LAND USE AND THE EXTENT OF ROAD SALT CONTAMINATION IN A SEMI-URBAN WATERSHED, EASTERN MASSACHUSETTS

Coefer, Josh, and Hon, Rudolph, Department of Earth & Environmental Sciences, Boston College

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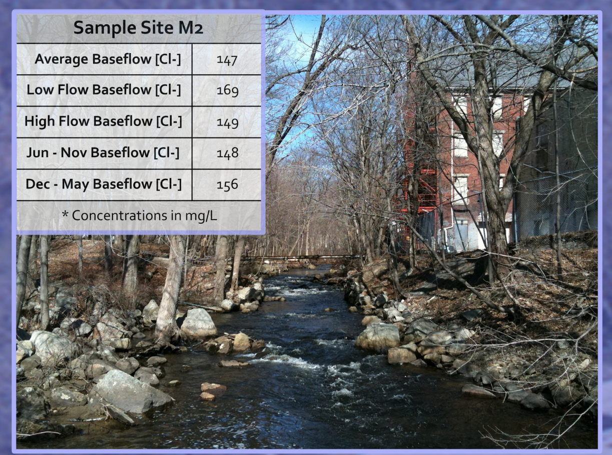
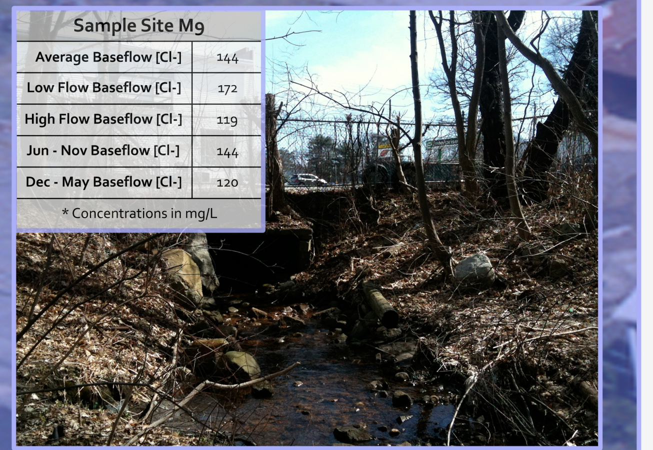


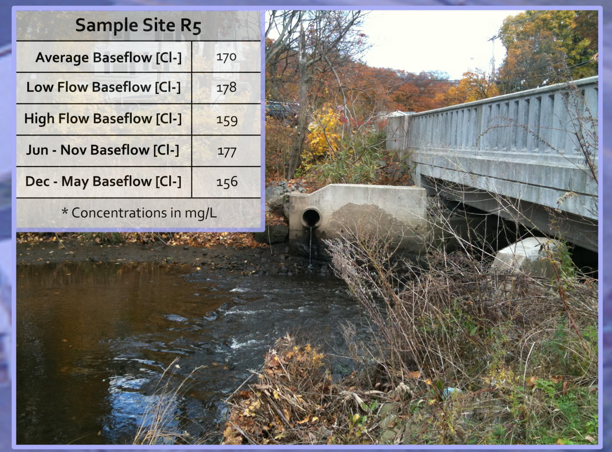
Sample Site M2	
Average Baseflow [Cl-]	147
Low Flow Baseflow [Cl-]	169
High Flow Baseflow [Cl-]	149
Jun - Nov Baseflow [Cl-]	148
Dec - May Baseflow [Cl-]	156

* Concentrations in mg/L



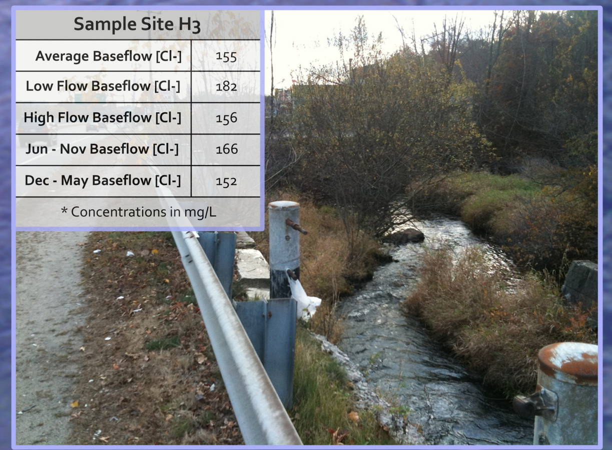
Sample Site M9	
Average Baseflow [Cl-]	144
Low Flow Baseflow [Cl-]	172
High Flow Baseflow [Cl-]	119
Jun - Nov Baseflow [Cl-]	144
Dec - May Baseflow [Cl-]	120

* Concentrations in mg/L



Sample Site R5	
Average Baseflow [Cl-]	170
Low Flow Baseflow [Cl-]	178
High Flow Baseflow [Cl-]	159
Jun - Nov Baseflow [Cl-]	177
Dec - May Baseflow [Cl-]	156

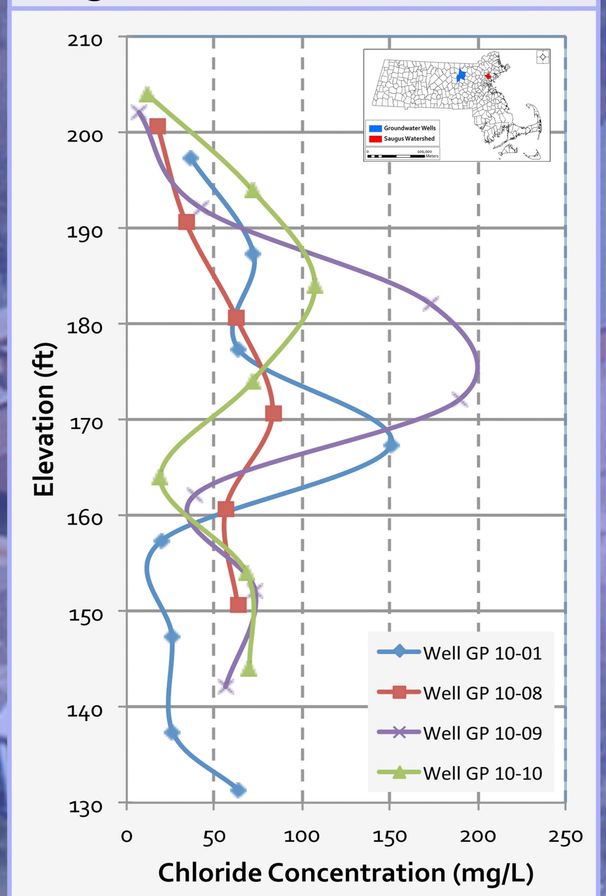
* Concentrations in mg/L

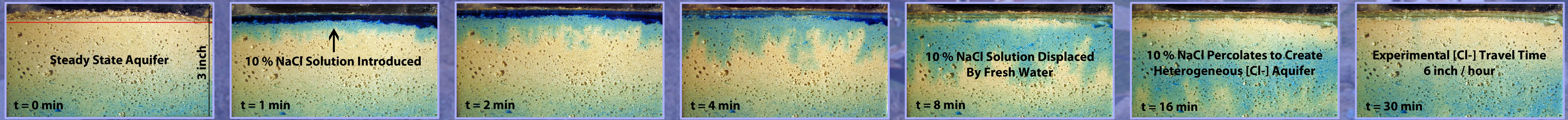


Sample Site H3	
Average Baseflow [Cl-]	155
Low Flow Baseflow [Cl-]	182
High Flow Baseflow [Cl-]	156
Jun - Nov Baseflow [Cl-]	166
Dec - May Baseflow [Cl-]	152

* Concentrations in mg/L

Regional Groundwater [Cl-]



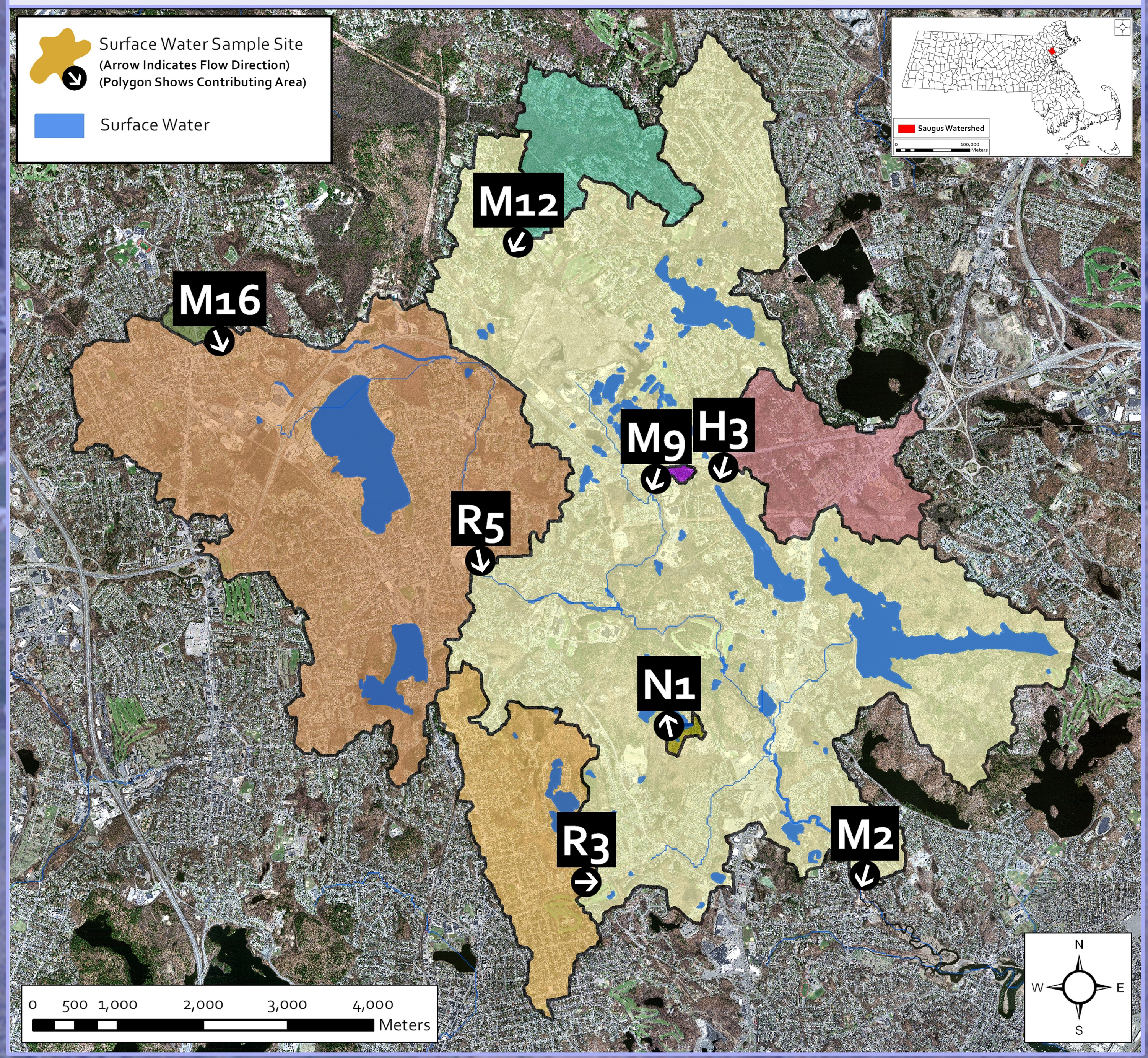


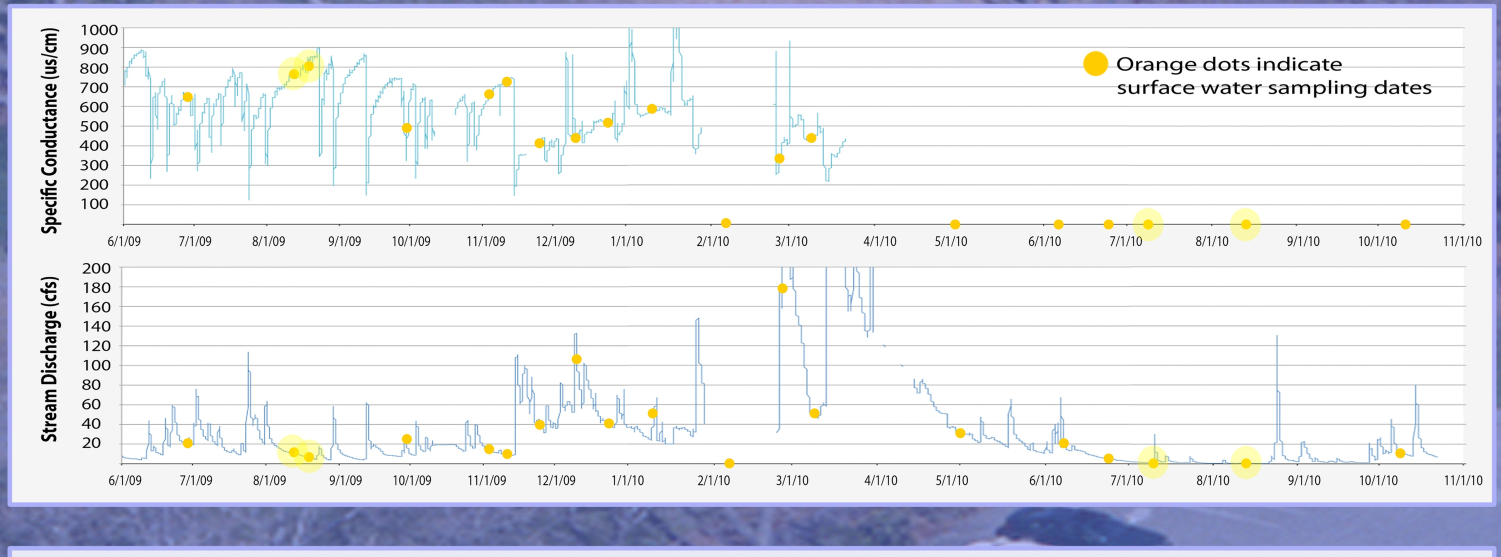
INTRODUCTION / BACKGROUND

To maintain safe winter driving conditions, over 15,000,000 tons of road salt is applied to US roadways each year (Transportation research Board, 2009). Road salt, predominately sodium chloride (NaCl) contaminates surface water, groundwater, and soils. The concentration of the chloride ion in natural waters has proven to be the best indicator of road salt contamination. Road salt contamination is correlated with the depletion of soil nutrients (Environment Canada, 2001), the release of other contaminants (Kelly et al., 2008), damage to infrastructure (Kelly et al., 2008), decreases in native animal, plant, and bacteria populations, the proliferation of invasive species (Kelly et al., 2010; Environment Canada, 2001), water body stratification and stagnation (Hon et al., 2010), and a decrease in water quality (Kelly et al., 2010). Tedder (2009) showed that the extent of chloride contamination in semi-urban watersheds is significantly greater than it is in rural watersheds. This study evaluates the extent of road salt contamination throughout one semi-urban watershed and quantifies the correlations between the extent of contamination and many land use factors, such as impervious surface coverage percentage and roadway density.

The Saugus Watershed is a 24.1 square mile watershed located in eastern Massachusetts. The watershed has significantly varied land use characteristics and several subcatchments exist with particularly unique land use attributes. Road salt budget models show that only about 50 % of road salt applied within the watershed each year is balanced by road salt leaving the watershed in stream discharge. The rest remains in the aquifer with a residence time of years to decades (Hon, 2010). Hydrograph separation calculations have shown that groundwater discharge (baseflow) contains approximately 75 – 85 % of the total road salt removed from the watershed each year. The remaining 15 – 25 % is removed in storm event flows (Tedder, 2009). The chloride concentration of stream discharge has been observed as low as 0.9 mg/L, during the summer and fall, and as high as 1,300 mg/L in the winter and spring (Tedder, 2009). The concentration of chloride throughout the watershed is frequently observed above the Environmental Protection Agency's secondary maximum contaminant level (sMCL) of 250 mg/L. Recent regional groundwater studies and benchtop model experiments suggest that a groundwater aquifer that is hetergenous with respect to chloride concentration may be present in the Saugus Watershed and many other developed watersheds. This study characterizes the road salt contamination of groundwater throughout the Saugus Watershed by analyzing seasonal changes in baseflow chemistry.

Surface Water Sample Sites and Contributing Subcatchments





METHODS

270 surface water samples were collected from 29 sites throughout the Saugus Watershed from June, 2009 – September, 2010. Most sample sites are stream channels of various magnitudes. Some sample sites, such as N1, are lakes or wetlands. The contributing area of sample site M2 defines the Saugus Watershed. The contributing areas of all other sample sites define subcatchments within the Saugus Watershed. Sample sites were chosen to maximize the number of differences in land use characteristics between subcatchments. This study presents the data from the 8 most frequently sampled sites.

Surface water samples were subdivided into non-exclusive categories based on the hydrological conditions at the time of sampling: 1) low flow baseflow (Q > 20 cfs at site M2), 2) high flow baseflow (Q > 20 cfs at site M2), 3) June – November baseflow, 4) December – May baseflow, 5) June – November storm flow, and 6) December – May storm flow. This study focuses on samples collected during baseflow-dominated conditions.

The concentrations of major ions (lithium, sodium, ammonium, potassium, magnesium, calcium, fluoride, chloride, nitrite, bromide, nitrate, phosphate, and sulfate) were measured using ion chromatography. Mean concentrations were calculated and compared for each subset of data acquired from the hydrological classifications.

The contributing areas (subcatchments) for each sample site were determined using ArcGIS and digital terrain model datasets from MassGIS.

The densities of roadways, impervious surfaces, and land use classifications in each subcatchment were determined using ArcGIS and datasets obtained from MassGIS.

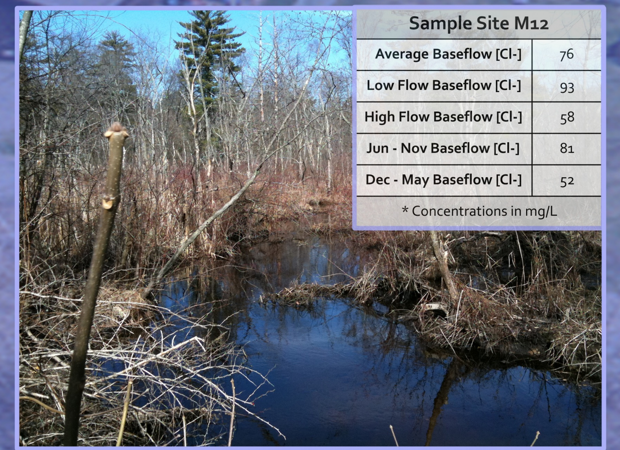
Linear correlations between mean chloride concentrations at each of the sample sites and the following land use density variables were analyzed: 1) impervious surface, 2) developed, 3) residential, 4) commercial and institutional, 5) industrial and infrastructure, 6) recreational, 7) Agricultural, 8) transportation, 9) total roadway, 10) highway, 11) highway and major road, 12) minor roadway.

Subcatchment Land Use

	M2	H3	R3	R5	M9	M12	M16	N1
Surface Area (m^3)	514522	30805	47354	203940	1678	20429	7311	1662
Impervious Surface Coverage	24%	22.20%	26.30%	31%	35.80%	16.90%	22.80%	2.50%
Developed Land Use	53.60%	50.30%	65.80%	70%	66.10%	52.50%	93.50%	0%
Undeveloped Land Use	46.40%	49.70%	34.20%	30.00%	33.90%	47.50%	6.50%	100.00%
Agricultural Land Use	0.10%	0%	0.03%	0.01%	0.00%	0.00%	0.00%	0.00%
Residential Land Use	39.10%	29.30%	56.20%	50.70%	24.80%	50.60%	57.40%	0%
Commercial and Institutional Land Use	6.50%	8.90%	1.90%	9.70%	25.80%	1.70%	10%	0.00%
Industrial and Infrastructure Land Use	2.10%	4%	2.90%	2.30%	0%	0.10%	0.20%	0.00%
Recreational Land Use	3.60%	1.10%	4.60%	4.10%	0.00%	0.10%	35%	0.00%
Transportation Land Use	2.20%	7.10%	0%	3.10%	15.50%	0%	0%	0.00%
Total Road Length to Surface Area Ratio	0.008	0.011	0.011	0.012	0.026	0.008	0.021	0.016
Highway Length to Surface Area Ratio	0.001	0.004	0	0.001	0.0015	0	0.004	0
Highway and Major Road Length to Surface Area Ratio	0.002	0.006	0.001	0.003	0.015	0.001	0.004	0
Minor Road Length to Surface Area Ratio	0.006	0.005	0.01	0.009	0.011	0.007	0.017	0.016

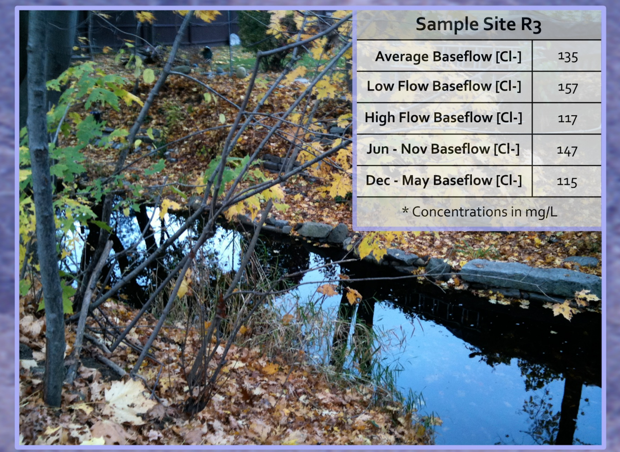
Sample Site M16	
Average Baseflow [Cl-]	106
Low Flow Baseflow [Cl-]	114
High Flow Baseflow [Cl-]	103
Jun - Nov Baseflow [Cl-]	101
Dec - May Baseflow [Cl-]	107

* Concentrations in mg/L



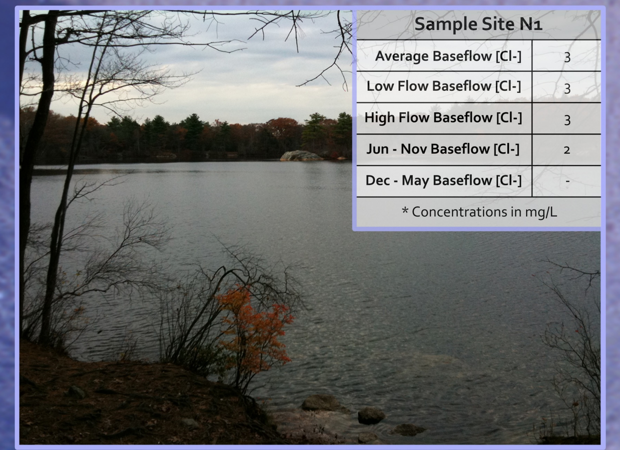
Sample Site M12	
Average Baseflow [Cl-]	76
Low Flow Baseflow [Cl-]	93
High Flow Baseflow [Cl-]	58
Jun - Nov Baseflow [Cl-]	81
Dec - May Baseflow [Cl-]	52

* Concentrations in mg/L



Sample Site R3	
Average Baseflow [Cl-]	135
Low Flow Baseflow [Cl-]	157
High Flow Baseflow [Cl-]	117
Jun - Nov Baseflow [Cl-]	147
Dec - May Baseflow [Cl-]	115

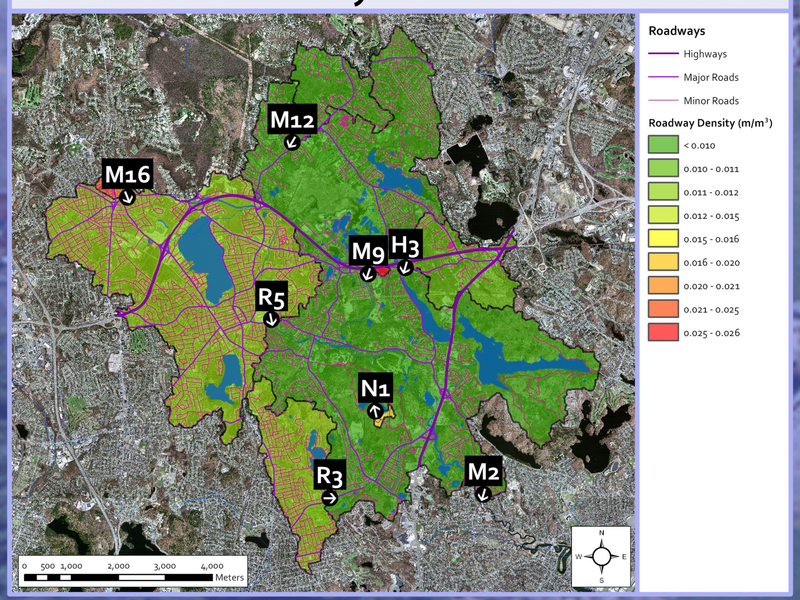
* Concentrations in mg/L



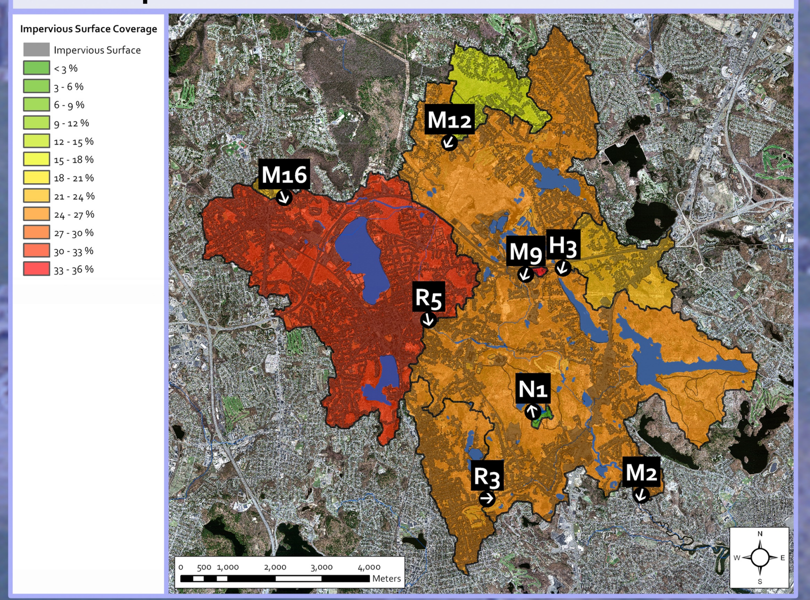
Sample Site N1	
Average Baseflow [Cl-]	3
Low Flow Baseflow [Cl-]	3
High Flow Baseflow [Cl-]	3
Jun - Nov Baseflow [Cl-]	2
Dec - May Baseflow [Cl-]	-

* Concentrations in mg/L

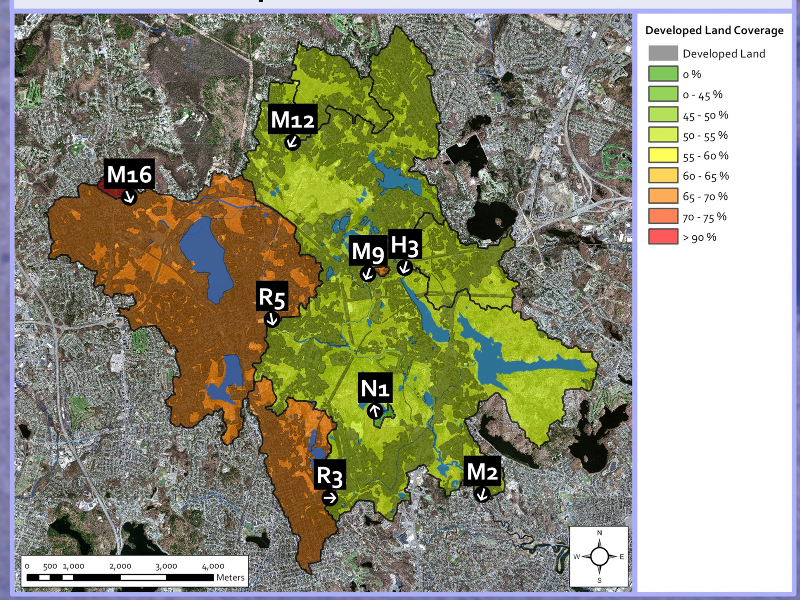
Roadway Distribution



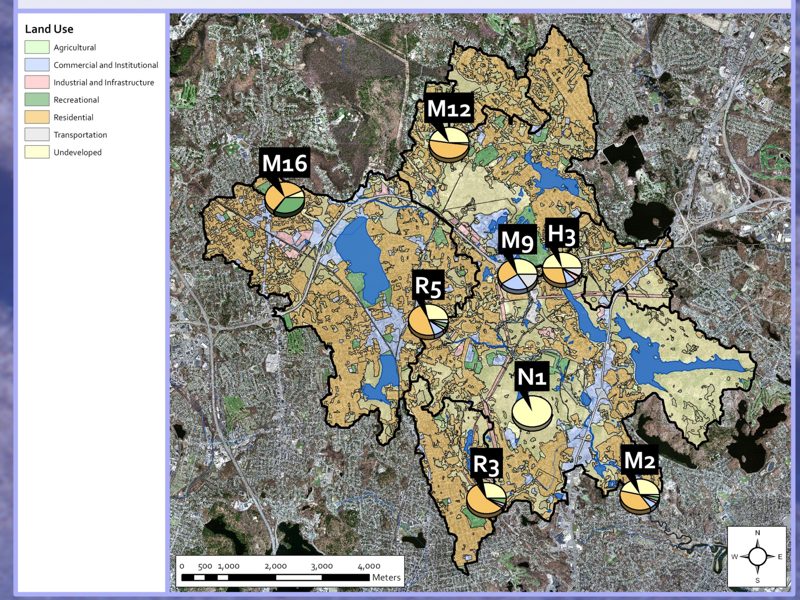
Impervious Surface Distribution



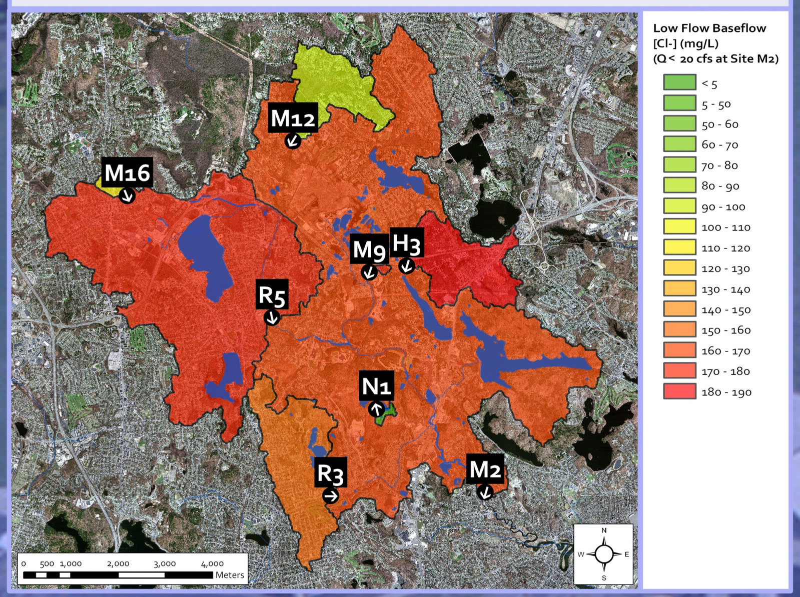
Developed Land Distribution



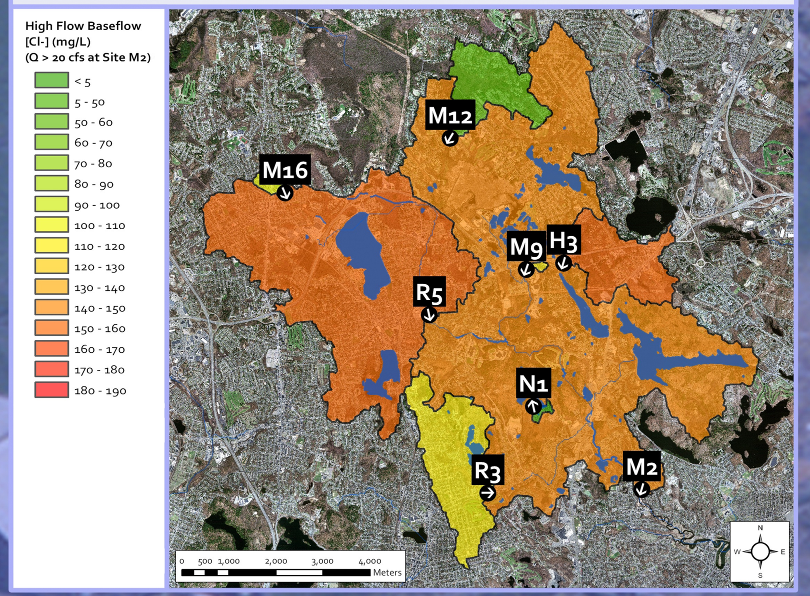
Land Use Distribution



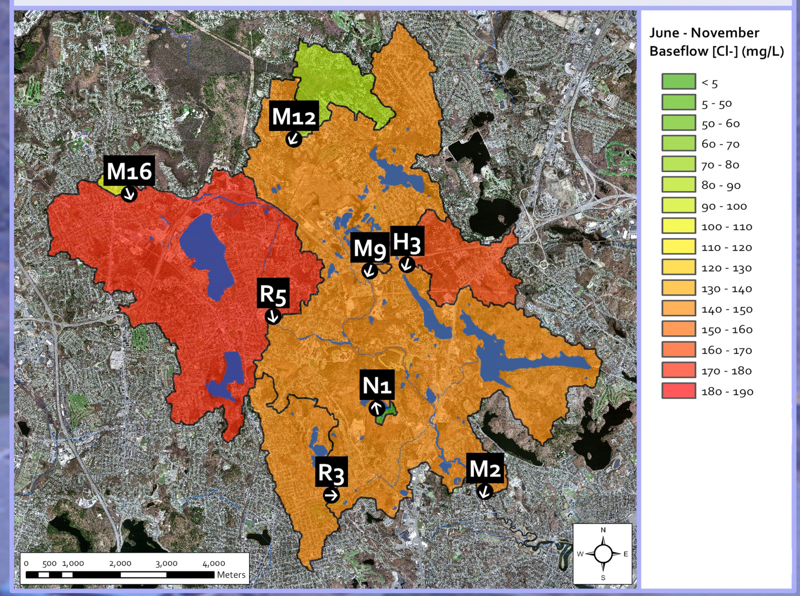
Low Flow Baseflow [Cl-]



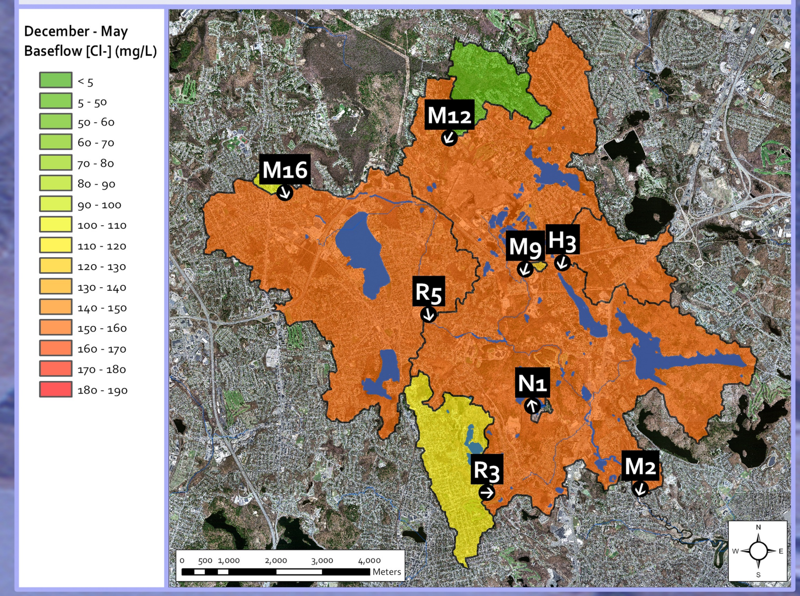
High Flow Baseflow [Cl-]



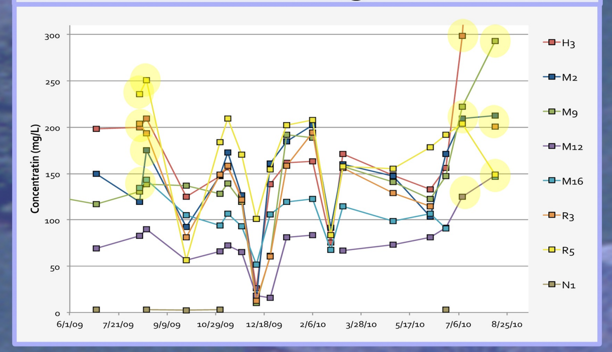
June - November Baseflow [Cl-]



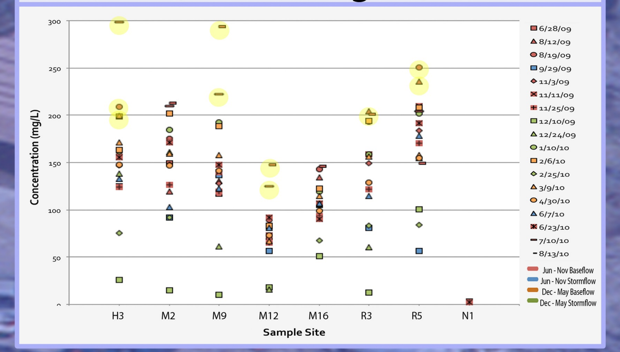
December - May Baseflow [Cl-]



Sample Site [Cl-] By Time June, 2009 - August, 2010



Sample Site [Cl-] By Site June, 2009 - August, 2010



CONCLUSIONS

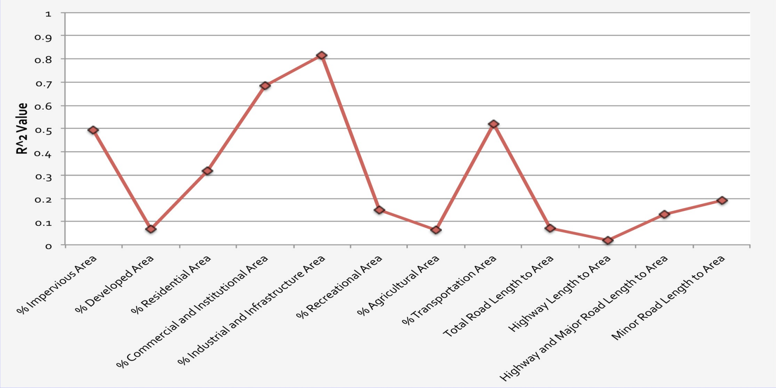
The contributing area of sample site N1 is virtually undeveloped with minimal anthropogenic influence. The chloride concentration consistently remains below 4 mg/L, a level that best approximates what the chloride concentration would be throughout the Saugus Watershed if road salt applications had never occurred.

The application of road salt has increased the background concentration of chloride in baseflow to as high as 180 mg/L, 50 – 200 times the approximate natural level. The highest concentrations are observed during the late summer and early fall, when stream discharge is at a minimum and evapotranspiration is at a maximum. The lowest concentrations are observed during the winter and spring, when stream discharge is at a maximum and evapotranspiration is at a minimum. The difference between the lowest and highest concentrations often exceeds the 10 – 30 % difference that should be expected due to evapotranspiration, suggesting the existence of a groundwater aquifer that is heterogeneous with respect to chloride concentration.

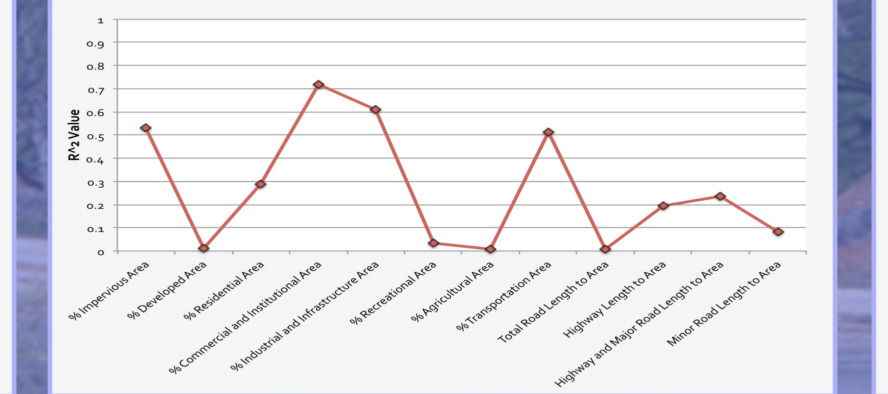
During low flow conditions (July - November), the chloride concentration of baseflow is occasionally 200 – 1000 % greater than the typical background concentration. These results further suggest that the groundwater aquifer is heterogeneous with respect to chloride concentration. The discharge of this particularly contaminated groundwater was only observed when the groundwater reservoir was most depleted in the late summer and early fall.

Significant correlations between baseflow chloride concentration and several land use characteristics exist. The strongest correlations are observed with impervious surface density, commercial and institutional density, industrial and infrastructure density, and transportation (land use classification) density. Surprisingly low correlations are observed with roadway density, residential density, and overall development density. These results suggest that road salt applications to major highways, and the businesses, industries, and institutions that often accompany them, are most responsible for groundwater chloride contamination.

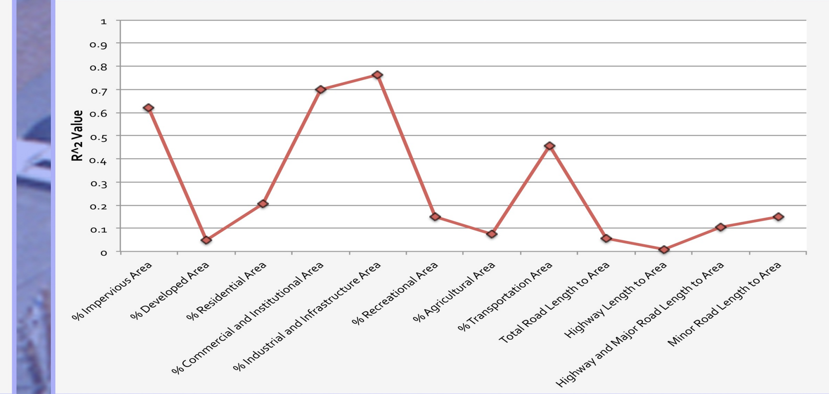
Low Flow Baseflow [Cl-] Linear Coorelation R^2 Values



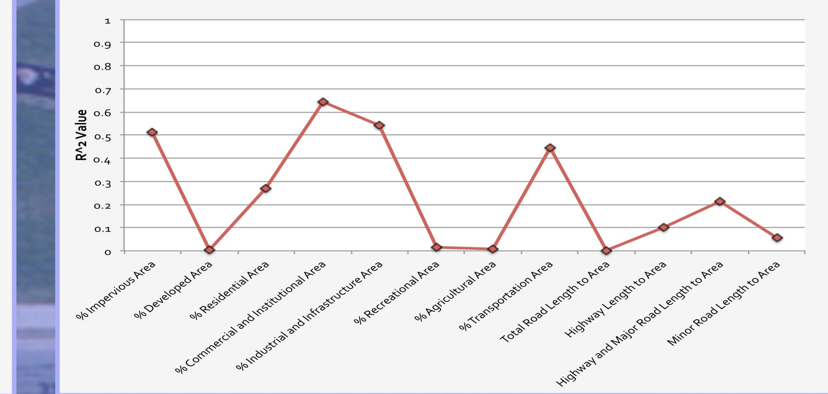
High Flow Baseflow [Cl-] Linear Coorelation R^2 Values



June - November Baseflow [Cl-] Linear Coorelation R^2 Values



December - May Baseflow [Cl-] Linear Coorelation R^2 Values



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