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Road Salt Transport at Two Municipal Wellfields in Wilmington, Massachusetts

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Abstract

Road salt applications on an interstate highway, town roads and parking areas since 1961 have increased chloride concentrations at two municipal wellfields in Wilmington, Massachusetts over 40 times. Average sodium concentrations are now six to seven times the State's drinking water guideline of 20 mg/l for people on sodium-restricted diets. From 2010-2012, approximately 1,175 tons of road salt were deposited into the wellfields' source water protection areas (SWPAs). Once dissolved in stormwater runoff, much of this salt flowed through 89 outfalls into streams, wetlands and aquifers. This paper describes a four-step process for estimating seasonal and total loads of deicing chemicals applied to the recharge area of a wellfield (i.e., the SWPA). These loading estimates can be used to develop strategies for optimizing salt applications and for selecting Best Management Practices (BMPs) to help mitigate the impact of saline runoff in drinking water and sensitive ecosystems.

Study Area Description

Browns Crossing Wellfield and Barrows Wellfield are located in Wilmington, Massachusetts about sixteen miles north of Boston. They were constructed in 1928 and 1955, respectively, in late-Pleistocene glaciofluvial deposits overlying crystalline bedrock in the Ipswich River watershed. Together they supply over half of Wilmington's drinking water which is combined with that from two other supply wells prior to treatment and distribution to residents and businesses.

Historical Chloride Trends Since 1950

Raw water chloride concentrations in wellfield samples collected since 1950 are shown in Figure 1. From 1950 to 1961, annual chloride concentrations averaged 6 mg/l. After I-93 was opened in 1960, the trend has been sharply upward, reaching as high as 320 mg/l in a sample collected by Wilmington Water & Sewer staff on May 17, 2011 at Browns Crossing. Grab samples collected at both wellfields from 2009 to 2012 have averaged 235 and 242 mg/l of chloride at Browns Crossing and Barrows, respectively. The state and federal secondary maximum contaminant level (SMCL) for chloride is 250 mg/l. Sodium levels over the same period have averaged 131 and 142 mg/l, respectively, and are six to seven times above EPA's and the Massachusetts Department of Environmental Protection's (MADEP) guidance level of 20 mg/l for those individuals restricted to a total sodium intake of 500 mg/day.

Wellfield Source Water Protection Areas

EPA delineated the Source Water Protection Areas (SWPAs) for the Browns Crossing and Barrows wellfields based on MADEP-defined Zone I and Zone II areas, topography, stormwater

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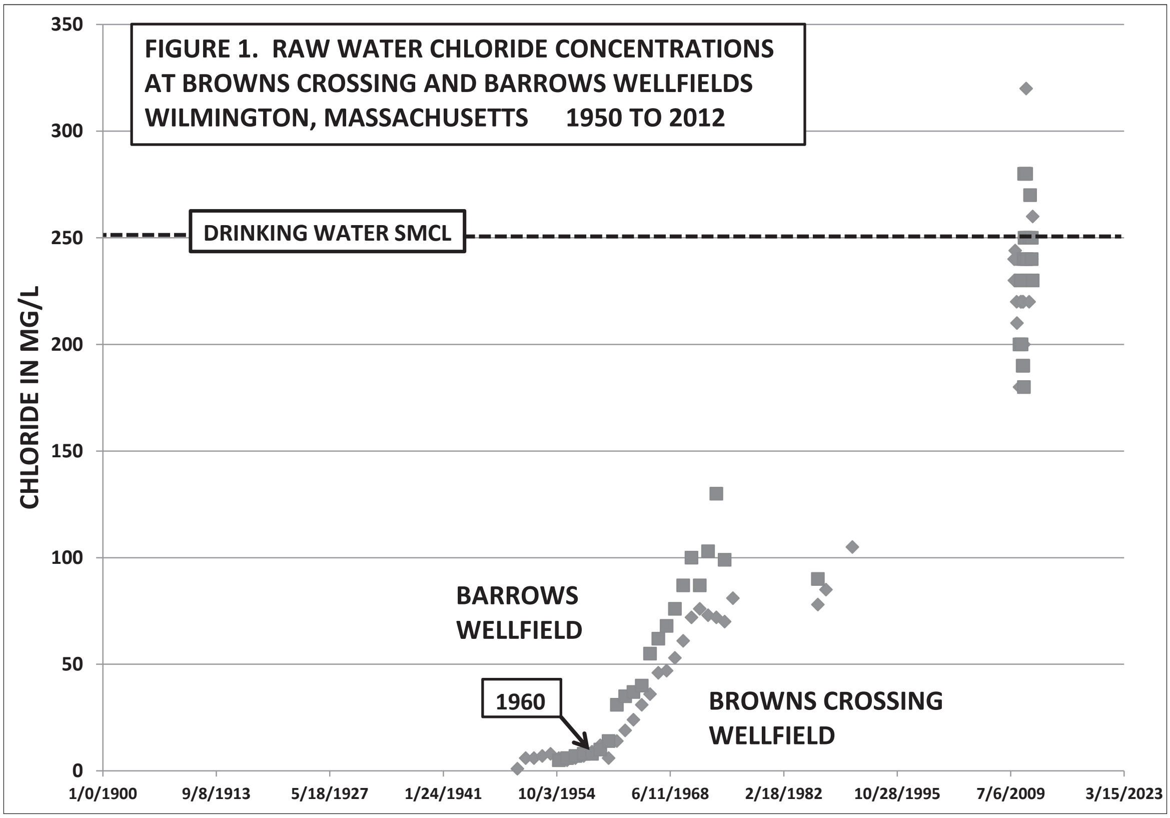


drainage systems, and field observations of water flow during precipitation events (Figures 2 and 3). A Zone I is defined as a 100- to 400-foot protective radius around the well or wellfield which must be owned or controlled by the water supplier using conservation restrictions. For tubular wellfields such as those in Wilmington, the radius is 250 feet. A Zone II is the aquifer area that contributes water to a well under the most severe pumping and recharge conditions, such as 180 days of no recharge. SWPAs include both Zone I and II areas, as well as upland areas that drain into them. Altogether, these cover 662 and 132 acres in the Ipswich River watershed, respectively. Land uses include residential and commercially-zoned neighborhoods, wetlands and forest. However, the interstate highway's eight lanes of impervious surface are the largest source of saline stormwater impacting supply wells, wetlands and streams.

With a combined capacity of about 1.5 MGD, both wellfields consist of shallow tubular wells installed in fine-to-coarse sand and gravel overlying bedrock. Both are surrounded by wetlands and peat deposits that provide some filtering of recharge between the aquifer and surface water for microbial contaminants. However, peat materials provide little filtering of sodium, chloride or other ions present in deicing chemicals. For most of its history, Browns Crossing Wellfield consisted of numerous small-diameter tubular wells installed in wetlands north, east and south of a centralized pump house or station. Because of falling yields and maintenance problems, sixteen new larger-diameter wells were drilled on dry land in 2010 in a horseshoe shaped array ranging in depths from 61 to 83 feet. After receiving operating permits from MADEP, Wilmington activated the new wellfield on March 24, 2011.

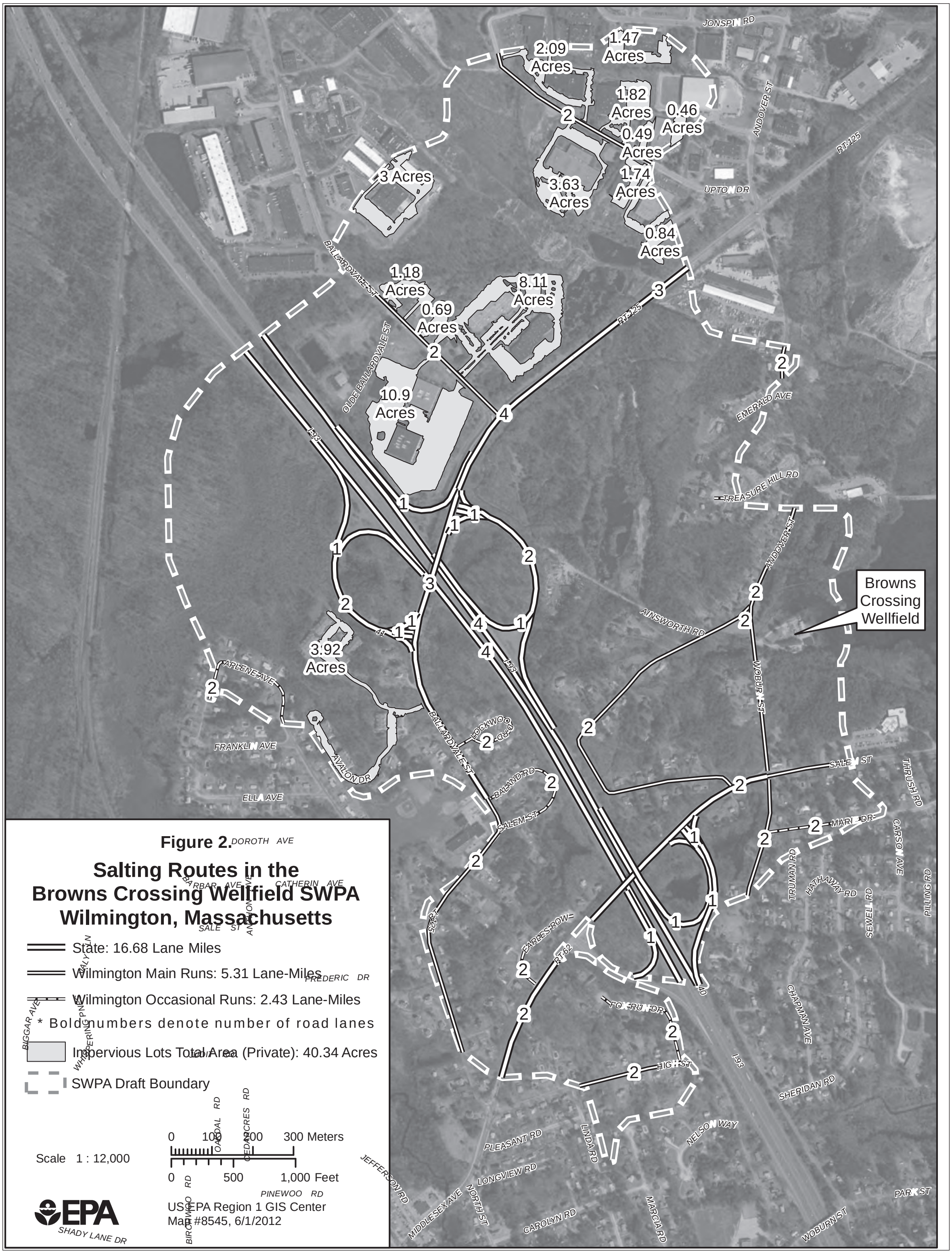


Figure 2.
Salting Routes in the
Browns Crossing Wellfield SWPA
Wilmington, Massachusetts
State: 16.68 Lane Miles
Wilmington Main Runs: 5.31 Lane-Miles
Wilmington Occasional Runs: 2.43 Lane-Miles
* Bold numbers denote number of road lanes
Impervious Lots Total Area (Private): 40.34 Acres
SWPA Draft Boundary
Scale 1 : 12,000
0 100 200 300 Meters
0 500 1,000 Feet
EPA
US EPA Region 1 GIS Center
Map #8545, 6/1/2012
Browns
Crossing
Wellfield
2.09 Acres
1.47 Acres
1.82 Acres
0.46 Acres
0.49 Acres
3 Acres
3.63 Acres
1.74 Acres
0.84 Acres
1.18 Acres
8.11 Acres
0.69 Acres
10.9 Acres
3.92 Acres
BALLARDVALE ST
OLDE BALLARDVALE ST
ANDOVER ST
RT-125
I-93
TREASURE HILL RD
EMERALD AVE
AINSWORTH RD
WOBURN ST
SALEM ST
FRANKLIN AVE
AVALON DR
SHERIDAN RD
CHAPMAN AVE
PLEASANT RD
LONGVIEW RD
CAROLYN RD
NORTH ST
LINDA RD
NELSON WAY
HIGH ST
TRUMAN RD
HATHAWAY RD
SEWELL RD
PILLING RD
THRUSH RD
CARSON AVE
JEFFERSON RD
MIDDLESEX AVE
MARCIA RD
PARK ST
SHADY LANE DR

Figure 3.
Salting Routes in the Barrows Wellfield SWPA Wilmington, Massachusetts

Barrows Wellfield is a rectangular grid of 43 active wells ranging in depth from 18 to 37 feet located 800 feet away from I-93, and about 3,500 feet south of Browns Crossing. It is next to a stream channel excavated by MassDOT in 1960 to conduct I-93 stormwater drainage through the wetlands. Both surface water and ground water flows generally from west to east towards Martin Brook, a tributary of the Ipswich River.

Road Salt Application Areas

Salt application routes in both SWPAs were delineated by the Wilmington Department of Public Works and are shown in Figures 2 and 3. For the Browns Crossing Wellfield SWPA, MassDOT treats 16.68 lane miles of roads, while Wilmington maintains 7.74 lane miles. EPA analysis of aerial photographs shows that there are also 40.34 acres of privately-maintained commercial parking lots, mostly along Ballardvale Street, Upton Drive and Jonspin Road in the north. In the Barrows Wellfield SWPA, MassDOT treats 5.63 lane miles of I-93 while the town maintains 4.43 lane miles of secondary roads. There are no significant commercial parking lots in this area.

Storm water outfalls (Figure 4) direct road and parking lot runoff captured by hundreds of catch basins as point discharges into wetlands, streams and road shoulders. These outfalls range from about nine inches to five feet in diameter. Water quality monitoring from this study shows that chloride concentrations in stormwater can exceed 8,000 mg/l at some locations. In the Browns Crossing SWPA, a total of 76 outfalls have been located by MassDOT and Wilmington: 41 outfalls on MassDOT treated roads, 17 on roads maintained by Wilmington and 18 that drain commercial parking areas. In the Barrows SWPA, MassDOT has mapped two outfalls which discharge storm water collected by approximately 44 catch basins and subsurface drainage systems along the I-93 right-of-way south of Exit 40, while Wilmington maintains 11 outfalls along its secondary and residential roads. Each are typically connected to one or two catch basins.

Road Salt Applications by Source

The overall amounts of road salt and chloride applied by MassDOT and the Town of Wilmington during the winters of 2010-2011 and 2011-2012 were estimated from reported tons per lane-mile multiplied by the number of lane miles in each SWPA. Loadings on parking lots in the Browns Crossing SWPA were estimated from amounts reported by contractors and the number of acres treated. Salt use on residential driveways was assumed to be a minor source because snow is mostly cleared by plows and shovels, not by deicing chemicals. Other salt sources were considered negligible. In its report establishing TMDLs for chloride at four watersheds impacted by I-93 in southeastern New Hampshire, NHDES estimated that chloride sources from atmospheric deposition, geology, food waste (septage) and water softening amounted to no more than 7% of the total (NHDES, 2007). In Wilmington, these sources are likely to total less than 7% because most residential and commercial areas use the municipal system for water supply, not private wells treated with water softeners. In addition, the Browns Crossing SWPA is partially sewered and therefore less impacted by individual septic systems than the watersheds in the New Hampshire TMDL.

According to MassDOT, approximately 24.94 tons of NaCl per lane-mile were applied to I-93 and associated ramps and interchanges in the Wilmington area during the winter of 2010 to 2011, and only 8.52 tons per lane-mile during the milder winter of 2011-2012.

The Wilmington Department of Public Works reported that a total of 3,620 tons of road salt were applied on approximately 220 lane-miles of town roads during the winter of 2010-2011 and 1,758.3 tons during the winter of 2011-2012. The average loading rates were 16.45 and 7.99 tons/lane-mile, respectively.

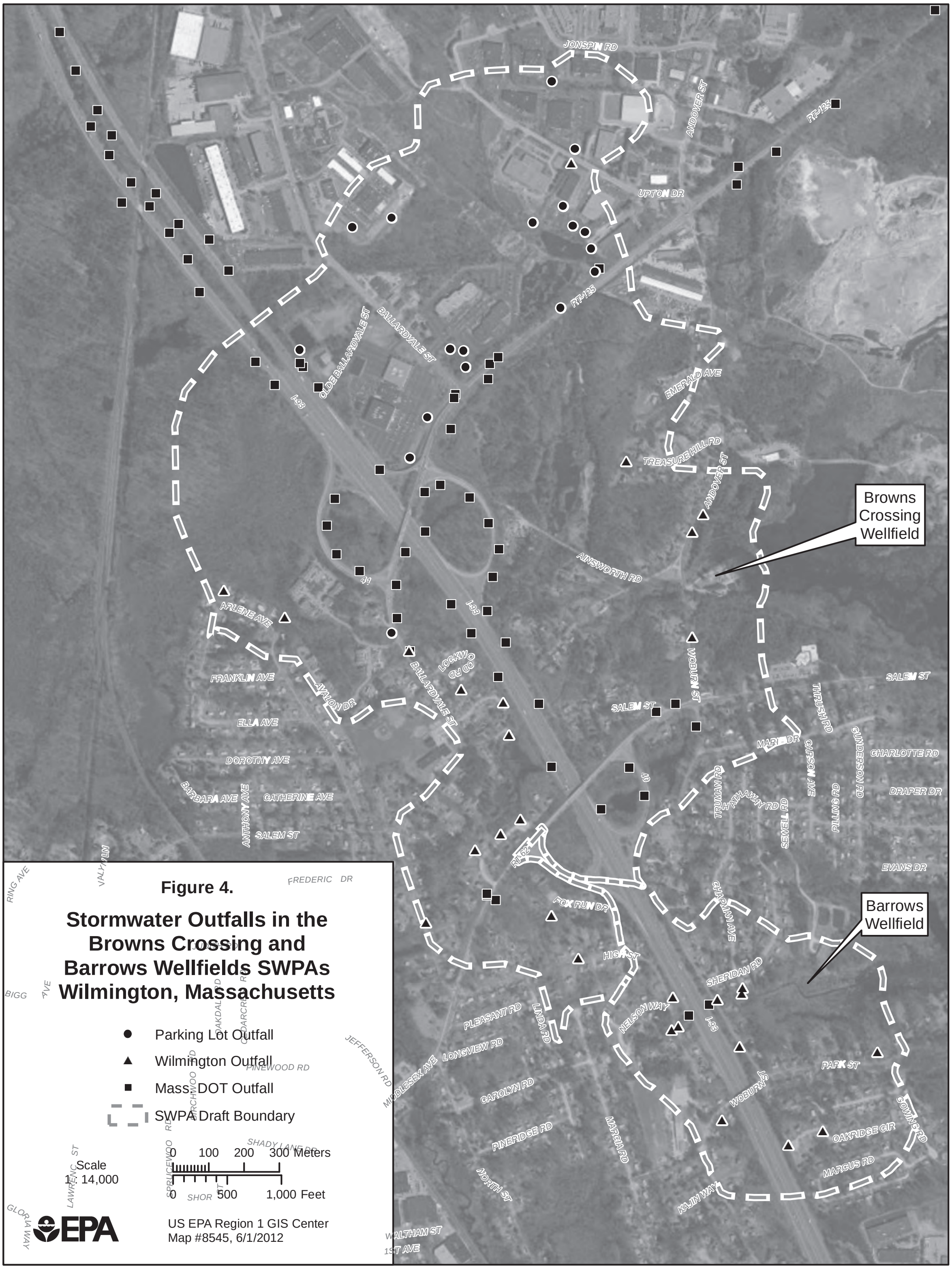


Figure 4.

Stormwater Outfalls in the Browns Crossing and Barrows Wellfields SWPAs Wilmington, Massachusetts

Conversion of road salt to tons of chloride was based on the molecular mass of sodium chloride (58.44 grams/mole), in which chloride (at 35.453 grams/mole) is approximately 61% per weight.

To more accurately account for salt loadings on commercial parking areas, the Wilmington Board of Health sent letters to each property owner requesting that they voluntarily report their deicing chemical usage during the winter months. Most owners rely on landscaping companies for snow and ice management. Several owners complied with the Town's request. Three major property owners that maintain 60% of these parking areas reported their chloride contributions as follows:

181-187-200 Ballardvale Street: 19 acres treated with 1 ton chloride/acre = 19 tons chloride (each winter)

40 Ballardvale Street: 4 acres treated at 1 ton NaCl/acre or 0.6 ton chloride/acre = 2.4 tons chloride in 2010-2011 and 1.2 tons in 2011-2012

10 Upton Drive: Only sand used (no salt) on 0.84 acres = 0 tons chloride during both winters

Remaining unreported properties of 16.5 acres (assume approximately 1 ton chloride/acre) = 16.5 tons chloride each winter

Approximate parking lot total = 37.9 tons chloride in 2010-2011 and 36.7 tons in 2011-2012

Tables 1 and 2 provide estimated loadings and percentages from roadways and parking lot sources for each wellfield over two winters. While most chloride in the SWPAs originates from MassDOT

Table 1. Browns Crossing SWPA – Chloride Load Estimates

	Winter 2010-2011				Winter 2011-2012			
Source	**Tons NaCl/ Lane-Mile**	**Lane-Miles**	**Tons Cl***	**% of Total Load**	**Tons NaCl/ Lane-Mile**	**Lane-Miles**	**Tons Cl***	**% of Total Load**
MassDOT	24.94	16.68	254	69%	8.52	16.68	87	53%
Wilmington	16.45	7.74	78	21%	7.99	7.74	38	24%
Commercial Parking Lots	(see text)	39.5 Acres	37.6	10%	(see text)	39.5 Acres	36.7	23%

Note: *Chloride is assumed to be approximately 61% of NaCl: Cl = 35.45 g/mole and Na = 22.99 g/mole.

Table 2. Barrows SWPA – Chloride Load Estimates

	Winter 2010-2011				Winter 2011-2012			
Source	**Tons NaCl/ Lane-Mile**	**Lane-Miles**	**Tons Cl***	**% of Total Load**	**Tons NaCl/ Lane-Mile**	**Lane-Miles**	**Tons Cl***	**% of Total Load**
MassDOT	24.94	5.63	86	64%	8.52	5.63	29	56%
Wilmington	16.45	4.73	47	36%	7.99	4.73	23	44%

Note: *Chloride is assumed to be approximately 61% of NaCl: Cl = 35.45 g/mole and Na = 22.99 g/mole.

snow and ice management, the percentages vary from winter to winter based on differences in storm duration and severity, truck runs per storm, contractor availability, and other factors. Improvements in tracking salt applications at the state and local level will increase the reliability of these percentages for municipal drinking water supplies.

Water Quality Monitoring

Monitoring for water quality followed the strategy, procedures and equipment from previous studies of road-salt impacts to streams along I-93 in Southeastern New Hampshire (Trowbridge, et al, 2010) and in Massachusetts (Heath, D. and M. Belaval, 2011). This study's Quality Assurance Project Plan describing sample collection, handling and analysis was approved by EPA on November 4, 2009, and revised on December 15, 2010 and December 19, 2011. Water-quality monitoring consisted of bi-weekly to monthly collection of grab samples and field parameters, the deployment of programmable datasondes that measured temperature and specific conductance at 15-minute intervals, and inspection of time series. Datasondes were anchored by concrete blocks and wire tethers, placed on the stream bottom or in flow-through cells, and retrieved every two to three weeks for cleaning, calibration and data retrieval. Specific conductivity of field meters was calibrated at the beginning of each field day using standard solutions. If the deployed datasondes read within 10% of the standard the calibration was considered accurate and the data retained. Conductivity standards ranged from 84 uS/cm to 30,100 uS/cm.

For quality assurance, 21% of all water samples consisted of field duplicates and trip blanks collected during each sampling round. Samples were collected in 125-ml and 250-ml containers, stored on ice and delivered within holding times to the EPA Region I New England Office of Environmental Measurement and Evaluation in North Chelmsford, MA. Holding times ranged from four weeks for anions and six weeks for cations. Samples were then analyzed using a Dionex ICS-3000 Ion Chromatograph following the EPA Region I Standard Operating Procedure EIASOPINGIC11 for common ion analytes. Alkalinity samples were processed following the EPA Region I SOP, INGALKCARB1.SOP based on SM 2320 B. Field data and laboratory results for all seven stations may be found in Appendix A.

Monitoring stations 1-7 were established for this study (Figure 5) and are described in Table 3. Raw water at Browns Crossing (Station 1) was monitored during the winters of 2009-2010 and 2010-2011 as part of an EPA assessment of I-93 stormwater impacts on streams in the Tri-Town area of Andover, Tewksbury and Wilmington (Heath and Belaval, 2011). The remaining stations were established in the winter of 2011-2012.

Monitoring accomplished two objectives: 1) characterizing temporal changes of stormwater chemistry from road salt applications on I-93 and secondary surfaces. These changes consisted of rapid fluctuations (pulses) of specific ions in stormwater, principally sodium and chloride, from meltwater events; and 2) monitoring wellfield raw water quality to evaluate how saline stormwater impacts drinking water.

Real Time Monitoring

From December 22, 2011 to April 19, 2012, equipment for remote real-time monitoring of temperature and specific conductivity was operated at Station 3 by EPA's Office of Environmental Measurement and Evaluation. A submersible datasonde at the downstream side of the I-93 culvert at Salem Street sent a continuous stream of data transmitted by radio to a secure server and website. Temperature and specific conductivity were displayed through on-line charts and graphs. Real-time information facilitated the coordinated collection of field samples during peak melt water

Figure 5.
Water Quality Monitoring Stations in the Browns Crossing and Barrows Wellfields SWPAs Wilmington, Massachusetts

Table 3

Station	Name and Sampling Interval	Description	Latitude/ Longitude
1	Browns Crossing Raw Water 12/1/09 to 2/29/12	Tap Inside Pump House Grab Samples/Sonde	42.58256795N/ -71.14678611W
2	Browns Crossing Surface Water 12/15/10 to 5/18/11	Culvert at Woburn Street Grab Samples/Sonde	42.582352626N/ -71.148288651W
3	I-93 Tributary to Browns Crossing 1/17/12 to 2/29/12	Downstream End of 42” Culvert at Salem Street Grab Samples/Sonde	42.579376929N/ -71.152891972W
4	Tributary to Browns Crossing at I-93 Southbound 1/17/12 to 2/29/12	Upstream end of 42” Culvert Grab Samples/Sonde	42.57904363N/ -71.15391268W
5	Barrows Wellfield Raw Water 12/15/10 to 2/29/12	Tap Inside Sargent WTP Grab Samples/Sonde	42.57272749N/ -71.14414727W
5a	Barrows Surface Water (not sampled)	Channel in Wellfield Sonde	42.57215668N/ -71.14497643W
6	I-93 Tributary to Barrows Wellfield 12/15/10 to 2/29/12	Downstream End of 60” Culvert at Woburn Street Grab Samples/Sonde	42.57177239N/ -71.14755764W
7	Tributary to Barrows Wellfield at I-93 Southbound 1/17/12 to 2/29/12	Upstream End of 40” Culvert Grab Samples/Sonde	42.571372025N/ -71.148592017W

events, such as during the snowstorm of February 29, 2012 when specific conductivity was observed to spike at 10,655 uS/cm at 10:30 pm. The author drove to the site to collect a sample fifty minutes later. This real-time information was invaluable for stormwater sample collection during periods of rapid change in water chemistry.

However, the sonde data from January 3–25, 2012 did not meet the specified QA/QC criteria for specific conductivity due to sand debris partially filling the sensor cavity during high flow events. Data during this period slightly exceeded the 15% allowance for adjacent meter measurements. Data from all other stations and periods were in compliance with quality assurance goals.

Regression Relationships for Chloride

Field measurements of specific conductivity combined with chloride concentrations from 68 stream and well samples support a linear regression equation: Chloride (in mg/l) = [0.3688*Specific Conductivity (in uS/cm)] – 109.28; ($r2 = 0.9932$). Using this relationship, shown in Figure 6, the chronic and acute chloride values for aquatic health in surface water (230 and 860 mg/l) and the federal SMCL for chloride in drinking water (250 mg/l) are equivalent to specific conductivities of 920, 2,628 and 975 uS/cm, respectively. These values compare favorably with those calculated from a regression equation derived from 649 paired measurements of chloride and specific

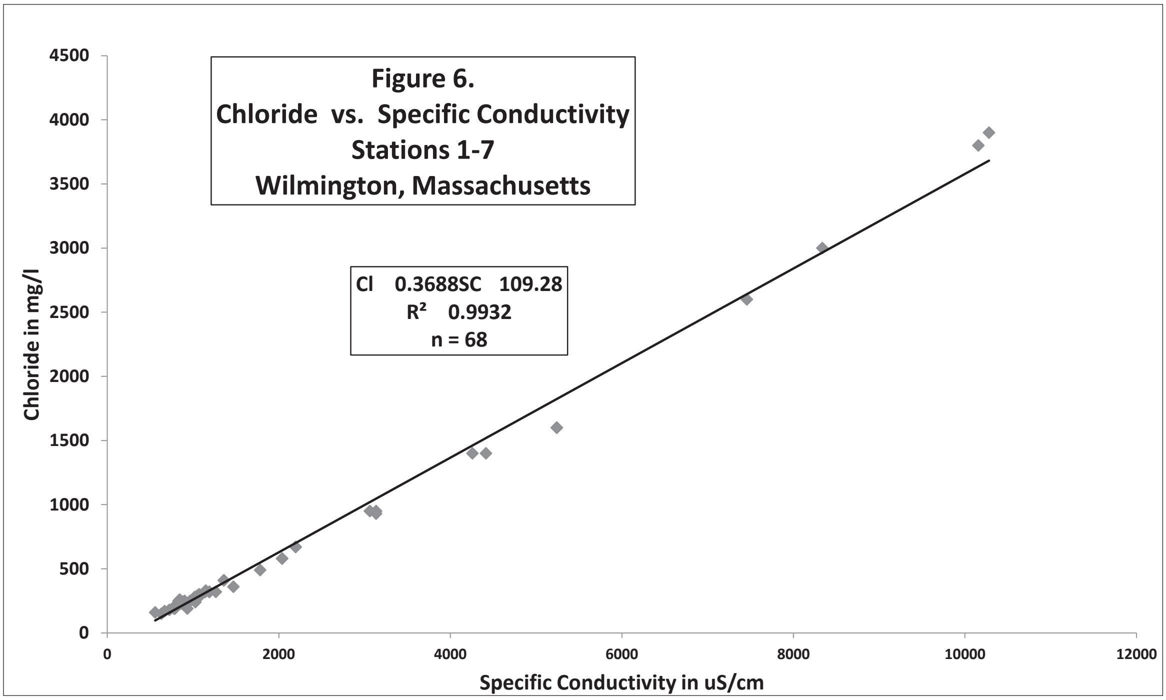


Figure 6.
Chloride vs. Specific Conductivity
Stations 1-7
Wilmington, Massachusetts

conductivity collected by EPA New England, NH Department of Transportation and NH Department of Environmental Services between 2002 and 2006 along I-93 in southern New Hampshire: Chloride (in mg/l) = [0.307*Specific Conductivity (in uS/cm)] – 22, (r2 = 0.97, n = 649). For that project, corresponding values of specific conductivity in streams were 833 and 2,886 uS/cm, respectively. In a study of storm water runoff in southeastern Massachusetts, Granato and Smith (1999) derived equivalent values of specific conductivities of 853 and 2,855 uS/cm, respectively. Differences in regression relations may be attributed to watershed variations in rock types, soil characteristics, proximity to coastal zones, wastewater disposal and other factors. Because of these differences, regression relationships between conductivity and dissolved ions, such as sodium and chloride, should be based on samples collected locally in the area under study.

Sodium in Drinking Water

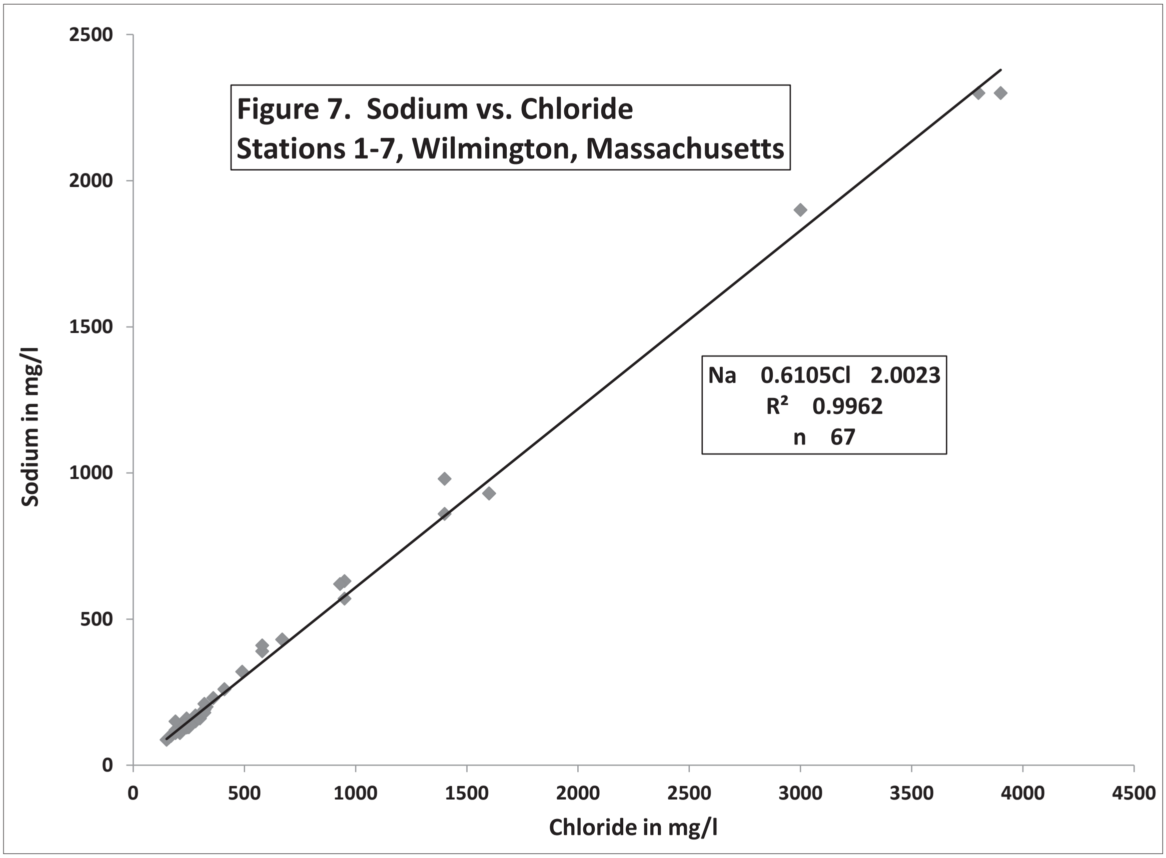
EPA's *Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Sodium* was updated in February of 2003 (EPA, 2003). It recommends that reducing sodium concentrations in drinking water to between 30 and 60 mg/L because of aesthetic effects on taste at higher concentrations. Concentrations below 30 mg/L contribute less than 1.5% of the sodium in an average American diet and less than 2.5% of the present sodium dietary goal, assuming consumption of two liters of tap water per day. For a concentration of 60 mg/L the comparable values are 3% and 5%.

The EPA guidance level was developed for those individuals restricted to a total sodium intake of 500 mg/day and should not be extrapolated to the entire population. EPA requires periodic monitoring of sodium at the entry point to the public water supply distribution system. Monitoring is conducted annually for surface water systems and every three years for groundwater systems (40 CFR 141.41, US EPA 2010). The water supplier must report sodium test results to local and State public health officials by direct mail within 3 months of the analysis, unless this responsibility is assumed by the State. This provides the public health community with information on sodium levels in drinking water.

Regression Relationship for Sodium

Sodium and chloride concentrations in 67 water-quality samples support the linear regression relationship of Na = 0.6105Cl -2.0023; r2 = 0.9962 as shown in Figure 7. This model allowed the approximation of sodium concentrations of stormwater based on chloride calculated from specific conductivity measurements. Comparison of these sodium levels with laboratory analyses of periodic grab samples showed generally good agreement. For example, a laboratory sample collected at 11:20 pm during the snowstorm of February 29, 2012 at the I-93 culvert on Salem Street (Station 3) had chloride and sodium levels of 3,900 and 2,300 mg/L, respectively. The calculated values based on sonde measurements recorded at 11:30 pm were 3,678 and 2,244 mg/L, respectively. The differences are 6 percent error in Na estimation and 2 percent error in Cl estimation. Differences in this data set and others in the study may be attributed to measurement or instrument bias, stratification, temporal differences during periods of rapidly changing concentrations in stormwater, and other factors. However, the method, while not perfect, provides useful information about ionic fluctuations and trends occurring between periodic laboratory samples that would otherwise be unknown.

Specific conductivity measurements combined with lab analyses for sodium and chloride allows for the conversion of sonde data into a time-series for these ions. Figures 8 and 9 show approximate



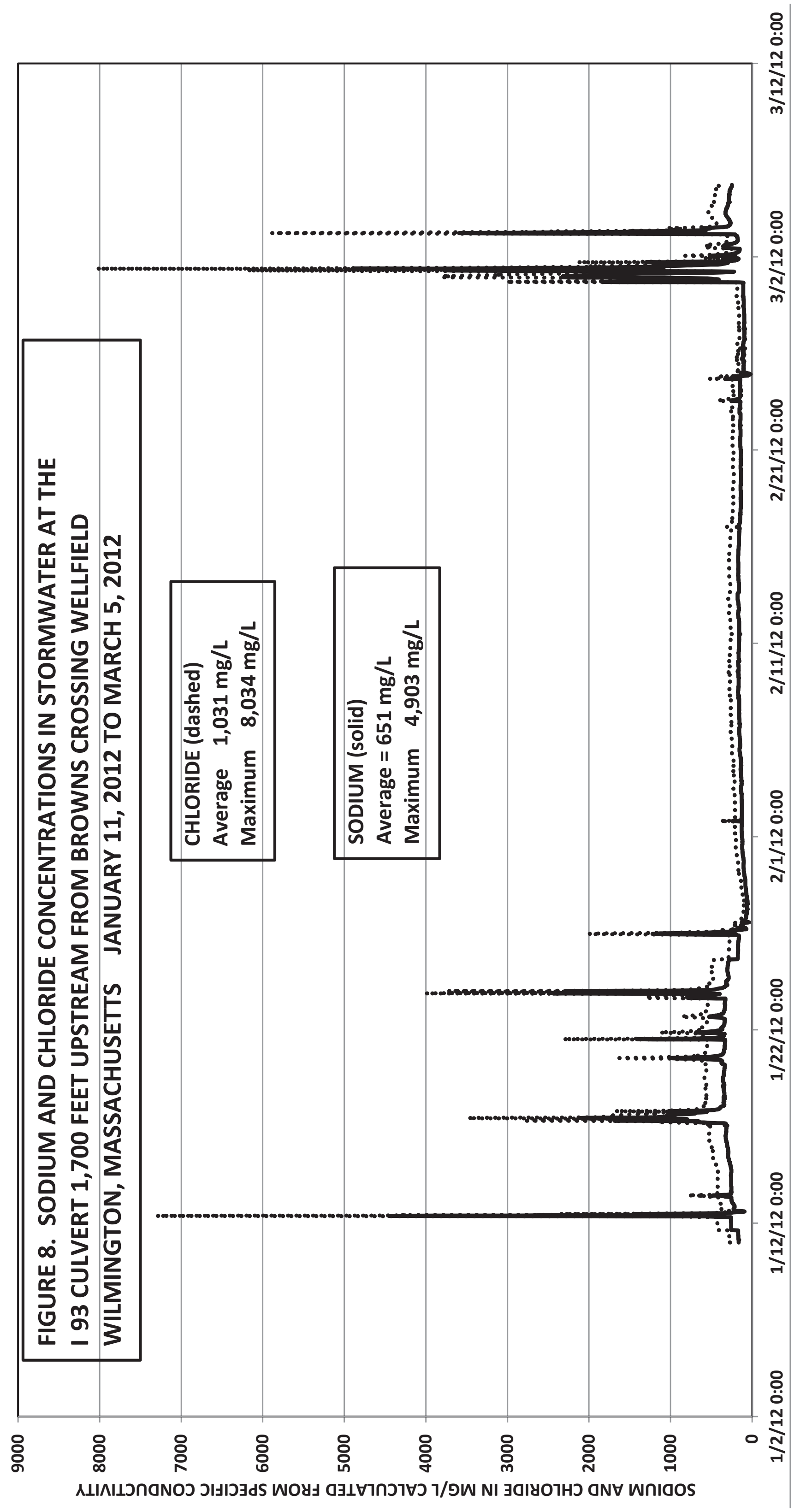


FIGURE 8. SODIUM AND CHLORIDE CONCENTRATIONS IN STORMWATER AT THE
I 93 CULVERT 1,700 FEET UPSTREAM FROM BROWNS CROSSING WELLFIELD
WILMINGTON, MASSACHUSETTS JANUARY 11, 2012 TO MARCH 5, 2012
CHLORIDE (dashed)
Average 1,031 mg/L
Maximum 8,034 mg/L
SODIUM (solid)
Average = 651 mg/L
Maximum 4,903 mg/L
SODIUM AND CHLORIDE IN MG/L CALCULATED FROM SPECIFIC CONDUCTIVITY
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
1/2/12 0:00
1/12/12 0:00
1/22/12 0:00
2/1/12 0:00
2/11/12 0:00
2/21/12 0:00
3/2/12 0:00
3/12/12 0:00

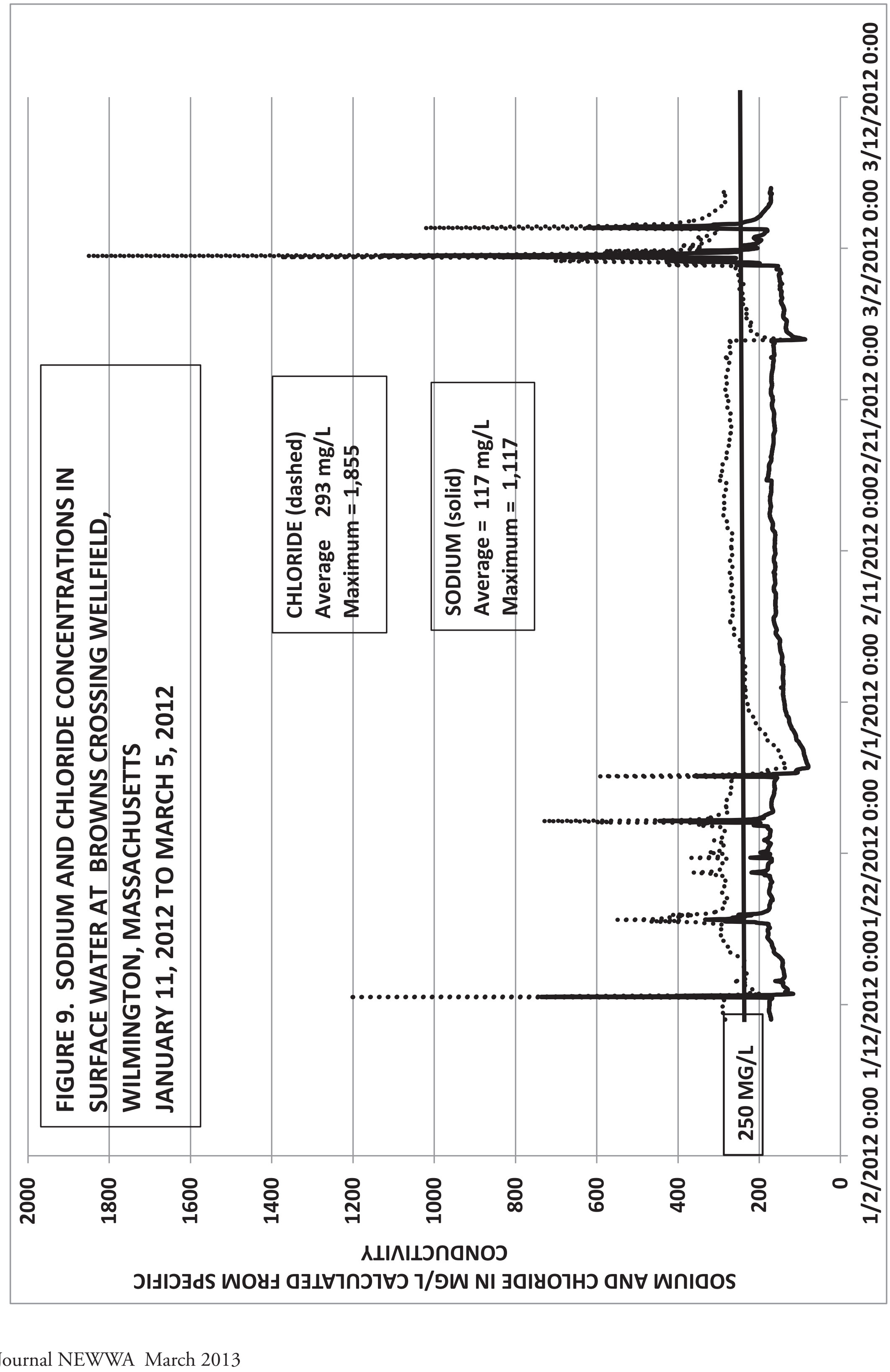


FIGURE 9. SODIUM AND CHLORIDE CONCENTRATIONS IN
SURFACE WATER AT BROWNS CROSSING WELLFIELD,
WILMINGTON, MASSACHUSETTS
JANUARY 11, 2012 TO MARCH 5, 2012
CHLORIDE (dashed)
Average 293 mg/L
Maximum = 1,855
SODIUM (solid)
Average = 117 mg/L
Maximum = 1,117
250 MG/L
SODIUM AND CHLORIDE IN MG/L CALCULATED FROM SPECIFIC CONDUCTIVITY
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1/2/2012 0:00
1/12/2012 0:00
1/22/2012 0:00
2/1/2012 0:00
2/11/2012 0:00
2/21/2012 0:00
3/2/2012 0:00
3/12/2012 0:00

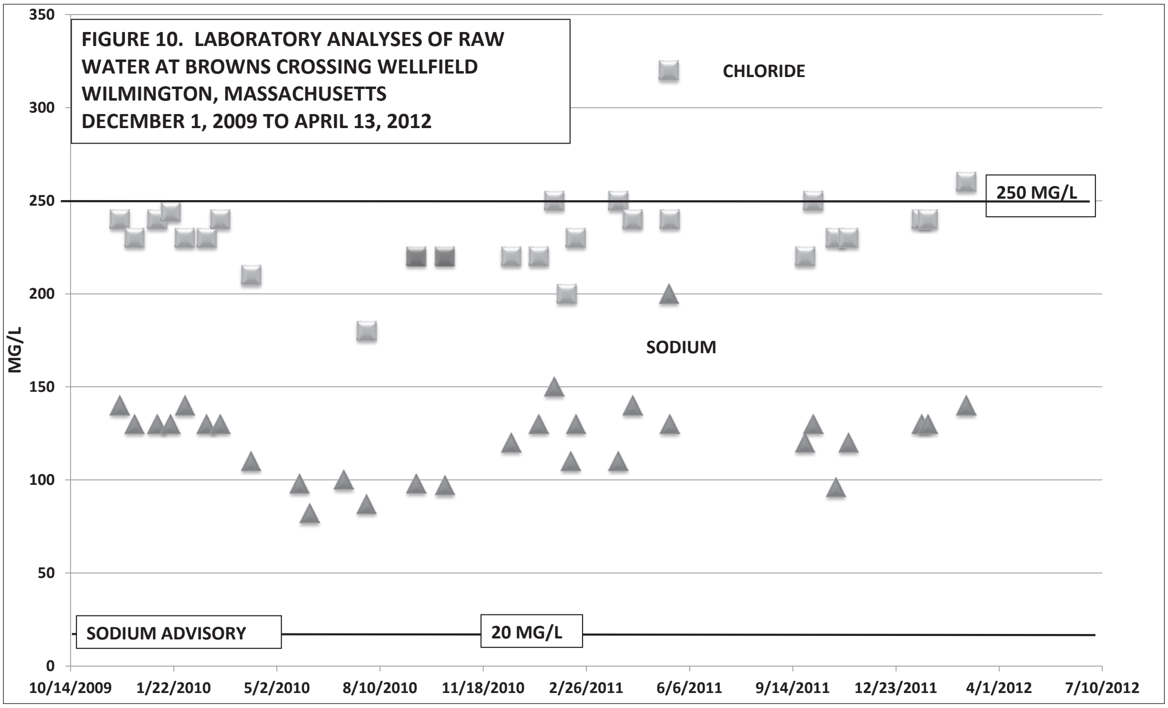
concentrations in stormwater at Stations 3 and 2 from January 11th to March 5th 2012 in the Browns Crossing SWPA. The stations are 1,700 feet apart. At Station 3, sodium and chloride averaged 651 and 1,031 mg/l over this period. At Station 2, approximately 1,700 feet downstream, these averages were 117 and 293 mg/l, respectively.

Since December 2009, the Town of Wilmington and EPA have collected 32 raw water samples from Browns Crossing for sodium and chloride analyses (Figure 10). Over that time, chloride has ranged from 180 to 320 mg/l, while sodium concentrations ranged from 82 to 200 mg/l. These results have been forwarded to MassDOT, which is evaluating salt reduction strategies.

Potential Stormwater Induction at Barrows Wellfield

The tubular wells at Barrows Wellfield are half as deep as those at Browns Crossing, and induce surface water during pumping intervals. Salty stormwater flowing next to the wellfield ends up in well water at measureable rates. For example, Figures 11 and 12 show sodium and chloride concentrations estimated from continuous conductivity measurements in the surface water tributary that drains I-93 and flows past the wellfield during the winter of 2010-2011. This winter had above-average snowfall rates, and both MassDOT and Wilmington applied an estimated 80 and 131 tons of sodium and chloride, respectively, to clear roads in the wellfield's recharge area.

On February 8, 2011, chloride in meltwater at I-93 (Station 6) peaked at nearly 8,200 mg/l. Seven and a half hours later, the chloride pulse reached the wellfield (Station 5a) with a measurement of 4,812 mg/l. Twenty days later, as shown in Figure 13, presumably as a result of this and other storms that month, chloride in the wellfield's raw water rose to an estimated 400 mg/l, and sodium was nearly at 250 mg/l.



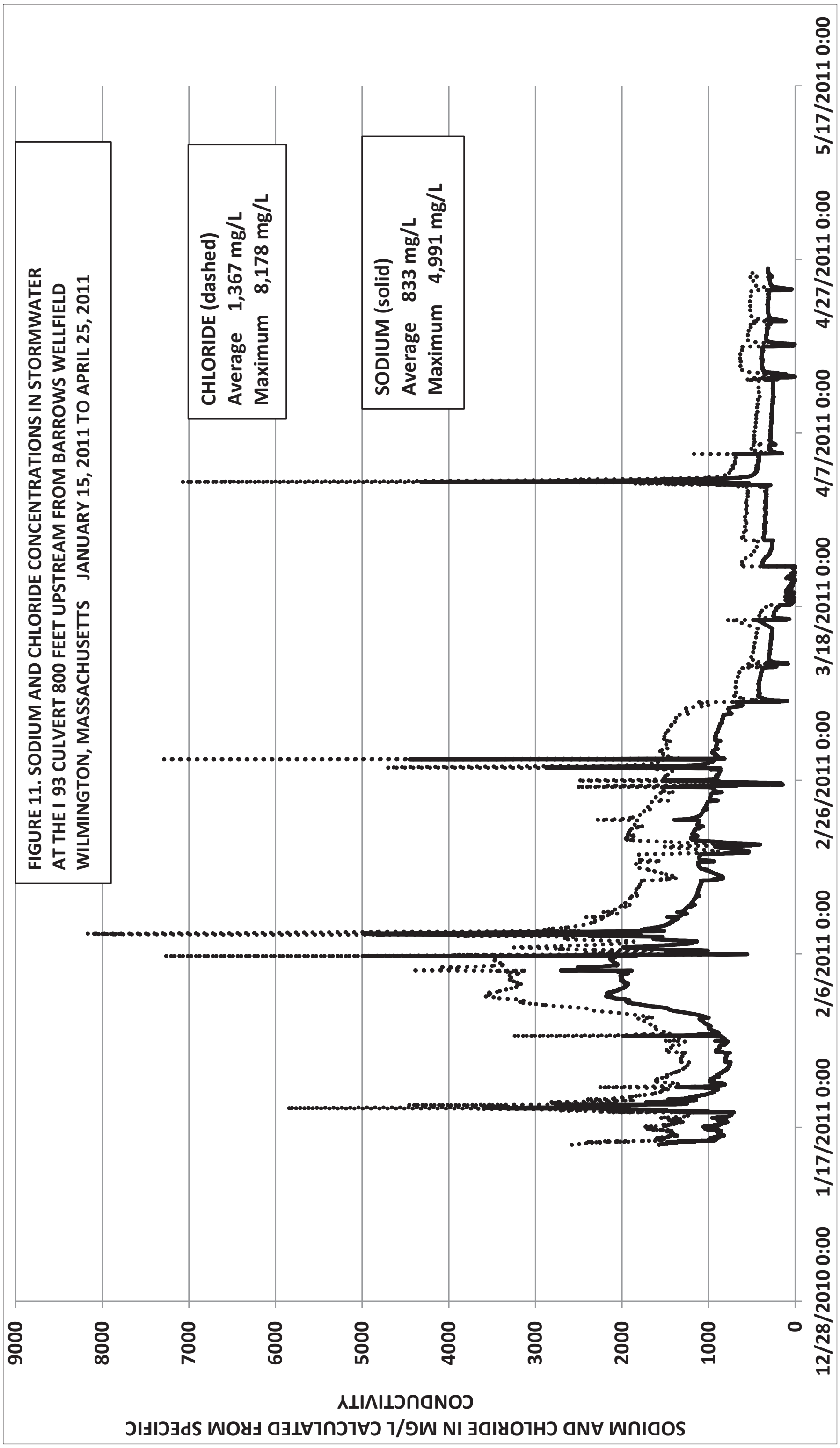


FIGURE 11. SODIUM AND CHLORIDE CONCENTRATIONS IN STORMWATER AT THE I 93 CULVERT 800 FEET UPSTREAM FROM BARROWS WELLFIELD WILMINGTON, MASSACHUSETTS JANUARY 15, 2011 TO APRIL 25, 2011

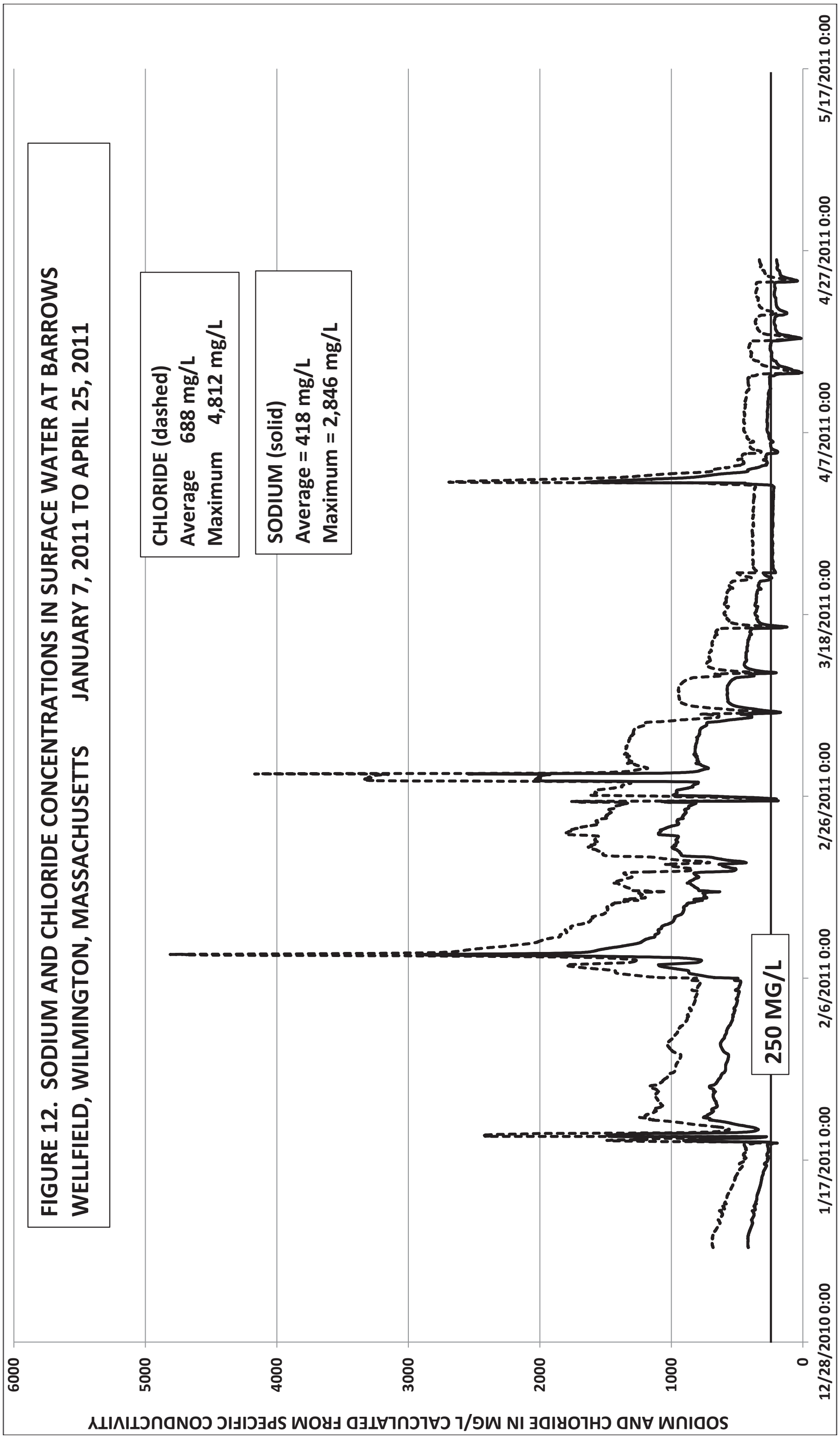


FIGURE 12. SODIUM AND CHLORIDE CONCENTRATIONS IN SURFACE WATER AT BARROWS WELLFIELD, WILMINGTON, MASSACHUSETTS JANUARY 7, 2011 TO APRIL 25, 2011
CHLORIDE (dashed)
Average 688 mg/L
Maximum 4,812 mg/L
SODIUM (solid)
Average = 418 mg/L
Maximum = 2,846 mg/L
250 MG/L
SODIUM AND CHLORIDE IN MG/L CALCULATED FROM SPECIFIC CONDUCTIVITY
0
1000
2000
3000
4000
5000
6000
12/28/2010 0:00
1/17/2011 0:00
2/6/2011 0:00
2/26/2011 0:00
3/18/2011 0:00
4/7/2011 0:00
4/27/2011 0:00
5/17/2011 0:00

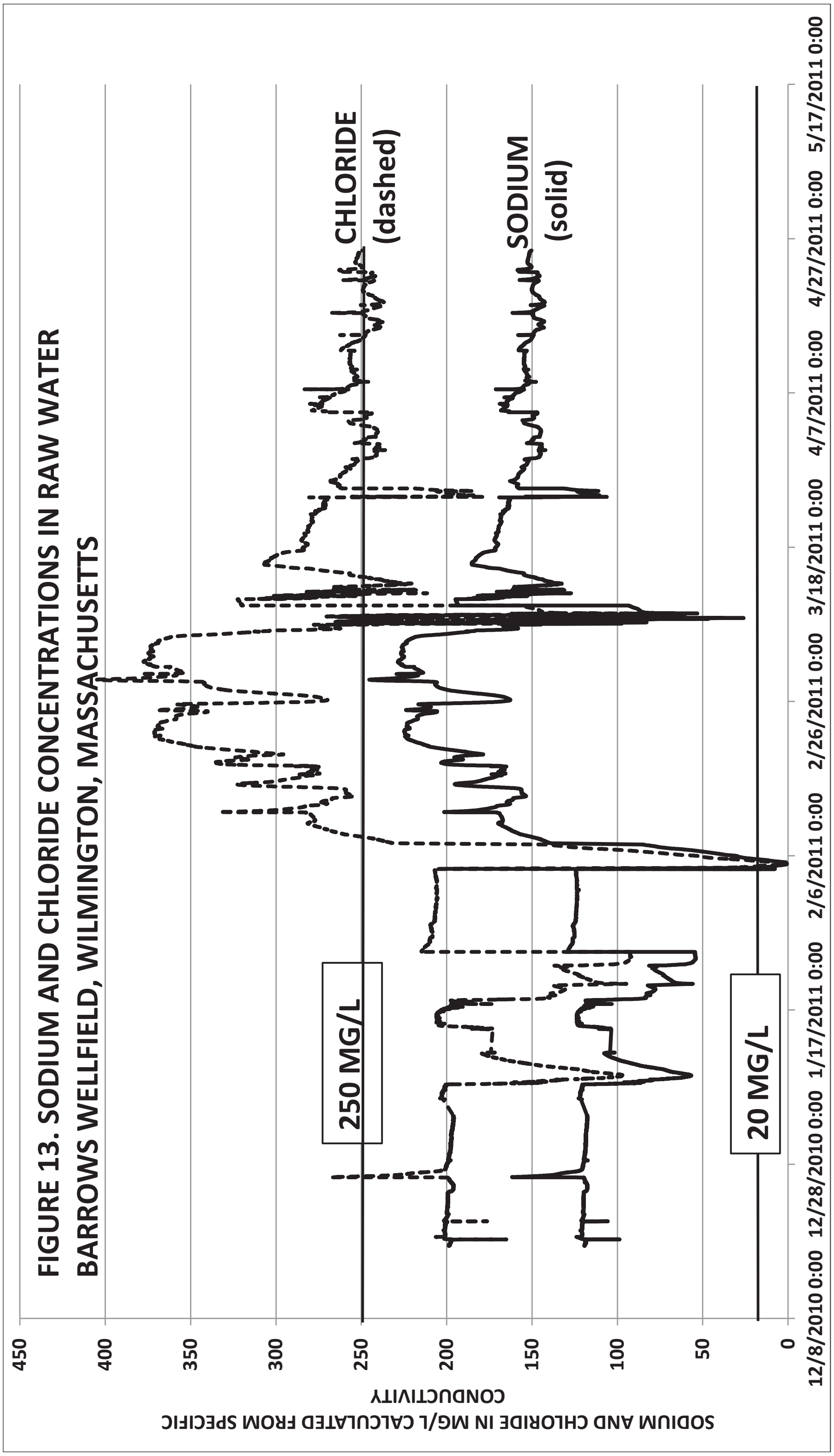


FIGURE 13. SODIUM AND CHLORIDE CONCENTRATIONS IN RAW WATER
BARROWS WELLFIELD, WILMINGTON, MASSACHUSETTS
CHLORIDE
(dashed)
SODIUM
(solid)
250 MG/L
20 MG/L
SODIUM AND CHLORIDE IN MG/L CALCULATED FROM SPECIFIC CONDUCTIVITY
450
400
350
300
250
200
150
100
50
0
12/8/2010 0:00
12/28/2010 0:00
1/17/2011 0:00
2/6/2011 0:00
2/26/2011 0:00
3/18/2011 0:00
4/7/2011 0:00
4/27/2011 0:00
5/17/2011 0:00

However, raw water chemistry did not show the same pronounced response during the winter of 2011-2012, which may be attributed to its much milder weather. Less than half as much salt was applied as during the winter of 2010-2011. Future monitoring of Barrows surface and raw water should be done over several winters to better characterize the influence of stormwater quality on raw water quality.

Winter Stormwater Travel Times

Storm water travel times from I-93 and town-maintained roads to each wellfield were determined using submersible datasondes. The first pair was located at Station 2 next to the wellfield and at Station 3, a 42-inch diameter culvert at Salem Street next to I-93. According to maps provided by the Wilmington Department of Public Works, discharge from this culvert combines some wetland drainage west (upstream) of I-93 with storm water captured by 21 catch basins along a 1,000-foot section of the highway. From here it flows in a shallow stream channel approximately 1,650 linear feet to Woburn Street next to the Browns Crossing wellfield. The second pair of sondes was deployed at Stations 5a and 6 at Barrows wellfield and the large I-93 culvert at Woburn Street, just 800 feet away. Stormwater at Station 6 represents the combined flow from 43 catch basins located along 3,300 feet of I-93. Woburn and High Streets, which are maintained by the Town of Wilmington, also contribute some runoff to this culvert.

Tables 4 and 5 list 29 discrete episodes of saline melt-water "pulses" detected by the four sondes at Stations 2, 3, 5a and 6. In addition to dates, the tables include times when the initial and peak pulses of specific conductivity were measured at each location, and their respective times of travel from I-93 to each wellfield. For example, at the I-93 culvert upstream of Browns Crossing (Station 3), specific conductivities ranged from 3,845 to 26,305 uS/cm, reflecting the elevated salt concentrations that can occur over short time intervals in highway runoff. By the time these pulses reached the wellfield an average of 3.6 hours later, they had been diluted an average of 79%,

TABLE 4. STORMWATER TRAVEL TIMES FROM I-93 TO BROWNS CROSSING WELLFIELD

TRIBUTARY AT STATION 3				TRIBUTARY AT STATION 2						
DATE	IP TIME	PP TIME	PP COND (uS/cm)	DATE	IP TIME	PP TIME	PP COND (uS/cm)	DILUTION (%)	IP TOT (hours)	PP TOT (hours)
1/13/2011	1435	1550	6350	1/13/2011	1945	2205	1330	79%	5.2	6.25
1/18/2011	1615	1955	16853	1/18/2011	1900	2150	5494	67%	2.75	1.9
1/27/2011	1045	1115	17136	1/27/2011	1400	1615	1793	90%	3.25	5.0
2/3/2011	1230	1400	11636	2/3/2011	1700	1925	1568	87%	4.5	5.4
2/5/2011	1645	1730	24455	2/5/2011	1915	2030	4610	81%	2.5	3.0
2/8/2011	515	745	15503	2/8/2011	800	1130	3339	78%	2.75	3.75
2/25/2011	130	930	7523	2/25/2011	800	1130	2498	67%	6.5	2.0
2/28/2011	830	1015	8584	2/28/2011	1130	1215	2424	72%	3.0	2.0
4/1/2011	30	845	26305	4/1/2011	300	1130	4245	84%	2.5	2.75
1/12/2012	730	900	20098	1/12/2012	1030	1145	3581	82%	3.0	2.75
1/17/2012	400	1030	9744	1/17/2012	730	1430	1786	82%	3.5	4.0
1/20/2012	945	1300	4713	1/20/2012	1200	1715	1278	73%	2.25	4.25
1/21/2012	1200	1230	6570	1/21/2012	1530	1645	1292	80%	3.5	4.25
1/23/2012	1500	1615	3845	1/23/2012	1830	2030	1255	67%	3.5	4.25
1/23/2012	2100	2115	11146	1/24/2012	15	115	1931	83%	3.25	4.0
1/23/2012	2330	1/24-0015	10397	1/24/2012	215	315	2285	78%	3.75	3.0
2/29/2012	1600	3/1-0900	22080	2/29/2012	1945	3/1-1200	5327	76%	3.75	3.0
3/3/2012	145	515	16270	3/3/2012	500	830	3075	81%	3.25	3.25
AVERAGE			13289				2728	78%	3.5	3.6

NOTE: IP INITIAL PULSE, PP PEAK PULSE, COND SP. CONDUCTIVITY IN US/CM, TOT TIME OF TRAVEL

TABLE 5. STORMWATER TRAVEL TIMES FROM 1-93 TO BARROWS WELLFIELD

TRIBUTARY AT STATION 6				TRIBUTARY AT STATION 5A						
DATE	IP TIME	PP TIME	PP COND (uS/cm)	DATE	IP TIME	PP TIME	PP COND (uS/cm)	DILUTION (%)	IP TOT (hours)	PP TOT (hours)
1/17/2011	1440	1815	4229	1/18/2011	900	1700	1508	64%	18.33	22.75
1/19/2011	0	520	16181	1/19/2011	1445	1830	6915	57%	14.75	18.5
2/7/2011	1100	2/8-0745	22470	2/7/2011	2345	2/8-1515	13344	41%	12.45	7.5
2/27/2011	930	1130	13081	2/27/2011	1400	2015	9348	29%	4.5	8.75
2/28/2011	915	1000	20066	2/28/2011	1015	1130	11603	42%	1.0	1.5
4/1/2011	630	900	19509	4/1/2011	1030	1330	7599	61%	4.0	4.5
1/12/2012	645	1000	6191	1/12/2012	1145	1245	2111	65%	5.0	2.75
1/17/2012	400	1330	8043	1/17/2012	1515	1/18-0315	4297	47%	11.5	13.75
1/23/2012	1400	2345	9409	1/23/2012	2300	1/24-0730	5626	40%	9.0	7.75
2/29/2012	1630	3/1-0845	12175	3/1/2012	345	1345	12221	none	11.25	5.0
3/3/2012	345	500	11030	3/3/2012	745	1015	9898	10%	4.0	5.25
AVERAGE			12944				7679	46%	8.7	8.9

NOTE: IP INITIAL PULSE, PP PEAK PULSE, COND SP. CONDUCTIVITY IN US/CM, TOT TIME OF TRAVEL

and ranged from 1,255 to 5,494 uS/cm. Dilution occurred from precipitation, ground water, and overland flow over a distance of nearly 2,000 feet.

In contrast, stormwater travel times in the Barrows SWPA were longer, averaging 8.9 hours and ranging from 1.5 to 22.75 hours from I-93 to the wellfield located 800 feet downstream. This slower flow may be due to a low channel gradient, as well as partial freezing during the winter. At 46%, dilution was also lower, possibly due to less overland flow in the frozen wetlands and less ground water bank flow through peat layers. In all, surface water conductivities in surface water were an average 2.8 times higher at the Barrows Wellfield than at the Browns Crossing Wellfield over the two winter periods.

Conclusions

Chloride concentrations in raw water at the Browns Crossing and Barrows Wellfields in Wilmington, Massachusetts have increased from an average of 6 mg/l in 1961 to 242 mg/l today. Average sodium concentrations since 2009 are six to seven times the state's drinking water guideline of 20 mg/l for those individuals restricted to a total sodium intake of 500 mg/day. These increases are assumed to be largely due to the use of thousands of tons of deicing chemicals (primarily sodium chloride) on Interstate-93, secondary roads and parking lots over the last five decades. During winter storms, saline stormwater is discharged into streams and wetlands through approximately 87 outfalls in the wellfields' source water protection areas (SWPAs) In order of tons applied, major sources of sodium and chloride are: 1) seasonal loadings of deicing chemicals applied on 22.3 lane-miles of roads by the Massachusetts Department of Transportation (MassDOT); 2) seasonal loadings on 12.5 lane-miles of local roads by the Town of Wilmington; and 3) seasonal loadings to 40 acres of commercial parking lots. During the winter of 2010-2011, the salt load apportionment to Browns Crossing among these three sources was 69%, 21% and 10%, respectively, and totaled approximately 370 tons of chloride. For the winter of 2011-2012, which was less severe, the allocations were 53%, 24% and 23%, respectively, and totaled about 162 tons of chloride. Allocations for Barrows Wellfield (which has no commercial parking lots in its recharge area) were 64% and 36% and 133 tons chloride in 2010-2011 and 56% and 44% and 52 tons chloride in 2011-2012. These totals demonstrate how loads may vary from year to year due to variations in winter severity. If historical trends continue, sodium and chloride concentrations in both wellfields may increase over time unless significant reductions are implemented by these sources. In addition, stormwater travel times in surface water flowing to the wellfields were determined from continuous monitoring of specific conductivity during the winter months. Stormwater transport from I-93 to the wellfields required an average 3.6 hours at Browns Crossing and 8.9 hours at the Barrows Wellfield.

References

Granato, Gregory E. and Kirk P. Smith, 1999, *Estimating Concentrations of Road-Salt Constituents in Highway-Runoff from Measurements of Specific Conductance*: U. S. Geological Survey WRIR 99-4077, 27 pp. http://pubs.usgs.gov/wri/wri99-4077.

Heath, Douglas L. and Marcel Belaval, 2011, *Baseline Assessment of Stream Water Quality in the I-93 Tri-Town Project Area From December 1, 2009 to April 7, 2010*: New England Water Works Association Journal, Vol. CXXV, No. 4, pp 315-339.

NHDES, 2007, *Data Report for the Total Maximum Daily Loads for Chloride for Waterbodies in the Vicinity of the I-93 Corridor from Massachusetts to Manchester, NH: Policy-Porcupine Brook, Beaver Brook, Dinsmore Brook and the North Tributary to Canobie Lake*: NHDES, NHDES-R-WD-07-40, December 2007. http://www.rebuildingi93.com/documents/environmental/Chloride%20TMDL%20Data%20Report%20-%20December%202007.pdf.

Trowbridge, Philip R., J. Steve Kahl, Dari A. Sassan, Douglas L. Heath, Edward M. Walsh, 2010, *Relating Road Salt to Exceedances of the Water Quality Standard for Chloride in New Hampshire Streams*: Environmental Science & Technology, 2010, Vol. 44, No. 13, pp. 4903-4909.

US EPA, 2003, *Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Sodium*: USEPA Office of Water, Health and Ecological Criteria Division, Washington, DC 20460, EPA 822-R-03-006, February 2003. www.epa.gov/safewater/ccl/pdf/sodium.pdf.

US EPA, 2010, *Special Monitoring for Sodium*: Code of Federal Regulations, Title 40, Chapter 1, Subchapter D, Part 141, Subpart E, Section 141.41.

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APPENDIX A

				FIELD PARAMETERS									LABORATORY RESULTS													
STATION	DATE	TIME	DUP	METER	CAL. STANDARD 1	CAL. STANDARD 2	CAL. CHECK @ 2	TEMP.	SPEC. COND.	TDS	SALINITY	pH	Cl	Na	Br	Fl	NO3	NO2	SO4	NO3 as N	NO2 as N	Ca	Mg	K	HARD NESS	Alk
					(uS/cm)	(uS/cm)	(uS/cm)	C	(uS/cm)	(g/L)	(ppt)		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg CACO3/L)	(mg/L)
1	12/1/2009	9:08		YSI 600LS	10000	500	501	10.43	903	0.587	0.45	NM	240	140	ND	ND	4.4	ND	13	0.99	ND	27	5.8	3.9	91	NM
1	12/1/2009	9:08	D	YSI 600LS	10000	500	501	10.43	903	0.587	0.45	NM	240	130	ND	ND	4.4	ND	13	0.99	ND	27	5.9	3.9	92	NM
1	12/15/2009	9:12		YSI 600LS	10000	500	503	11.39	875	0.569	0.43	5.82	230	130	ND	ND	4.8	ND	13	1.10	ND	27	5.6	3.7	90	NM
1	1/6/2010	9:20		YSI 600LS	10000	500	504	10.58	873	0.566	0.43	5.85	240	130	ND	ND	5.2	ND	13	1.20	ND	26	5.7	3.6	88	NM
1	1/19/2010	9:51		YSI 600LS	10000	500	502	11.08	876	0.569	0.43	6.03	244	130	ND	ND	5.3	ND	13	1.20	ND	27	5.6	3.6	90	NM
1	2/2/2010	9:10		YSI 600LS	10000	500	518	10.55	853	0.555	0.42	6.12	230	140	ND	ND	4.8	ND	13	1.10	ND	27	6.3	3.5	93	NM
1	2/23/2010	9:07		YSI 600LS	10000	500	514	11.05	862	0.560	0.43	6.05	230	130	ND	ND	4.4	ND	13	0.99	ND	27	5.8	3.5	91	NM
1	3/8/2010	9:05		YSI 600LS	10000	500	509	11.02	846	0.550	0.42	6.21	240	130	ND	ND	5.4	ND	13	1.20	ND	26	5.8	3.7	89	NM
1	4/7/2010	9:04		YSI 600LS	10000	500	519	10.75	802	0.521	0.40	6.32	210	110	0.13	ND	7.0	ND	16	1.60	ND	24	5.1	3.4	81	NM
1	12/15/2010	10:53		YSI 600LS	10000	84	90	11.09	805	0.523	0.40	NM	220	120	ND	ND	2.6	ND	14	0.59	ND	25	5.5	3.9	85	26
1	12/15/2010	10:53	D	YSI 600LS	10000	84	90	11.09	805	0.523	0.40	NM	220	120	ND	ND	2.7		14	0.61	N	25	5.5	3.7	85	28
1	1/11/2011	10:16		YSI 600LS	10000	84	89	10.71	825	0.536	0.41	NM	220	130	0.14	0.14	4.4	ND	19	0.99	ND	30	6.4	2.3	101	28
1	1/26/2011	12:01		YSI 600LS	10000	84	88	10.83	965	0.626	0.48	NM	250	150	0.21	0.13	2.7	ND	21	0.61	ND	30	6.5	2.2	102	33
1	2/16/2011	9:10		YSI 600LS	10000	84	90	11.00	847	0.551	0.42	NM	230	130	0.18	ND	2.8	ND	16	0.63	ND	28	6	2.3	95	27
1	4/12/2011	9:25		YSI 600LS	10000	84	95	11.24	870	0.566	0.43	NM	240	140	0.26	ND	3.4	ND	16	0.78	ND	31	6	3.3	100	22
1	5/18/2011	9:12		YSI 600LS	10000	84	94	10.76	880	0.572	0.44	NM	240	130	0.30	ND	6.7	ND	16	1.50	ND	28	6.1	3.4	95	23
1	9/26/2011	12:50		YSI 600LS	10000	84	91	13.90	805	0.523	0.40	NM	220	120	0.40	ND	3.0	ND	12	0.68	ND	23	5.1	3.8	78	31
MW 1-09*	9/26/2011	17:25		YSI SONDE 3	1000	1000	996	13.32	631	NM	NM	6.24	150	87	ND	ND	1.6	ND	4.5	0.36	ND	22	4.3	3.1	73	51
MW 2-09*	9/26/2011	16:40		YSI SONDE 6	1000	1000	998	15.63	873	NM	NM	6.14	230	130	0.41	ND	1.7	ND	9	0.38	ND	24	4.6	3.3	79	53
MW 3-09*	9/26/2011	15:35		YSI SONDE 3	1000	1000	996	15.52	913	NM	NM	6.22	240	140	0.44	ND	1.6	ND	8.2	0.36	ND	22	4.6	3.9	74	35
MW 4-09*	9/26/2011	14:55		YSI SONDE 6	1000	1000	998	14.95	1019	NM	NM	6.40	280	170	0.60	0.11	1.6	ND	11	0.36	ND	17	2.8	3.8	54	40
MW 5-09*	9/26/2011	14:00		YSI SONDE 3	1000	1000	996	15.00	724	NM	NM	6.29	180	110	0.38	0.06	1.6	ND	4.8	0.36	ND	15	2.8	3.5	49	42
MW 6-09*	9/26/2011	13:10		YSI SONDE 6	1000	1000	998	19.11	668	NM	NM	6.49	170	100	0.38	ND	1.6	ND	5.7	0.36	ND	12	2.8	3.1	41	40
MW 7-09*	9/26/2011	12:15		YSI SONDE 3	1000	1000	996	15.10	991	NM	NM	5.94	260	140	ND	ND	2.0	ND	15	0.45	ND	29	6.6	4.6	100	51
MW 8-09*	9/26/2011	11:40		YSI SONDE 6	1000	1000	998	13.63	1068	NM	NM	5.86	280	160	0.46	ND	ND	ND	27	ND	ND	28	6.1	5.2	95	32
MW 8-09*	9/26/2011	11:40	D	YSI SONDE 6	1000	1000	998	13.63	1068	NM	NM	5.86	290	160	0.46	ND	ND	ND	27	ND	ND	28	6.1	5.2	95	31
MW 9-09*	9/26/2011	10:00		YSI SONDE 3	1000	1000	996	12.94	1049	NM	NM	6.03	290	160	0.30	ND	2.1	ND	18	0.47	ND	27	5.4	4.6	90	25
MW 10-09*	9/26/2011	10:15		YSI SONDE 3	1000	1000	996	13.88	1074	NM	NM	5.95	300	170	0.51	ND	1.6	ND	15	0.90	ND	26	5.2	3.3	86	20
1	1/17/2012	9:40		YSI 600LS	15000	500	503	12.30	831	0.540	0.41	NM	240	130	0.42	ND	4.0	ND	14	0.90	ND	26	5.2	3.3	86	20
1	1/23/2012	14:15		YSI 600LS	15000	500	509	12.45	841	0.547	0.42	NM	240	130	0.30	ND	4.4	ND	14	0.99	ND	26	5.1	2.9	86	22
1	2/29/2012	14:00		YSI 600LS	15000	500	508	12.12	844	0.549	0.42	NM	260	140	0.50	ND	4.2	ND	13	0.95	ND	27	5.6	3.6	91	26
2	12/15/2010	12:17		YSI 600LS	10000	84	90	1.49	558	0.363	0.27	NM	160	94	0.09	ND	3.9	ND	21	0.88	ND	17	4.2	3	60	8
2	1/11/2011	10:56		YSI 600LS	10000	84	89	0.68	1142	0.742	0.56	NM	320	190	0.21	0.10	3.1	ND	29	0.70	ND	37	8.4	2.6	127	23
2	2/16/2011	9:54		YSI 600LS	10000	84	90	0.53	1192	0.775	0.58	NM	320	190	0.26	ND	2.4	ND	26	0.54	ND	30	6.7	2.3	103	13
2	3/16/2011	8:10		YSI 600LS	10000	84	91	3.51	831	0.540	0.41	NM	250	140	0.28	ND	2.2	ND	17	0.50	ND	20	4.2	3.1	22	8
2	4/12/2011	10:15		YSI 600LS	10000	84	95	12.46	1148	0.746	0.57	NM	330	200	0.38	ND	0.9	ND	19	0.20	ND	32	6.2	4.5	100	16
2	5/18/2011	9:46		YSI 600LS	10000	84	94	10.93	1067	0.694	0.53	NM	300	160	0.42	ND	4.5	ND	14	1.00	ND	28	6.1	4.3	95	17
3	1/17/2012	11:18		YSI 600LS	15000	500	503	1.98	7457	4.847	4.04	NM	2600	1100	0.95	ND	3.7	ND	66	0.84	ND	42	8.1	12	138	20
3	1/24/2012	7:57		YSI 600LS	15000	500	509	1.33	1188	0.771	0.58	NM	320	190	0.41	ND	4.0	ND	23	0.90	ND	29	5.9	4.3	97	22
3	2/29/2012	23:20		YSI 600LS	15000	500	508	2.96	10280	6.677	5.71	NM	3900	2300	0.70	ND	4.2	ND	45	0.95	ND	39	14	6.4	152	23
4	1/17/2012	11:35		YSI 600LS	15000	500	503	1.96	4415	2.870	2.32	NM	1400	980	0.76	ND	4.6	ND	44	1.00	ND	35	6.3	8.8	113	22
4	1/24/2012	8:15		YSI 600LS	15000	500	509	1.43	1137	0.739	0.56	NM	320	180	0.39	ND	4.2	ND	24	0.95	ND	30	6.1	4.4	100	22
4	2/29/2012	23:50		YSI 600LS	15000	500	508	2.73	10156	6.590	5.63	NM	3800	2300	0.70	ND	3.9	ND	51	0.88	ND	38	11	6.5	139	23
5	12/15/2010	12:55		YSI 600LS	10000	84	90	9.44	778	0.506	0.38	NM	190	110	ND	ND	8	ND	27	1.80	ND	33	5.4	3.5	105	39
5	1/11/2011	11:20		YSI 600LS	10000	84	89	9.20	788	0.513	0.39	NM	190	120	0.15	0.14	9.7	ND	31	2.20	ND	34	6.1	2.2	110	45
5	2/16/2011	10:43		YSI 600LS	10000	84	90	7.70	1027	0.664	0.51	NM	240	160	0.16	ND	7.4	ND	31	1.70	ND	40	6.2	2.4	125	48

				FIELD PARAMETERS									LABORATORY RESULTS													
STATION	DATE	TIME	DUP	METER	CAL. STANDARD 1	CAL. STANDARD 2	CAL. CHECK @ 2	TEMP.	SPEC. COND.	TDS	SALINITY	pH	Cl	Na	Br	Fl	NO3	NO2	SO4	NO3 as N	NO2 as N	Ca	Mg	K	HARD NESS	Alk
					(uS/cm)	(uS/cm)	(uS/cm)	C	(uS/cm)	(g/L)	(ppt)		(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg CACO3/L)	(mg/L)
5	3/16/2011	8:45		YSI 600LS	10000	84	91	9.02	1037	0.674	0.52	NM	280	160	0.17	ND	9.9	ND	26	4.30	ND	37	5.9	3.6	120	44
5	4/12/2011	11:54		YSI 600LS	10000	84	95	10.18	1049	0.682	0.52	NM	280	170	ND	ND	10	ND	25	2.30	ND	46	6.6	3.8	140	42
5	5/18/2011	10:21		YSI 600LS	10000	84	94	10.47	1058	0.688	0.53	NM	280	150	0.26	ND	18	ND	30	4.10	ND	44	7.0	3.8	139	42
5	1/17/2012	9:25		YSI 600LS	15000	500	503	10.35	903	0.587	0.45	NM	240	140	0.46	ND	14	ND	25	3.20	ND	35	5.5	3.2	110	45
5	1/23/2012	13:50		YSI 600LS	15000	500	509	10.35	901	0.586	0.45	NM	250	130	0.38	ND	15	ND	26	3.40	ND	36	5.6	3.1	113	42
5	2/29/2012	13:35		YSI 600LS	15000	500	508	10.65	867	0.563	0.43	NM	230	139	0.44	ND	15	ND	25	3.40	ND	36	5.9	3.5	114	48
6	12/15/2010	13:51		YSI 600LS	10000	84	90	7.01	933	0.606	0.46	NM	190	150	ND	0.10	21	ND	23	4.70	ND	45	4.3	3.8	130	28
6	1/11/2011	12:25		YSI 600LS	10000	84	89	0.36	3134	2.037	1.60	NM	950	630	0.41	0.14	4.5	ND	33	1.00	ND	89	9.8	2.7	263	87
6	1/11/2011	12:25	D	YSI 600LS	10000	84	89	0.36	3134	2.037	1.60	NM	930	620	0.38	0.13	4.5	ND	33	1.00	ND	87	9.9	2.7	258	95
6	2/16/2011	10:22		YSI 600LS	10000	84	90	3.74	5241	3.408	2.80	NM	1600	930	0.94	ND	31	ND	37	7.00	ND	170	18	4.7	499	97
6	2/16/2011	10:22	D	YSI 600LS	10000	84	90	3.74	5241	3.408	2.80	NM	1600	930	0.99	ND	30	ND	37	6.80	ND	170	18	4.7	499	97
6	3/16/2011	8:25		YSI 600LS	10000	84	91	5.47	2196	1.427	1.12	NM	670	430	0.36	ND	23	ND	22	5.20	ND	54	5.3	6.7	160	61
6	3/16/2011	8:25	D	YSI 600LS	10000	84	91	5.47	2196	1.427	1.12	NM	670	430	0.37	ND	23	ND	22	5.20	ND	55	5.3	6.7	160	62
6	4/12/2011	11:00		YSI 600LS	10000	84	95	8.62	2038	1.325	1.04	NM	580	390	ND	ND	15	ND	23	3.40	ND	74	6.3	5.8	210	82
6	4/12/2011	11:00	D	YSI 600LS	10000	84	95	8.62	2038	1.325	1.04	NM	580	410	ND	ND	15	ND	23	3.40	ND	75	6.3	6.6	210	82
6	5/18/2011	10:57		YSI 600LS	10000	84	94	11.35	1359	0.884	0.69	NM	410	260	ND	ND	28	ND	31	6.30	ND	62	5.5	5.1	177	120
6	5/18/2011	10:57	D	YSI 600LS	10000	84	94	11.35	1359	0.884	0.69	NM	410	260	ND	ND	28	ND	30	6.30	ND	62	5.5	5.2	177	120
6	1/17/2012	11:20		YSI 600LS	15000	500	503	6.51	4257	2.768	2.26	NM	1400	860	0.81	ND	12	ND	25	2.70	ND	45	9.7	7.2	152	85
6	1/24/2012	7:35		YSI 600LS	15000	500	509	6.69	1782	1.158	0.90	NM	490	320	0.43	ND	15	ND	24	3.40	ND	48	5.0	4.2	140	100
6	2/29/2012	23:40		YSI 600LS	15000	500	508	4.83	8337	5.418	5.63	NM	3000	1900	0.63	ND	11	ND	24	2.50	ND	85	12	5.7	260	72
7	1/17/2012	11:45		YSI 600LS	15000	500	503	4.41	3061	1.990	1.59	NM	950	570	0.71	ND	8.2	ND	20	1.90	ND	38	8.5	6.3	130	82
7	1/24/2012	8:28		YSI 600LS	15000	500	509	3.19	1265	0.822	0.63	NM	320	210	0.35	ND	12	ND	19	2.70	ND	41	4.2	3.3	120	90
7	2/29/2012	23:59		YSI 600LS	15000	500	508	3.64	1470	0.953	0.73	NM	360	230	0.50	ND	18	ND	25	4.10	ND	87	6.1	4.0	242	138

NOTE: * Wellfield Monitoring Wells; NM not measured; ND not detected