used to evaluate which existing MassDOT drainage catchments had the highest overall load and highest concentrations of deicing materials in the stormwater runoff, and as such would be candidate locations for drainage modifications. An overview of the SWMM analysis and the proposed locations for structural modifications are presented below.

A surface water quality model using EPA's SWMM was developed to evaluate locations where drainage modifications could be implemented to reduce stormwater runoff to areas with shallow bedrock. Principal hydrologic parameters were estimated from imperviousness data, slope data, and calculations based on the delineated drainage catchments. Deicing material loading data (salt and magnesium chloride) from MassDOT's records were normalized by lane-mile and input to the model as a time series to approximate wet weather runoff concentrations and loads.

The model was used to estimate runoff volumes and concentrations for individual catchments along the highway. While rigorous model calibration was not performed, simulated concentrations were compared with measured concentrations collected during the 2014 winter sampling events to evaluate whether measured concentrations could be generally represented by the model. Details regarding model development and results are provided in **Appendix M**. The model simulated runoff from highway catchments only and did not include any local town drainage catchments.

The results of the baseline runs were used to help identify areas where high load catchments drain to areas of shallow bedrock, where loads have greater potential to impact groundwater quality. The highest load is correlated both with catchment size and the total number of lane-miles, so the high-load catchments are disproportionately represented by large drainage areas where the load is high but concentrations are low. Conversely, the highest concentrations occur in smaller catchments comprised entirely of impervious highway area. This explains the difference between high load and low concentration catchments (e.g., WS-PB-04, which has the highest modeled load but a much lower relative modeled average concentration). High load and high concentration catchments identified using the model results were examined in the context of proximity to areas of shallow bedrock and residents with salt impacted domestic wells.

Drainage systems with high modeled or observed concentration and/or loads that discharge to susceptible areas were screened to determine the feasibility of implementing drainage system modifications, snow berms, or lined swales. Several of the identified high load or concentration catchments investigated are not conducive to these proposed changes. For example, in some areas grading prohibits new connections to fast moving streams. Similarly, several areas do not have sufficient space or grading to accommodate snow berms or lined swales for the collection of snowmelt. These areas were excluded based on these criteria.

A total of ten catchments were identified for potential stormwater drainage modifications. Eight of these catchments were included in the model, whereas two were not. All are summarized on **Table 5-18** with regard to location, rationale for inclusion, and description of the potential structural improvement. The general area of each catchment is shown on **Figure 5-3**. They are centered around the three areas with known salt impacted wells.

- ***Exit 53***: Three catchment areas are located east of Exit 53, and are intended to benefit areas of shallow bedrock with salt impacted domestic wells extending to Pye Brook.
- ***Boxford Depot/Exit 52/Titus Lane and Silverbrook Road:*** Two areas are located in the vicinity of the Boxford Depot and Exit 52. WS-FB-04 is meant to reroute drainage from the Boxford Depot and Old Topsfield Road area south, whereas WS-SB-09 reroutes drainage from I-95. Implementation of these drainage improvements would require modifications to WS-SB-05 and WS-SB-14. These modifications are intended to benefit the Titus Lane and Silverbrook Road areas which have experienced salt impacted domestic wells.
- ***South of Lockwood Lane and Exit 51***: There are three areas of improvements centered around Fuller Lane based on domestic well impacts and high concentrations of salt detected in both surface water and groundwater samples in this area. WS-FB-11 addresses potential snowmelt north of Fuller Lane along I-95 northbound; the Fuller Lane discharge addresses an existing town drainage discharge by extending it west to Fish Brook; and WS-FB-12 is a smaller catchment off I-95 northbound near Fish Brook Road. WS-IR-01 would address portions of Exit 51 drainage and provide BMP improvements for the Ipswich River as part of the Impaired Waters Program.

5.6.4 Conceptual Design and Implementation of Structural Modifications

AECOM Technology Corp. (AECOM), under contract to MassDOT relative to the Impaired Water Program, performed an engineering assessment as to the viability of each area recommended for drainage improvements along with a conceptual plan and cost estimate. AECOM's technical memorandum summarizing their methodology, design criteria, and findings for each area, along with figures depicting each conceptual improvement and associated cost of construction is included in **Appendix N**.

A summary of the conceptual designs developed by AECOM is presented in **Table 5-19**. The following should be noted regarding the conceptual stormwater management improvements presented in **Table 5-19**:

- Where appropriate, improvements in close proximity have been grouped together. Others would proceed independently.
- Improvements in the vicinity of Exit 52 are suggested to proceed in two phases. Phase 1 would include work along Topsfield Road near the Boxford Depot with connection to existing drainage on the I-95 southbound on-ramp, such that discharge will be south to Silver Brook. This conceptual layout was sized to accommodate a connection to any drainage improvements made at the Boxford Depot, as discussed in **Section 5.5**.
- Phase 2 in the area of Exit 52, can proceed by either of two options (Option A or B) shown on **Table 5-19**. Option A allows the combination of four catchment areas in the vicinity of Topsfield Road (WS-FB-04, WS-SB-09, WS-SB-05, and WS-SB-14), whereas Option B excludes WS-SB-09 which is an I-95 catchment north of Topsfield Road discharging south to Silver Brook.

Table 5-18
Summary of Potential Stormwater Management Improvements

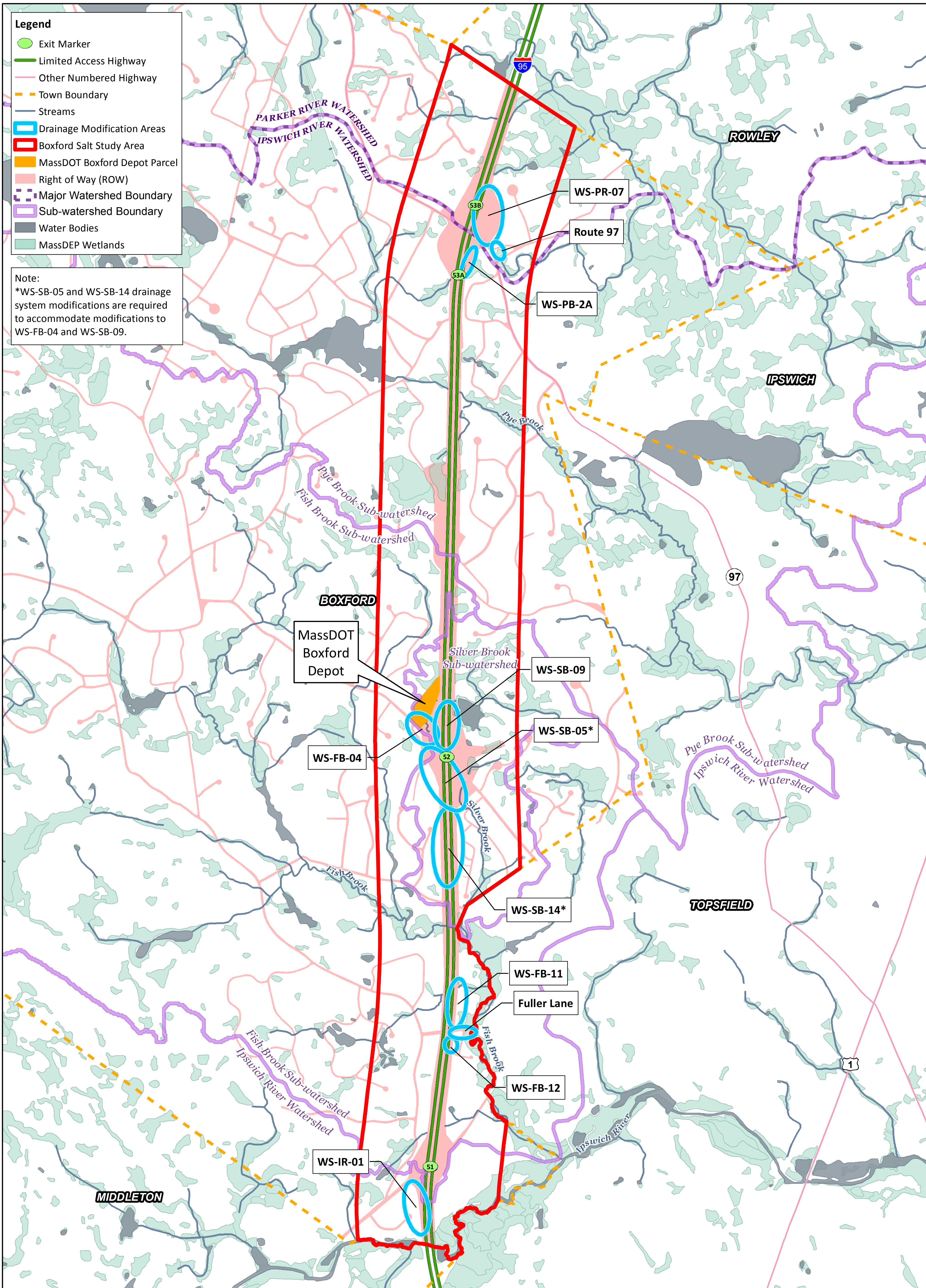
Catchment[1]	Map Panel No. [1]	Outfall Sample No.[2]	Location Description	Modeled[3] (yes/no)	Rationale for Inclusion	Potential Improvement	Comments
Exit 53							
WS-PR-07	2	PRW2C	Exit 53 NB on-ramp	yes	Known high runoff load	Snow berm/ lined swale	▪ Current Discharge: area over shallow bedrock and near salt impacted wells. ▪ Proposed Discharge: snow berm or lined swale to direct snowbank melt to drainage system
Route 97	2	PRW3K	Exit 53, Intersection of Killam Hill Road and Rowley Road	no	High surface water and groundwater sodium and chloride concentrations	Reroute drainage	▪ Current Discharge: northwest corner of the intersection. ▪ Proposed Discharge: downstream to southeast corner of intersection.
WS-PB-2A	3	IRW3A	I-95 NB south of Exit 53, near School Street	yes	High constituent concentration	Snow berm/ lined swale	▪ Current Discharge: area over shallow bedrock and near salt impacted wells. ▪ Proposed Discharge: snow berm or lined swale to direct snowbank melt to drainage system.
Boxford Depot/Exit 52/Titus Lane and Silverbrook Road Area							
WS-SB-09[4]	7	FBW2Q	I-95 north of Exit 52	yes	High constituent load	Reroute drainage	▪ Current Discharge: drainage ditch over area of shallow bedrock. ▪ Proposed Discharge: drainage system to the south (WS-SB-14).
WS-FB-04[4]	7	FBW2W	Topsfield Road and Old Topsfield Road west of Exit 52	yes	Proximity to area with historic water quality issues	Reroute drainage	▪ Current Discharge: WS-FB-04 and Old Topsfield Road. ▪ Proposed Discharge: drainage system to the south (WS-SB-14) that discharges to downstream end of Silver Brook.
South of Lockwood Lane and Exit 51							
WS-FB-11	10	-	I-95 NB drainage north of Fuller Lane	yes	High constituent load	Snow berm/ lined swale	▪ Current Discharge: area over shallow bedrock and near salt impacted wells. ▪ Proposed Discharge: snow berm or lined swale on the east side of I-95 to direct snowbank melt to the drainage system.

Table 5-18 (Cont'd)
Summary of Potential Stormwater Management Improvements

Catchment[1]	Map Panel No. [1]	Outfall Sample No.[2]	Location Description	Modeled[3] (yes/no)	Rationale for Inclusion	Potential Improvement	Comments
South of Lockwood Lane and Exit 51 (Cont'd)							
Fuller Lane	10	-	Town drainage south of Fuller Lane and east of I-95	no	Proximity to salt impacted wells	Reroute drainage	▪ Current Discharge: edge of wetland adjacent to Fish Brook. ▪ Proposed Discharge: directly to Fish Brook.
WS-FB-12	10	-	I-95 NB near Fish Brook Road	yes	High constituent concentration	Reroute drainage	▪ Current Discharge: small area with single catch basin ▪ Proposed Discharge: WS-FB-11 collection system.
WS-IR-01[5]	12	-	I-95 SB south of Exit 51 at Ipswich River	yes	High constituent load	Reroute drainage	▪ Current Discharge: drainage ditch over area of shallow bedrock. ▪ Proposed Discharge: farther south to Ipswich River.

Notes:
[1] I-95 catchment areas shown on Map Panels in Appendix C.
[2] Identifies catchment outfall station if water quality sample was collected during field programs.
[3] Yes means catchment area was modeled using SWMM; No means catchment area was not modeled.
[4] Improvements at WS-SB-09 and WS-FB-04 would require improvements to WS-SB-05 and WS-SB-14.
[5] Would be conducted in association with BMPs for the Impaired Water Program relative to the Ipswich River.
"-" = No sample collected at outfall of catchment.

Abbreviations:
FB: Fish Brook
IR: Ipswich River
NB: northbound
PB: Pye Brook
PR: Parker River
SB: southbound/Silver Brook
WS: watershed



CDM Smith

MassDOT Boxford Salt Study
Figure 5-3
Potential Drainage Modification Areas

Source: MassGIS, CDM Smith

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Table 5-19
Conceptual Stormwater Management Improvements

Catchment	Location Description	Summary of Improvements[1]
Exit 53		
WS-PR-07	Exit 53 NB on-ramp	Installation of 1,000-foot-long, 10-foot-wide snow berm.
Route 97	Intersection of Killam Hill Road (Rt. 97) and Rowley Road	Reroutes discharges from northwest corner of intersection to southeast corner of intersection. Includes abandonment/removal of four existing outfalls at northwest corner of intersection, installation of 12- and 15-inch-diameter reinforced concrete pipe, two new manholes, one new outfall at southwest corner of intersection, and modifications to existing catch basins.
WS-PB-2A	I-95 NB south of Exit 53, near School Street	Installation of 500-foot-long, 10-foot-wide snow berm.
Boxford Depot/Exit 52/Titus Lane and Silverbrook Road Area		
Phase 1[2] **WS-FB-04**	Topsfield Road and Old Topsfield Road west of Exit 52	Reroutes discharges from Old Topsfield Road to point east of Exit 52 southbound off-ramp. Includes abandonment/removal of two existing outfalls at Old Topsfield Road, installation of 125 linear feet of reinforced concrete pipe ranging from 12- to 18-inch-diameter, three new manholes, one new outfall east of Exit 52 southbound off-ramp, and modifications to existing catch basins.
Phase 2 – Option A[2] **WS-FB-04** **WS-SB-05** **WS-SB-14** ***Includes* WS-SB-09**	Exit 52 SB on-ramp, I-95 south of Topsfield Road overpass	Reroutes discharges from WS-FB-04 and WS-SB-09 to WS-SB-14 outfall near Andrews Farm Road. Allows for entire flow from WS-SB-05 to discharge to that outfall as well. Includes abandonment of new outfall installed during Phase 1; installation of 3,500 linear feet of new/replacement reinforced concrete pipe ranging from 12- to 42-inch-diameter; installation, replacement, or retrofitting of 24 manholes; replacement of one existing outfall; and modifications to existing catch basins. Option A includes the area north of the Topsfield Road overpass and as such downstream pipes are larger.
Phase 2 – Option B[2] **WS-FB-04** **WS-SB-05** **WS-SB-14** ***Excludes* WS-SB-09**	I-95 north of Topsfield Road, Exit 52 SB on-ramp, I-95 south of Topsfield Road overpass	Reroutes discharges from WS-FB-04 to WS-SB-14 outfall near Andrews Farm Road. Allows for entire flow from WS-SB-05 to discharge to that outfall as well. Includes abandonment of new outfall installed during Phase 1; installation of 3,200 linear feet of new/replacement reinforced concrete pipe ranging from 12- to 36-inch-diameter; installation, replacement, or retrofitting of 21 manholes; replacement of one existing outfall; and modifications to existing catch basins. Option B does not include the area north of the Topsfield Road overpass and as such downstream pipes are smaller.
South of Lockwood Lane and Exit 51		
WS-FB-11	I-95 NB drainage north of Fuller Lane	Installation of a 9,000-foot-long, 20-foot-wide snow berm and lining of 500 linear feet of an existing drainage ditch.
Fuller Lane	Town drainage south of Fuller Lane and east of I-95	Drainage improvements include installation of 300 linear feet of 12-inch-diameter reinforced concrete pipe, and modifications to one existing catch basin structure.
WS-FB-12	I-95 NB near Fish Brook Road	Drainage improvements include abandonment of one existing outfall, installation of 50 linear feet of 12-inch-diameter reinforced concrete pipe, and modifications to two existing catch basin structures.
WS-IR-01	I-95 SB south of Exit 51 at Ipswich River	Reroutes discharges from drainage ditch adjacent to Exit 51 southbound on-ramp to conceptual BMP that would then discharge to Ipswich River. Includes abandonment of five existing outfalls, installation of 800 linear feet of reinforced concrete pipe ranging in diameter from 12- to 18-inch, installation of two new manholes, and modifications to existing catch basin structures.

Notes:

[1]See Appendix N for conceptual layouts of improvements (AECOM, 2014)

[2]Phase 2 may proceed as either Option A or Option B following completion of Phase 1.

Abbreviations:

FB: Fish Brook
IR: Ipswich River
NB: northbound
PB: Pye Brook
PR: Parker River
SB: southbound/Silver Brook
WS: watershed

- Improvements in the WS-IR-01 area should be coordinated with potential BMPs to be implemented as part of the MassDOT Impaired Waters Program, also discussed in the AECOM memorandum. Any BMP improvements should avoid infiltration as that could increase salt impacts to area domestic wells.
- Coordination with applicable federal, state, and local agencies may be required during final design to meet permitting requirements. Examples may include the U.S. Army Corps of Engineers, Massachusetts Department of Environmental Protection, Massachusetts Natural Heritage and Endangered Species Program, and the Boxford Conservation Commission.

5.6.5 Opinion of Probable Project Costs

Construction cost estimates based on the conceptual design of stormwater management improvements were developed by AECOM and included as part of their memorandum. The construction costs developed by AECOM are in present day dollars (Engineering News Record Construction Cost Index for June 2014 is 9800) and include mobilization and construction contingency. CDM Smith's opinion of probable project costs in **Table 5-20** includes an allowance for permitting, engineering, and implementation added to AECOM's conceptual construction estimate. Easements, land acquisition, and legal fees are not included. The cost estimates are based on June 2014 prices, and do not include inflation to future time periods. The costs presented for WS-IR-01 do not include any potential BMP associated with the MassDOT Impaired Waters Program.

Table 5-20
Opinion of Probable Costs – Stormwater Management Improvements

Catchment	Opinion of Probable Project Costs[1]	Proposed Modification
Exit 53		
WS-PR-07	$ 400,000	Snow berm
Route 97	$ 120,000	Drainage modification
WS-PB-2A	$ 230,000	Snow berm
Boxford Depot/Exit 52/Titus Lane and Silverbrook Road Area		
Phase 1 **WS-FB-04**	$ 310,000	Reroutes discharges from Old Topsfield Road to point east of Exit 52
Phase 2 – Option A **WS-FB-04** **WS-SB-05** **WS-SB-14** ***Includes* WS-SB-09**	$ 1,800,000	Reroutes discharges from area northeast of Exit 52 to outfall on Andrew's Farm Road
Phase 2 – Option B **WS-FB-04** **WS-SB-05** **WS-SB-14** ***Excludes* WS-SB-09**	$ 1,500,000	Reroutes discharges from area northeast of Exit 52 to outfall on Andrew's Farm Road
South of Lockwood Lane and Exit 51		
WS-FB-11	$ 860,000	Snow berm and lining of swale
Fuller Lane	$ 60,000	Town drainage modification
WS-FB-12	$ 110,000	Drainage modification
WS-IR-01	$ 360,000	Reroutes discharges to MassDOT Impaired Waters Program BMP

Notes:
[1]Represents construction cost estimates by AECOM (**Appendix N**) with an additional allowance for permitting, engineering, and implementation.

5.7 Evaluation of Community Water Supply Options

As shown on **Table 5-21**, the screening procedure resulted in the following items being retained for the evaluation of community water supply options:

Table 5-21
Retained Alternatives: Community Water Supply Options

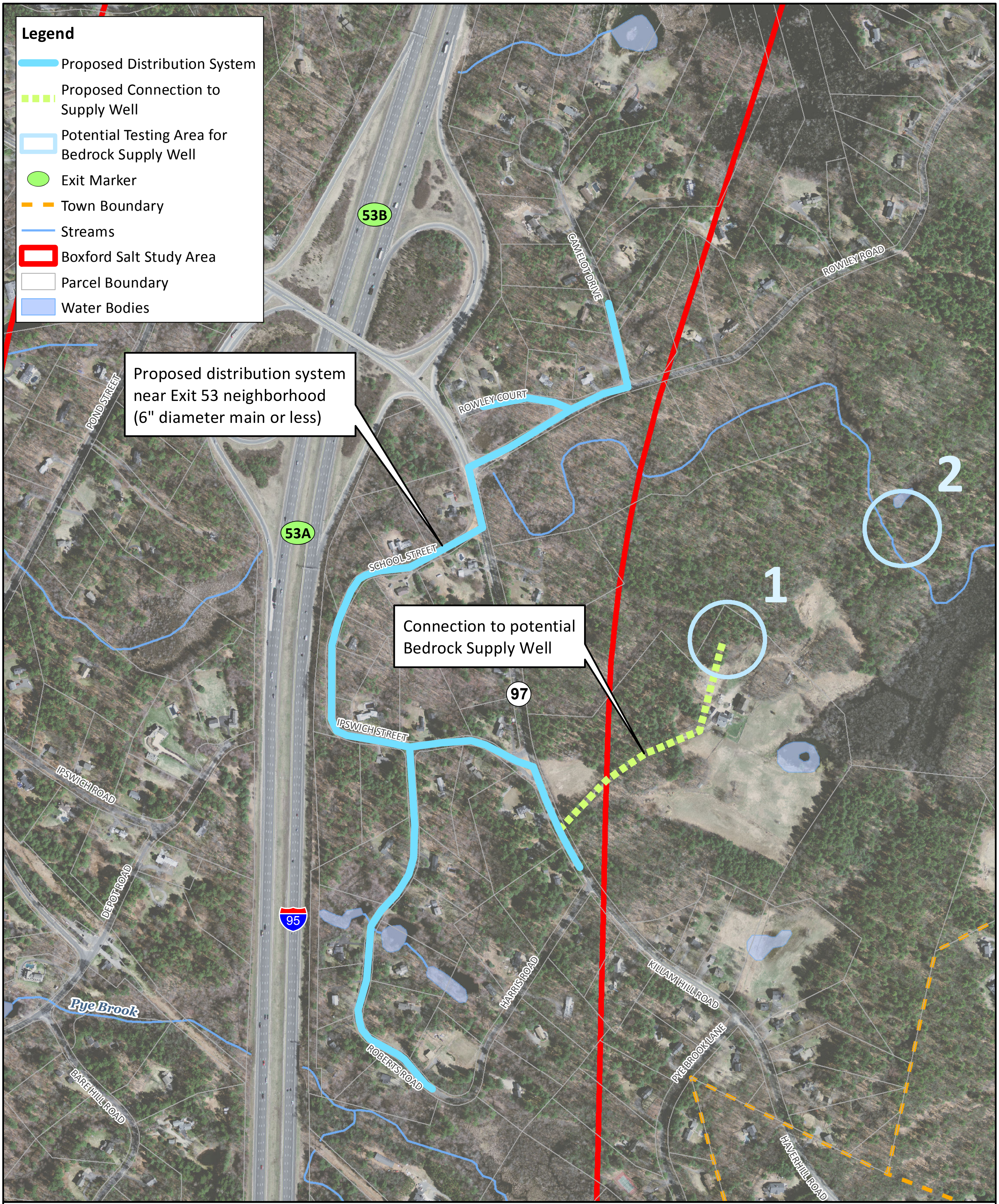
Alternative	Description
WELL SUPPLY OPTIONS	
Bedrock Wells	▪ Implement bedrock wells for community use ▪ Provide treatment as necessary and distribution system
Sand-and-Gravel Wells	▪ Implement sand-and-gravel wells for community use ▪ Provide treatment as necessary and distribution system
WATER SYSTEM MANAGEMENT OPTIONS	
Town of Boxford Supply	▪ Establish Town Water Department to own and operate water supply, treatment and distribution system for local community
Water Supply District	▪ Establish local Water Supply District to own and operate water supply, treatment, and distribution system
Private or Homeowner Association System	▪ Water supply, treatment and distribution system owned and operated by private entity or home owner association
ADJACENT COMMUNITY SUPPLY	
Adjacent Community Supply	▪ Provide potable water to neighborhoods by extending distribution systems from adjacent town; dependent on availability of supply

5.7.1 Areas to be Served by Community Water Systems

Areas that could be served by community water systems were determined by anticipated need due to known water quality concerns related to salt impacted groundwater in area domestic wells, and also by the practicality of water system development. The high cost of water system development (likely more than $100 million for the entire Study Area) renders impractical the construction of a public water system to serve the entire Study Area. Thus, that concept was not considered herein. On the other hand, where a number of salt-impacted domestic wells are clustered together, water system development may be feasible in localized areas.

Figure 1-3 in **Section 1** illustrated the general areas of salt-impacted domestic wells. As shown therein, there are several significant clusters of such residences. Areas that could be served by community water systems are mapped on **Figure 5-4** for the Exit 53 area, and **Figure 5-5** for the Exit 52 area. Three distinct service areas can be considered:

- The Exit 53 neighborhood east of I-95
- The Silverbrook Road neighborhood, east of I-95 at Exit 52
- The Titus Lane neighborhood, west of I-95 at Exit 52

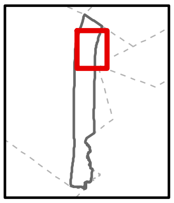


0 500 1,000 Feet

MassDOT Boxford Salt Study

Figure 5-4

Community Water Distribution System Option - Exit 53



Source: MassGIS, CDM Smith

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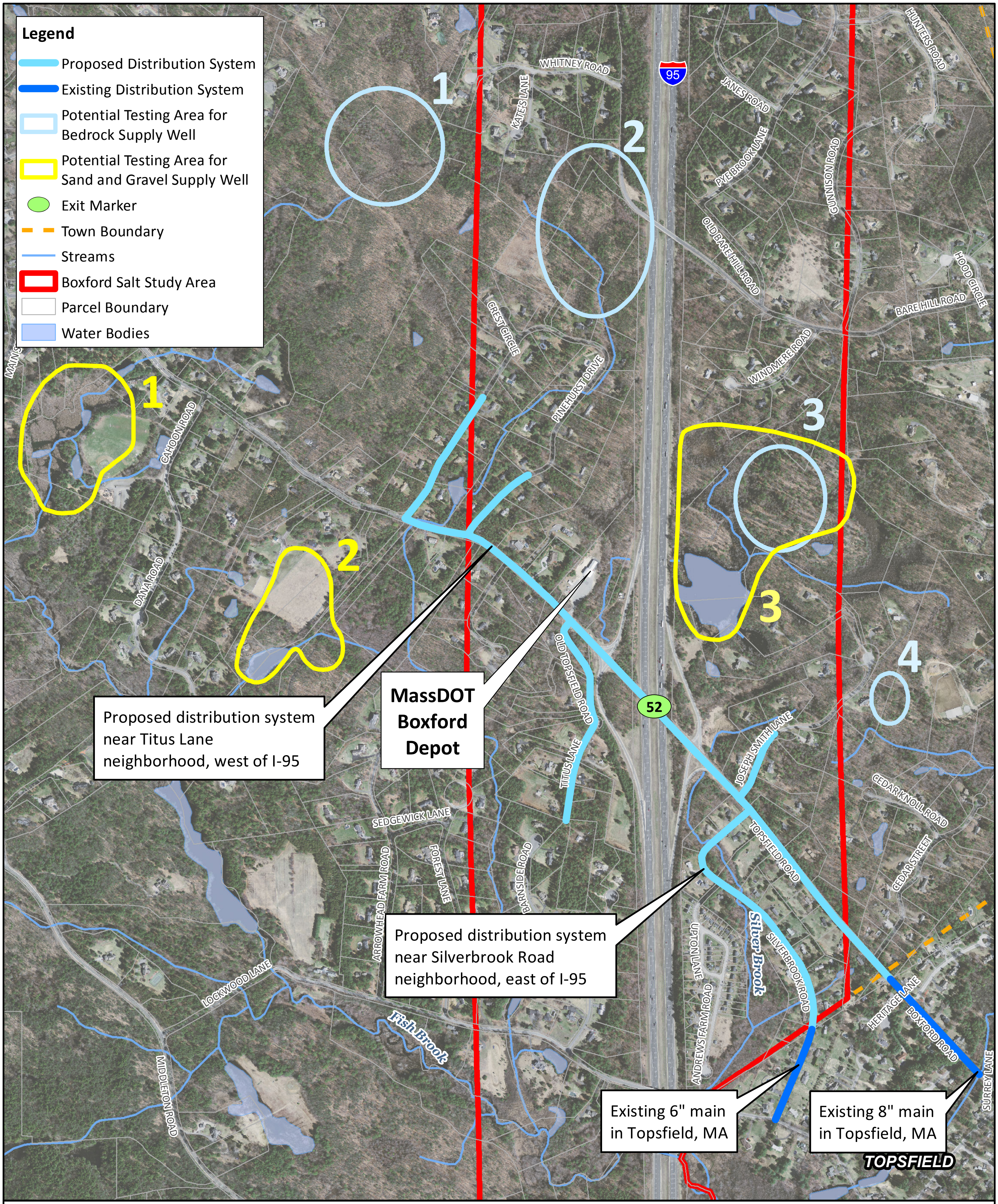

MassDOT Boxford Salt Study

Figure 5-5

Community Water Distribution System Option - Exit 52

Source: MassGIS, CDM Smith

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Locations of potential water distribution systems are shown, and are based on available data regarding residential well water quality and on known residences with salt-impacted domestic wells as reported to the MassDOT Salt Remediation Program. Additional mains beyond those shown in the figures could be constructed, but are not necessary for serving the known areas of concern and thus have not been considered herein. We have assumed the community water systems would be constructed only for potable water service and not for fire protection as existing fire protection arrangements for these residences would continue to serve those needs.

Based on the number of affected households in each service area, typical household sizes in Boxford, and typical residential water consumption rates, we have prepared estimates of water demand for each service area. **Table 5-22** presents the expected water demands for the Exit 53 service area.

Table 5-22
Water Demand Data for Exit 53 Service Area

Exit 53 Service Area, East of I-95	
40	Households
3.5	People per household
65	Gallons per person per day
9,100	Average Day Demand (Gal/Day)
36,400	Maximum Day Demand (Gal/Day)
72,800	Peak Hour Demand (Gal/Day)

The number of households listed in the table assumes that all houses along the path of the water mains would hook into the system. The average household population in the 2010 U.S. Census for Boxford was 3.0, but a slightly higher figure was utilized herein to provide a conservative estimate. The 65 gallons per person per day water demand cited in Table 5-23 is the Massachusetts Department of Environmental Protection's performance standard for public water systems, a standard which applies to all water systems in the Commonwealth irrespective of irrigation demands as well as to other types of water systems.[7] The multipliers used to derive maximum day demand and peak hour demand were 4 and 8, respectively, taken from an extrapolated version of the "Merrimack Curve". This curve is a standard tool used in water system planning, and it relates maximum day and peak hour demands to any given average day demand.

Table 5-23 presents water demands for the Exit 52 service areas, derived in the same manner as described above for Exit 53. In this case, we have elected to show the water demands for eastern service area alone, and then the water demands for the two Exit 52 service areas combined.

Table 5-23
Water Demand Data for Exit 52 Silverbrook Road and Titus Lane Service Areas

Silverbrook Road Service Area – East of I-95		Silverbrook Road Service Area - East of I-95 and Titus Lane Service Area - West of I-95	
30	Households	50	Households
3.5	People per household	3.5	People per household
65	Gallons per person per day	65	Gallons per person per day
6,800	Average Day Demand (Gal/Day)	11,400	Average Day Demand (Gal/Day)
27,300	Maximum Day Demand (Gal/Day)	45,500	Maximum Day Demand (Gal/Day)
54,600	Peak Hour Demand (Gal/Day)	91,000	Peak Hour Demand (Gal/Day)

[7]MassDEP. Performance Standards for Public Water Supplies - RGPCD & UAW. 2014. Web. August 29, 2014 <http://www.mass.gov/eea/agencies/massdep/water/watersheds/performance-standards-for-public-water-supplies.html>

The actual demands could vary from these projections, particularly if the water systems were ever to be enlarged to serve additional households. There is a major additional permitting hurdle (the Water Management Act withdrawal permit process) for average day withdrawals of 100,000 gallons per day (gpd) or more, but it does not appear likely that the withdrawals for these systems would approach that level.

5.7.2 Potential Water Supply Sources for Community Water Systems

For each service area, a water source is needed to deliver potable water to the distribution system. The three potential types of water sources were noted earlier in the screening process:

- Bedrock wells
- Sand-and-gravel wells
- Supply from an adjacent community (Topsfield water system)

It is recognized that the Boxford Town Code prohibits sand-and-gravel wells for private water supplies. Of those Massachusetts residents receiving water from public groundwater supply sources, however, the overwhelming majority are served by sand-and-gravel wells. As there is no technical reason for excluding such wells, and given that the Town Code does not indicate that it is intended to address public water supply wells (which are under the jurisdiction of the Massachusetts Department of Environmental Protection (MassDEP)), sand-and-gravel wells have been retained for consideration in this evaluation.

Bedrock Wells

Potential bedrock well locations were determined from the previously-discussed fracture trace analysis (**Section 3.6**), by considering those areas with intersecting fractures which appeared from aerial mapping to be sufficiently distant from land uses that would rule out siting of a community water supply well. No field work was performed in this study to verify the land use condition, access conditions, or the presence of fractures; such work would be needed in future efforts, should a bedrock groundwater supply be pursued.

A well with an approved yield of, for example, 10,000 gpd requires a separation distance of 250 feet; a 100,000 gpd or greater well requires a separation distance of 400 feet. Using the specific withdrawal values in the preceding tables, the range of separation distances that would apply to the Exits 52 and 53 water system configurations would be 315 to 349 feet. These separation distances are based on a formula in the Public Water System Guidelines of MassDEP. The area within this distance around each wellhead is termed the Zone I protection area. The approved yields are based on the maximum daily withdrawal from the well. This entire Zone I area must become owned or controlled by the entity responsible for the water system, unless MassDEP considers the existing ownership arrangements satisfactory for the purpose of groundwater protection.

Areas which could warrant further testing for bedrock well supply potential are shown by numbered grey circles or ellipses on **Figures 5-4** and **5-5**.

Sand-and-Gravel Wells

Surficial geology maps were examined to determine areas that may warrant testing for sand-and-gravel wells. Only locations that appeared on aerial mapping to have sufficient separation distances were considered. Field reconnaissance would be needed to verify land use and access conditions.

Areas near Exit 52 which may warrant testing for sand-and-gravel well potential are shown on **Figure 5-5** as numbered areas with yellow outlines. Such areas also exist near Exit 53, but are off the mapped area of **Figure 5-4**, immediately east of the potential bedrock well testing sites.

Permitting for New Community Water Supply Wells

Development of new community water supply wells typically involves the following permit and approval processes:

- ***MassDEP Source Approval.*** This is the overall approval process, into which the other processes are typically integrated. Chapter 4.1 of MassDEP's Public Water System Guidelines provides a synopsis of what can be as much as a 25-step process. Major features of the process include field exploration for a suitable site, site examination and approval, pumping test proposal development, pumping test performance and approval, Source Final Report, design plans, and approval of permanent waterworks facilities.

- ***MassDEP Water Management Act (WMA).*** As noted earlier, it is not expected that development of the wells discussed herein will trigger WMA permitting. The average day demand of the community water systems, even if the Exit 52 and 53 systems were to be added together, is well below the 100,000 gpd trigger.

- ***Massachusetts Endangered Species Act (MESA).*** The Natural Heritage and Endangered Species Program (NHESP) maintains mapping showing "Estimated Habitats of Rare Wildlife" and "Priority Habitats of Rare Species". Projects in such areas may be subject to review and approval by NHESP. For example, the potential well sites that were illustrated for the Exit 53 community water system, located east of Route 97, are within an NHESP-designated area.

- ***Massachusetts Environmental Policy Act (MEPA).*** If any of the regulatory MEPA thresholds, which are presented in 301 CMR 11.03, would be triggered by a specific proposed project, an Environmental Notification Form (ENF) would need to be prepared for public review and comment. The need for such a process would need to be determined once a specific site is under consideration for development. The MEPA threshold related to water withdrawals will not be triggered by new community wells, for the same reason described in the paragraph above on the WMA. It is, however, possible that a specific project could trigger other thresholds. For example, a one located in an NHESP-mapped area may trigger MEPA review.

- ***Boxford Conservation Commission.*** In accordance with the Massachusetts Wetlands Protection Act, the Commission has jurisdiction over activities within 100 feet of regulated wetlands. If the water supply wells and/or ancillary facilities are located within that Buffer Zone, a filing with the Commission would be required.

- ***Local Permits.*** Local permits for building construction and for pipeline construction in public ways would be required.

Water Supply from Topsfield

The Town of Topsfield's water system is too distant to warrant consideration for the Exit 53 service area. Along Route 97, (which proceeds north from Topsfield to Exit 53), Topsfield's water system only extends as far north as the intersection with Bare Hill Road. Construction of 2.1 miles of water main would be necessary to connect the Topsfield water system from this point to the Exit 53 water distribution system. This substantial work is expected to render this option economically unfeasible, plus there are reliability and other technical concerns about a water system with such an unusually-long dead-end main such as this.

Topsfield's water system is, however, in close proximity to the eastern Exit 52 service area as shown on **Figure 5-5**.

On May 5, 2014, CDM Smith contacted the Town of Topsfield's Water Superintendent regarding the option of extending Topsfield's water distribution system into Boxford. Information collected suggests that Topsfield has sufficient capacity to serve the 30-to-50 homes in the Exit 52 service areas with residential water supply and that there is sufficient water pressure in the system. There are no known water quality issues in the distribution system at the Topsfield/Boxford town line.

Boxford Road and Silverbrook Road in Topsfield both have water mains that terminate near the Boxford town line. Boxford Road has a 6-inch water main installed in the 1940s and 1950s, and Silverbrook Road has an 8-inch water main installed in the 1960s. Both mains could be extended into Boxford to serve affected areas, providing redundancy for service to Boxford. Based on the Topsfield water distribution system operations information and ground elevations in the potential Boxford service areas, the anticipated water pressures are estimated to be in the 65-70 psi range. These are satisfactory pressures, thus it is not anticipated that a booster pump station would be required.

The extended distribution system could either serve the Silverbrook Road neighborhood east of I-95, or the Silverbrook Road neighborhood plus the Titus Lane neighborhood west of I-95.

5.7.3 Water System Facilities and Costs

The following presents assumptions regarding water supply sources used in the development of costs for community systems.

Water System for Exit 53 Service Area

We have assumed for the purpose of this report that the supply source would be a bedrock wellfield located at potential testing area No. 1 on **Figure 5-4**. This location is privately-owned, a short distance north of the private residence. Immediately north of the potential testing area is a large parcel within the Cleaveland Farm State Forest, owned and operated by the Massachusetts Department of Conservation and Recreation (DCR).

Should this area prove infeasible, the next-closest potential testing area is No. 2, located on the DCR property. Siting a community water supply well on State conservation property involves additional challenges but could be allowed with approval of the Legislature. If this location were also to prove infeasible, the next-closest testing areas are sand-and-gravel deposits located farther east on the DCR property.

Water system facilities would include the following:

- Two bedrock wells are required by MassDEP for redundancy purposes, each with its own pump and motor. Well depths of 400 feet have been assumed. Each well would need to have sufficient capacity to meet the entire service area's needs. The approved yield of each well, using the previously-presented water demand estimates, would be 36,400 gpd. The instantaneous pumping capacity would, however, need to be higher to meet the peak hour demand and avoid the need for water storage facilities. The peak hour demand estimate is 72,800 gpd, which equals 51 gallons per minute (gpm). Note that the approved yield translates to a separation distance (or Zone I radius) of about 335 feet.

- Treatment requirements would be determined during field testing of the well site. We have assumed that chemical treatment for disinfection and corrosion control would be needed, but that removal of salt constituents or radionuclides would not be required. Some bedrock wells require filtration to remove iron and/or manganese, which impair the taste and appearance of the water, and cause staining of plumbing fixtures and laundry. The possible need for such filtration is considered herein.

  Note that we excluded salt treatment because of the high costs of a large treatment system, including the required handling of a brine waste stream. The potential bedrock well testing site may be far enough from I-95 that it will not encounter high salt levels in the groundwater. If, however, testing were to prove otherwise, then moving farther away to the sand-and-gravel well location could be considered.

- A control and treatment building would be constructed at the wellfield.

- Raw water transmission mains would be constructed to convey water the short distance from the wells to the treatment building. A 6-inch diameter, 1,200-foot long finished water transmission main would convey the water southwest to the property driveway, and then to the distribution system in Route 97 as shown on **Figure 5-4**.

- It has been assumed that the entire distribution system would consist of 6-inch diameter ductile iron pipe. Smaller-diameter mains, and alternative pipe materials, could be considered in future evaluations. The total footage of the system shown on the figure would be approximately 6,900 feet. Gate valves would be included, but no hydrants given that the system is not intended for fire protection.

- A service connection, typically 1-inch in diameter, would convey water from the distribution system into each residence. Within the basement of the house, a water meter and other fixtures would be installed in order to connect to the household plumbing.

- The existing residential well at each house would be abandoned. Alternatively, consideration could be given to allowing residents to retain their private wells for use in outdoor irrigation. If this is considered, there must be a physical separation of the private well and the household plumbing, to eliminate risk of contamination of the community water system.

A cost estimate is presented later herein.

Water System for Exit 52 Service Areas

For the purpose of this report, the supply source for these two service areas is assumed to be connections to the Topsfield system as shown on **Figure 5-5**. Water system facilities would include the following:

- Meter vaults located at the town line, to meter the flow into Boxford from the two Topsfield water mains.
- We have assumed the entire distribution system would consist of 6-inch diameter ductile iron pipe. Smaller-diameter mains, and alternative pipe materials, could be considered in future evaluations. The total footage of the system shown on the figure would be approximately 5,370 feet for just the Silverbrook Road service area, or 13,820 feet for both service areas. Gate valves would be included, but no hydrants given that the system is not intended for fire protection. The extension to the west side of I-95 includes a directionally-drilled water main under I-95.
- A service connection, typically 1-inch diameter, would convey water from the distribution system into each residence. Within the basement of the house, a water meter and other fixtures would be installed in order to connect to the household plumbing.
- The existing residential well at each house would be abandoned. Alternatively, consideration could be given to allowing residents to retain their private wells for use in outdoor irrigation. If this is considered, there must be a physical separation of the private well and the household plumbing, to eliminate risk of contamination of the community water system.

We note in passing that, if desired, a single metered connection to Topsfield could be pursued instead of the redundant connections considered herein. This would reduce the pipe length by about 700 feet.

If for any reason it proves infeasible to connect to the Topsfield water system, then a community water system could be considered, using supply wells at one of the locations indicated on **Figure 5-5**.

Opinion of Probable Project Costs

Preliminary opinions of probable project costs for each alternative were developed based on conceptual facilities identified above, and are presented in **Table 5-24** .

Table 5-24
Cost Estimate for Community Water System Alternatives

Alternative	Cost Estimate
Options for Exit 53 Service Area	
Exit 53 Service Area, Bedrock Wellfield without Filtration	$ 4,000,000
Exit 53 Service Area, Bedrock Wellfield with Filtration	$ 5,000,000
Options for Exit 52 Service Areas	
Exit 52, Topsfield Extension for Silverbrook Road Service Area	$ 2,600,000
Exit 52, Topsfield Extension for Silverbrook Road and Titus Lane Service Areas	$ 6,400,000

If the Topsfield water system connection concept for supplying the Exit 52 service areas cannot be pursued, then separate community water systems with wells could be pursued for each of the Exit 52 service areas. In that case, the Exit 53 service area cost may be considered representative of a community water system for either of the Exit 52 service areas.

The costs above include construction of the facilities noted in the text; an allowance for permitting, engineering, and implementation; and contingencies. Land acquisition and legal fees are not included, nor are financing costs, effects of grants, or betterments. Assumptions were made on the amount of bedrock to be encountered during construction of the water mains and service connections. The cost estimates are based on June 2014 prices, and do not include inflation to future time periods. The Engineering News-Record Construction Cost Index for June 2014 is 9800.

Operations and maintenance costs would also be incurred for running the water systems, but have not been addressed herein. They would depend upon the level of water treatment actually needed, the actual number of and actual demand of the households on the systems, and (for the Exit 52 service areas) the results of future negotiations with Topsfield regarding water purchase price.

5.7.4 Water System Ownership and Management

For a new community water system to gain MassDEP approval, MassDEP must determine that the entity owning the system has the technical, managerial, and financial capacity to operate and maintain a public water system in accordance with State and Federal regulations. It is not the intent of this report to review all the issues MassDEP considers in determining whether a new system has adequate "capacity" in this sense; the reader is referred to Section 11 of the MassDEP Public Water System Guidelines[8] for such a discussion. Herein, we list several types of legal entities which can be considered when determining who should own and operate a new community water system.

Town of Boxford

The Town of Boxford could assume ownership and control over one or more new community water systems. MGL Ch. 40N[9], known as the "Model Water and Sewer Commission" act, should be considered by the Town if this option is pursued. That act could be reviewed and edited by the Town in developing its own enabling act for approval by the Legislature.

[8] MassDEP, Public Water System Guidelines. Chapter 11 - Capacity Development and Standard Operation Procedures. 2011. Web. August 29, 2014. <http://www.mass.gov/eea/docs/dep/water/laws/a-thru-h/glchpt11.pdf>

[9] Massachusetts General Laws Chapter 40N, Model Water and Sewer Commission. 2014. Web. August 29, 2014 <https://malegislature.gov/Laws/GeneralLaws/PartI/TitleVII/Chapter40N>

Typically, the Town would establish an appointed or elected Board of Water Commissioners to govern the operation of the community water system(s). In some cases, the Board of Selectmen would act as the Board of Water Commissioners for this purpose, depending upon the provisions of the enabling act. The Board of Water Commissioners might choose to have municipal employees operate the system, or might outsource part or all of the system operation by engaging the services of a private firm to provide certified water system operators.

The budget for water system operation would be established by Town Meeting each year. MassDEP strongly encourages that this be done within the framework of an Enterprise Account. This allows all revenues and expenditures for the water system to be identified and tracked separately from the rest of the municipal government costs, helps ensure that sufficient revenues will be available for system operation, and helps ensure that revenues from water billings are directed only to the water system.

Water District

Ownership and operation of a community water system could be under the control of a Water District. Such a District would typically be its own legal entity, distinct from the Town itself. It could have its own enabling act, which would need to address the same types of issues presented in MGL Ch. 40N (cited previously).

The geographic area of the Water District would be defined in its legislation. In this case, the area would presumably encompass the areas of the community water system(s) shown on **Figures 5-4** and/or **Figure 5-5**. The act would define whether all those within the geographic area must connect to the new system, or only those who so desire.

The District's Board of Water Commissioners would hold an annual District Meeting. At this meeting, residents of the District would conduct business such as adoption of a budget, establishment of water rates and fees, and election of Commissioners. The District Meeting would be separate from, and unrelated to, Boxford's Town Meeting.

Most likely, the District would outsource the operation of the water system to a private firm that would provide certified water system operators.

Homeowners Association

It is not mandatory to have a community water system be under municipal or District control. Instead, a private entity such as a homeowners association could be formed to own and operate the community water system. The association would operate in accordance with its own charter. Its members would consist of the homeowners who agreed at its inception to be part of the association and are named in the charter. Membership in the association would be a right and responsibility written into the property deeds.

The association would charge its members a fee to cover the costs of water system operation and maintenance. The association would engage a private firm to provide certified water system operators.

Should the formation of one or more community water systems be selected for implementation in Boxford, much further discussion would be required regarding the options for water system ownership and management. Legal counsel should be involved in such discussions.

For the Exit 52 area, consideration could also be given to the concept of the Town of Topsfield owning and operating the system in Boxford. In this case, Topsfield would issue water bills to Boxford customers in the same manner that it does for Topsfield customers. Approval of both towns would be needed, most likely in the form of an Intermunicipal Agreement (IMA) that would govern these arrangements.

5.7.5 Another Potential Water System Extension

Section 5.7 has focused on the areas of greatest impact upon domestic water supply wells, namely the Exits 52 and 53 areas. As was shown on **Figure 1-3**, however, there is a very small cluster of additional affected residential wells in the southernmost part of the Study Area. The affected residential areas of Fuller Lane and Fish Brook Road in Boxford are east of I-95 and close enough to the Topsfield water system that one could consider a water main extension to serve these homes.

The Topsfield water system has an 8-inch main on River Road in Topsfield, extending a very short distance west of that road's intersection with Ross Road. A new 6-inch main could be extended the rest of the way west to the town line, cross the town line at Fish Brook, and continue into Boxford on Fuller Lane and Fish Brook Road to serve these residents.

The new main would be approximately 1,950 feet long. We have prepared a cost estimate assuming that a meter vault would be constructed and that directional drilling would be utilized to install the new main under Fish Brook. Using the same procedures previously described, the preliminary opinion of probable project cost is $1,000,000.

The community water supply options in this **Section 5.7** may be compared to residential water supply options discussed in **Section 5.8** below.

5.8 Evaluation of Residential Water Supply Options

As was shown on **Table 5-25**, the screening procedure resulted in the following items being retained for the evaluation of residential water supply options:

Table 5-25
Retained Alternatives: Residential Water Supply Options

Alternative	Description
APPROACH TO INDIVIDUAL HOMES	
Point-of-Entry (POE) Treatment	▪ Whole house treatment system for salt constituents and other drinking water parameters.
Point-of-Use (POU) Treatment	▪ At point of use (typically kitchen faucet), install treatment systems at individual homes, for salt constituents.
Combined Point-of-Entry (POE) and Point-of-Use (POU) Treatment	▪ Treats water entering home (softener & neutralizing pH) with additional treatment to meet drinking water standards at locations where water is used for consumption.
Replacement Wells	▪ Replace existing domestic well when water quality declines due to salt concentrations; such replacement wells could be in bedrock or overburden depending on geology, yield, bylaw status, water quality, and surrounding land uses.
COMMUNITY APPROACH	
"District" for Operations and Maintenance of POE/POU Treatment Systems	▪ Establish a District solely devoted to the operation and maintenance of residential POE/POU devices.
POLICY/PROGRAM	
Revise Local Regulations	▪ Implement revisions to the Town of Boxford Board of Health (BOH) Private Water Supply Regulations to provide homeowners greater flexibility in type of domestic well.
Public Education	▪ Provide public education regarding aquifer protection, well head protection, domestic well operations, and water quality.

5.8.1 Current Practice

In 1986, MassDOT, formerly MassHighway, began the Salt Remediation Program to address the environmental and health impacts associated with winter deicing activities performed on state-owned roads throughout the Commonwealth of Massachusetts. There are steps a resident is required to take to report a well suspected to be impacted by deicing activities. MassDOT will perform a site visit if the Massachusetts Office of Research and Standards Guideline (ORSG) for sodium or Secondary Maximum Contaminant Level (SMCL) for chloride is exceeded, or if the resident is on a sodium-restricted diet.

If water quality suggests impacts from deicing materials, MassDOT will implement one or more remedial actions which may include:

- Connection to a public water supply
- Well replacement
- Rehabilitation of the existing well
- Water treatment installation, with either point-of-use (POU) or point-of-entry (POE) treatment, which are described below. POU treatment such as reverse osmosis (RO) is installed if sodium and chloride concentrations are at or slightly above their respective drinking water standard. At the written request of the resident, MassDOT will also consider the potential for corrosion of plumbing fixtures if groundwater chloride concentrations exceed 250 milligrams per liter (mg/L). In situations where chloride concentrations greatly exceed 250 mg/L, MassDOT may suggest a POE "whole house" treatment as a remedial action.
- Other measures not directly related to water supply, such as highway drainage modification, implementation of a RSZ, and/or improved salt storage, handling, and housekeeping practices.

A Salt Remediation Program entry request is denied by MassDOT if it is determined that:

1. Non-MassDOT related activities are the cause of salt-impacted groundwater (such as the use of a sodium based water softening system in the home).
2. Poor well construction allows surface contamination to enter the well, based on inspection or review of available well construction log.
3. The septic system is within the prohibited limits (50 feet) of the drinking water supply well as outlined in 310 CMR 15.0, The State Environmental Code, Title V (MassDEP, January, 2014).

More information on MassDOT's Salt Remediation Program can be found in **Section 2.4.1** of this report.

5.8.2 Residential Water Treatment Options

There are two general approaches to treating salt-impacted residential well water: POE treatment and POU treatment. Sometimes the two are used together. Both approaches are described herein.

The intent of all treatment systems is to remove salt to a level that will provide aesthetically-pleasing drinking water. These treatment systems employ a membrane-based process, RO, to remove salt constituents. The nature of the RO systems would be determined on a house-by-house basis, and may vary due to influent water quality and water demand.

RO treatment systems remove some other contaminants from drinking water as well, and supplementary treatment equipment may be appropriate to treat for additional contaminants. For example, RO systems also remove arsenic. The percentage of arsenic removed will vary based on the treatment system selected, but may be in the 80-95% range. RO systems may, however, be fouled by hard water containing iron higher than approximately 0.3 mg/L and manganese higher than approximately 0.05 mg/L. The systems may have restrictions on influent water quality parameters, such as hardness, total dissolved solids (TDS), pH, and pressure. Locations with high levels of iron and manganese would likely need to consider a supplementary filtration system to remove iron and manganese prior to the RO system. Locations with high hardness would need a water softener before RO treatment to prevent clogging of minerals (i.e., calcium and magnesium).

The discussion that follows is based on information from the following two manufacturers of residential treatment systems, both of which are familiar with the Boxford area:

- Atlas Watersystems; www.atlaswater.com
- Secondwind Water Systems; www.secondwindwater.com

Point-of-Entry System

POE systems treat all of the water entering the home, either to drinking water standards or (if desired) to a lesser degree. Such systems can eliminate corrosiveness, can remove hardness to a level that does not scale, and can provide potable drinking water to all fixtures in the house.

The Atlas POE product is designed to resolve the sodium and chloride issues for water containing less than 2,000 mg/L of TDS, which includes sodium and chlorides. The Secondwind POE product can treat raw water containing up to 2,500 mg/L. Based on available data of residential well sodium and chloride levels, it appears both of these products would readily provide satisfactory salt removal treatment for residents throughout the Study Area. For example, as was shown on **Table 3-10**, the highest values observed in CDM Smith's domestic well sampling program were 230 mg/L sodium and 390 mg/L chloride.

Treatment components typically include a water softener, a large RO desalination system including a storage tank and booster pump, upflow neutralizer to raise the pH and add some hardness to the water, and an optional carbon cartridge for taste control. The dimensions of Secondwind's RO desalination system are approximately 54 x 20 x 22 inches. This system also requires a water storage tank between 35 and 48 inches in diameter.

Atlas Watersystems RO System

A large RO system is capable of treating at least 300 gpd to supply a family of four. An RO system of this size would require a drywell outside the house, which would receive the discharge from the RO system backwash.

The Atlas POE system requires the addition of salt for the water softener filter backwash. A homeowner could choose to add the salt on their own or they can opt to have a company take care of this. Typically the water softener requires the addition of salt every three months. Secondwind's water softening unit also requires the addition of salt in the "brine tank" and filter cartridge replacement; both are maintenance procedures that the homeowner can complete on their own. The frequency of salt addition and filter replacement is dependent on the raw water quality and water usage. Annual service checks by a manufacturer's representative are recommended.

Typically, the salt used in the process is sodium chloride, hence the discharge to the drywell adds sodium and chloride to the groundwater. Another option, however, is to utilize potassium chloride for the water softener salt. The discharge would then contain potassium and chloride, but no sodium.

Point-of-Use System

POU systems treat water at water faucet locations through the use of a small RO system.

The discharge from a POU RO system could be piped into the septic system. Otherwise a small drywell would be required.

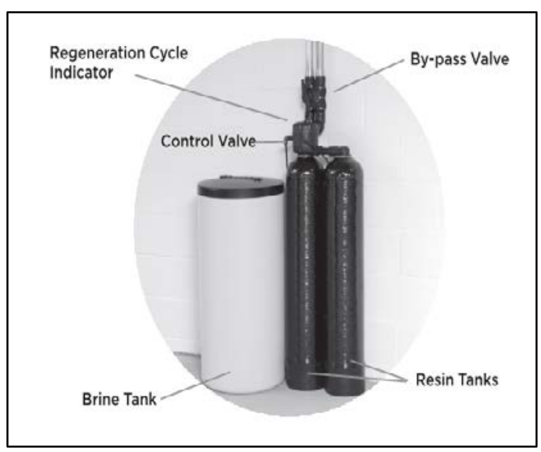
Additional information about POU systems appears in the next subsection.

Secondwind Water Systems POU RO System

Point-of-Entry and Point-of-Use System Combination

In this option, the POE system treats all water entering the home by softening the water and neutralizing the pH, but the POE treatment does not attempt to meet drinking water standards. Additional treatment to meet drinking water standards at one or more faucets in the house is provided by a POU system.

For this combination option, Secondwind offers a POE water softener unit and a POU RO system. The POU RO system can treat raw water containing less than 3,000 mg/L total dissolved solids, assuming a twin tank non-electric RO system is used. The twin tank system has a useful life of 20-25 years, as compared to a single tank system with a useful life of 10-15 years.



Secondwind POE Water Softening System

Filter cartridges can be used with Secondwind's POU RO system to remove constituents such as volatile organic compounds (VOCs), perchlorate, and others. Filter cartridges should be changed every 500 gallons; for a family of four, this is typically 9-12 months. The user's manual offers guidance for homeowners to perform this maintenance on their own, including a sanitization kit provided by the manufacturer to be used after changing out the filter cartridges.

According to Secondwind, it is anticipated that the neutralizer and RO system should be serviced annually and the water softener should be serviced every one to three years depending on water usage, raw water quality, and if the homeowner chooses to add salt to the water softener and change filter cartridges on their own.

Discharges from the two types of treatment units would be handled as described earlier and are expected to be from one to a few hundred gallons per week.

Costs of Treatment Systems

Capital costs and typical O&M costs were obtained from the vendors, who were told to anticipate hard water with elevated levels of sodium and chloride.

Operation and maintenance service intervals and cost can vary based on water quality, treatment and usage. A running toilet, leaky faucet, or long showers are examples of significant increased water usage that can affect operation and maintenance.

Quotes are presented in the table below.

Table 5-26
Direct Vendor Quotes – Residential Treatment Systems

Company	System	Furnish and Install (Labor and Material) Cost	Annual Operation and Maintenance Cost[4]
Secondwind Water Systems, Inc.[1]	POE & POU[3]	$ 9,500	$ 900
	POE	$25,000	$2,600
Atlas Watersystems, Inc.[2]	POU[3]	$ 3,500	$ 200
	POE	$28,500	$1,200

Notes:

[1]The Secondwind Water Systems cost estimate includes individual site evaluation, installation, post installation homeowner training, and an allowance for a plumber. The treatment provided includes a water softener, a RO system, and an upflow neutralizer. The POE & POU cost includes the optional carbon cartridge and assumes a single tank electrical softener. The POU cost assumes a twin tank non-electric system, regardless of whether the POU system is in a stand-alone application or part of a combined POE/POU system. The estimate does not include the cost for a drywell (necessary for the POE system). Electrical upgrades may be required.

[2]The Atlas Watersystems cost estimate includes pre-filtration, storage tank with re-pressurization pump, post-filtration, and the plumbing and electrical work required to install a basic system. The price does not include facilities required to accept discharge from the system, dry wells, or septic upgrades (if required).

[3]POU costs assume a single system in the home; additional cost for multiple POU systems.

[4]The level of O&M depends on the treatment system chosen; costs provided do not include electricity to operate the system. Note that the use of potassium-based salt instead of conventional salt would add cost. For example, at the time of this writing, Home Depot was offering 40-pound bags of potassium chloride for water softeners at about $27, while 40-pound bags of sodium chloride for water softeners were under $5.

5.8.3 Replacement Wells

As noted earlier, MassDOT's Salt Remediation Program has historically provided several types of remediation activities, one of which is well replacement.

In general, replacement wells can be an appropriate remedial response for residential water supply wells in the following cases:

1. When a well seal is severely corroded or otherwise broken, allowing near-surface contamination in overburden to enter the bedrock well. (This situation is not eligible for MassDOT participation through the Salt Remediation Program, but such a well will nevertheless need replacement.)

2. When a well cannot maintain satisfactory yield. (Again, this is not a MassDOT concern.)

3. When a constituent of concern is localized in its extent either horizontally or vertically, and can be avoided by moving the location of the water withdrawal.

Regarding the last case above, the use of replacement wells for salt constituents in Boxford is complicated by these factors:

1. In some cases, it may be difficult on a given residential property to find a suitable location for a replacement well that meets all the relevant siting criteria in the Town's "Private Water Supply Well Regulations".

2. Multiple attempts at drilling a replacement well may be needed, if the first attempt is unsuccessful in terms of either quantity or quality. As noted below, this has occurred in a number of locations in the Study Area.

3. As was discussed in **Section 3.6**, the hydrogeologic evaluations of the Study Area concluded that the Study Area's bedrock is highly fractured throughout the vertical column in many areas. Such a high degree of fracturing indicates a high degree of hydraulic interconnectedness across the vertical profile. When groundwater is withdrawn from a particular depth in such a profile, there is a tendency for groundwater at other depths to move toward the withdrawal point.

CDM Smith reviewed available residential well water quality data for Study Area replacement wells installed through the Salt Remediation Program. Of the18 replacement wells installed, 13 required multiple attempts before a successful well was drilled. Of these, only three locations had water quality records available long-term after replacement well installation. In two of those three, it appeared there was long-term improvement in the water quality. In one, there was no improvement.

Because of the hydrogeologic characteristics of the Study Area bedrock, there will always be a risk of salt-impacted groundwater migrating into a replacement well. Even if the initial water quality results from such a well appear favorable, the water quality could change over time as nearby groundwater is drawn into a new replacement well, a process that could take months or longer. This, in turn, could mean a treatment system would have to be installed anyway, with the result being that the cost of the replacement well is wasted. A representative cost of a 400-foot deep replacement well, including pump, motor, and 50-foot connecting pipe, is $10,000.

If the first test well installed as a potential replacement well is not successful with regard to yield or water quality, then additional test well(s) must be attempted at a cost of about $5,000 per test well (not including a permanent pump, motor, and connecting pipe). It should also be noted that in several cases, replacement wells have been installed at substantial depth, upwards of 1,000 feet-BGS. For comparison, a 1,000-foot test well is estimated to cost about $11,000.

Therefore, given the extensive nature of the fractured bedrock in the Study Area, pursuit of replacement wells to secure a safe drinking water supply for residents should proceed with caution in consideration of specific site geologic characteristics.

Should any existing or future replacement well in the Study Area eventually need to be abandoned, whether via the MassDOT Salt Remediation Program or private home owner, CDM Smith recommends that proper well abandonment procedures be followed. Given the hydrogeology of the Study Area's bedrock, the procedures should ensure that salt-impacted water cannot mix through the borehole with clean groundwater at other depths. Recommended well abandonment procedures are provided in MassDEP's "Guidelines and Policies for Public Water Systems" and in their "Private Well Guidelines".

CDM Smith contacted Skilling & Sons, Inc. to obtain a cost estimate for well abandonment of $3,000. This cost was based on a 400-foot-BGS bedrock well with a 40-foot casing. Well abandonment also should apply to any attempts at replacement wells (i.e., test wells) which are proven unsuccessful due to lack of yield or poor water quality, in which case the cost for the entire replacement well effort increases.

5.8.4 Institutional Issues

This subsection discusses three issues concerning residential water supply facilities.

Assurance of Water Treatment System Maintenance

As discussed above in **Section 5.8.2**, residential water treatment systems all require periodic maintenance to assure continued system performance and to assure the long-term potability of the residential drinking water. Typically it is the property owner who is responsible for performing maintenance on these systems. As with many maintenance issues, it may not be unusual for maintenance to be deferred or ignored, but with drinking water systems the consequences of such neglect can be more significant than with other home maintenance items.

Consideration could be given to an institutional arrangement to provide assurance that all residential treatment systems would be properly maintained. A Water District, or homeowner association or other type of arrangement, could be developed to fulfill this responsibility. An outline of the concept follows, and would be essentially the same regardless of the type of governing entity:

1. A charter or enabling act from the Legislature (depending on the nature of the entity) would be developed to define the roles and responsibilities of the new entity. The founding documents would define the geographical extent of the District, most likely as a list of residential properties rather than as a contiguous geographic area. If desired, the Town or another entity could function as the coordinator to develop these legal arrangements. If a homeowner association were pursued, these arrangements may become part of the property's deed.

2. The entity would maintain a database of all residential properties, property owners, contact information, treatment systems at each property, and maintenance requirements for each treatment system.

3. The entity would engage the services of a licensed plumber or certified water system operator to carry out all vendor-recommended maintenance activities. Each type of activity and its cost would be defined in the maintenance contract.

4. The contractor would make appointments to enter the residences annually or more frequently as needed, to carry out the maintenance activities. The contractor would also be available for emergency service.

5. The entity would be funded by annual payments from the property owners. Payment schedules would be set at an annual meeting.

There are several advantages to such an approach, especially when there are a number of residences in close proximity that could benefit from such service:

1. It would provide substantial assurance of the continued proper operation of the residential water treatment systems.

2. Economies of scale may be achieved by property owners acting as a group, rather than separately as individuals.

3. There could be a "stigma" associated with having a private well affected by salt constituents, particularly when a home is placed on the market. If, however, the home is part of a Water District or has some other formal arrangement to assure regular treatment system maintenance and drinking water quality, that should offset most if not all of any such negative appearance.

The foregoing concept is potentially applicable at any of the areas previously identified as having potential for a community water system, should such a water system not be pursued. Property owners in the potential Exit 53 service area, plus either or both of the potential Exit 52 service areas, could be part of this new entity. Affected properties outside these potential service areas could also participate.

Town Regulation Modification

CDM Smith reviewed the Town's "Private Water Supply Regulations", which are Chapter 202 of the Town Code. Section 202-3E(1) prohibits water supply wells from being installed in sand-and-gravel deposits which overlie bedrock. This could unnecessarily restrict homeowners who need a new or replacement well, whether due to a yield issue, elevated salt concentrations, or other water quality concern. Having available options in consideration of local geology, land uses, potential contaminant sources and water quality seems appropriate to maximize a homeowner's opportunity for a safe and adequate domestic water supply. Further, the depths of drilling for sand-and-gravel wells are much less than for typical bedrock wells, and thus the costs are typically less. While we have not performed a detailed search, we are not aware of any such regulation affecting water supply well drilling activities in the other cities and towns of the Commonwealth. For these reasons, CDM Smith recommends that the Town regulation be revised to allow sand-and-gravel wells for domestic purposes.

Public Education

MassDOT and the Town share an interest in educating the residents of the Study Area about their wells, drinking water, and the effects of homeowner activities. Private drinking water wells in Boxford are under the jurisdiction of the Boxford Board of Health (BOH). The BOH's webpage notes that one element of BOH's mission is to "Inform, educate, and empower people about health issues." Public education efforts regarding private wells and residential water treatment systems fit well within that mission.

Public education about private drinking water wells could fall into any or all of several broad categories, such as:

- Water well construction
- Water well maintenance
- Drinking water quality and public health
- Residential water treatment systems
- Groundwater quality protection

Specific topics that are particularly relevant to the Study Area, and which would be fruitful focuses of public education, include the following:

- Residents should always use a State-certified well driller when constructing or rehabilitating a domestic water supply well. The driller should follow industry-standard construction procedures, especially including provision of a sanitary seal to prevent any near-surface contaminants from migrating downward along the well casing and entering the borehole.
- Encouraging awareness that all wastewater disposal in Boxford is through septic systems. Everything discharged through septic systems, including not only the water but all substances disposed down sinks and toilets, ends up in Boxford's groundwater, and could potentially affect private drinking water wells. The disposal of household cleaners, pharmaceuticals, and personal care products through residential septic systems are among the activities that should be discouraged. In many cases, the first residential well that would be affected by such activities would be that of the individual disposing of the substances.
- While road salt utilized by MassDOT and the Town can be a source of salt constituents in groundwater, homeowner activities can also result in increased salt levels in local groundwater. Examples of such activities include use of rock salt on driveways and walkways, and the use of water softeners for residential water treatment. Such systems have a brine waste which commonly is disposed of through the residential septic system.
- All the components of a residential water system need maintenance from time to time. The well itself, the pump, the motor, and plumbing system components all will need work from time to time. Understanding these components, and the typical issues associated with their use, is beneficial to the homeowner.

- A residential water system which includes treatment equipment has even greater operations and maintenance requirements than other systems. Each treatment system manufacturer has made available recommended procedures for operations and maintenance, which the homeowner should be aware of and follow. The value of residential well water quality sampling can be promoted. EPA and MassDEP offer recommendations for analytical parameters and monitoring frequency which are presented in **Table 5-27**. Residents may consider increased sample frequency to provide regular checks on water quality.

Table 5-27
Sampling Plan for Residential Well Water Quality

EPA/MassDEP Recommendations for Private Well Sampling
Initially and Every Ten Years
Metals: Arsenic, Copper, Iron, Lead, Manganese
Salt constituents: Sodium, Chloride
Radiological constituents: Radon, Gross Alpha Screening
Volatile Organic Chemicals
Other: pH, Hardness, Fluoride
Initially and Annually
Coliform Bacteria
Nitrate/Nitrite

Source: www.mass.gov/eea/docs/dep/water/laws/i-thru-z/prwellgd.pdf

Among the means by which public education can be provided are the following:

- Town website, through links on the Board of Health webpage
- Printed materials available at Board of Health office
- Stuffers with property tax bills
- Booth at Town events or fairs
- Public service announcements in newspapers or on cable TV

The following is a list of websites which contain information about private wells. A number of educational materials are available which could readily become part of a local public education program.

- U.S. Environmental Protection Agency Website on Private Drinking Water Wells: www.water.epa.gov/drink/info/well/index.cfm

- MassDEP Website on Private Drinking Water Wells: www.mass.gov/eea/agencies/massdep/water/drinking/private-wells.html

- New Hampshire Department of Environmental Services Checklist for Private Well Inspection: www.des.nh.gov/organization/divisions/water/dwgb/well_testing/documents/checklist.pdf

- National Ground Water Association's Wellowner.org website, which includes educational webinars for private well owners: www.wellowner.org

The public education efforts identified are relatively low in cost but could prove beneficial to residents relative to the operation and protection of their domestic wells. The most practical avenue for implementation of such public education is locally through the Town. The Boxford Watershed Association could also be a mechanism for dissemination of information and public education material. Finally, MassDOT should continue efforts to educate residents about the availability of the Salt Remediation Program in cases of salt impacts to domestic wells, and provide information about other efforts being undertaken to limit the future impacts of deicing materials.

5.9 Evaluation of Remediation Options

Based on the screening procedure described in **Section 5.3**, **Table 5-28** lists the remediation options retained for evaluation.

Table 5-28
Retained Alternatives: Remediation Approaches

Alternative	Description
Scavenger Well #3 (at Boxford Depot)	▪ Continue operation of Scavenger Well #3 at Boxford Depot with discharge to stream (status quo - no treatment)
	▪ Continue operation of Scavenger Well #3 at Boxford Depot with treatment

Several additional items are also addressed in this section, as follows:

- ***Future Disposition of Scavenger Well #3:*** Considerations are provided regarding a hydrogeological evaluation and future discharge monitoring of Scavenger Well #3 as a means of assessing the effectiveness of continuing Scavenger Well #3 operation.

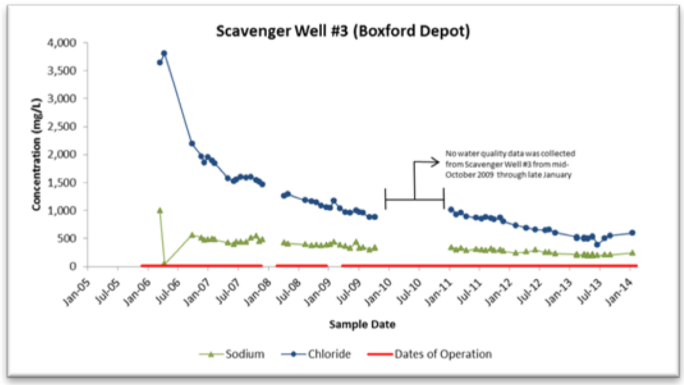
- ***Onsite Soils Remediation at the Boxford Depot:*** Soil treatment (ex situ) at the Boxford Depot was screened in **Table L-6** and not retained as an option for further evaluation. However, further inquiries relative to the advisability of undertaking a soil removal effort at the site given soil and groundwater quality data necessitated further consideration.

- ***Abandonment of Old Wells at the Boxford Depot and within the Study Area:*** Consideration should be given to abandonment of several old wells remaining at the Boxford Depot, which could be serving as potential conduits for salt migration.

- ***Record-keeping of the Salt Remediation Program:*** Suggestions are provided for improved record keeping of the MassDOT Salt Remediation Program.

The screening effort eliminated the installation of multiple scavenger wells in the Study Area as a means of collecting impacted groundwater. This decision was based on new information gathered from the borehole geophysics conducted as part of this study which identified the extensive bedrock fractures in the Study Area. Other factors considered included potential impacts to domestic wells (water quality and flow) from scavenger well operations, the number of scavenger wells that would need to be installed to address the water quality impacts, conveyance and treatment of pumped groundwater and disposal of treatment byproducts (brine), and concerns about the efficacy of such a measure in improving groundwater quality given the scale of existing impacts both laterally and vertically. While scavenger wells would be successful to a degree in removing salt constituents from groundwater, extensive additional work would be needed (as described below) to determine the extent of the capture zone of new or existing scavenger wells, and the degree to which they accelerate overall remediation.

5.9.1 Future Disposition of Scavenger Well #3



Historical Water Quality at Scavenger Well #3

In an effort to address salt impacts in bedrock groundwater, MassDOT began operating Scavenger Well #3 in 2006. Scavenger Well #3 pumps continuously at about 5 gpm, extracting groundwater from the bedrock and discharging the water to a nearby stream east of the salt shed. **Section 2.4** presented further information about this well and its historic operation. **Figure 2-9** shows how the sodium and chloride levels have declined since operation of the well began. Concentrations in the past 1-2 years, however, appear to have leveled off. Concentrations of both sodium and chloride remain above their drinking water standards. Recent sodium levels are 200-300 mg/L, as compared to the Massachusetts ORSG of 20 mg/L, and recent chloride levels are 400-600 mg/L, as compared to the SMCL of 250 mg/L.

The operation of this well has removed salt from the bedrock groundwater system over time. Assuming pumping at this well has remained relatively constant, and based on the measured chloride concentrations at this well, Scavenger Well #3 has extracted approximately 90 tons of chloride during its period of operation. This is approximately equivalent to 120-150 tons of deicing materials (NaCl, $CaCl_2$, or $MgCl_2$). Sodium and chloride concentrations in the pumped groundwater at Scavenger Well #3 remain elevated, and so with continued pumping, more salt mass can be removed from the bedrock.

5.9.1.1 Additional Hydrogeological Evaluation of Scavenger Well #3

Although there is a good database of historical water quality at Scavenger Well #3, there is also a need for additional information to make a more informed decision about the value of long-term operations of this well and the effect of well operation upon transport of salt constituents. The extent of the capture zone of Scavenger Well #3 and the mass of salt constituents remaining at the Boxford Depot are not well known at this time.

To provide additional information and to refine the assessment of these issues, a hydrogeological evaluation is recommended, the scope of which may consist of the following elements:

- Installation of at least one new bedrock well, located downgradient of Scavenger Well #3 and the collection of groundwater quality data from this well.

- Geophysical logging of the new bedrock test well and existing well TW-1 located on the Boxford Depot parcel.

- Additional shallow monitoring wells on the Boxford Depot property to obtain soil and groundwater quality data.
- A pumping test on Scavenger Well #3 to monitor the effects of pumping at nearby wells, especially the new bedrock test well and TW-1, as well as any other off site wells that may be available for monitoring.
- Hydrogeologic evaluation of the new data to estimate the capture zone of the well and mass of remaining salt constituents.

The cost of such a program may be in the range of $100,000 to $150,000, depending on the number of monitoring wells installed.

Regardless of the results of a future hydrogeological evaluation at Scavenger Well #3, there is a need to consider whether to modify the current facilities for discharging this water. The next two subsections address this issue.

5.9.1.2 Continuation of Current Operations with No Treatment

At this time, MassDOT has no plans to change the continuous operation of this well nor its discharge to the nearby stream. This discharge, however, reintroduces the salt to the environment via untreated discharge to surface water. There is a potential for this discharged water to reenter the groundwater system further downstream, depending on the surface water/groundwater interactions and the depth to bedrock in downstream areas.

Alternatively, there is an option to connect the Scavenger Well #3 discharge to the stormwater drainage system in the Exit 52 southbound on-ramp, resulting in discharge of the well water approximately 4,000 feet downgradient to an I-95 drainage channel outfall (see sampling location FBW2AA on Map Panel 8 in **Appendix B**) that flows to Silver Brook at Lockwood Lane. This would include approximately 1,200 linear feet of drainage and the associated wellhead connection, at a total cost of about $130,000. Cost savings would be achieved if drainage infrastructure at the Boxford Deport, discussed in **Section 5.5** and shown on **Figures 5-2A** and **5-2B** were constructed and connected to the Phase 1 and 2 stormwater drainage improvements discussed in **Section 5.6**. In this case, only 150 linear feet of drain pipe would be needed to connect Scavenger Well #3 to the closest proposed catch basin on the west edge of the pavement at the Boxford Depot. This alternative is estimated to cost about $16,000 including the wellhead connection, assuming it was conducted during other site upgrades. These costs include allowances for construction contingency, engineering, and implementation.

5.9.1.3 Continuation of Current Operations with Treatment

The possibility of treating the discharge for removal of salt constituents was considered as a remediation alternative. Such treatment would eliminate the possibility of salt constituents being reintroduced to the surface water and groundwater downstream of the discharge point.

The prior section on residential water supply discussed reverse osmosis (RO) treatment for desalination of residential drinking water. The same process could be employed for the Scavenger Well #3 water, albeit at a larger scale for the 5.5 gpm (8,000 gpd) discharge. The treatment systems discussed in the prior section can readily address the salt levels now being extracted by this well.

CDM Smith contacted one of the RO vendors, Secondwind Water Systems, to discuss possible salt removal treatment for the Scavenger Well #3 water. The vendor indicated the following:

- The skid-mounted RO system for such an application would have dimensions of about 6 feet wide by 15 feet long by 8 feet high.
- The building to house the treatment system would need to be at least 20' x 20'.
- The facilities would include a storage tank to collect the large amount of backwash water and brine generated by the treatment system.
- The total construction cost for the system would approach $500,000.

CDM Smith calculates that about 35% of the water treated by the RO system would become a brine waste, needing to be stored and disposed. There is no sewer system within reasonable distance, for disposing of the brine. Disposal to the environment cannot be considered, as the purpose of this treatment system would be to eliminate such discharge. Therefore, the brine would need to be stored onsite and trucked away for disposal elsewhere. Such trucking would occur on a daily or near-daily basis because of the volume being generated, thereby leading to significant continuing operational costs. Because of the potentially significant added cost, CDM Smith recommends not treating the pumped groundwater from Scavenger Well #3.

5.9.1.4 Scavenger Well #3 Water Quality Monitoring

Continued sampling of Scavenger Well #3 discharge on a regular basis is recommended. The current sampling frequency is monthly, but quarterly sampling would be sufficient for tracking water quality changes and trends. The flow rate of the well should also be checked and recorded at least annually. The benefit of continuing the discharge from Scavenger Well #3 could be reconsidered annually, based on the latest analytical results.

5.9.2 Onsite Soils Remediation at the Boxford Depot

To further evaluate onsite soils remediation at the Boxford Depot, two potential scenarios are discussed below.

- No action, beyond continued routine monitoring at onsite overburden wells and Scavenger Well #3 discharge.
- Excavation of onsite soils that are impacted by deicing materials.

5.9.2.1 No Action

Deicing material groundwater concentrations in the overburden at the Boxford Depot have decreased over time. At monitoring well WS-2 located near Scavenger Well #3, groundwater chloride concentrations have decreased from about 520 mg/L in 1995 (based on specific conductance of 1,940 microsiemens per centimeter (µS/cm)) to 2 mg/L in 2014. Sodium groundwater concentrations at WS-2 are within the range of background concentrations. At another onsite location, the reported 2014 chloride concentration at WS-3 (420 mg/L) is much smaller than the estimated 1995 chloride concentration at nearby well WS-1 (about 6,000 mg/L), based on a 1995 specific conductance measurement (18,900 µS/cm). Wells WS-3 and WS-1 are about 100 feet apart and are located downgradient of the paved area at the Boxford Depot, generally cross-gradient to one another.

The soil analytical results from MDOT-SB-3, which is slightly upgradient from WS-3, show that the surface and vadose zone soil (0-5 feet) has very low to background concentrations of salt (i.e., chloride concentration is 5.9 micrograms per gram (µg/g), see **Table 3-7**). Therefore the surface soil/vadose zone soil in this area is not contributing significantly to any groundwater contamination via infiltration (direct rainfall). In general, soil concentrations in the shallow sampled intervals (typically 0-5 feet deep) at the Boxford Depot were lower than those reported for the deeper intervals (typically 5-10 feet deep). The soils in the saturated zone soils at MDOT-SB-3 (5 to 8 feet) have slightly elevated salt concentrations (i.e., chloride is 200 µg/g, see **Table 3-7**) and will continue to potentially impact groundwater. Given the significant decreases in overburden groundwater concentrations observed in Boxford Depot wells compared to historical values, the reduced amount of mass that may be released via infiltration because of lower unsaturated shallow soil concentrations, and the expectation that groundwater concentrations will continue to decrease, it is concluded that soil removal is not warranted.

Other soil samples in the vicinity of the Boxford Depot (i.e., MDOT-SB-1 and MDOT-SB-2, see **Table 3-7**) have some elevated concentrations of chloride. However, because of the locations of these samples (not in the open area, see **Figure 3-5**) and limited infiltration (i.e., periodic dry wells), only additional monitoring at overburden well locations is warranted.

5.9.2.2 Excavation of Onsite Soils

Assuming that the portion of the Boxford Depot parcel where soil has been impacted by deicing material infiltration is approximately 65,000 square feet in size, and the depth of impacted soil is approximately 10 feet, approximately 24,000 cubic yards would need to be removed. Removal and replacement of soil and the associated site restoration is estimated to cost $25 per cubic yard. Additional efforts would be required to assess soil concentrations for different contaminants to determine off-site disposal requirements and costs. If there are no soil quality limitations based on analytical results, a low cost option for transportation and disposal of the soil at an in-state landfill costs about $75 per cubic yard. More expensive scenarios, which could include treatment and/or out of state disposal of the soil, could cost $150 per cubic yard or more. As such, the construction cost of this effort could potentially range from $2.4 million to $4.2 million or more, depending on disposal requirements. Given the high costs, CDM Smith does not recommend further consideration of this option, especially in consideration that the need for soil removal at the Boxford Deport has been determined unwarranted based upon review of soil and groundwater concentrations (see **Section 5.9.2.1**).

5.9.3 Abandonment of Old Wells at the Boxford Depot and within the Study Area

Abandoning wells that are no longer of use reduces the likelihood that the wells become conduits for salt and other contaminant transport to the subsurface. Recommended bedrock well abandonment procedures were presented in **Section 5.8**.

The following wells at the Boxford Depot could be considered for abandonment:

- ***MW-D.*** No information is available about this well. It should be abandoned.

- ***WS Wells.*** Four wells were installed in the 1995 study by Weston & Sampson, Inc. They are numbered as WS-1 through WS-4, and are shallow monitoring wells in the overburden. WS-1 is damaged and should be abandoned. The other three remain useful for sampling purposes and should be retained. Consideration should be given to replacing well WS-1.

- ***TW-1.*** This well, installed in 2006, was intended at the time to become a new water supply well for the Boxford Depot. It is a 560 feet-BGS bedrock well, including ten feet of overburden. If it were never to be used for water supply purposes, it would be a candidate for abandonment. Alternatively, MassDOT may wish to retain this well for use as a water supply source for the Boxford Depot. The water quality from TW-1 is much better than that of Scavenger Well #3.

- ***Inactive Replacement Wells and Scavenger Wells.*** An inventory of inactive replacement wells and scavenger wells should be completed throughout the Study Area, and any wells that will not be used for future study should be properly abandoned. For instance, Scavenger Well #2 which is 900 feet-BGS should be considered for abandonment.

5.9.4 Salt Remediation Program Records Keeping

Based on existing data collection and review conducted for the Boxford Salt Study, the following improvements to MassDOT Salt Remediation Program record keeping are suggested for consideration:

- Ensure well logs are prepared for all replacement wells installed, whether or not activated. In addition to standard stratigraphic and well construction information, well logs should include approximate GPS coordinates of the well's location (in addition to parcel number and address) and a unique identification number.

- There has been difficulty in tying the available historical water quality data to individual test wells or replacement wells. Using the unique well identification number on the laboratory sample would alleviate this problem. Sample depths should also be recorded and tied to water quality data collected, as it has been established that water quality may vary at depth depending on fracture presence.

- Building a comprehensive database to include new water quality data by identification number and date would facilitate evaluation of water quality trends and allow for tracking the progress of implemented measures.

- Standard nomenclature should be established to clearly identify raw and finished (i.e., treated) water samples collected at residences. Such records should also indicate the location of the finished water sample collected. This information is necessary in order to successfully assess salt concentrations over time in groundwater, and the potential influence softeners and other treatment processes may have on water quality results.

It is recommended that MassDOT develop a SOP for record keeping which could incorporate these suggestions. Such an SOP would be applicable to all data collection efforts of the Salt Remediation Program throughout the Commonwealth.

5.10 Alternatives Evaluation Summary

An alternative analysis has been conducted to evaluate mitigation measures that may be implemented to reduce the impacts of salt storage and handling, and deicing materials application within the Study Area. Measures to provide residents in the Study Area with safe drinking water are also identified. As stated in **Section 5.1**, these objectives included the following:

- To determine "what measures need to be taken to prevent [infiltration of deicing chemicals to groundwater aquifers and bedrock fissures] from occurring in the future."
- To develop recommendations for "short-term and long-term remedial actions necessary to restore groundwater quality to a safe drinking water standard within the I-95 corridor".
- To develop "a plan to modify highway drainage systems to prevent stormwater run-off and highway drainage from adversely impacting aquifers, bedrock and adjacent wetland resource areas".
- To develop "an alternative means to provide a reliable and adequate safe drinking water supply to the residents located within the I-95 corridor meeting all state and local requirements."

To address these objectives, six categories of alternatives have been evaluated. **Table 5-29** identifies the alternative categories and the options evaluated for each relative to the stated objectives. Based on the results of the evaluation and associated recommendations, follow-up actions are identified in **Table 5-29** for both MassDOT and the Town. In some cases, actions will also be required by residents; such needs are identified under the Town of Boxford column.

Specific recommendations pertaining to each alternative category are provided in the respective **Sections 5.4** through **5.9**. In addition, the recommendations of the alternatives analysis have been packaged into suggested plans which may be implemented in different locations of the Study Area based on salt impacts locally. These plans are presented as recommendations in **Section 6.2**.

Independent of which alternatives are implemented in the future, it is recommended that routine groundwater monitoring continue on an annual basis to monitor groundwater quality trends in the Study Area. Establishing a monitoring program, which may consist of both surface water and groundwater components, before any alternatives are implemented will allow the monitoring of conditions before, during, and after mitigation measures are put in place. Monitoring of environmental conditions should be accompanied by detailed record keeping and database management to provide a basis for analyzing and comparing data as measures to reduce groundwater impacts in the study area are implemented, and for helping to demonstrate that mitigation measures are achieving the intended objectives.

Table 5-29
Summary of Alternatives and Actions to be Considered

Alternatives	Actions to be Considered	
	MassDOT	Town of Boxford
Deicing Methods and Materials		
▪ **Alternative Deicing Materials**	Piloting of deicing alternatives	Consider alternative materials
▪ **Deicing Technologies and Procedures** - **Improved Program Management (calibration, record keeping, staff training, good practices)** - **Increase pre-treatment of roads and highways** - **Meet material application protocols** - **Increase use of equipment and technologies**	Implementation of recommendations (Section 5.4.6.1)	Phased program of improvements (Section 5.4.6.2)
Salt Storage Facility & Handling		
▪ **Continued Storage and Operations out of the Rowley Depot vs. New Salt Storage Facility at the Boxford Depot**	MassDOT decision	Local permits as needed
▪ **Site Improvements at the Boxford Depot** - **Pavement Replacement to Limit Infiltration** - **Addition of Drainage Infrastructure**	Implementation of recommendations regardless of future salt storage at Boxford Depot	N/A
▪ **Operational Improvements (Boxford and/or Rowley)** - **Improved Deicing Chemical Storage** - **Improved Solid Deicing Material Handling (add scale for record keeping)**	Implementation of recommendations regardless of future salt storage at Boxford Depot	N/A
Stormwater Management		
▪ **Drainage System Improvements (structural)**	Consider I-95 drainage improvement recommendations	Consider Town drainage improvement recommendation
▪ **Annual O&M (non-structural)**	Ongoing implementation	Ongoing implementation
Community Water Supply Options		
▪ **Water Supply & System (Well, Treatment, Distribution)** ▪ **Water System Management Options (Town, District, Private, or Home Owner Association)** ▪ **Adjacent Community Supply (Topsfield)**	▪ Requires joint discussion and collaboration between MassDOT, the Town, and residents ▪ May require Legislative action ▪ Adjacent community supply option requires cooperation of the Town of Topsfield	
Residential Water Supply Options		
▪ **Residential Home Water Treatment Systems**	Execution through the MassDOT Salt Remediation Program, as requested	Action by residents
▪ **Replacement Wells**	Given extent of bedrock fractures and impacted groundwater, consider treatment before proceeding with replacement wells, unless declining yield	
▪ **Community Approach – "District" for O&M of Residential Water Treatment Systems**	▪ Requires joint discussion and collaboration between MassDOT, the Town, and residents ▪ May require Legislative action	
▪ **Revisions to Town "Private Water Supply Regulation"**	N/A	Recommend implementation
▪ **Public Education**	Collaborative approach between MassDOT and the Town	

Table 5-29 (Cont'd)
Summary of Alternatives and Actions to be Considered

Alternatives	Actions to be Considered	
	MassDOT	Town of Boxford
Remediation Options		
▪ **Assess Future of Scavenger Well #3 Operations**	Hydrogeologic evaluation of Scavenger Well #3 to determine future operations and discharge options	N/A
▪ **Groundwater & Surface Water Monitoring**	Expand ongoing monitoring program in consideration of action items implemented	Assist MassDOT as required
▪ **Abandonment of Old Wells at the Boxford Depot**	▪ Implementation of recommendation ▪ Consider use of TW-1 for water supply at the Boxford Depot	N/A
▪ **Use of Proper Well Abandonment Procedures throughout the Study Area**	Implementation as part of the Salt Remediation Program	▪ Residents to implement locally ▪ Town to advise as necessary
▪ **Improved Record Keeping of Well Logs, Well Locations, and Water Quality**	Develop SOP to improve record keeping by the Salt Remediation Program	▪ Continue record keeping by Town departments ▪ Submission of records by residents to the Town

Section 6

Summary of Study Findings and Implementation Planning

The Massachusetts Department of Transportation (MassDOT) retained CDM Smith to perform the Boxford Salt Study (the Study), which is a requirement of the Commonwealth of Massachusetts *Chapter 199 of the Acts of 2010, An Act to Conduct a Study of Chemicals Infiltrating Aquifers and Bedrock Fissures Along the Interstate 95 Corridor* (approved July 30, 2010). The focus of the Study has been salt impacts on bedrock groundwater attributed to MassDOT's deicing operations along I-95 in the Town of Boxford (the Town), as well as the salt shed at the MassDOT Boxford Depot located at 100 Topsfield Road in Boxford which operated from 1974 to 2009. The Study Area is defined in the Legislation as the area within the municipal limits of the Town that lies within 1,500 feet from any portion of I-95. Specific objectives of the Study cited in the Legislation include the following:

- To "determine the cumulative and immediate effects of deicing chemical storage and deicing operations on the groundwater aquifers and bedrock fissures within the I-95 corridor."
- To determine "the proximate causes of deicing chemicals, including sodium and chloride, infiltration into the groundwater aquifers and bedrock fissures within the I-95 corridor."
- To determine "what measures need to be taken to prevent [infiltration of deicing chemicals to groundwater aquifers and bedrock fissures] from occurring in the future."
- To develop recommendations for "short-term and long-term remedial actions necessary to restore groundwater quality to a safe drinking water standard within the I-95 corridor."
- To develop "a plan to modify highway drainage systems to prevent storm water run-off and highway drainage from adversely impacting aquifers, bedrock and adjacent wetland resource areas."
- To develop "an alternative means to provide a reliable and adequate safe drinking water supply to the residents located within the I-95 corridor meeting all state and local requirements."

Study findings relative to each of the above stated objectives are presented below, followed by example implementation plans for consideration.

6.1 Summary of Findings

Report findings are summarized below in terms of project objectives cited in the Legislation.

To "determine the cumulative and immediate effects of deicing chemical storage and deicing operations on the groundwater aquifers and bedrock fissures within the I-95 corridor."

Groundwater in the Study Area has been impacted by deicing materials, primarily road salt (sodium and chloride), but also by the pre-wetting and pre-treatment agents magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$). Of particular concern are the deicing material impacts at individual domestic water supply wells in the Study Area, as there is no municipal water supply in the Town.

The Legislation defines safe drinking water as "water meeting or exceeding all primary and secondary standards and recommended guidelines for drinking water as defined by [the Massachusetts Department of Environmental Protection (MassDEP)]." Primary standards are health-based drinking water standards referred to as Maximum Contaminant Levels (MCLs) which are set by the Environmental Protection Agency (EPA). Secondary standards, commonly known as Secondary Maximum Contaminant Levels (SMCLs), are non-enforceable standards established by EPA for which there is no direct risk to consumer health. SMCLs are meant to address aesthetic effects (undesirable tastes or odors), cosmetic effects (effects which do not damage the body but are still undesirable), and technical effects (damage to water equipment or reduced effectiveness of treatment for other contaminants). MassDEP, being a primacy agency managing the Safe Drinking Water Act (SDWA) under the EPA, has the authority to make these standards more stringent if the science, as well as benefits versus cost, justifies the change.

While there is no health-based drinking water MCL for sodium, chloride, magnesium, or calcium, MassDEP has established guidelines or secondary limits for sodium and chloride. Specifically, sodium has a MassDEP Office of Research and Standards Guideline (ORSG) of 20 milligrams per liter (mg/L) which is meant to be protective of individuals on a sodium-restricted diet (U.S. EPA, 2003). Chloride has a SMCL of 250 mg/L in drinking water (MassDEP, 2012), established in consideration of the aesthetic and technical effects. Aesthetically, some individuals may experience a salty taste when chloride concentrations exceed 250 mg/L. Technically, chloride in sufficient concentrations can lead to the corrosion of home piping systems and other household appliances, however, the rate and extensiveness of corrosion is dependent on a host of associated water quality characteristics such as hardness, high pH and/or sulfate concentrations.

Sodium and chloride concentrations at many of the domestic wells sampled in 2014 and at Scavenger Well #3 located at the Boxford Depot, currently exceed the respective MassDEP OSRG of 20 mg/L and 250 mg/L. Specifically, sodium and chloride concentrations at domestic wells sampled during the Study in 2014 ranged from 9 to 230 mg/L and 16 to 390 mg/L, respectively. At Scavenger Well #3, which pumps salt-impacted groundwater from the bedrock at the Boxford Depot, sodium and chloride concentrations in January 2014 were reported as 240 mg/L and 600 mg/L, respectively. In addition, residents have identified corrosion impacts on home copper plumbing and household appliances which may be attributed to high chloride concentrations in association with other water quality parameters. However, there may be other water quality parameters contributing to such impacts and the actual causes cannot be established with certainty.

Based on study data, bedrock groundwater quality impacts associated with deicing have been observed at parcels up to and more than 1,500 feet east of I-95, at parcels up to 1,500 feet west of I-95, and at depths of 440 feet and possibly deeper. The areas most affected by groundwater deicing impacts are:

- Areas east of the Exit 53 northbound on-ramp (north of Rowley Road and Killam Hill Road) and southeast of Exit 53 (from Killam Hill Road south to Pye Brook).
- Areas in the vicinity of Exit 52 including the Boxford Depot, the Titus Lane area south of the Boxford Depot and in the Silverbrook Road area southeast of Exit 52.
- Two smaller areas located in the southern portion of the Study Area adjacent to Fuller Lane and Middleton Road near Exit 51.

Available data suggest that the greatest sources of deicing material impacts to bedrock in the Study Area are MassDOT deicing operations of I-95 and former materials storage and handling at the Boxford Depot. From 1974 until 2005, materials storage and handling operations at the Boxford Depot were sources of salt and other deicing materials to the environment. Between 2005 and 2009, contributions of salt to the environment at the Boxford Deport are expected to have been less than in previous years following the implementation of Best Management Practices (BMPs) which included loading salt trucks under cover. Stormwater runoff sampling conducted during the Study indicates that runoff sodium and chloride concentrations were higher at sampling locations near the interchanges, with elevated concentrations also observed in drainage outfalls along the I-95 highway. Concentrations in Town drainage outfalls were generally much lower. At locations where bedrock is close to the land surface, bedrock groundwater is particularly susceptible to impacts from stormwater runoff containing deicing materials. To address this issue, drainage modifications are proposed and discussed below for shallow bedrock locations where high stormwater runoff concentrations have been measured.

The measured bedrock groundwater concentrations likely reflect contributions from earlier sources of deicing materials such as the Boxford Depot, as well as more recent I-95 deicing operations. Groundwater quality improvements associated with operational changes at the Boxford Depot from 2005 to present, or from I-95 drainage modifications constructed in 2005 and 2006, may not be evident for many years because of the scale of impacts and the rate of groundwater flow in the bedrock of the Study Area. Likewise, groundwater quality changes associated with any measures that are implemented in the future may not be immediate, and long-term monitoring would be needed to track groundwater quality changes over time.

To determine "the proximate causes of deicing chemicals, including sodium and chloride, infiltration into the groundwater aquifers and bedrock fissures within the I-95 corridor."

The two most significant sources of deicing material impacts to bedrock in the Study Area are MassDOT deicing operations and former materials storage and handling at the Boxford Depot.

I-95 Deicing Operations

MassDOT maintains responsibility for ensuring snow removal and deicing along I-95 and the associated ramps and overpasses at Exits 51, 52, and 53 within the Study Area. During winter precipitation events, when deicing materials are used by MassDOT for I-95 maintenance, and during snowmelt events, deicing materials in the surface water runoff are transported by roadway drainage systems to drainage channels and local streams. Once in stream channels or wetlands, surface water transport of deicing materials is governed by watershed hydrology. In other areas, I-95 runoff and snowbank melt infiltrates directly through overburden into the underlying bedrock. Locations in the Study Area most sensitive to deicing material impacts in bedrock are locations where the top of the bedrock is close to the land surface. Along I-95, shallow bedrock has been observed in the Exit 53 vicinity, near Exit 52, and in Study Area locations south of Lockwood Lane. In these locations, there is a shorter pathway from surface water and shallow groundwater to the deeper bedrock groundwater system.

Boxford Depot

The Boxford Depot was operational from 1974 until 2009. There are no records of materials spillage or releases during this period, but it is reasonable to believe that deicing materials were introduced to the subsurface during the course of operations, especially prior to 2005. After 2005, materials handling was conducted under cover and additional measures were taken by MassDOT to reduce and minimize spillage. Since it opened, there have been no stormwater runoff controls in operation at the Boxford Depot to collect and redirect salt impacted stormwater runoff. As a result, runoff from the paved area of the facility entered shallow groundwater and surface water onsite. The bedrock at the Boxford Depot is within ten feet of land surface, resulting in a short pathway from the land surface and overburden groundwater to bedrock. Groundwater impacts from past Boxford Depot operations have been observed at the Boxford Depot overburden and bedrock monitoring wells and are likely present at bedrock wells downgradient of the Boxford Depot in the Titus Lane and Silverbrook Road neighborhoods.

Bedrock Transport Pathways

Field investigations conducted during the Study confirmed that bedrock in the Study Area is heavily fractured with both horizontal and vertically dipping fractures at depths of 440 feet, and possibly more. These fractures have likely provided ready pathways for salt transport both laterally and vertically in the bedrock. Steeply dipping fractures, like those observed in the Study Area, are expected to provide connections between the bedrock and overburden, as well as connections between horizontal and sub-horizontal fracture sets. The fractures likely explain the extent of domestic well impacts further from the Boxford Depot and I-95, especially in areas where depth to bedrock is deeper. Open boreholes, as well as scavenger and domestic well operation, also influence transport of salt-impacted groundwater.

To determine "what measures need to be taken to prevent [infiltration of deicing chemicals to groundwater aquifers and bedrock fissures] from occurring in the future."

To lessen the impact of known sources, alternatives for roadway deicing operations were evaluated. As roadway deicing operations require the use of salt, alternatives were also identified and evaluated relative to future salt storage and handling to meet the needs of the Boxford Depot Service Area in a manner that would be protective of the environment. The results of these evaluations are summarized below.

Deicing Operations

Wherever possible, MassDOT and the Town should undertake efforts to reduce the amount of salt used in deicing operations on both a per-storm event and annual basis. This is a difficult task given the need for road salt application during winter months to help ensure the safety of the driving public. Even so, there are measures which can be taken over both the short-term and long-term which may lead to a reduction in overall salt usage. Recommendations for both MassDOT and the Town are summarized below.

MassDOT I-95 Deicing Operations

There are several broad areas of recommendations to be considered by MassDOT, each having the goal of helping to reduce salt use.

- ***Meeting Established Operating Protocols:*** Available records suggest that application rates for the liquid deicing agent $MgCl_2$ were below MassDOT protocol for both pre-wetting and roadway pre-treatment. Pre-wetting and pre-treatment work to enhance the effectiveness of road salt, which should result in a reduction of overall salt usage. Therefore, efforts should be directed at meeting established protocols whenever possible.

- ***Enhancement of Quality Assurance Procedures/Programs:*** Improved recording and tracking of material usage and application rates for both salt and $MgCl_2$ will provide a better guide for future operations. This should include improved measurements of materials during loading and annual benchmarking to identify deficiencies and/or further areas for improvement. Improved and more frequent equipment calibration will also work to better account for both the application rate and seasonal usage of salt. MassDOT provides internal training for employees regarding proper material handling, usage, equipment operation and calibration, and best management practices. Such training should be similarly required of contractors, perhaps via a contractor certification program.

- ***Enhanced Roadway Pre-Treatment Program:*** Currently, MassDOT only provides pre-treatment of I-95 mainlines. Such pre-treatment should be expanded to interchanges, overpasses, and ramps to further the reduction in salt usage. Similarly, there may be opportunities to perform pre-treatment for an increased number of storm events. A commitment to an enhanced roadway pre-treatment program would require purchase of sufficient equipment or an increase in the number of contracted pre-treatment tankers to cover the Boxford Depot Service Area and meet that commitment.

- ***Pilot Testing:*** MassDOT has ongoing pilot programs in several areas of the Commonwealth to explore the potential of eliminating or reducing sand application in Reduced Salt Zones (RSZs). Although this approach may result in an increased application rate of salt, the frequency of spreader passes is expected to be less, thereby decreasing the total volume of salt used and benefiting the environment. The results of these pilot programs may be used to guide similar testing programs for the Boxford Depot Service Area. Furthermore, there may be opportunity to assess alternative products for pre-wetting and pre-treatment (such as salt brine, agricultural byproducts, and blended chemicals). These too should be piloted in conjunction with any altered sand application rates. Water quality sampling in association with any pilot program is also critical to assess environmental impacts of the products employed. For instance, agricultural byproducts may contribute to increased biological oxygen demand to surface water bodies, thus resulting in a potential decrease in dissolved oxygen concentrations in the surface water. Any modified material ratios, changes in liquids, and/or policy changes relative to the RSZs must be conducted with a thoughtful and thorough pilot testing process before any formal, long-term changes are implemented. Pilot tests should be rigorously documented so that information can be used for analysis and as the basis for future study. Pilot test results could be shared with Boxford should the Town wish to utilize these technologies in its own deicing operations.

- ***Continued Use of Technology:*** MassDOT currently employs closed-loop controllers on all spreaders which automatically adjust salt application rates to account for vehicle and auger-feed speeds. Mobile pavement temperature sensors are also employed to help the decision making process of when to initiate anti-icing (prior to a storm event) and/or deicing operations. Remote Roadway Weather Information Systems (RWIS) are used to obtain local weather data for storm event planning. Continued use of these technologies is recommended.

- ***Introduction and Expansion of New Equipment and Technologies:*** To compensate for any modified application rates of sand and/or salt, tools such as mobile friction meters to monitor roadway traction or flexible/segmented plow blades to achieve greater mechanical removal of winter precipitation should be considered in order to maintain road safety.

- ***Local Road Weather Information System:*** Consider implementation of a local RWIS in Boxford to provide more accurate and relevant weather data for use in storm tracking and deicing event scheduling. This may enhance decisions for pre-treatment based upon anticipated storm events.

- ***Geofencing:*** As a new technology, geofencing offers the best means currently available of controlling and monitoring material application rates. A geofencing system can improve the efficiency of plow and deicing routes, eliminate duplicate or over-applications, and optimize material application. With such systems, the deicing vehicle location is tracked in real-time at a remote station via a global positioning system (GPS) device on each vehicle. Deicing operations parameters such as material application rates can be programmed and recorded. Wi-Fi systems or hardware connections can be used to download recorded data and upload desired changes to deicing parameters. Implementation of geofencing technology would likely require institutional changes in MassDOT operations for the Boxford Depot Service Area, such as a changeover from contracted vehicles and manpower to use of MassDOT vehicles and employees, which would ensure consistent equipment and operations.

Salt Storage and Handling for the MassDOT Boxford Service Area

Deicing of the MassDOT Boxford Depot Service Area requires the use of salt as well as deicing/anti-icing agents. Such operations require a consistent and assured location for spreaders to obtain salt during a storm event. Environmental protections must also be implemented relative to salt storage to limit the potential for future impacts to surface water and groundwater. Options evaluated relative to salt storage and handling included continued partial closure of the Boxford Depot with no salt storage at the site (i.e., maintaining the 'status quo'), and resumption of salt storage and handling at the Boxford Depot with construction of a replacement salt shed.

- ***Maintaining the Status Quo:*** This option includes the continued partial closure of the Boxford Depot, with deicing operations for the Boxford Depot Service Area being conducted primarily out of the Rowley Depot. There would be no salt storage at the Boxford Depot under this alternative. However, the Boxford Depot would continue to provide sand storage and liquid $MgCl_2$ storage/loading with the associated truck operations and equipment storage. In consideration of these uses and to provide improved environmental protection, it is recommended that the liquid magnesium storage tanks be replaced with double-walled storage tanks for additional leakage protection, new drainage infrastructure be installed to capture site runoff, and the pavement be replaced. Estimated project cost: $1,300,000.

- ***Resumption of Salt Storage and Handling at the Boxford Depot with a New Salt Shed:*** Under this option, existing facilities at the Boxford Depot would be removed and a new salt shed would be constructed for a resumption of salt storage and handling at the site. Storage and loading of both sand and liquid $MgCl_2$ would continue, with the possibility of other liquid deicing chemicals also to be stored at the Boxford Depot. The resumption of salt storage and handling would require extensive planning to ensure protection of the environment relative to salt impacts to groundwater and surface water. There are state-of-the-art designs which MassDOT is employing elsewhere in the Commonwealth to limit the potential for such impacts. A new center-load shed at the Boxford Depot would allow for all storage and loading to be conducted under cover within the confines of the shed. Constructing a timber, high-arch gambrel structure with a metal roof and concrete buttress walls would reduce the potential for roof leakage and salt loss through the walls, thereby enhancing containment of the salt. The paved area of the Boxford Depot, including the new salt shed floor, would be reconstructed using a heavy duty pavement application with an impervious liner as a means of preventing direct infiltration of runoff into the ground. Stormwater drainage infrastructure would be incorporated into the site to capture and direct runoff to a lined basin, with associated stormwater BMPs. The new drainage system could be coordinated with drainage improvements in Topsfield Road so that runoff is discharged further south in the Study Area. New liquid storage tanks for deicing agents would be double-walled to reduce the potential for significant, concentrated discharges of stored liquids. A rigorous pre-and post-construction monitoring program would be incorporated via wells and stormwater/surface water sampling to track water quality changes. BMPs and associated quality control measures relative to salt handling and loading would be practiced by all operations personnel. Estimated project cost: $4,200,000.

A comparison of costs (operations over 30 years and capital costs) for the two options on a net present value (NPV) basis is summarized below.

Salt Storage Facility Options – Summary of Present Value Costs

Improvement	Boxford Depot Remains Partially Closed (no salt storage)	Resumption of Salt Storage at the Boxford Depot
NPV of Operations Costs[1]	$13,100,000	$12,100,000
Capital Cost	$1,300,000	$4,200,000
Total NPV	**$14,400,000**	**$16,300,000**

Notes:

[1]NPV refers to Net Present Value and is based on costs for 30 years of operation, with 3% annual inflation.

Town of Boxford Deicing Recommendations

Although the Town's winter season salt usage within the Study Area and salt concentrations in Town drainage outfalls are in general less than those associated with I-95, some improvements can be made to Boxford's deicing operations. A phased program for deicing operation improvements is recommended for implementation by the Town. Initial efforts should focus on improved recording and tracking of material usage and application rates. These include improved measurement and recording of materials during loading; meeting industry standard protocols for the application of the deicing agent $MgCl_2$; continued annual employee training on material handling, usage, equipment operation, and BMPs; and annual benchmarking to identify deficiencies and/or areas for further improvement.

As these recommendations are implemented, the Town may look to future investments in equipment and technologies that can be integrated into operating procedures to monitor and maintain application rates, roadway conditions, and weather tracking. A sharing of knowledge and/or resources between the Town and MassDOT's Boxford Depot Service Area could prove to be mutually beneficial. Future supplemental alternatives for the Town may include pre-treatment, alternative deicing/anti-icing agents based on piloting, addition of closed-loop controllers to spreaders, and consideration of advanced technologies such as RWIS and geofencing.

Public Awareness

To a lesser extent, the public also has a role in helping to maintain water quality and helping to reduce salt impacts to the environment. For example, domestic well softening units add sodium and chloride to the water which is then released to on-site septic systems or dry wells. An alternative may be for homeowners to switch to potassium-generating softening units. Also, increased public awareness that rock salt placed on driveways and walkways can result in localized, though minor, salt impacts on surface water and groundwater, should be recognized.

To develop recommendations for "short-term and long-term remedial actions necessary to restore groundwater quality to a safe drinking water standard within the I-95 corridor."

The short-term remediation alternatives presented below focus on understanding the effectiveness of continued salt mass removal by Scavenger Well #3 at the Boxford Depot, and reducing potential transport pathways in both surface water and groundwater. Because of the lateral and vertical extent of groundwater impacts, and the relatively low groundwater flow velocities and travel times, groundwater quality changes resulting from any implemented measures may not be immediate as it may take many years before appreciable changes in groundwater quality are observed.

Wide-scale use of scavenger wells for long-term remediation is not a proposed alternative. While MassDOT has successfully removed salt mass from the groundwater at the Boxford Depot via Scavenger Well #3, implementation of scavenger wells throughout the Study Area is not recommended because of the scale of impact, the potential impacts to domestic well yields and water quality, and treatment byproduct disposal considerations.

Short-term and long-term measures which may be undertaken to improve groundwater quality are identified below.

- ***Scavenger Well #3 Hydrogeologic Assessment (short-term):*** Scavenger Well #3 at the Boxford Depot continues operation with discharge to a nearby stream. In the short-term, a hydrogeological evaluation is recommended to obtain additional information to make a more informed decision about the value of long-term operation of this well and the effect of well operation upon transport of salt constituents. An objective of this assessment would be to estimate the Scavenger Well #3 capture zone extent and the mass of salt constituents remaining in the groundwater near the Boxford Depot, and to better understand groundwater/surface water interaction at the onsite stream. This would allow development of a long-term operations plan and help to establish criteria for eventual shutdown based on monitoring data. The cost of a hydrogeologic assessment may be in the range of $100,000 to $150,000.

- ***Future Scavenger Well #3 Operation and Discharge (long-term):*** Continued operation of Scavenger Well #3 will be dependent on the assessment results and recommended monitoring. The current discharge of Scavenge Well #3 water to the nearby stream may be resulting in re-introduction of salt into the groundwater system further downstream depending on groundwater/surface water interactions. Results of the hydrogeological evaluation may suggest the need for alternative approaches to well discharge. Options may be to pipe the discharge into the I-95 stormwater drainage system for downgradient discharge into a faster moving surface water system.

- ***Proper Well Abandonment (short- and long-term)***: Any test wells installed in the Study Area that are not used for drinking water or monitoring purposes should be immediately and properly abandoned to ensure that the well does not serve as a conduit for salt constituent transport. In addition, monitoring wells no longer in use at the Boxford Depot should be abandoned (MW-D and WS-1). Abandonment procedures defined by MassDEP should be followed.

- ***Groundwater and Surface Water Monitoring (short- and long-term):*** Groundwater and surface water monitoring should continue with an expanded focus on known impact areas to track water quality changes over time. The scope of such a program should be developed in consideration of the action items selected for implementation based on this Study.

- ***Improved Record Keeping (short- and long-term):*** It is recommended that MassDOT develop a Standard Operating Procedure (SOP) for data collection and record keeping related to domestic well assessments performed by the Salt Remediation Program. Such a SOP would be applicable to all such data collection efforts throughout the Commonwealth.

To develop "a plan to modify highway drainage systems to prevent storm water run-off and highway drainage from adversely impacting aquifers, bedrock and adjacent wetland resource areas."

The following conceptual level drainage system modifications are aimed at mitigating infiltration of runoff potentially having high concentrations of deicing materials. Modifications include combining and rerouting drain pipe networks so that runoff discharges to streams are less susceptible to infiltration. Snow berms are also identified as a means of redirecting snowbank melt to highway drainage systems that may otherwise infiltrate into the groundwater or drain to adjacent wetland resource areas.

- ***Exit 53 Area:*** To prevent immediate infiltration or runoff of snowbank melt, a 1,000-foot-long snow berm along the Exit 53 northbound on-ramp and a 500-foot-long snow berm along I-95 and the Exit 53 northbound off-ramp are recommended. The intent is to protect groundwater and water bodies susceptible to infiltration near homes east of the highway and wetland resource areas. Similarly, a drainage system modification near the intersection of Killam Hill Road (Route 97) and Rowley Road would divert flow further downstream to help reduce the potential for infiltration. Estimated total project cost: $750,000.

- ***Exit 52 – Silverbrook Road and Titus Lane Areas:*** Two options for combining and rerouting drainage systems were developed for the Exit 52 area. Both options include combining the drainage system along Topsfield Road west of I-95 and the drainage system serving I-95 south of Topsfield Road. Modifications to the drainage system along Topsfield Road west of I-95 include provisions to allow for the connection of a drainage system at the Boxford Depot. Runoff captured by the combined systems would discharge to a drainage ditch near Andrews Farm Road that flows to Silver Brook. The difference between the two options is the inclusion of the drainage system serving I-95 immediately north of Topsfield Road. The option that includes a connection to the system would divert more flow and require larger pipes downstream than the option that keeps the system's present discharge location at Silver Brook near Topsfield Road. Rerouting these flows further downstream will help bypass slower moving open channels over shallow bedrock that are more susceptible to infiltration. Estimated total project cost: $1,800,000 - $2,100,000.

- ***Fuller Lane Area:*** To prevent immediate infiltration or runoff of snowbank melt to wetland resource areas, a 900-foot-long snow berm north of Fuller Lane along I-95 northbound is recommended. The discharge from a catch basin on I-95 northbound, south of Fuller Lane, can be rerouted to join a larger system that discharges to a swale north of Fuller Lane. The existing swale has a natural bottom that can be paved to prevent infiltration. Also, the outfall from a Town drainage system can be extended from its current location near the edge of wetlands directly to Silver Brook, protecting the wetland resource area. Further south, a series of outfalls adjacent to the Exit 51 southbound on-ramps can be combined a join a system with an outfall closer to the Ipswich River, removing flow from a drainage ditch. Estimated total project cost: $1,390,000.

To develop "an alternative means to provide a reliable and adequate safe drinking water supply to the residents located within the I-95 corridor meeting all state and local requirements."

There are several means of providing an adequate and safe drinking water supply to residents of the Study Area. The following summarizes community water system options and costs.

Community Water Supply System Summary

Water System Information	Exit 53 Area	Exit 52 Area		Fuller Lane Area
		Silver Brook Road Service Area (east of I-95)	Silver Brook Road Service Area (east of I-95) and Titus Lane Service Area (west of I-95)	
# of Households[1]	40	30	50	10
Water Demand Estimates[2]				
▪ **Average Day Demand (gpd)**	9,100	6,800	11,400	3,000
▪ **Maximum Day Demand (gpd)**	36,400	27,300	45,500	12,000
Water Supply Source	New Well Supply[3]	Town of Topsfield	Town of Topsfield	Town of Topsfield
Project Cost[4]	$4.0 - $5.0 million	$2.6 million	$6.4 million	$1.0 million

Notes:

[1]Based on number of homes along water main route.

[2]Average Day Demand estimates assume 3.5 persons per home and water usage of 65 gallons per person per day; Maximum Day Demand estimates assume a factor of 4 based on the “Merrimack Curve”.

[3]Well design yield would be 36,400 gpd (equivalent to maximum day demand estimate).

[4]Project costs include construction, contingency, engineering, and implementation. ENR 9800 (June 2014).

Options for Community Systems

- ***Exit 53 Area:*** Salt impacted domestic wells are known to be present east of Exit 53 extending south to Pye Brook. Water service in this area would be provided by a community water system served by new production wells. Potential groundwater supply testing sites east of Exit 53 have been identified. New Source Approval would be required from the MassDEP including evidence of technical, financial, and managerial capacity by either a new municipal water department, Water District, or private homeowners association for system operations. Additional permits/approvals may be required from federal, state, and/or local agencies relative to wetlands, endangered species, and state lands depending on the final well location.

- ***Exit 52 – Silverbrook Road and Titus Lane Areas:*** The Town of Topsfield has indicated water supply availability to service areas of salt impacted domestic wells in the Silverbrook Road and Titus Lane areas near Exit 52. Alternatively, potential groundwater supply testing sites have been identified should there be interest in pursuing a community water system served by new groundwater supply wells in these areas. Such an approach would require establishment of a municipal water department, Water District, or private homeowners association. A community system served by wells in either the Silverbrook Road or Titus Lane area would be similar in cost to that of Exit 53, with similarly applicable permitting efforts.

- ***Fuller Lane Area:*** If desired, Topsfield water could be extended to a small area of known salt impacted domestic wells on Fuller Lane, just east of I-95.

Options for Continued Residential Supply

- ***Residential Home Treatment Systems:*** Many homes in the Study Area with salt impacted wells have installed point-of-entry (POE, whole house treatment) or point-of-use (POU, treatment at the faucet) treatment systems. These options remain available to homes throughout the Study Area and may be especially important for residents on sodium restricted diets. One means of obtaining such treatment is via application to the MassDOT Salt Remediation Program assuming acceptance by MassDOT. Alternatively, home owners may pursue such treatment individually. Estimated costs range from $25,000 - $28,500 for whole house POE systems, and only $3,500 for POU systems. Combination units (POE/POU) are about $10,000. The treatment of salt in these systems is accomplished by reverse osmosis, with brine waste to a dry well. These systems require annual maintenance in order to maintain treatment efficiency.

- ***Community Approach to Residential Water Treatment System Operations and Maintenance (O&M):*** Consideration may be given to establishing a "District" or private homeowners association to address annual operation and maintenance of home treatment systems. Under this scenario, a group of residents would join together to create a formal entity which could then engage the services of a licensed plumber or certified water system operator to perform vendor recommended maintenance activities on each member's home treatment system. The entity would be funded via annual payments by property owners.

- ***Replacement Wells:*** The MassDOT Salt Remediation Program has achieved some success over the years in the installation of replacement wells at properties having salt impacted domestic wells. However, often times this has required installation of multiple test wells to identify a site of suitable capacity and water quality. Given the new information of this study regarding the highly fractured nature of the bedrock and the extent of salt concentrations vertically in the bedrock, use of replacement wells to secure a safe drinking water supply for residents should proceed with caution in consideration of site specific geologic characteristics. In cases of declining yield, replacement wells are recommended. Otherwise, home treatment should be considered.

- ***Town Regulation Modification:*** The Town's "Private Water Supply Regulations" (Chapter 202 of the Town Code, Section 202-3E(1)) prohibits water supply wells from being installed in sand and gravel deposits which overlie bedrock. This restriction unnecessarily burdens homeowners who may need a new or replacement well, whether due to a yield issue, elevated salt concentrations or other water quality concern. CDM Smith recommends that the Town regulation be revised to allow sand and gravel wells for domestic purposes.

- ***Public Education:*** Efforts by MassDOT and the Town to educate the public relative to such items as well construction and maintenance, drinking water quality and public health, maintenance of residential water treatment systems, and groundwater quality protection should be continued. These efforts are directed at helping homeowners ensure a safe and adequate drinking water supply.

6.2 Example Implementation Plans

Example implementation plans are presented below for four areas of impact: Exit 53, the Boxford Depot, Exit 52/Titus Lane and Silverbrook Road Areas, and South of Lockwood Lane including Exit 51. These are example plans to illustrate how different measures can be implemented together; however, in practice, MassDOT may elect different measures and combinations to achieve the objective of reducing impacts of salt and deicing chemicals on area domestic wells, and providing alternative water supply options.

6.2.1 Plan A, Plan B, Plan C Methodology

Within the example implementation plans for each area are three Plans termed Plan A, Plan B, and Plan C. Plan A includes the least number of items and would be expected therefore to involve the least cost of the three plans while still addressing the most-critical issues. In many cases, Plan A may be considered to offer some short-term actions that could be completed while expanded efforts are considered for the long-term implementation. Items in Plans B and C include additional, more involved and potentially more costly items. As presented, these plans are intended to be illustrative, not restrictive. MassDOT may determine other groupings or scenarios as optimal for implementation based on their current and future planned operation and capital needs. The plans include the following elements:

- Roadway Deicing Materials and Methods
- Approach to Salt Storage and Associated O&M
- Stormwater Drainage Approaches
- Community Water System Approaches
- Residential Water System Approaches
- Remediation Approaches

6.2.2 Location Specific Implementation Plans

6.2.2.1 Exit 53

The conclusions of this study suggest that the primary cause of salt impacted domestic wells in the Exit 53 area is highway deicing, particularly along the ramps and overpasses of Exit 53. Due to stormwater discharges, runoff, and snowmelt to locations with shallow depths to bedrock in this area, salt constituents have entered and migrated along bedrock fractures. **Table 6-1** provides example implementation plans for Exit 53. Each of the categories of alternatives is identified, and as relevant, a recommendation is proposed. For Exit 53, recommendations include deicing strategies, stormwater drainage improvements, an approach to providing a safe water supply, and ongoing monitoring.

Table 6-1
Exit 53 Implementation Plan Options

Plan A	Plan B	Plan C
Roadway Deicing Materials and Methods		
Implement deicing strategies – MassDOT and Town of Boxford		
Approach to Salt Storage and Associated O&M		
N/A	N/A	N/A
Stormwater Drainage Approaches		
Implement three suggested drainage improvements (WS-PR-07, Route 97, WS-PB-2A) ($0.75M)		
Community Water System Approaches		
N/A	N/A	▪ New community water system ($4.0M - $5.0M) ▪ New Water District (local and Legislative approvals)
Residential Water System Approaches		
▪ Home treatment via MassDOT Salt Remediation Program (status quo) ▪ No District, homeowner association, or other entity	▪ Area-wide home treatment via the MassDOT Salt Remediation Program ▪ District, homeowner association or other entity formed to manage treatment system O&M	For areas not served by community system, home treatment via MassDOT Salt Remediation Program
Remediation Approaches		
Groundwater and surface water monitoring program Abandonment of replacement and monitoring wells not in use Modification of Town Water Supply Regulations		

Notes:
M: million
N/A: not applicable
O&M: operations and maintenance

6.2.2.2 Boxford Depot

From 1974 until 2005, materials storage and handling operations at the Boxford Depot were sources of salt and other deicing materials to the environment. Between 2005 and 2009, contributions of salt to the environment at the Boxford Depot are expected to have been less than in previous years following the implementation of BMPs which included loading salt trucks under cover. Deicing materials entered bedrock via shallow overburden at the Boxford Depot and moved with groundwater flow along bedrock fractures toward the south and southeast impacting downgradient domestic wells.

Plans A through C for the Boxford Depot are presented in **Table 6-2**. Plans A and B are representative plans should salt storage and handling not return to the Boxford Depot. Under these scenarios, operations would instead continue out of the Rowley Depot with new office space at that location. Plan C has been developed to include additional environmental protections should a new modern shed be selected for construction at the Boxford Depot site. In the case of a new shed, it is suggested that Plan C of the Exit 52/Titus Lane and Silverbrook Road Areas (**Table 6-3**) also be considered for implementation as a means of providing further protections to downgradient residents.

While highway deicing is not applicable per se at the Depot, it is important that any pavement deicing be minimized and conducted in accordance with proper operating procedures. Other recommended site improvements include new pavement, drainage infrastructure, and improved deicing chemical storage. The pavement and drainage recommendations increase in scope from Plans A to C to reflect needs relative to a new shed, if installed under Plan C. Water supply at the Boxford Depot itself is addressed as is the future of Scavenger Well #3 for all three plans. Existing unused wells at the Depot are recommended for abandonment, and a monitoring program should be implemented, increasing in scope under Plan C should a new shed be constructed.

6.2.2.3 Exit 52/Titus Lane and Silverbrook Road Areas

Bedrock groundwater impacts in the Exit 52 vicinity are likely associated with groundwater and surface water transport of deicing materials originating from the Boxford Depot and I-95 deicing operations. This area has a number of properties assessed by the MassDOT Salt Remediation Program over the years. A major component of Plans A through C on **Table 6-3** for these neighborhoods is the provision of a safe drinking water supply. Options range from continued home treatment supported by the MassDOT Salt Remediation Program (Plan A), to home treatment with perhaps a homeowner association or District to manage the treatment systems for member residents (Plan B), to provision of public water via water main extension from the Town of Topsfield (Plan C). Other components of the Exit 52 package include global deicing strategies, drainage improvements, and continued monitoring.

6.2.2.4 South of Lockwood Lane and Exit 51

In this area, the main areas of domestic well impact from salt are centered near Fuller Lane, with one other location near Exit 51. Therefore, an increasing level of drainage improvements are recommended in the Fuller Lane vicinity in Plans A through C, presented in **Table 6-4**. A drainage improvement at Exit 51 which can be conducted jointly with the MassDOT Impaired Water Program is included in Plan C. Regarding water supply, there is a Plan C option for connecting the Fuller Lane area to the Topsfield water system. Less costly approaches presented in Plans A and B to ensure safe drinking water include home treatment with perhaps a home owner association or District in Plan B to manage the treatment systems for member residents. Global deicing improvements within the Study Area and monitoring are also a component of this package.

Table 6-2
Boxford Depot Implementation Plan Options

Continued Partial Closure of the Boxford Depot with No Salt Storage at the Site		Resume Salt Storage & Handling at the Boxford Depot
Plan A	**Plan B**	**Plan C[1]**
Roadway Deicing Materials and Methods		
Minimal deicing on Depot pavement (for safety concerns only)	Minimal deicing on Depot pavement (for safety concerns only)	Increased deicing on Depot pavement with salt shed reactivated
Approach to Salt Storage and Associated O&M		
Boxford Depot remains partially closed ▪ Salt storage/handling at Rowley Depot; support from Newbury & Peabody Depots ▪ Sand & deicing chemical storage continues at Boxford Depot ▪ No alternative deicing chemicals stored at Boxford Depot ▪ Add office space at Rowley ($0.35M) ▪ New scale at Rowley for material loading ($0.08M) ▪ Repave Depot without impermeable liner ($0.5M) ▪ Two new double-wall storage tanks for deicing chemical ($0.24M)	***Boxford Depot remains partially closed*** ▪ Salt storage/handling at Rowley Depot; support from Newbury & Peabody Depots ▪ Sand & deicing chemical storage continues at Boxford Depot ▪ Store alternative deicing chemicals at Boxford Depot ▪ Add office space at Rowley ($0.35M) ▪ New scale at Rowley for material loading ($0.08M) ▪ Repave Depot with impermeable liner ($0.67M) ▪ Two new double-wall storage tanks for deicing chemical(s) ($0.24M)	***Salt storage at Boxford Depot reactivated*** ▪ Resume salt storage at the Boxford Depot with construction of a new center-load shed ($2.7M) ▪ Sand & deicing chemical storage continues at Boxford Depot ▪ Store alternative deicing chemicals at Boxford Depot ▪ New office space at Boxford ($0.35M) ▪ New scale at Boxford Depot for material loading ($0.08M) ▪ Repave Depot with impermeable liner ($0.67M) ▪ Two new double-wall storage tanks for deicing chemical(s) ($0.24M)
Stormwater Drainage Approaches		
▪ New drainage infrastructure at the Boxford Depot (lined pond BMP) ($0.13M)	▪ New drainage infrastructure at the Boxford Depot with Phase I (WS-FB-04) improvement ($0.44M)[2]	▪ New drainage infrastructure at the Boxford Depot with Phase 1 (WS-FB-04) and Phase 2 – Option B improvement ($1.9M)[2]
Community Water System Approaches		
N/A	N/A	N/A
Residential Water System Approaches		
▪ Continue use of existing supply well or activate existing well TW-1 for water supply	▪ Activate existing well TW-1 for water supply	▪ Activate existing well TW-1 for water supply with treatment as needed
Remediation Approaches		
Scavenger Well #3 Short-Term: ▪ Perform hydrogeologic assessment regarding continued Scavenger Well #3 operations and establish criteria for determining shutdown ▪ Scavenger Well #3 continuous pumping/discharge to stream (status quo) while assessment is in process		
Scavenger Well #3 Long-Term: ▪ Implement recommendations of the hydrogeologic assessment including a sampling program to determine shutdown ▪ Continue discharge to stream while operating	***Scavenger Well #3 Long-Term:*** ▪ Implement recommendations of the hydrogeologic assessment including a sampling program to determine shutdown ▪ Consider new discharge pipe to Exit 52 ($0.13M)[3] if long-term operations	***Scavenger Well #3 Long-Term:*** ▪ Implement recommendations of the hydrogeologic assessment including a sampling program to determine shutdown ▪ Consider new discharge pipe to Phase 2 – Option B improvement ($0.06M)[3] if long-term operations
Abandon wells at Boxford Depot: MW-D, WS-1		
Groundwater and surface water monitoring program	Groundwater and surface water monitoring program	More comprehensive groundwater and surface water monitoring program

Notes: [1]Plan C allows for the return of salt storage and handling at the Boxford Depot with construction of a new shed and the addition of environmental protections. It is recommended that if a new shed is constructed, Plan C of the Exit 52/Titus Lane and Silverbrook Road Areas also be implemented.

[2]Coordinate with drainage improvements in the Exit 52/Titus Lane and Silverbrook Road Areas.

[3]Coordinate with stormwater drainage approaches for the Boxford Depot.

M: million
N/A: not applicable
O&M: operations and maintenance

Table 6-3
Exit 52/Titus Lane and Silverbrook Road Areas Implementation Plan Options

Plan A	Plan B	Plan C
Roadway Deicing Materials and Methods		
Implement deicing strategies – MassDOT and Town of Boxford		
Approach to Salt Storage and Associated O&M		
N/A	N/A	N/A
Stormwater Drainage Approaches		
N/A	I-95 Phase I (WS-FB-04) improvement[1] ($0.31M)	I- 95 Phase I and Phase II - Option A improvement[1] ($2.1M)
Community Water System Approaches		
N/A	N/A	▪ Extend Topsfield water - Silverbrook Road Service Area east of Exit 52 ($2.6M) - Combined Silverbrook Road and Titus Lane Service Areas east and west of Exit 52 ($6.4M) ▪ Topsfield to own and operate the extended system ▪ Local approvals required
Residential Water System Approaches		
▪ Home treatment via MassDOT Salt Remediation Program (status quo) ▪ No District, homeowner association or other entity	▪ Area-wide home treatment via the MassDOT Salt Remediation Program ▪ District, homeowner association or other entity formed to manage treatment system O&M	▪ For areas not served by Topsfield water, home treatment via MassDOT Salt Remediation Program
Remediation Approaches		
Groundwater and surface water monitoring program Abandonment of replacement and monitoring wells not in use. Modification of Town Water Supply Regulations		

Notes:
[1]Coordinate with drainage improvements at the Boxford Depot.
M: million
N/A: not applicable
O&M: operations and maintenance

Table 6-4
South of Lockwood Lane and Exit 51 Implementation Plan Options

Plan A	Plan B	Plan C
Roadway Deicing Materials and Methods		
Implement deicing strategies – MassDOT and Town of Boxford		
Approach to Salt Storage and Associated O&M		
N/A	N/A	N/A
Stormwater Drainage Approaches		
▪ WS-FB-11 improvement ($0.86M)	▪ Three Fuller Lane area improvements ($1.1M) [1]	▪ Three Fuller Lane area improvements ($1.1M)[1] ▪ WS-IR-01 improvement ($0.4M)
Community Water System Approaches		
N/A	N/A	▪ Extend Topsfield water to Fuller Lane Area ($1.0M) ▪ Topsfield to own and operate the extension
Residential Water System Approaches		
▪ Home treatment via MassDOT Salt Remediation Program (status quo) ▪ No District, homeowner association or other entity	▪ Area-wide home via the MassDOT Salt Remediation Program ▪ District, homeowner association or other entity formed to manage treatment system O&M	▪ For areas not served by Topsfield water, home treatment via MassDOT Salt Remediation Program
Remediation Approaches		
Groundwater and surface water monitoring program Abandonment of replacement and monitoring wells not in use Modification of Town Water Supply Regulations		

Note:

[1]Includes one Town drainage system improvement at Fuller Lane.
M: million
N/A: not applicable
O&M: operations and maintenance

6.2.3 Concluding Remarks

A number of strategies and improvements have been identified to reduce future impacts to groundwater from deicing materials, and to identify alternative water supply sources for residents whose domestic wells have been impacted.

Implementation of improvements could proceed in a phased approach starting with some short-term measures such as MassDOT and the Town adopting the recommended deicing practices, developing a monitoring program to track water quality trends at impacted wells for signs of water quality improvement, and evaluating the effectiveness of Scavenger Well #3 operations. While these measures are being implemented, a more comprehensive and holistic approach to improving groundwater quality and providing safe drinking water to residents based on the Example Implementation Plans can be developed for each of the areas described above. A key success factor with these more extensive plans is collaboration between MassDOT and the Town. Working together, both entities can develop long-term capital improvement plans that complement each other but also take into consideration the important mission of maintaining safe roadways for the traveling public.

Section 7
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