Road Salt Loadings Study:

Waterford River, Leary's Brook, and Virginia River;

Northeast Avalon Urban Region

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Prepared for:

Northeast Avalon Atlantic Coastal Action Program

(NAACAP)

October 2008

Executive Summary

The three major river systems that run through Newfoundland's most urbanized region are susceptible to road salt input from street runoff. Being highly productive trout rivers, this is a potential concern for the aquatic ecosystems in which they thrive (Gibson, 2006). The rivers were sampled, analysed, and compared with corresponding reference sites during the icy season to determine the extent of road salt contamination. The consequent results showed that salt was definitely entering the aquatic ecosystems during the winter. A proportional link between specific conductance and sodium concentration was also established during the testing period, as well as an estimate of approximate chloride concentrations present in the samples. This report details the results of the testing and provides interpretations and information on the potential consequences of road salt contamination within the rivers, while also making recommendations on a better management plan for winter road salt applications.

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1.0 Introduction

Winter in Eastern Canada can be cold and often tends to be snowy. These subzero conditions can cause hazardous ice to form on many types of surfaces, such as roadways and parking lots. In the interest of public safety, public works crews on Newfoundland's Avalon Peninsula are frequently challenged to keep asphalt surfaces ice-free, as its typical winter climate often experiences repeat partial thawing followed by a refreezing period. As this region is also the most densely populated portion of the province of Newfoundland and Labrador, its roadways are subject to the heaviest traffic use. To combat the slippery conditions, municipalities have chosen road salt and sand as the primary means of de-icing and improving the overall traction for vehicles. The salt has proven to be fairly efficient and cost effective in making the roads safer for winter traffic, ensuring a lower risk of ice-related car accidents and any ensuing lawsuits. Although road salt may be the product of choice that is used to keep roadways and parking lots free of ice, it has been placed on the *2001 Canadian Environmental Protection Act* (CEPA), *List of Priority Substances* in 2001 (Environment Canada, 2001) as a harmful toxin upon entering the environment.

Once applied to roads and parking lots, salt can easily leave these surfaces in the form of run-off and contaminate the surrounding soil and waterways, destroying habitat for both plant and aquatic life. There is also the potential for groundwater contamination as well. One of the main problems is the method of delivery, in that too much salt is often applied at times when it is not needed. The current method of applying the salt needs to be reevaluated to ensure it has a minimal impact upon the environment. A "greener" method of producing safer winter driving conditions could be adopted to protect vulnerable ecosystems at risk. This report shows that salt does enter the urban river systems of St. John's and Mount Pearl in the cold season.

Photo 1: *Outline of excessive salting on Hayward Avenue. This particular spillage was about three to four days old and subjected to melt water.*

1.1 Scope

This study concentrated on determining whether road salt is entering the Waterford River, Leary's Brook, and Virginia River during the icy season, and whether the amount of road salt may at times be at sufficient quantities to pose a risk to aquatic organisms. It is possible that other substances can enter the rivers through the same

pathways. The study attempts to establish a correlation between conductivity readings and measured sodium levels in the rivers to aid in developing a simpler method for carrying out any follow-up salt loading studies. Some preliminary literary research regarding the known toxicity of road salt was conducted to strengthen the basis for need of this baseline research as well.

2.0 Background

Road salt has been used in Canada as a deicer for approximately 70 years. In other road applications, it is also used as a dust suppressant (Environment Canada, 2001). As a deicer, road salt acts by dissolving water in the accumulated snow or ice. The salty brine that forms is effective in lowering the freezing temperature of the water and thus enables the bond that forms between the road surface and the ice to weaken or break (Riversides, 2005). The change in freezing temperature and the weakened surface bonds would essentially cause the ice to melt away, and any left over slush would be much easier to remove with snow clearing machinery.

2.1 Physical-Chemical Properties

Road salts are made of chloride ions (Cl^-) and an associated cation – the predominant being sodium (Na^+), but calcium (Ca^{2+}), magnesium (Mg^{2+}) or potassium (K^+) are also present but in decreasing amounts. The anti-clumping agent, ferrocyanide salt, is commonly mixed with road salt as well (Riversides, 2005). Since chloride ions are fairly stable and do not easily degrade naturally, they are able to retain their form in the environment. Thus, chloride ions, introduced through road salt and transported though runoff, tend to reach surface and ground waters with little attenuation. This often results in increasing the Cl^- concentration well above the water's natural levels (Riversides, 2005).

As a salt, Cl^- compounds have certain properties that make them ideal for use on icy roads in particular conditions. Sodium chloride (NaCl) is the most common deicer in North America. Although pure NaCl is made up of approximately 40% sodium and 60% chloride by weight, road salt tends to be less pure and up to 5% of its total weight may be comprised of various trace elements, such as sulphur, phosphorus and nitrogen; and metals, such as copper and zinc. On roads, NaCl has a versatile working temperature range of between 0°C and -15°C (Environment Canada, 2001).

Calcium chloride ($CaCl_2$) is also commonly used in some regions, and is second in usage to NaCl throughout North America. It is also the most popular chemical agent used for suppressing dust in Canada (Environment Canada, 2001). It is very useful in liquid form not only for its aggregating properties on dusty roads but also for pre-wetting of sand or salt to produce a more efficient means of ice control on winter roads (Donahey T. J., and Burkheimer D. 2006). When salt is pre-wet with liquefied calcium chloride, it has a much better chance of sticking to the road surface, making it much more effective

than dry salt, which could easily be blown away by the wind, or swept off by traffic. This would minimize the amount of salt needed to effectively control road ice. The solution also ensures that enough moisture is present to melt the ice when temperatures drop below the freezing point (Donahey T. J, and Burkheimer D. 2006). When used in its pure form, $CaCl_2$ has an effective working temperature of less than -23°C, which would serve useful in parts of the country that experience cold, dry winters. However, the $NaCl/CaCl_2$ brine mixture has a higher working temperature of about -12°C, which would make it suitable for more coastal regions that do not experience as cold winters (Environment Canada, 2001). Although it is not widely in use in Canada at this time, the amount of brine mixture used on roads for deicing purposes is expected to increase in the coming years as more municipalities and businesses begin to experiment with pre-wetting methods (Environment Canada, 2001).

Other potential road salt compounds could include magnesium chloride ($MgCl_2$) and potassium chloride (KCl), however both are rarely used in most parts of Canada, as they are expensive substitutes (Environment Canada, 2001). Although little information is available on its use as a road deicer in Canada, $MgCl_2$ has a working temperature of about -15°C and is more soluble than NaCl. While NaCl can be pre-wet with $MgCl_2$ to provide a working temperature of less than 15°C where needed, it is not known to be in use in Canada (Environment Canada, 2001). Potassium chloride is used even less than $MgCl_2$, but occasionally potash mine tailings have been used on certain roads in Canada, although the KCl content is generally quite low, with the majority of the brine content actually being NaCl. The most effective working temperature of KCl is close to -4°C (Environment Canada, 2001). While currently being used as a dust suppressant on dry roads, the brine formed from oil field operations could also be potentially used as a road deicer, since the liquid essentially contains chloride, sodium, calcium and magnesium (Environment Canada, 2001). However any of these options could potentially contain particular contaminants, as the elemental sources would not be guaranteed to be pure.

One additive in particular, which is often present in road salt, is ferrocyanide. This substance, which is found in the forms sodium ferrocyanide and ferric ferrocyanide, is sometimes added to prevent the road salt from clumping due to moisture present in the air during storage and road application (Environment Canada, 2001). These solid forms can break down to the relatively harmless ferrocyanide anion ($Fe(CN)_6^{4-}$) in water, but the new ion can undergo other chemical reactions, either chelating with transition metals in the water to form precipitates, or photolysing in direct sunlight to form harmful free cyanide ions (Environment Canada, 2001).

2.2 Sources

Chloride salts enter the environment from many natural and anthropogenic sources. Naturally, these substances are released during the weathering and erosion of rocks and soil from precipitation and groundwater flow (Environment Canada, 2001). The runoff that forms during precipitation, or continuous fluvial processes, can then transport these salts to other locations in the environment, such as water bodies and soils,

away from the source material. Coastal areas can also receive salt spray and mist from wave action along the coastline (Environment Canada, 2001). When used as a deicer, chloride salts can contaminate surface water, soil, and groundwater through road runoff, as well as runoff from salt storage depots and snow deposits. Road salt can also become airborne on dry days from wind action, as well as being sprayed into the air by vehicle tires (Environment Canada, 2001). In addition to natural weathering processes and intentional road application, salts can also enter the environment unnaturally through industrial discharges. Petrochemical and other chemical effluent tends to contain inorganic chloride salts, as well as the wastes from gas manufacturing and acid mine drainage. Domestic sewage can also contribute to the release of salts into the environment (Environment Canada, 2001).

2.3 Impacts

In nature, a watershed essentially drains the runoff from the land into river channels, which end up in water basins, such as lakes, or in other rivers, and eventually discharges to the sea. Due to the flat, non-porous characteristics of asphalt roads, overland flow from precipitation and melt water easily transports chloride ions away from the roads and into the environment where eventually they are discharged into waterways. Chloride ions also infiltrate the ground and are transported though groundwater flow contaminating aquifers as well as surface water (Riversides, 2005).

Road salts that enter surface water can be toxic to freshwater plants, fish and other freshwater organisms (Environment Canada. 2003). It has been demonstrated that in high enough concentrations chloride can be lethal to many freshwater species (Riversides, 2005). Road salt significantly disrupts the growth of vegetation by directly harming the plant's cells osmotic balance, thus hindering the plant's ability to absorb water and nutrients, and causing a reduction in root growth (Riversides, 2005). Microorganisms and other soil species can also be harmed indirectly when soil becomes contaminated with road salt because the salt changes the soil's chemical and physical properties, such as its conductivity, permeability, and osmotic potential, altering the conditions necessary for certain species to survive (Environment Canada, 2001).

The tolerance of different organisms to various substances, such as road salts, is dependant on the species (Environment Canada, 2001). Human beings tend to have a higher tolerance to certain substances than many aquatic species, thus the new *Canadian Environmental Protection Act* definition of an acceptable exposure limit for a person may be directly or indirectly harmful to an organism or aquatic ecosystem (Environment Canada, 2001). Acute toxicity has been shown to occur in aquatic organisms exposed to very high chloride concentrations during laboratory testing, whereas chronic toxicity was estimated to begin at significantly lower concentrations of about 210 mg/L, (*Table 1*, Evans and Frick, 2002). These elevated concentrations were shown to increase the bioavailability of metals as well as affect the density gradient in lake systems, changing the availability of oxygen and nutrients at particular depths (Evans and Frick, 2002).

Table 1: *Cumulative percent of species affected by varying chronic concentrations of chloride* (From Environment Canada, 2001)

Cumulative % of Species Affected	Mean Chloride Concentration (ppm)	Lower Confidence Limit (ppm)	Upper Confidence Limit (ppm)
5	212.6	135.9	289.5
10	237.9	162.3	313.6
25	328.7	260.2	397.2
50	563.2	504.8	621.7
75	963.7	882.3	1045.1
90	1341.1	1253.8	1428.4

Recent studies have shown that road salts can affect terrestrial mammals and birds. They are attracted to the salty roadside ditches, increasing their chances of collisions with automobiles, or becoming poisoned from drinking the salty water (Riversides, 2005). These animals can also be affected by habitat loss in areas affected by excessive salt use, due to a reduction in vegetative covering, subsequently resulting in a reduction of food sources, shelter, and breeding or nesting sites (Environment Canada, 2001).

Due to its high susceptibility to photolysis when in solution, the ferrocyanide salt additive in road salt releases toxic free cyanide ions, which quickly form hydrogen cyanide (HCN) (Environment Canada, 2001). Since these ions and compounds are highly toxic to aquatic life, the effects of ferrocyanide are considered a part of the road salt assessment (Environment Canada, 2001). However, it should also be noted that cyanide ions are easily chelated with various metal ions present in the water and thus tend to form back into stable complexes, such as the precipitate ferric ferrocyanide. Sulphur also is able to oxidize cyanide into several harmless forms. Cyanide can adsorb to the surfaces of clay minerals in water as well, rendering them harmless to aquatic life (Environment Canada, 2001).

While road salts have no known toxic effects on humans, they can threaten the potability of drinking water supplies, particularly in terms of how the water tastes (Environment Canada, 2003). This happens most often to people who rely on groundwater and well supplies when salty water infiltrates though the soil (Environment Canada, 2001). The loss of a clean drinking water supply, such as when tainted with salt, can lead to substantial human impacts, as people affected would have to find a new drinking water supply (Riversides, 2005).

2.4 Application and Loadings

At the time of publication, it was estimated by Environment Canada (2001) that about 4.9 million tonnes of road salt are typically applied nationwide every year. More than 60% of this, or approximately 3.0 million tonnes, is made up of chloride. Due to having the most roads, Ontario and Quebec receive the highest loadings of road salt

annually, however more is applied to roads in the Atlantic Provinces than in the Western Provinces (Environment Canada, 2001).

Through their comprehensive *Salt Management Plan* (2005) the City of St. John's outlines the methods used in spreading salt. Essentially there are specific spreading trucks that utilize a more advanced technology, one that electronically controls and records the amount of salt being placed in a given location at any given time, no matter what speed the truck is moving. This technology has been proven to effectively reduce the amount of salt applied to the roads during winter while still maintaining an ice-free status. It also serves the purpose of identifying when too much or too little salt has been placed, so that adjustments can be made for future applications. Additionally, trucks capable of applying liquefied NaCl brine have also begun to be integrated into the City's deicing fleet in an effort to decrease the amount of salt placed on the roadways per year while increasing the overall efficacy of the salt's ability to reduce ice (City of St. John's, 2005).

Photo 2: *Close-up of road salt crystals on Hayward Avenue from improper application. Note the clumping effect of the excessive salt covering the pavement.*

3.0 Methods

3.1 Sampling

Water sampling for the Road Salt Loadings project began in November 2005 and continued until April 2006 with sampling taking place at regular two-week intervals. Water samples were collected in three prominent urban river systems:

The Waterford River; The Virginia River; and Leary's Brook.

Five stations were chosen along each river system (one at the headwaters, one at the mouth and three along the length of the river system). Digital images of each site are included in Appendix A. The study was designed to sample from the headwaters to the

mouth of each system. In all cases, the headwater stations were located in areas where there is little development and thus should not have been significantly impacted by the application of road salts. As the three river systems run into the urban area there is significant development and the potential of impact from road salts applied to nearby roadways during the winter months is greatly increased. Additionally, when establishing the stations along the length of the river systems, the location of major parking lots were taken into consideration. In most cases, the stations along the length of the river systems (with the exception of the headwaters and mouth stations) were situated upstream and downstream of major parking lots. This was done in order to take into account the application of road salt in parking lots where there is concern that a very different practice of deicing is exercised than in the application of road salt to city streets. The following table (*Table 1*) identifies the selected sample sites.

Table 2: *Selected sample sites along each river and their descriptions.*

	Waterford River	**Virginia River**	**Leary's Brook**
Site #1	**Reference Site:** at headwaters in Bremigan's Pond	**Reference Site:** at headwaters near top of Firdale Drive	**Reference Site:** at headwaters near Outer Ring Road
Site #2	**Upstream Site:** Donovan's Industrial Park near Corisande Drive	**Upstream Site:** Penney Lane (off Torbay Road)	**Upstream Site:** (a) at Vatcher's Garage, (b) at Pippy Place in Leary's Industrial Park area
Site #3	**Parking Lot Site:** at the Piper's parking lot (on Commonwealth Ave)	**Parking Lot Site:** at the Fall River Plaza parking lot (below Wedgewood Clinic)	**Parking Lot Site:** at the Avalon Mall parking lot (along Prince Phillip Drive)
Site #4	**Downstream Site I:** Brookfield Rd. adjacent to the ball field	**Downstream Site I:** below crossing at Newfoundland Dr.	**Downstream Site I:** near the Canadian Blood Services building
Site #5	**Downstream Site II:** towards the mouth of the river (across from Michelle's Bakery)	**Downstream Site II:** towards the mouth of the river (near Royal Legion on The Boulevarde)	**Downstream Site II:** Health Sciences area (before entering Long Pond)

When sampling, standard protocol established by the Province of Newfoundland and Labrador Water Resources Division was followed to ensure that the best quality and most accurate results were achieved during testing. The pre-washed bottles and lids used were made of plastic and were rinsed with river water three times each prior to obtaining a sample in order to minimize the chances of any contamination. Also, a random triplicate sample was taken at one sample site during each sweep to ensure that the testing

methods were working properly. Where possible, the samples were obtained with the use of a sample nabber, which is essentially a pivoting bucket on an extendible rod, or a bucket tied to a rope. This method greatly aided in the sampling process in terms of increased safety and accessibility.

3.2 Lab Analysis

The element sodium (Na) was measured analytically using a Flame Atomic Absorption Spectrometer (FAAS). The FAAS technique was a very useful method in accurately determining the concentration of sodium in the samples. Before use, the machine was calibrated with a blank of nanopure water and subsequently with four standardized sodium solutions. As the sodium concentrations were expected to be higher in the samples than in the standards, the samples were diluted before being introduced to the FAAS unit so an accurate concentration could be obtained.

When the sample is analysed it is drawn into an aspirator, which directs the water into a nebulizer chamber, where an air/acetylene mixture enters at high speed and breaks up the sample. The small droplets then hit a small bead or impeller and break down into smaller water particles. In an aerosol form, these particles are then drawn through the burner head into the flame, where they are then essentially atomized in temperatures as high as 2300°C. The atoms then come in contact with the Na cathode ray source light, set at a particular wavelength, and a monochromator then isolates the sodium analyte photons from the rest of the mixture and scatters unwanted light produced from any other elements present. The isolated light waves from the sodium are then finally sent to the photomultiplier tube where the resulting intensity (absorbance) of sodium photons in the sample is detected. The concentration of sodium in the sample is directly related to the absorbance and is thus calculated by the FAAS's internal computer at the end of the process.

3.3 In-Situ Analysis

The conductivity measurements were obtained through the use of a high tech multi-parameter water quality monitoring sonde called a Hydrolab Minisonde. The Department of Environment and Conservation, Water Resources Division regularly use this type of equipment and generously permitted the use of one Minisonde for the purposes of this study. The sonde was calibrated using a standardized method before each sampling sweep to ensure the results were consistent and accurate every time. The Minisonde operates *in-situ*, and collects real-time water quality data with a series of sophisticated sensors, one of which measures the conductivity parameter. It then displays the measurements on an LCD panel. A Horiba company probe, kindly loaned by the Marine Institute Department of Fisheries chemistry lab was also utilized in an identical manner on days when the Minisonde was not available.

3.4 Statistical Analysis

The statistical analysis of the raw sodium values formed the main method of interpreting the data. Because the data were all found to be non-parametric through a Ryan-Joiner test, other statistical steps were taken to conduct two-way Analysis of Variance tests (ANOVAs) on the data. The two-way ANOVAs revealed statistically whether there was a significant difference in the sodium concentrations at one site with another. These particular tests were very useful in determining whether there was a significant difference between the reference site and the other sites, which could then potentially indicate an anthropogenic input or change of salinity within the system away from the reference site. Simultaneously, the two-way ANOVA also determined whether there was a difference in the amount of sodium input in the different sites depending on any particular date, while taking into account the data means. A simple Pearson correlation test was performed as well to determine whether the specific conductance of a sample was related to a particular concentration of sodium. All statistical work was performed on computer software called Minitab12® (1998).

4.0 Results and Discussion

This section will serve several purposes in determining whether road salt enters the rivers during the winter months; whether there is any potential impact that would result from this; mathematically determining the proportionate amount of chloride in each sample; and establishing a probable correlation between conductivity levels and sodium concentration. Determining the levels and the potential impacts were achieved by the analytical and statistical interpretation of the sample data means of sodium and also of the mathematically derived chloride concentrations. The sodium – conductivity correlation was derived from a simple side-by-side statistical comparison of both data sets.

The interpretations made took into account the statistical and analytical contrast of the mean concentrations of sodium in the downstream stations (derived from the raw data from *Appendix C,* presented in *Appendix B*) to the concentration of sodium in the reference site (site 1). The analytical and statistical interpretations were often made independently of one another, and raw data presented in the appendices was often taken into account as well to make the most comprehensive analysis and interpretation of the results possible. Derived mean chloride values were compared with a known toxic concentration obtained from unique scientific studies (Environment Canada, 2001, Evans and Frick, 2002) to establish whether the loadings in the rivers were potentially harmful. Additionally, geographic features of the sites were taken into account when interpreting the data in individual cases, such as a site's particular proximity to a road or parking lot.

4.1 Sodium (Na) in the Waterford River, Virginia River, and Leary's Brook

Sodium was detected at every site on every river during every sampling date. Near equal concentrations between the headwaters and the downstream sites on each river on the first sample date were found just before winter road salting had begun for the season. However, the Na content began to increase in the downstream section of each river thereafter. The sodium levels in the headwater sites remained fairly stable over the sampling period. Since the rivers flowed through an urban area, thus passing under and adjacent to roads and parking lots, it would be expected that sodium levels would rise over time, especially if road salt were being applied during that time. Although it was a relatively mild winter, there were periods in late January to late March when there were more frequent and sustained snowfall and freezing periods. This is reflected in the results as the sodium content spiked several times in mid to late winter, reaching a peak loading in mid to late March. The following graphs show these increases and spikes in each of the rivers with their accompanying statistical interpretations, where "upstream" represents the headwater or reference site (site 1), and the "downstream" corresponds to the mean Na value of all sites downstream of site 1 for each river on a given date (sites 2 – 5).

Figure 1*: Data means for sodium (Na) in ppm in the Waterford River showing the upstream vs. the downstream sites.*
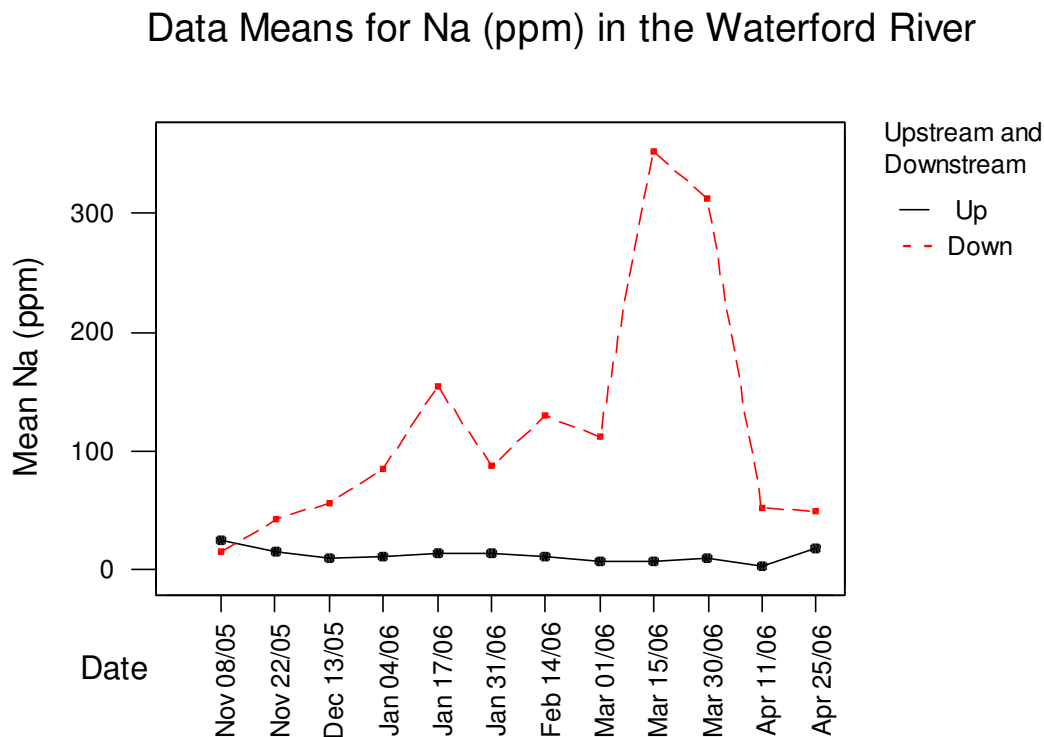
As seen by the Figure 1 graph, the Na concentrations vastly increased in the Waterford downstream by the middle of March. While the levels in the headwaters remained at 10 ppm or less at that time, the downstream levels averaged from 352.5 ppm on March 15th to 312.5 ppm on March 30th (derived from the raw data from *Appendix C;* presented in *Appendix B*). This was the time of year when the most snow had accumulated but had also begun to partially melt, which probably indicates much road salt had been sequestered in the snow banks from previous months' salting and released in higher amounts when it began to melt during the warmer daytime temperatures and increased sun exposure. Salting also continued to take place in March, which would have added to the increased loadings into the Waterford.

The results of the two-way ANOVA for the upstream and downstream comparison of the Waterford's sodium concentrations with respect to the sampling dates showed that the loadings were significantly higher in the downstream samples ($p = 0.005$) versus the reference samples, but that the difference did not relate to the sampling date in terms of the whole sampling period ($p = 0.556$). However the test did suggest that the dates March 15th, March 30th, and to a lesser extent January 17th, were important in terms of a relative increase in sodium input.

Figure 2: *Data means for sodium (Na) in ppm in the Virginia River showing the upstream vs. the downstream sites.*

Data Means for Na (ppm) in the Virginia River
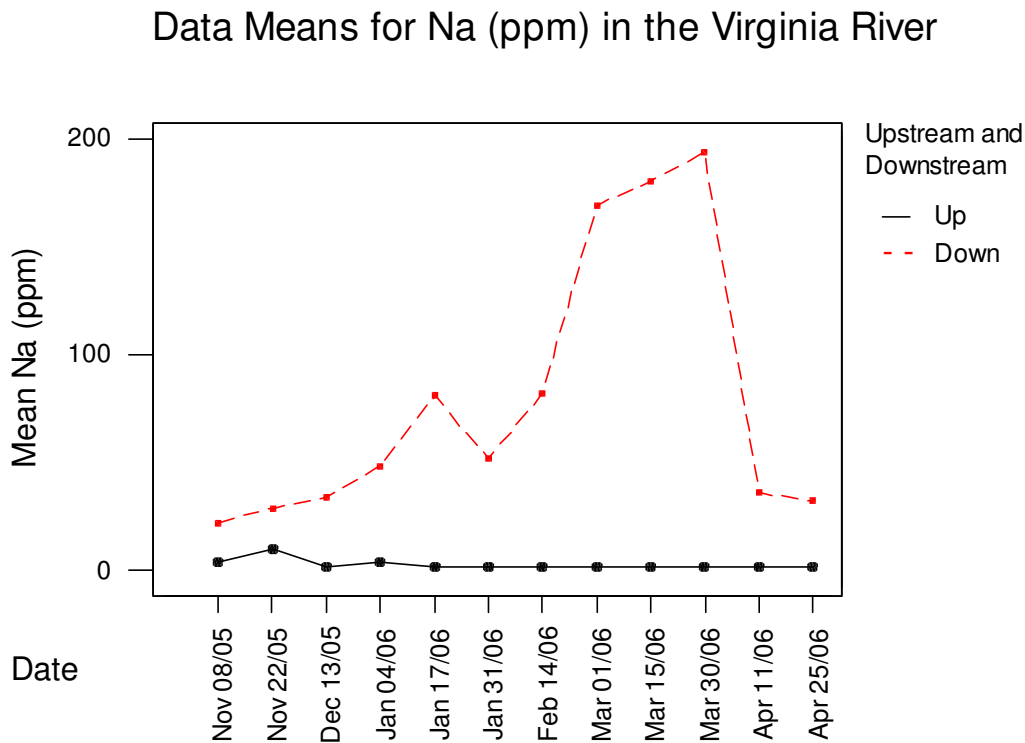
Similarly to the Waterford results, the sodium concentration in the Virginia River downstream greatly increased in March relative to the first month's concentration and to the values of the reference site in any month (*Figure 2*). While the Na in the headwaters remained stable at an average of about 2 ppm for the month of March, the downstream sites had average concentrations of 169.00, 180.00, and 193.75 ppm Na for each consecutive sampling date in March (derived from the raw data from *Appendix C;* presented in *Appendix B*). While these values were not as high as those in the Waterford, they still represent particular salt loading events in the Virginia River, whether due to melting of contaminated snowdrifts, or to salty road runoff.

The results of the two-way ANOVA for the upstream and downstream comparison of the Virginia's sodium concentrations with respect to the sampling dates showed that the downstream means were significantly higher than in the reference mean ($p = 0.002$) but that the difference did not relate to the sampling date in terms of the whole sampling period ($p = 0.534$). The statistical analysis did suggest, however, that in regards to a relative mean sodium increase, the dates March 1st, 15th, and 30th, and to a lesser extent January 17th and February 14th were important.

Figure 3: *Data means for sodium (Na) in ppm in Leary's Brook showing the upstream vs. the downstream sites.*

Data Means for Na (ppm) in Leary's Brook
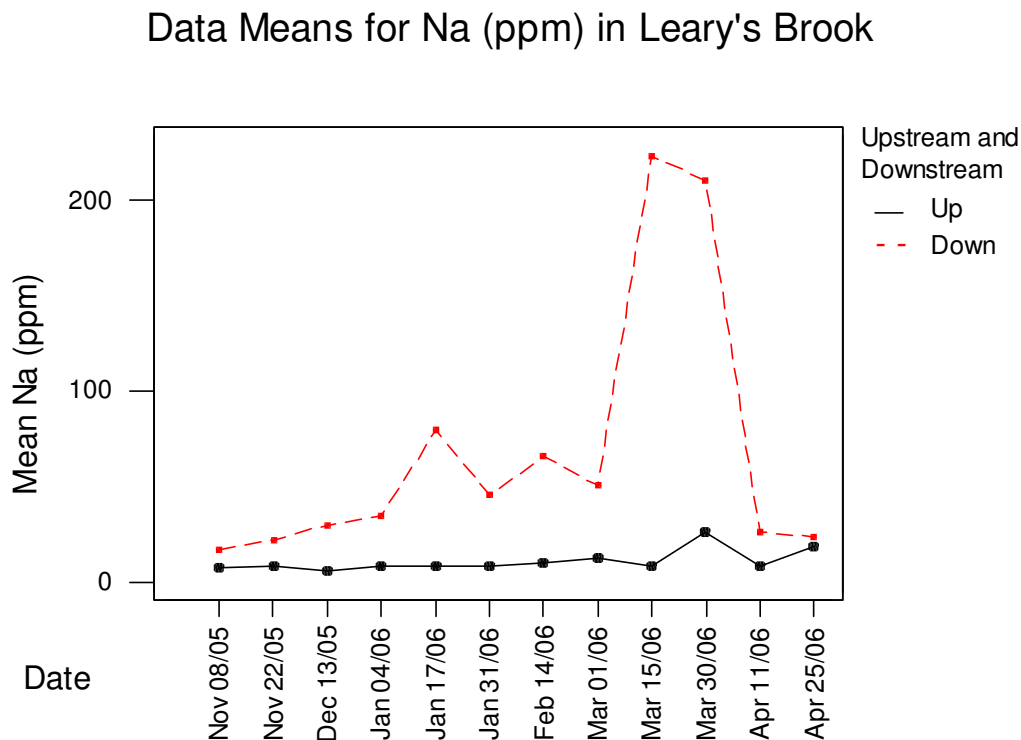
The mean sodium concentrations in the downstream section of Leary's Brook rose and fell in a similar fashion to those in the Waterford and Virginia Rivers (*Figure 3*), such that the Na again peaked at the March 15th to the March 30th mark, with mean values of 223.2 ppm and 210.4 ppm respectively (derived from the raw data from *Appendix C;* presented in *Appendix B*). As well as in the other rivers, the upstream and downstream mean values were nearly equal during the first sampling date, and the downstream values rose thereafter relative to the reference concentrations, again showing the smaller peaks at January 17th and February 14th. However, it should be noted that on March 30th the reference site showed a small spike in Na concentration with a value of 26.0 ppm, and this may have been due to the fact that this site was actually located on the upstream side of the Ring Road, thus there may have been some contamination at that time.

The two-way ANOVA results of the upstream and downstream comparison of the Leary's Brook sodium concentrations with respect to the sampling dates again showed a significant difference in the downstream means versus the upstream, however again did not necessarily relate to the sampling dates in terms of the entire sampling period. Although in the same regard as the other two rivers, the dates March 15th and March 30th, and to a lesser extent January 17th and February 14th, were important with regards to higher sodium loadings.

4.2 Calculated Chloride (Cl) concentrations in the Waterford River, Virginia River, and Leary's Brook

The purpose of this sub-section is to graphically show the concentrations of chloride (proportional to the amount of salt-associated sodium) present in the rivers (*Appendix B*), and to compare the mean results with a scientifically derived value of chronic toxicity (Evans and Frick, 2002). The amounts of sodium found in the rivers at any point in the initial sampling stage before winter road salting began were minimal enough to be not of significance when deriving chloride concentrations associated with salt (NaCl). Thus all sodium values were considered to be associated with road salt in the sampling sweeps that took place during the salting period. This was taken into account when determining the concentrations of chloride in the samples.

Although sodium loadings in river water are not normally associated with aquatic toxicity or stress, chloride in river water has been demonstrated to have negative effects on freshwater aquatic species and ecosystems (Environment Canada, 2001), and a study by Evans and Frick (2002) has shown that a steady concentration of approximately 210ppm Cl will start to cause chronic toxicity (*Table 1*).

The following graphs (*Figures 4, 5, and 6*) show the mean amounts of chloride associated with road salt in the samples. They also show clearly the level at which chronic Cl toxicity occurs. It should be noted that these graphs have trends identical to those (above) showing the mean sodium concentrations, and is due to the proportionality of the two parameters.

Data Means for Cl (ppm) in the Waterford River

As shown by Figure 4, the mean chloride levels in the Waterford River exceeded the minimum chronic exposure limit on three sampling occasions, and nearly met it on at least one other. Essentially, as what was indicated in the corresponding sodium chart (*Figure 2*), Figure 5 demonstrates that there were excessive salt loadings to the Waterford River in the month of March and also in mid January. Particularly in mid to late March, the chloride concentrations were more than double the limit specified, indicating by Figure 1 an exponential increase in toxicity due to road salt loadings at that time.

Figure 5: *Derived data means for chloride (Cl) in ppm in the Virginia River showing the upstream vs. the downstream sites against the chronic exposure limit of 210 ppm Cl.*

Data Means for Cl (ppm) in the Virginia River
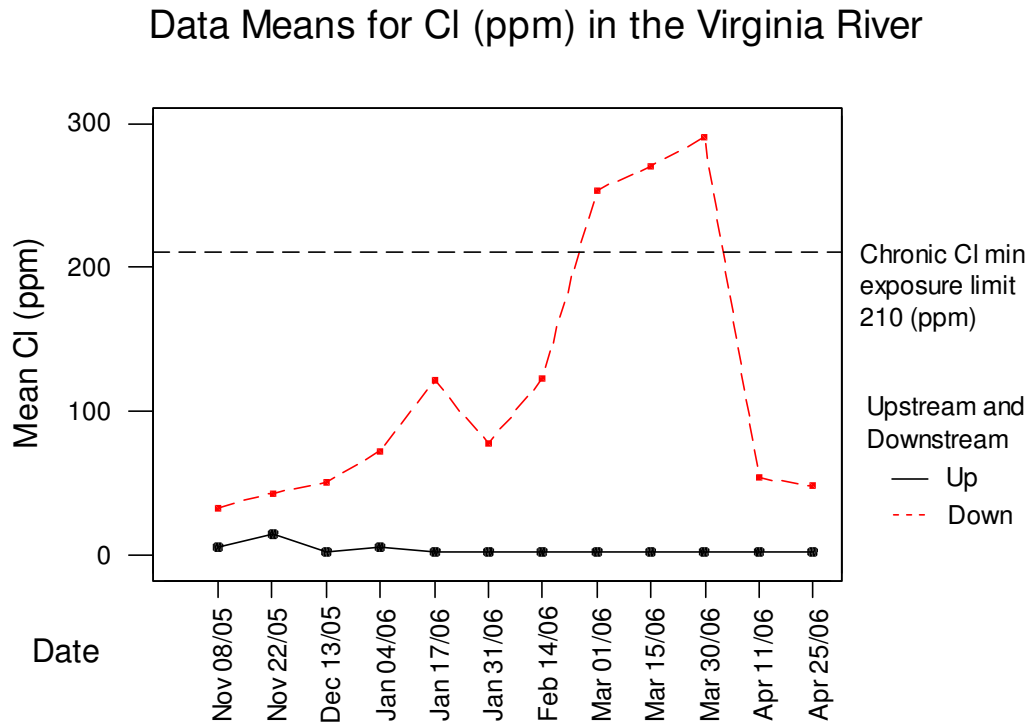
Figure 5 shows lower chloride levels overall in the Virginia River than in the Waterford (*Figure 4*), but portrays the same trend in that the chloride concentrations exceeded the minimum limit of chronic toxicity in the month of March. A level of scientifically derived toxicity associated with these excessive concentrations is found in Figure 1. However, since much less salt entered the Virginia River in the first half of the winter, chloride was not a problem until the beginning of March.

Data Means for Cl (ppm) in Leary's Brook

In the same trend as in the Waterford and the Virginia Rivers (*Figures 4 and 5*), Leary's Brook (*Figure* 6) had an increase of chloride in the month of March that exceeded the minimum level specified for chronic toxicity in Figure 1. Again, not enough road salt entered the Leary's system to be of concern in the first half of winter.

4.3 Correlation Established Between Conductivity and Sodium

It was noted in the raw data (*Appendix C*) that as the conductivity values rose in each sample, so did the concentrations of sodium in the same samples. It was established through a simple statistical analysis that these occurrences were proportional, due to the fact that all the derived p-values in the downstream samples were zero. Thus, there was a direct correlation between conductivity values and concentrations of sodium within the samples. This information would be useful in future tests as an *in-situ* conductivity reading in the winter months could indicate a proportional increase of sodium, and thus could be interpreted as an increase in road salt.

5.0 Conclusions

It has been determined that road salt is entering the city's river systems during the icy season in the form of runoff. The headwaters sites proved relatively unaffected, but the sites that were near and downstream of major parking lots generally experienced higher concentrations during the salting periods. The runoff originated from roads that had been salted, and entered the rivers either directly through storm sewers or indirectly through overland flow. It was also speculated from findings in the literature review that road salt could be entering the aquatic systems through groundwater flow. As a note, it was also hypothesized that if road salt originating from roadways could enter surface and groundwater systems through runoff, then any other type of contaminant present on the road at any given time could also be transported to these waterways in the runoff at the same time.

The literature review provided evidence that road salt is potentially harmful to aquatic ecosystems and even terrestrial ecosystems, thus, since road salt had been determined to be entering the three urban rivers then aquatic organisms could effectively be at risk. This was easily backed up by comparing the high values of chloride calculated from some of the samples with a scientifically derived minimum chronic value of toxicity (Evans and Frick, 2002). Essentially it was determined that each river was potentially under considerable stress for the month of March, and certainly at risk of being under stress in late January and early February as well.

In addition, it was established that the specific conductance detected in the samples was statistically proportional to the concentration of sodium measured in the same samples for the winter salting period. This would be particularly useful in future sampling projects in terms of minimizing lab costs and data-collection.

6.0 Recommendations

Continued monitoring is needed to further assess the potential harmful effects that salt may have on aquatic ecosystems and associated organisms. For example, fish and invertebrates could be further examined in terms of their species diversity, population, and overall health, and even vegetation could be studied for similar effects. Additionally, although road salts have been placed on the *Priority Substances List Assessment Report* (Environment Canada, 2001), there are no federal environmental water quality guidelines or application guidelines associated with road salt (Environment Canada, 2006). A final study needs to be conducted to officially show the minimum concentration of road salt needed to cause harmful effects to aquatic ecosystems and species in order to establish such a guideline. The Province of British Columbia has taken independent steps to establish ambient water quality guidelines for road salt (Sierra Legal Defense Fund, 2006), however there needs to be a nation-wide effort so that appropriate standards can be set.

Also, continued action from Non-Governmental Organizations (NGOs) and citizens groups that pressure governmental agencies to reduce or regulate salt usage is recommended. For example, the NGO Riversides Stewardship Alliance has recently requested that the Ontario Ministry of the Environment revoke a certain regulation (Reg. 339) in the Ontario Environmental Bill of Rights (1993), which essentially exempts road salts from actually being a contaminant under CEPA (2001), and prevents the issuing of Certificates of Approval with regards to salt storage, application and disposal, both of which would contradict the current literature expressed in the *Priority Substances List* on road salt (Sierra Legal Defense Fund, 2006). In place of Reg. 339, Riversides has requested the phasing in of a mandatory federal road salt management policy (Sierra Legal Defense Fund, 2006). The federal government has since released a Risk Management Strategy for Road Salts (2006) that is based on the findings of CEPA (2001). This is a good start towards more effective and responsible road salt usage. As a note, the City of St. John's does have a comprehensive *Salt Management Plan* (2005) of its own, and although it does not stop salt from entering urban waterways, it does recognize and give details of responsible salt application practices, and will most likely show improvement in the coming years. Also mentioned in their *Salt Management Plan*, the City has effectively cut its salt application in half on a two-lane kilometer basis and is currently phasing in new pre-wetting and anti-icing techniques (City of St. John's, 2005).

Other recommendations include ensuring that road salt authorities independently store road salt responsibly prior to application, and also ensuring that salt-laden snow banks are properly disposed of. Snow stockpiled at the edges of parking lots can release a lot of road salt into the environment at one time during a melt period. Care should be taken to ensure that no runoff will leave the lot and enter an aquatic system, whether it is groundwater or in streams and ponds. In fact, snow should be piled on the downhill side of parking lots to prevent melt water from cascading across the pavement, resulting in more salting when it refreezes at night. Additionally, the Risk Management Strategy for

Road Salts (2006) recommends a decreased dependence on ferrocyanide use in road salt, as well as utilizing newer technologies, such as pre-wetting techniques to allow more temperature related versatility, to reduce clumping, and to reduce the amount of road salt that needs to be applied to a surface during an icy period.

Even newer technologies could be experimented with as well, such as sugar beet juice. A report by CBC News (CBC, 2005), states that the City of Saint John, New Brunswick, is using sugar beet juice with its road salt applications on a major bridge because it lowers the working temperature of salt during extremely cold conditions, and it effectively reduces the amount of salt needed to melt the ice on the bridge, thus making their road salting practices much more efficient. Also of note, a study in Finland demonstrated that the organic solid chemical, potassium formate (KCOOH), could be used instead of NaCl as a very effective deicer (Hellstén *et al.*, 2005). While meeting the stringent environmental protection standards in that country, potassium formate was shown to be highly successful in maintaining winter road safety and in minimizing the contamination of surface and groundwater supplies. Although it is much more expensive than road salt, potassium formate would have a much less detrimental effect on road infrastructure and car frames and tires as well, reducing the overall costs of maintenance and repairs (Hellstén *et al.*, 2005). So although road salt is the standard deicer presently used on Canadian roads, other options could be explored and experimented with to potentially minimize adverse environmental effects and dangerous road conditions.

7.0 Addendum

As an addendum to the previous study, more information had been collected in the winter season from 2006 to 2007 and will be added here to compliment the results from the 2005 to 2006 winter season sampling. This section is less detailed but will take into account any slight modifications in methodology to present the data collected in the most relevant and interpretive way.

7.1 Approach and Methodology

For consistency, the samples were taken from the same locations on the three rivers as in the 2005 – 2006 sampling period. The samples were also taken within the same monthly time period from November 2006 to April 2007, and the sweeps were meant to be bi-weekly. However, due to unforeseen circumstances, the frequency was reduced to monthly sampling from February to April. This was not a problem as enough data was collected for the purposes of this report.

It was determined in the main report that there was a positive correlation between increasing sodium values and increasing specific conductance in the winter months. This implied that as more road salt entered the rivers (measured as a concentration of sodium in ppm) the more the measured conductivity would increase, proportionately, at the same sample locations. Thus in the 2006 – 2007 sampling period, the samples were tested for conductivity rather than sodium or chloride, knowing that an increase in conductivity during these months would signify an increased loading of road salt at that time.

The conductivity levels were determined *in situ* using a calibrated Hydrolab Quanta-G multiparameter probe, known technically as a multiparameter water quality monitoring sonde. The probe accurately collected many parameters at once including, but not limited to, conductivity, pH, dissolved oxygen, temperature, and salinity. The conductivity and salinity, as well as the daytime weather will be discussed in the results.

7.2 Results and Discussion

This section will detail the results obtained for conductivity values on the Waterford, Virginia and Leary's river systems from 2006 – 2007. It will help to determine whether road salt had been entering these waterways at that time, and will take into account the corresponding weather patterns in relation to the conductivity values measured. It will also show a simple comparison of the 2006 – 2007 values to the results of the 2005 – 2006 season, as well as establish a probable correlation between the conductivity levels and the salinity measurements taken at the same time. The interpretations were derived using the same approach as in the previous year's interpretations in the main report; in particular the downstream results have been

converted to an average to better compare with the upstream results. The raw data can be found in the Appendix D.

Also, a site-specific value of 1000 μS/cm was chosen as a minimum chronic exposure limit for conductivity in the rivers, since it is a very high value compared with those normally found in reference sites, and it correlates well with the chronic minimum exposure limit for chloride derived in the main report, based on the results (210 mg/L Chloride). It also correlates well with the level of salinity that would otherwise determine the threshold in which fresh water begins to turn brackish (500 mg/L Salinity).

7.3 Conductivity in the Waterford River, Virginia River, and Leary's Brook

Although the conductivity values were similar in the downstream sites to the headwaters (upstream) sites during the first sample sweep in November, the downstream values rose during the winter sampling season. Meanwhile, the headwaters sites generally remained at their normal levels. This was expected because the rivers flowed through urban areas, under roads, and near parking lots, and their headwaters were located in areas much less affected by the applications of road salt. The bulk of the loadings in this case appeared in January 2007 with some slightly smaller loadings in March. This was due to the fact that most of the precipitation for that season fell within the January to February period. Overall, the loadings were less in the 2006 – 2007 season than they were for the 2005 – 2006 season, and may have been due to the fact that the winter of 2006 – 2007 was much drier and colder than that of the previous year (Environment Canada, 2008). The following graphs show the increases and spikes of conductivity in each of the rivers with accompanying interpretations, where "upstream" represents the headwater or reference site (site 1), and the "downstream" corresponds to the mean conductivity value of all sites downstream of site 1 for each river on a given date (sites 2 – 5).

Figure 7: *Mean conductivity (μS/cm) in the Waterford River, showing the upstream vs. downstream sites as well as the chronic minimum exposure limit for conductivity.*

Data Means for Conductivity (uS/cm) in the Waterford River
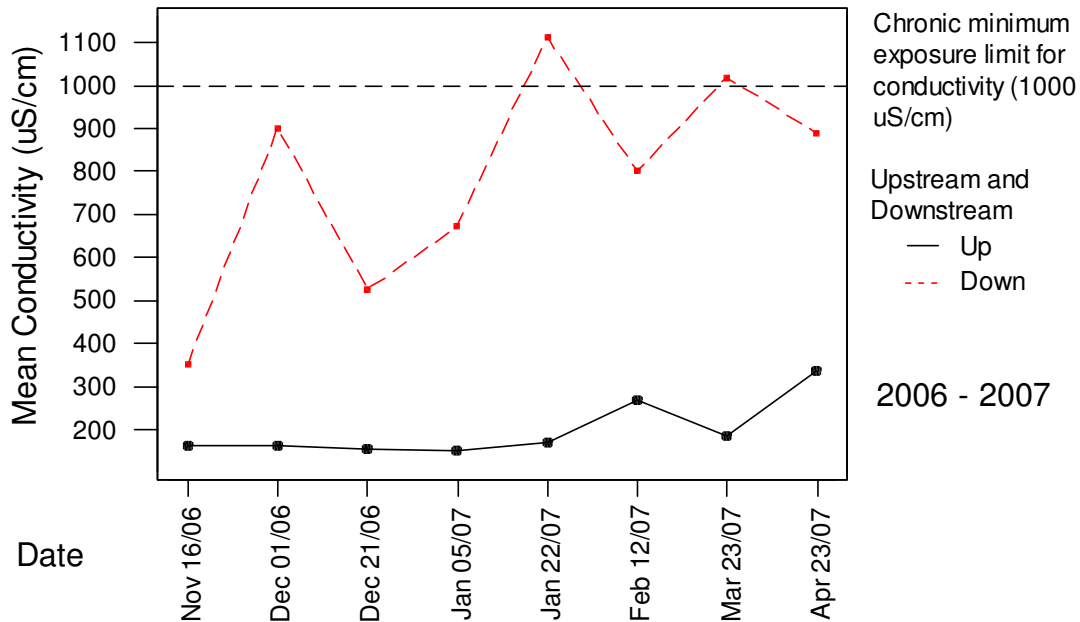
        The Waterford River showed high downstream values of conductivity during the 2006 – 2007 period. There was not much fluctuation of the conductivity in the headwaters site with the exception for a few small spikes in February and April. It is unknown what may have caused these spikes in the headwaters, as the values seem to have gone up as they went down in the downstream sites. But generally the headwaters values stayed between 150 and 185 μS/cm, rising to 338 μS/cm once in April. The downstream values, however, exceeded the minimum exposure limit for conductivity of 1000 μS/cm twice. The first was on January 22nd when the average value was 1114 μS/cm and the second surpassed at 1020 μS/cm. The other average values recorded downstream were also high in comparison with the upstream values with the lowest being in a dry December period.

Figure 8: *Mean conductivity (μS/cm) in the Virginia River, showing the upstream vs. downstream sites*

Data Means for Conductivity (uS/cm) in the Virginia River
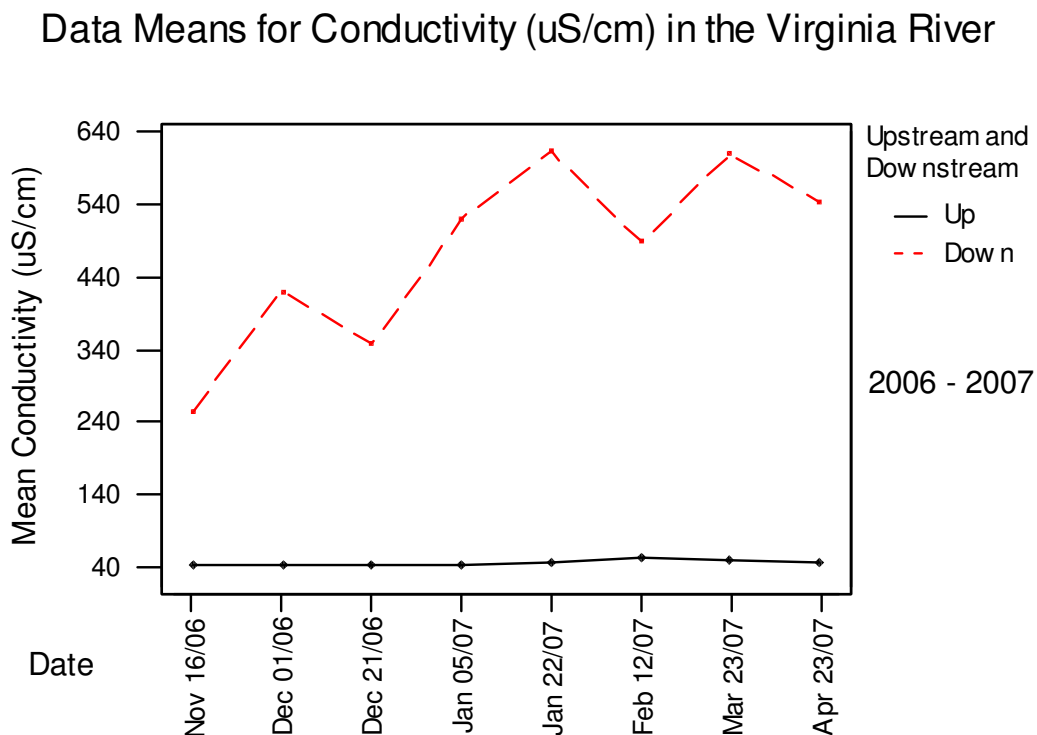
The downstream conductivity values were much higher than the upstream values in the Virginia River in 2006 – 2007. While the upstream values stayed within a steady range between 43 and 54 μS/cm, the downstream values rose to averages of over 600 μS/cm in January and March. Although the conductivity values were not as high as they were in the Waterford, they were still much higher than the reference values, especially in the peak winter months from January to March. The raw data (*Appendix D*) also shows that the conductivity values in site 5 on most of the dates were the highest, particularly on January 22nd when it was over 900 μS/cm, demonstrating that the lower reaches of the rivers become more concentrated as they collect more contaminants from upstream.

Figure 9: *Mean conductivity (μS/cm) in Leary's Brook, showing the upstream vs. downstream sites as well as the chronic minimum exposure limit for conductivity.*

Data Means for Conductivity (uS/cm) in Leary's Brook
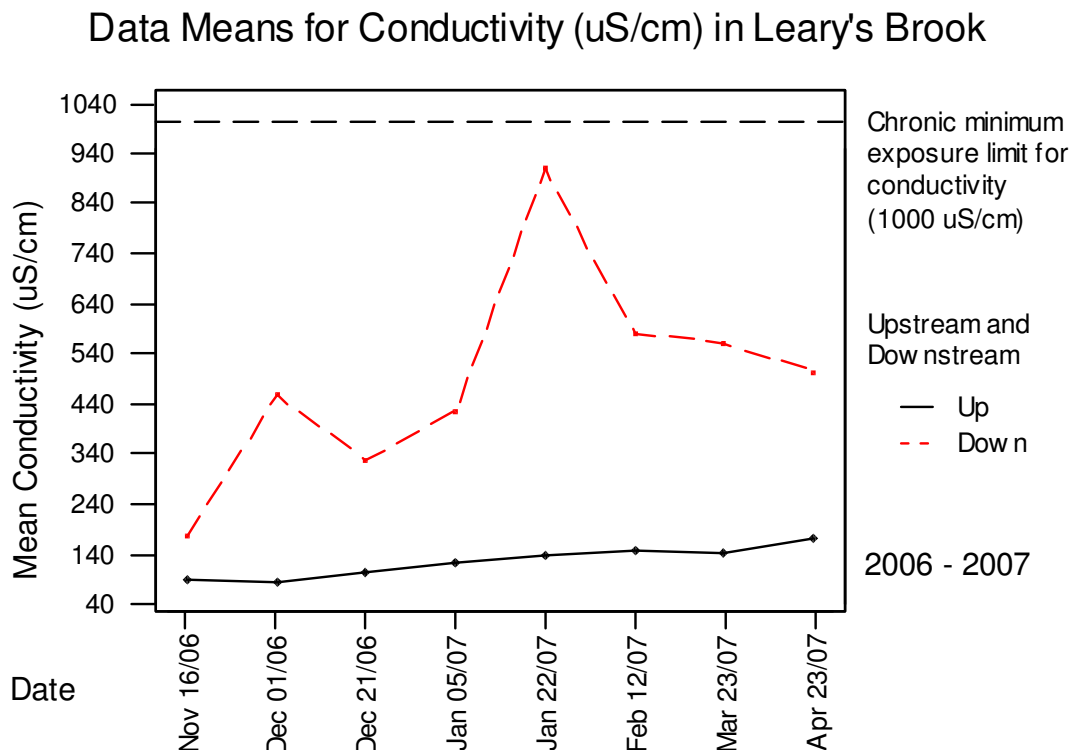
In a similar fashion to the other rivers, Leary's Brook showed a relatively stable range of conductivity within the headwaters, but increased values in the downstream samples. As before, there was a large spike in conductivity in late January at a mean value of 908 μS/cm. The downstream conductivity values sharply declined and generally leveled-off after the January sampling period, although they were still quite high in comparison to the corresponding headwaters values. The raw data suggests that all of the downstream sites except for site 2 (New) actually exceeded the stated minimum exposure limit for conductivity on January 22nd, thus the stated average did not reflect this due to the less urban proximity of site 2 (New). In fact, the downstream averages were lower than would be expected on all of the sampling dates for the reason that site 2 (New) generally showed lower conductivity values, due to its location on the river and knowing that the conductivity values are generally higher further downstream. The headwaters values did increase slightly throughout the sampling season, and could have been influenced by the raised highway located a short distance downstream.

7.4 Salinity in the Waterford River, Virginia River, and Leary's Brook

Salinity measurements in the rivers were obtained simultaneously with the conductivity measurements. Salinity is a measure of the amount of dissolved salt in a water body and is expressed in Practical Salinity Units (PSU), which, for the purposes of this report, are essentially the same as parts per thousand (permille, ‰). For ease of interpretation, the salinity values shown here will be in parts per million (ppm), or mg/L.

The salinity data was shown by Pearson Correlation to correlate with the corresponding conductivity data, and as shown by the following graphs, the trends were practically identical. The salinity graphs show the increases and spikes of salinity in each of the rivers and are accompanied by interpretations. On the graphs, "upstream" represents the headwater or reference site (site 1), and the "downstream" corresponds to the mean salinity value of all sites downstream of site 1 for each river on a given date (sites 2 – 5). Compared with the conductivity results, the level of salinity in the headwaters sites remained consistently low, whereas throughout the winter months, the salinity levels increased in the downstream sites, particularly in January as well as March.

Figure 10: *Mean salinity (ppm) in the Waterford River, showing the upstream vs. downstream sites noting the transition boundary from the limnetic zone (freshwater) to the oligohaline zone (slightly brackish).*

Data Means for Salinity (mg/L) in the Waterford River
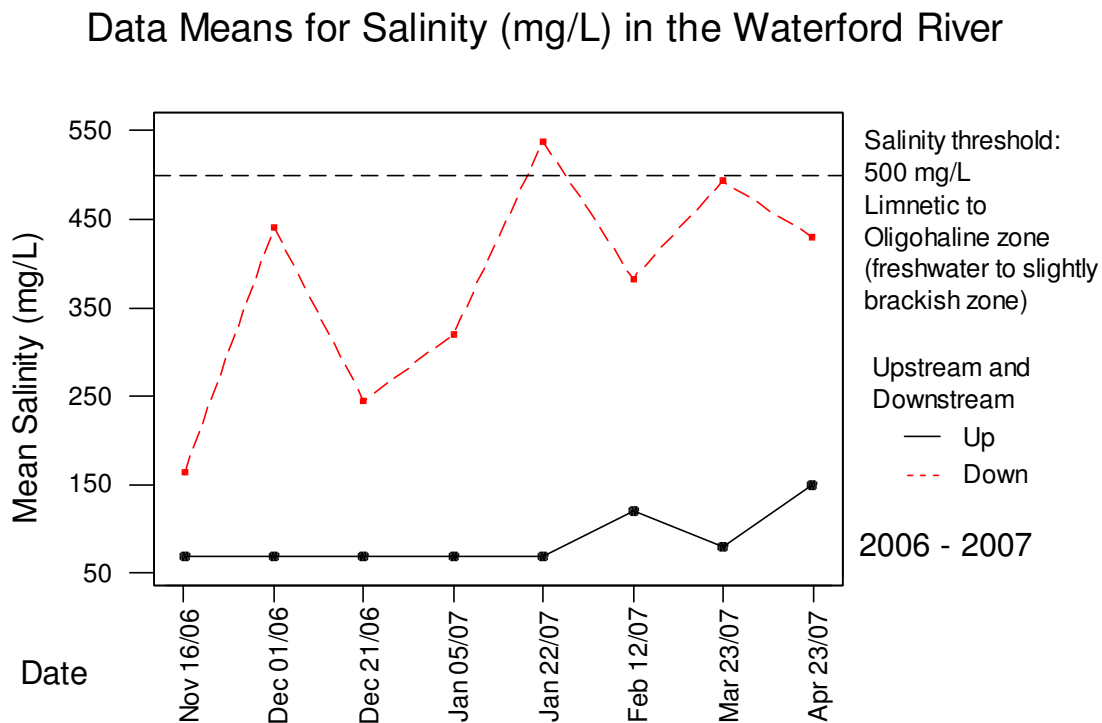
As can be seen by Figure 10, the Waterford was at its saltiest during late January and late March. The water was determined to be so salty on the January 22nd sampling date that it had actually crossed a recognised salinity threshold (Venice Classification System, 1959). At 538 ppm salinity on that date, the Waterford was slightly brackish in quality. The saltiest point on that sampling date, as shown in the raw data (*Appendix D*), was at 640 ppm just downstream of a parking lot. Environment Canada data shows that there was significant snowfall prior to January 22nd, which indicates that the high level of salting on that date may have been associated with poor road conditions due to the bad weather conditions.

Figure 11: *Mean salinity (ppm) in the Virginia River, showing the upstream vs. downstream sites*

Data Means for Salinity (mg/L) in the Virginia River
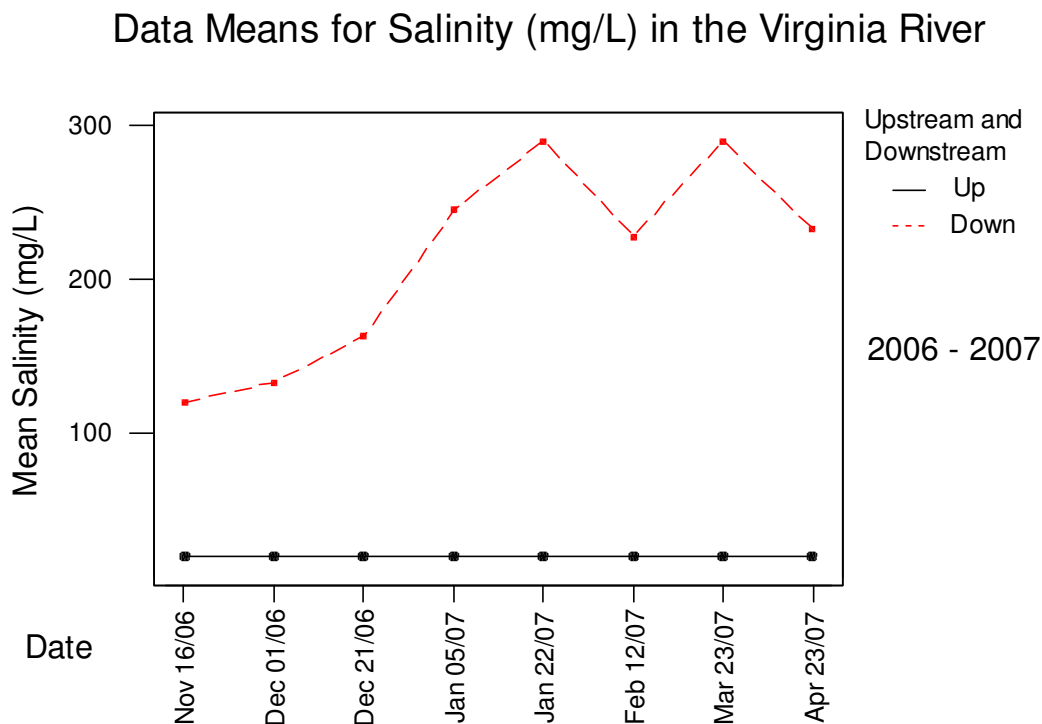
The Virginia River showed the highest levels of salinity late January and late March, a trend similar to the salinity of the Waterford River. The levels downstream were not as high however, with the highest average salinity of 290 ppm falling on both January 22nd and on March 23rd (*Figure 11*). These values were still much higher than the corresponding upstream measurements of salinity, which remained steady at 20 ppm in all downstream samples along the Virginia River. From the raw data (*Appendix D*), none of the samples exceeded the salinity threshold of 500 ppm, with the highest single salinity reading being 440 ppm recorded at the Royal Canadian Legion (Site 5) the day after a snowfall.

Figure 12: *Mean salinity (ppm) in Leary's Brook, showing the upstream vs. downstream sites noting the transition boundary from the limnetic zone (freshwater) to the oligohaline zone (slightly brackish).*

Data Means for Salinity (mg/L) in Leary's Brook
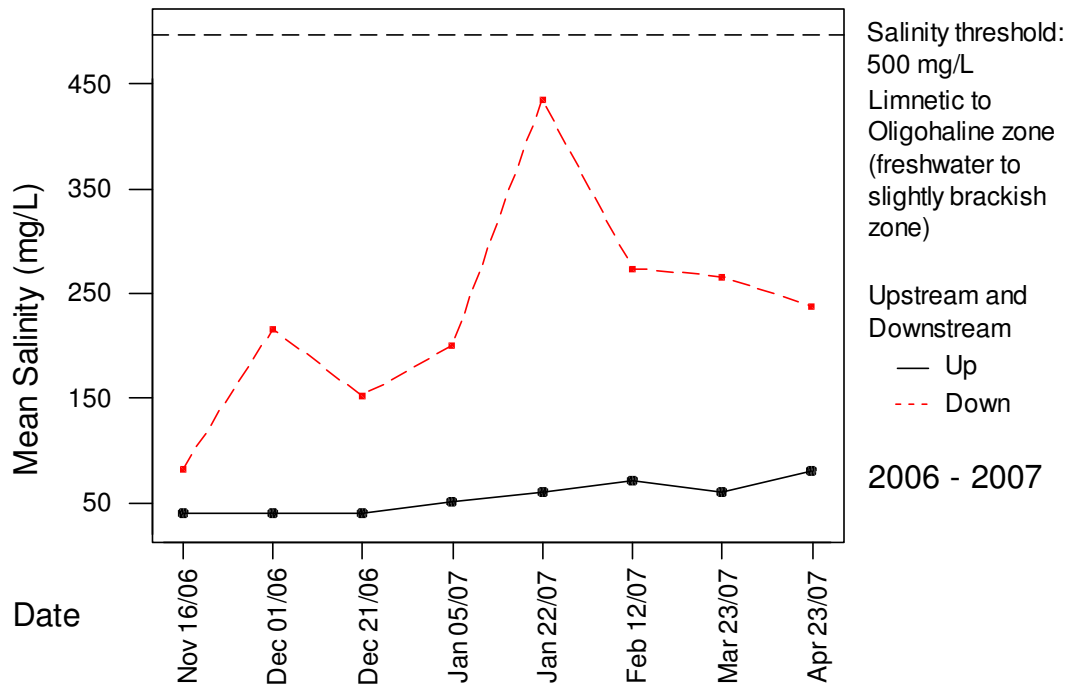
As with the other sites, the salinity in Leary's Brook was higher in late January, although it was observed to be tapering down in late March (*Figure 12*). Similarly to the Virginia River data, Leary's Brook was not quite as affected by road salt as the Waterford was, however, the highest average salinity in Leary's Brook at 438 ppm (on January 22nd) was still higher than Virginia River's highest average of 290 ppm (*Figures 12 and 11 respectively*). This value (438 ppm) was close to the salinity threshold (Venice Classification System, 1959) but did not exceed it (Figure 12), however most of the sites from the raw data on that date actually did exceed this threshold (*Appendix D*). As mentioned above, the date January 22nd 2007 was associated with a prior snowfall event and may explain the higher values of salinity in the river on this date.

Also from Figure 12, the headwaters values in Leary's Brook were low in comparison to the downstream averages, however they did steadily increase in salinity upstream as the winter progressed, with a value of 40 ppm in November and a maximum of 80 ppm at the end of April. The reference site was near the Outer Ring Highway, however, and may have experienced some contamination from salt being blown off the highway by the wind upstream to the water.

7.5 Correlation Established Between Conductivity and Salinity

In looking at the graphs from the figures shown in Sections 7.3 and 7.4, It was noted in the raw data (*Appendix D*) that as the conductivity values rose in each sample, so did the concentrations of salinity in the same samples. It was established through a simple statistical (Pearson) analysis that these occurrences were proportional, due to the fact that all the derived p-values in the downstream samples were zero. Thus, there was a direct correlation between conductivity values and concentrations of salinity within the samples. This information would be useful in future tests as an *in-situ* conductivity reading in the winter months could indicate a proportional increase of salinity, and thus could be interpreted as an increase in road salt.

7.6 Conclusions to Addendum

The results of the research conducted within this addendum as it relates to the research conducted within the main body of this report illustrate that road salt concentrations can be accurately represented by values obtained for both of the parameters, specific conductance and salinity, which have been statistically proven to correlate directly with each other. It was shown that the three rivers become saltier during the winter months, particularly during the months that received the most precipitation in the form of snow, namely in January and February, and to some extent March. Similar to the results of the previous year's data, it was shown that the Waterford River became the most saline in the winter months, followed by Leary's Brook and Virginia River respectively. While the levels of salinity were not as high as they were in the previous year, they were still noticeably higher due to an increase in winter salt loadings, and in some cases on the Waterford they breached a chronic maximum value in terms of specific conductance (greater than 1000 µS/cm), as well as in the same cases on the Waterford breaching the threshold of salinity that defines fresh water as begins to turn brackish (500 mg/L). Leary's Brook came close to these salinity thresholds during the saltiest periods as well.

Due to the fact that precipitation and weather conditions likely contributed to the somewhat lower levels of salinity within the city rivers during the 2006 – 2007 period, as well as to the higher levels found from the previous year's data, it is quite possible that more or less road salt would be applied during future winter seasons depending upon the weather conditions at the time, resulting in further salt loadings of varying degrees. Thus, more road salt monitoring should take place during future winter seasons to determine whether dangerous levels of salting might occur. Additionally, as it was established within the main body of this report that since road salt was determined to be entering the city rivers during the winter, and hence, it could then be inferred that other toxic constituents could also be entering the rivers via the same pathways, it is recommended that monitoring for other toxic constituents should take place in the future at the same locations along the three rivers to determine the extent of contamination which may occur within the rivers due to urban runoff.

8.0 References

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Appendix A

Photo scans depicting each site of each river. Note: Sites 4 and 5 on the Virginia River were unavailable.

Photo 3: *View of Site 1 on the Waterford River, looking downstream. Headwaters; Bremigan's Pond*

Photo 5: *View of Site 3 on the Waterford River, downstream is to the right.*

Photo 4: *View of Site 2 on the Waterford River, looking upstream*

Photo 6: *View of Site 4 on the Waterford River, downstream is to the right.*

Photo 7: *View of Site 5 on the Waterford River, downstream is to the right.*

Photo 10: *View of Site 3 on the Virginia River, looking downstream*

Photo 8: *View of Site 1 on the Virginia River, downstream is towards the top. Headwaters site. Note the Quanta-G sonde in the water*

Photo 11: *View of Site 1 on Leary's Brook, downstream is toward top-left. Headwaters site.*

Photo 9: *View of Site 2 on the Virginia River, downstream is to the right*

Photo 12: *View of Site 2 (old) on Leary's Brook, looking downstream*

Photo 13: *View of Site 2 (new) on Leary's Brook, looking downstream*

Photo 15: *View of Site 4 on Leary's Brook, looking upstream.*

Photo 14: *View of Site 3 on Leary's Brook, looking downstream.*

Photo 16: *View of Site 5 on Leary's Brook, downstream is to the left.*

Appendix B

Mean concentrations (ppm) of sodium (Na), derived chloride (Cl), and derived salt (NaCl) for each river showing upstream values and downstream means. Values in bold indicate an exceedance of a set value of chronic toxicity of approximately 210 ppm Cl.

Waterford River

Date	Mean Sodium (Na) Concentrations (ppm)		Mean Chloride (Cl) Concentrations (ppm)		Total Mean Sodium Chloride (NaCl) Concentration (ppm)	
	Upstream	*Downstream*	*Upstream*	*Downstream*	*Upstream*	*Downstream*
Nov 08/05	25.00	16.25	37.500	24.375	62.500	40.625
Nov 22/05	16.00	42.33	24.000	63.495	40.000	105.825
Dec 13/05	10.00	57.00	15.000	85.500	25.000	142.500
Jan 04/06	12.00	85.50	18.000	128.250	30.000	213.750
Jan 17/06	14.00	155.33	21.000	**232.995**	35.000	388.325
Jan 31/06	14.00	87.50	21.000	131.250	35.000	218.750
Feb 14/06	12.00	129.50	18.000	194.250	30.000	323.750
Mar 01/06	8.00	112.50	12.000	168.750	20.000	281.250
Mar 15/06	8.00	352.50	12.000	**528.750**	20.000	881.250
Mar 30/06	10.00	312.50	15.000	**468.750**	25.000	781.250
Apr 11/06	4.00	52.50	6.000	78.750	10.000	131.250
Apr 25/06	18.00	50.00	27.000	75.000	45.000	125.000

Virginia River

Date	Mean Sodium (Na) Concentrations (ppm)		Mean Chloride (Cl) Concentrations (ppm)		Total Mean Sodium Chloride (NaCl) Concentration (ppm)	
	Upstream	*Downstream*	*Upstream*	*Downstream*	*Upstream*	*Downstream*
Nov 08/05	4.00	22.10	6.000	33.150	10.000	55.250
Nov 22/05	10.00	29.00	15.000	43.500	25.000	72.500
Dec 13/05	2.00	34.00	3.000	51.000	5.000	85.000
Jan 04/06	4.00	48.50	6.000	72.750	10.000	121.250
Jan 17/06	2.00	81.00	3.000	121.500	5.000	202.500
Jan 31/06	2.00	52.00	3.000	78.000	5.000	130.000
Feb 14/06	2.00	82.00	3.000	123.000	5.000	205.000
Mar 01/06	2.00	169.00	3.000	**253.500**	5.000	422.500
Mar 15/06	2.00	180.00	3.000	**270.000**	5.000	450.000
Mar 30/06	2.00	193.75	3.000	**290.625**	5.000	484.375
Apr 11/06	2.00	36.00	3.000	54.000	5.000	90.000
Apr 25/06	2.00	32.25	3.000	48.375	5.000	80.625

Leary's Brook

Date	Mean Sodium (Na) Concentrations (ppm)		Mean Chloride (Cl) Concentrations (ppm)		Total Mean Sodium Chloride (NaCl) Concentration (ppm)	
	Upstream	*Downstream*	*Upstream*	*Downstream*	*Upstream*	*Downstream*
Nov 08/05	7.0	16.5	10.50	24.75	17.50	41.25
Nov 22/05	8.0	22.0	12.00	33.00	20.00	55.00
Dec 13/05	6.0	29.7	9.00	44.55	15.00	74.25
Jan 04/06	8.0	34.7	12.00	52.05	20.00	86.75
Jan 17/06	8.0	79.5	12.00	119.25	20.00	198.75
Jan 31/06	8.0	45.6	12.00	68.40	20.00	114.00
Feb 14/06	10.0	65.6	15.00	98.40	25.00	164.00
Mar 01/06	12.0	50.4	18.00	75.60	30.00	126.00
Mar 15/06	8.0	223.2	12.00	**334.80**	20.00	558.00
Mar 30/06	26.0	210.4	39.00	**315.60**	65.00	526.00
Apr 11/06	8.0	26.0	12.00	39.00	20.00	65.00
Apr 25/06	18.0	23.6	27.00	35.40	45.00	59.00

Appendix C

Raw data values associated with field and lab derived results.

Virginia River

Sample Date	Sample #	Conductivity (uS/cm)	Dilution	FAA Reading (ppm)	Actual Na Concentration (ppm)
8-Nov-05	1	39	\	\	4
	2	124	\	\	26
	3	134	\	\	14
	4	181	\	\	22
	5a	289	\	\	28
	5b	289	\	\	26
	5c	289	\	\	25
22-Nov-05	1	\	1\20	0.5	10
	2	\	1\20	1.2	24
	3	\	1\20	1.4	28
	4	\	1\20	1.4	28
	5	\	1\40	0.9	36
13, 14-Dec-05	1	40	1\20	0.1	2
	2	228	1\20	1.3	26
	3	257	1\20	1.4	28
	4	309	1\20	1.9	38
	5	394	1\40	1.1	44

4-Jan-06	1	35	1\20	0.2	4
	2	270	1\20	1.7	34
	3	393	1\40	1.3	52
	4	425	1\40	1.3	52
	5	447	1\40	1.4	56
17-Jan-06	1	22	1\20	0.1	2
	2	403	1\40	1.5	60
	3	473	1\40	1.8	72
	4	662	1\60	1.7	102
	5	631	1\60	1.5	90
31-Jan-06	1	36	1\20	0.1	2
	2	288	1\20	1.9	38
	3a	392	1\40	1.1	44
	3b	392	1\40	1.1	44
	3c	392	1\40	1.1	44
	4	523	1\60	1	60
	5	572	1\60	1.1	66
14-Feb-06	1	\	1\20	0.1	2
	2a	\	1\40	1	40
	2b	\	1\40	1	40
	2c	\	1\40	1	40
	3	\	1\60	1.3	78
	4	\	1\60	1.5	90
	5	\	1\80	1.5	120

Date					
1-Mar-06	1	\	\	\	\
	2	338	1\40	0.9	36
	3	2686	1\300	1.2	360
	4	861	1\100	1	100
	5	1350	1\150	1.2	180
15-Mar-06	1	49	1\20	0.1	2
	2	1400	1\150	1.1	165
	3a	1700	1\150	1.3	195
	3b	1700	1\150	1.3	195
	3c	1700	1\150	1.3	195
	4	1220	1\150	0.8	120
	5	1810	1\150	1.6	240
30-Mar-06	1	55	1\20	0.1	2
	2	1180	1\100	1.4	140
	3	1870	1\200	1.1	220
	4	1630	1\150	1.3	195
	5	1890	1\200	1.1	220
11-Apr-06	1	37	1\20	0.1	2
	2a	233	1\20	1.3	26
	2b	233	1\20	1.3	26
	2c	233	1\20	1.3	26
	3	263	1\20	1.5	30
	4	402	1\40	1.1	44
	5	421	1\40	1.1	44

25-Apr-06	1	49	1\20	0.1	2
	2	244	1\20	1.3	26
	3	281	1\20	1.4	28
	4	333	1\30	1.1	33
	5	394	1\30	1.4	42

Follow up	Site	Conductivity (uS/cm)	Salinity (ppm)
26-May-06	1	40	20
	2	313	150
	3	361	170
	4	327	150
	5	427	200

Leary's Brook

Sample Date	Sample #	Conductivity (uS/cm)	Dilution	FAA Reading (ppm)	Actual Na Concentration (ppm)
8-Nov-05	1	74	\	\	7
	2	87	\	\	18
	3	123	\	\	14
	4	132	\	\	18
	5	131	\	\	16
22-Nov-05	1	\	1\20	0.4	8
	2	\	1\20	0.6	12
	3	\	1\20	1.2	24
	4	\	1\20	1.3	26
	5	\	1\20	1.3	26
13, 14-Dec-05	1	68	1\20	0.3	6
	2	210	1\20	1.2	24
	3	245	1\20	1.5	30
	4	250	1\20	1.5	30
	5a	266	1\20	1.6	32
	5b	266	1\20	1.6	32
	5c	266	1\20	1.7	34

9-Jan-06	1	88	1\20	0.4	8
	2	225	1\20	1.3	26
	3	270	1\20	1.8	36
	4	279	1\20	1.9	38
	5a	293	1\20	2	40
	5b	294	1\20	2	40
	5c	\	1\20	1.8	36
17-Jan-06	1	94	1\20	0.4	8
	2	24?	1\60	1.3	78
	3	498	1\60	1.2	72
	4	440	1\60	1.2	72
	5	590	1\60	1.6	96
31-Jan-06	1	43	1\20	0.4	8
	2 (old)	324	1\40	0.9	36
	2 (new)	158	1\20	0.9	18
	3	431	1\40	1.3	52
	4	446	1\40	1.4	56
	5	526	1\60	1.1	66
14-Feb-06	1	\	1\20	0.5	10
	2 (old)	\	1\40	1.7	68
	2 (new)	\	1\40	0.5	20
	3	\	1\60	1.3	78
	4	\	1\60	1.2	72
	5	\	1\60	1.5	90

1-Mar-06	1	126	1\20	0.6	12
	2 (old)	\	\	\	\
	2 (new)	\	\	\	\
	3	684	1\60	1.5	90
	4	681	1\60	1.6	96
	5	526	1\60	1.1	66
15-Mar-06	1	185	1\20	0.4	8
	2 (old)	2590	1\300	1	300
	2 (new)	425	1\40	0.9	36
	3	1540	1\150	1.8	270
	4	2080	1\300	0.7	210
	5	2530	1\300	1	300
30-Mar-06	1	197	1\20	1.3	26
	2 (old)	1890	1\200	1.2	240
	2 (new)	490	1\40	1.3	52
	3a	1970	1\200	1.2	240
	3b	1970	1\200	1.2	240
	3c	1970	1\200	1.2	240
	4	1960	1\200	1.2	240
	5	2190	1\200	1.4	280

11-Apr-06	1	92	1\20	0.4	8
	2 (old)	218	1\20	1.2	24
	2 (new)	120	1\20	0.6	12
	3	260	1\20	1.5	30
	4	259	1\20	1.5	30
	5	264	1\20	1.7	34
25-Apr-06	1	196	1\20	0.9	18
	2 (old)	200	1\20	1	20
	2(new)	113	1\20	0.5	10
	3	250	1\20	1.4	28
	4	252	1\20	1.5	30
	5	274	1\20	1.5	30

Followup	Site	Conductivity (uS/cm)	Salinity (ppm)
26-May-06	1	125	60
	2 (old)	276	130
	2(new)	166	80
	3	321	150
	4	330	160
	5	344	160

Waterford River

Sample Date	Sample #	Conductivity (uS/cm)	Dilution	FAA Reading (ppm)	Actual Na Concentration (ppm)
8-Nov-05	1	136	\	\	25
	2	201	\	\	15
	3	212	\	\	16
	4	218	\	\	16
	5	166	\	\	18
22-Nov-05	1	\	1\20	0.8	16
	2	\	1\40	1	40
	3	\	1\40	1	40
	4	\	1\40	1.3	52
	5a	\	1\40	1	40
	5b	\	1\40	0.9	36
	5c	\	1\40	0.9	36
13, 14-Dec-05	1	114	1\20	0.5	10
	2	455	1\40	1.4	56
	3	137?	1\40	1.3	52
	4	460	1\40	1.5	60
	5	373	1\40	1.5	60
4-Jan-06	1	122	1\20	0.6	12
	2	633	1\60	1.4	84
	3	657	1\60	1.4	84
	4	733	1\60	1.6	96
	5	610	1\60	1.3	78

17-Jan-06	1	\	1\20	0.7	14
	2	1200	1\100	1.7	170
	3a	1210	1\100	1.7	170
	3b	1210	1\100	1.9	190
	3c	1210	1\100	1.9	190
	4	1230	1\100	1.9	190
	5	529	1\60	1.3	78
31-Jan-06	1	129	1\20	0.7	14
	2	824	1\100	1	100
	3	713	1\80	1.1	88
	4	661	1\60	1.5	90
	5	552	1\60	1.2	72
14-Feb-06	1	\	1\20	0.6	12
	2	\	1\100	1.1	110
	3	\	1\80	1.6	128
	4	\	1\100	1.6	160
	5	\	1\100	1.2	120
1-Mar-06	1	112	1\20	0.4	8
	2	871	1\100	1.2	120
	3	888	1\100	1.1	110
	4	1032	1\100	1.3	130
	5a	801	1\100	0.9	90
	5b	807	1\100	0.9	90
	5c	812	1\100	0.9	90

15-Mar-06	1	115	1\20	0.4	8
	2	2690	1\300	1.1	330
	3	3120	1\300	1.3	390
	4	1610	1\150	1.8	270
	5	3350	1\300	1.4	420
30-Mar-06	1	107	1\20	0.5	10
	2	2700	1\300	1.1	330
	3	2860	1\300	1.2	360
	4	2640	1\300	1	300
	5	2070	1\200	1.3	260
11-Apr-06	1	69	1\20	0.2	4
	2	494	1\40	1.5	60
	3	523	1\40	1.6	64
	4	502*	1\100	0.5	50
	5	355	1\40	0.9	36
25-Apr-06	1	194	1\20	0.9	18
	2	503	1\40	1.4	56
	3	496	1\40	1.4	56
	4a	481	1\40	1.3	52
	4b	481	1\40	1.3	52
	4c	481	1\40	1.3	52
	5	558	1\60	0.6	36

Follow up	Site	Conductivity (uS/cm)	Salinity (ppm)
26-May-06	1	183	90
	2	514	250
	3 (up)	497	240
	3 (down)*	978 - 1500*	670
	4	506	24
	5	400	190

*Sewer outfall (oily; parameters would not stabilize) ~30m downstream of site 3

Appendix D

Results of the 2006 – 2007 sampling sweeps for downstream data obtained for specific conductance, salinity, and temperature within the Waterford River, Virginia River, and Leary's Brook. The downstream means of each sweep are also listed for each. Data obtained for the headwaters sites are not listed as they are already displayed in the Results section of the Addendum.

	Conductivity (uS/cm)							
	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
Virginia	207	377	260	365	374	358	448	427
	236	318	337	527	588	436	502	478
	254	363	343	541	578	561	764	616
	323	623	450	648	907	598	723	649
mean	255	420	348	520	612	488	609	543
	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
Leary's	106	128	157	242	313	249	317	288
	149	655	368	444	1010	610	567	498
	195	505	366	497	1054	687	627	573
	209	437	357	482	1087	652	635	561
	214	553	393	466	1075	706	657	600
mean	175	456	328	426	908	581	561	504
	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
Waterford	385	688	540	726	1205	902	1053	984
	361	752	508	698	1334	932	1112	978
	355	1105	580	707	1003	772	1095	902
	302	1063	476	561	914	605	819	701
mean	351	902	526	673	1114	803	1020	891

	Salinity (mg/L)							
	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
Virginia	100	180	120	170	170	170	210	200
	110	150	160	250	280	200	240	230
	120	170	160	250	270	260	360	290
	150	30	210	310	440	280	350	210
mean	120	133	163	245	290	228	290	233

	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
Leary's	50	60	70	110	140	110	150	130
	70	310	170	210	490	290	270	230
	90	240	170	230	510	330	300	270
	100	210	170	230	520	310	300	270
	100	260	180	220	520	330	310	290
mean	82	216	152	200	436	274	266	238
Waterford	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
	180	330	250	350	590	430	510	480
	170	370	240	330	640	450	540	470
	170	540	270	340	480	370	530	440
	140	520	220	260	440	280	390	330
mean	165	440	245	320	538	383	493	430

Temperature								
	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
Virginia	10.04	6.78	2.90	3.17	1.15	-0.32	2.70	5.58
	10.14	7.20	2.90	3.27	1.15	0.14	3.07	5.34
	9.69	5.34	1.83	2.75	1.28	0.88	2.31	5.88
	9.83	6.83	3.52	4.05	2.06	1.68	3.40	6.21
mean	9.93	6.54	2.79	3.31	1.41	0.60	2.87	5.75
	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
Leary's	9.38	2.54	0.40	0.42	-0.27	-0.21	0.23	4.72
	9.40	5.33	1.36	1.55	0.01	-0.20	1.81	5.19
	10.02	6.57	2.18	2.75	0.78	0.28	2.25	5.07
	10.05	6.93	2.49	3.06	1.09	0.61	2.43	5.20
	10.05	6.70	2.04	2.73	0.90	0.22	2.60	5.80
mean	9.78	5.61	1.69	2.10	0.50	0.14	1.86	5.20
	Nov 16th	Dec 1st	Dec 21st	Jan 5th	Jan 22nd	Feb 12th	Mar 23rd	Apr 23rd
Waterford	9.33	5.78	1.71	2.08	0.46	-0.04	2.08	4.48
	9.82	6.29	2.48	2.71	1.19	0.48	2.35	4.86
	10.23	6.39	2.26	2.76	0.90	-0.06	2.88	5.1
	10.24	6.24	1.68	2.66	0.72	-0.27	2.81	5.08
mean	9.91	6.18	2.03	2.55	0.82	0.03	2.53	4.88