ENVIRONMENTAL CONSULTING
Tri-Star

A Comparative Study of Site-specific Guideline Methods
Results from the 2009 Testing Program

Prepared for the Department of Environment and Conservation for the

Government of

Newfoundland and Labrador

and for

Environment Canada

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Executive Summary

In 2007, the Newfoundland Department of Environment and Labour initiated a project to develop site-specific water quality guidelines (SSGs) in selected water bodies in the province. This initiative resulted from the fact that under national reporting on water quality through the Canadian Environmental Sustainability Initiative (CESI) of the federal government, site-specific guidelines are recommended to determine the status of water quality. A number of water bodies were considered for evaluation. In 2008 Pound Cove Brook in north-eastern Newfoundland and Pinchgut Brook in western Newfoundland were selected for development of SSGs. In 2009, the Virginia River in eastern Newfoundland and the Northwest Gander River in central Newfoundland were selected. This report summarizes the data for the 2009 program and develops SSGs on an ecoregion basis for aluminum in Newfoundland.

The WER Approach requires that toxicity testing be performed on actual site waters and also using laboratory test waters. A ratio of the toxicity in the site water to the laboratory water is developed and the generic guideline is multiplied by the ratio that has been determined in order to calculate a SSG. This procedure was used in both 2008 and 2009 for aluminum in the four water bodies.

Aluminum has two separate CCME (Canadian Council of Ministers of the Environment) guidelines depending on the pH of the water body; 0.005mg/L for water bodies with pH < 6.5 and 0.100 mg/L for water bodies with pH > 6.5. The pH of Pound Cove Brook and the Virginia River is < 6.5 while that of Northwest Gander River and Pinchgut Brook is >6.5. The current CCME guideline was used in the development of the SSGs.

In order to develop SSGs for aluminum, toxicity tests were conducted using the actual site waters and the laboratory waters (hardness and pH adjusted to match site water). The fact that actual toxicity data were generated for the water bodies means that actual SSGs can be developed for the water bodies with great confidence, since guidelines are not

being developed using studies conducted by other researchers who may have been performing tests for totally different purposes and under restrictive conditions with potentially arbitrary safety factors applied.

Tests performed were acute toxicity tests using Rainbow trout (*Oncorhynchus mykiss*) with measurements after 24 hours and the standard 96 hours. In addition, reproduction and survival tests using the Cladoceran *Ceriodaphnia dubia* were measured with effects measured and reported for survival as LC_{50}, NOEC (No Observed Effects Concentration), LOEC (Lowest Observed Effects Concentration), and for reproduction as NOEC, LOEC, and IC_{25}. Results were reported both as total and dissolved concentrations.

In 2009, WER values for the dissolved and total concentrations for chronic tests for the Virginia River were similar, but were quite different for the Northwest Gander River. Ratios were 2.83:1 for the IC_{25} total aluminum value and 3.66:1 for the IC_{25} dissolved aluminum value for the Virginia River, and 2.8:1 for total and 21.4:1 dissolved for the Northwest Gander River.

Since the water quality guideline for aluminum is currently expressed as dissolved aluminum, the resulting SSG values were calculated to be 0.020 mg/L for the Virginia River and 0.110 mg/L for the Northwest Gander River. These SSG values were confirmed based on the toxicity data from this work.

Staff from the Department of Environment and conservation collected aluminum data from a number of different water bodies in Newfoundland and Labrador and these samples were tested between two and nine times each by Environment Canada. The purpose of the test program was to assess whether there may be a correlation between dissolved and monomeric (free) aluminum concentrations. Our analysis indicated that no relationship existed.

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Acknowledgements

This project is the result of considerable collaboration among individuals from the beginning. Haseen Khan and Ali Khan from Newfoundland Department of Environment and Labour conceived of the project in collaboration with Joe Pomeroy from Environment Canada. Meetings were held and advice obtained from Kyla Brake of Newfoundland Department of Environment and Labour. Ken Doe from Environment Canada provided crucial advice on toxicity testing. Keith Holtze of Aquatox Testing and Consulting Inc. coordinated the toxicity testing program and provided valuable insights into the testing results. Kyla Brake and Joanne Sweeney of the Department of Environment and Conservation provide review comments on the draft report for this project.

To these people our thanks are given. We alone are responsible for errors and omissions in this report.

1. Introduction

Water quality guidelines have been used in Canada for many decades as a means of managing water quality. The guidelines apply to individual water uses and identify levels above which effects might be noted in that user group. For nearly as long as guidelines have been used in Canada, the need to modify these because of site-specific factors has been known.

There are numerous methods available to develop site-specific water quality guidelines (SSG) or objectives (SSO). The Department of Environment and Conservation in Newfoundland and Labrador initiated a program to develop site-specific guidelines in 2008. During that year, it was determined that site-specific guidelines should be developed for aluminum in two water bodies, and that information has been reported (Tri-Star Environmental Consulting, 2008 a).

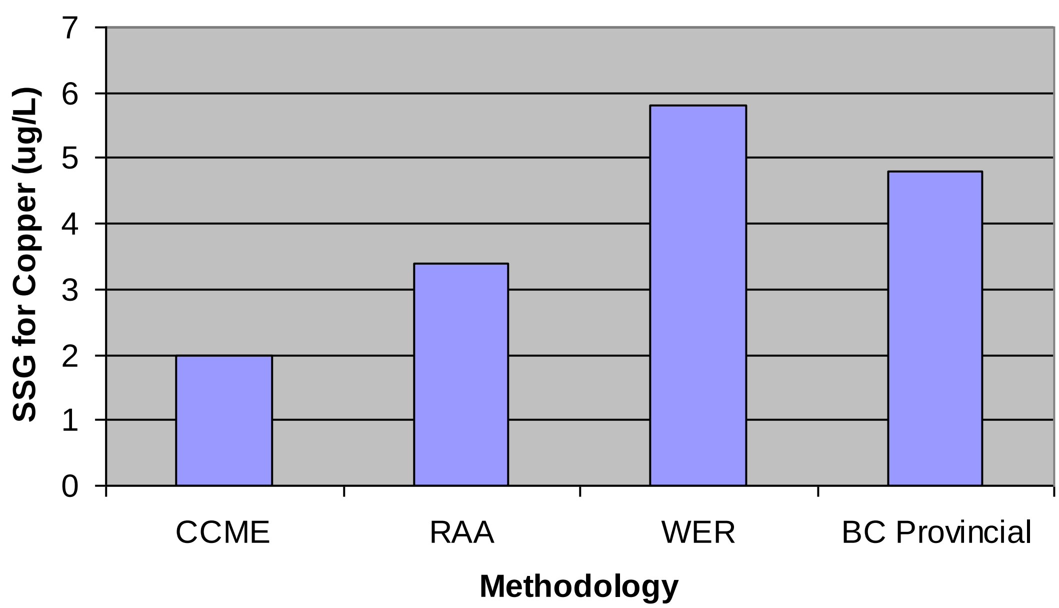
The techniques used to develop the site-specific guidelines were to use the water effects ratio (WER) procedure. This procedure was used because other more commonly used procedures such as the background concentration approach, physio-chemical adjustments, the Rapid Assessment Approach or the Re-calculation procedure did not provide improvements with an adequate degree of safety. The WER is developed using the toxicity of site water relative to laboratory water.

A comparison of guidelines developed using some of these techniques is shown in Figure 1 for copper in the Sumas River (British Columbia). Environment Canada performed a series of toxicity tests on copper using 96-h Chinook salmon, 96-h rainbow trout and 48-h Daphnia magna tests[1].

[1] Source: Environment Canada. Poster Presentation to the CCME WQI Workshop, Victoria, B.C. January 2006.

Figure 1 illustrates the fact that the generic CCME guideline can be overly protective, relative to a background concentration value determined using the Rapid Assessment Approach, and that calculated using the WER. In fact, the WER allows as much as three times the amount of copper in the system with no obvious impact to either aquatic life or the safety factor used to derive the original generic guideline.

Figure 1 - Guideline Comparison: Generic vs. RAA vs. WER for the Sumas River



1.1 National Reporting on Water Quality

In 2005, annual reports began to be released by Statistics Canada and Environment Canada on the quality of ambient waters in Canada. The reports provide information on water quality as calculated using the Water Quality Index. The basis for the Index is that comparisons between ambient water quality measurements are made with either ambient guidelines or site-specific objectives (guidelines adjusted to reflect ambient ameliorating factors).

The province of Newfoundland and Labrador is interested in investigating the use of the WER because there have been no site-specific objectives developed in the province and a number of water bodies with no human influence do not receive the WQI score in line with what is expected from the experts. CCME advice on use of the WQI is that site-specific objectives should be used and not national guideline values.

1.2 Principle Behind the Water Effects Ratio

The guiding principles behind the use of the WER are that during the testing of aquatic organisms in the laboratory (to generate the data from which guidelines are eventually derived), very pure water is used which does not have any of the inherent attributes that may be present in a water body to ameliorate the toxicity of particular contaminants. To adjust for this shortfall, the WER procedure calls for the use of water body-specific water for testing in side-by-side toxicity tests with the traditional laboratory water used for toxicity testing. Since an ambient guideline developed using toxicity data has an inherent safety factor incorporated into it that is to compensate for effects or un-tested organisms and additive or synergistic effects of multiple contaminants, the logic employed in the WER is that the guideline value for a specific water body tested in side-by-side tests can be multiplied by a ratio of the toxicity test value determined using site water to that determined using laboratory water.

1.3 Summary of the 2008 Assessments using the Water Effects Ratio

During 2008, toxicity testing was performed on two water bodies in Newfoundland and Labrador to develop SSGs for aluminum: Pound Cove Brook (Figure 2) and Pinchgut Brook (Figure 3).

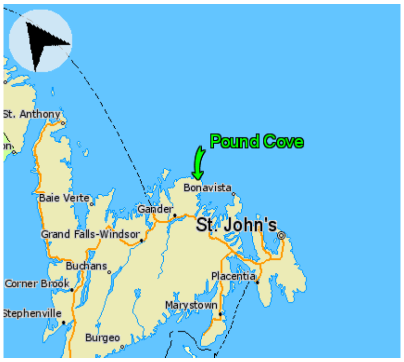


Figure 2: Location Map for Pound Cove Brook

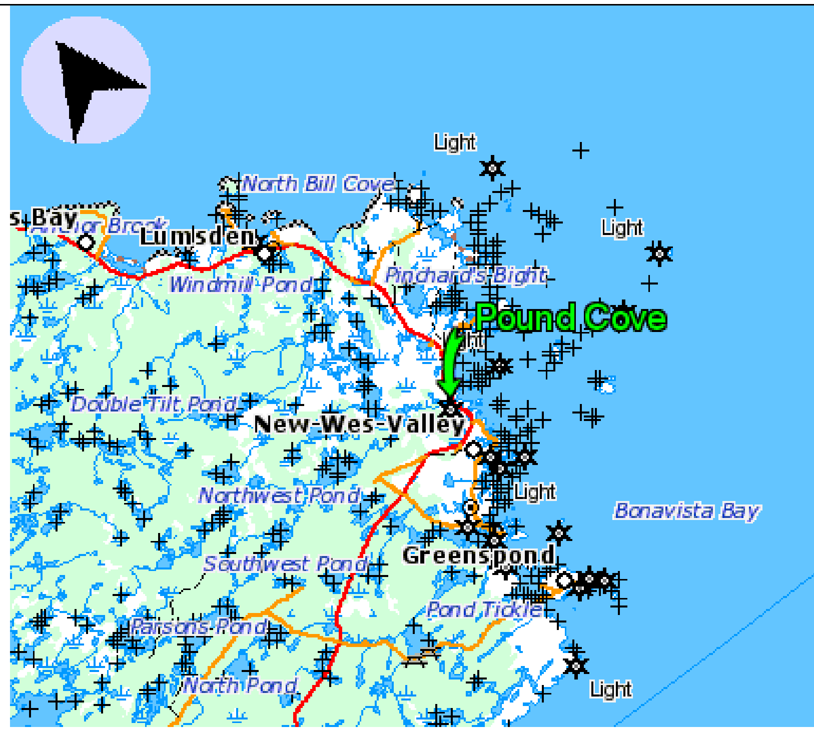
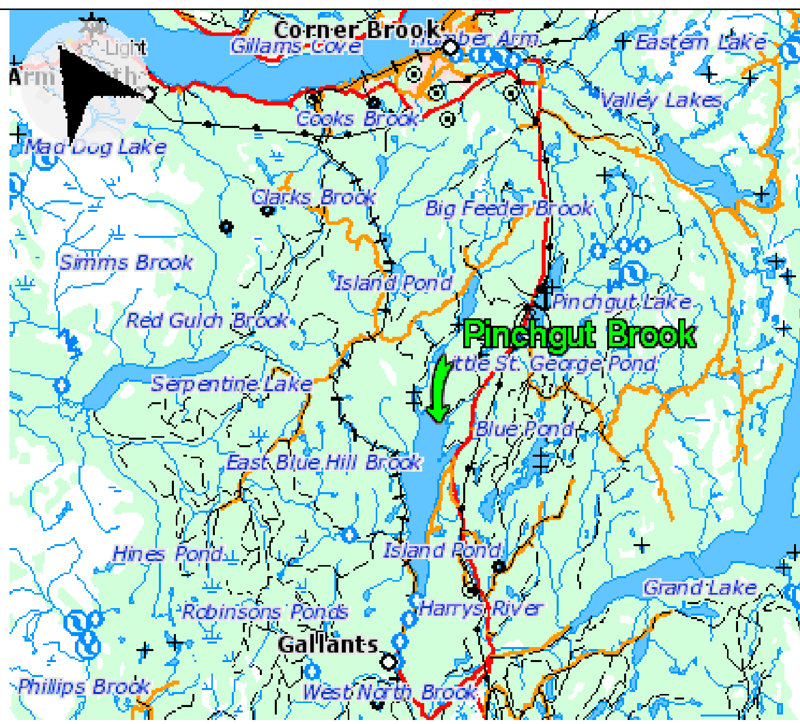


Figure 3: Location Map for Pinchgut Brook



In order to develop SSGs for the two water bodies for aluminum, toxicity tests were conducted using the actual site waters and the laboratory waters (hardness adjusted to match site water). The fact that actual toxicity data were generated for the two water bodies means that actual SSGs can be developed for the water bodies with great confidence, since guidelines are not being developed using studies conducted by other researchers who may have been performing tests for totally different purposes and under restrictive conditions with potentially arbitrary safety factors applied.

Tests performed for both Pound Cove Brook and for Pinchgut Brook were acute toxicity tests using Rainbow trout (*Oncorhynchus mykiss*) with measurements after 24 hours and the standard 96 hours. In addition, reproduction and survival tests using the Cladoceran *Ceriodaphnia dubia* were measured with effects measured and reported for survival as LC_{50}, NOEC (No Observed Effects Concentration), LOEC (Lowest Observed Effects Concentration), and for reproduction as NOEC, LOEC, IC_{25} and IC_{50}. Results were reported both as total and dissolved concentrations.

WER values for the chronic and acute tests for Pound Cove Brook were similar, being up to a ratio of 1.41:1 for the IC_{25} total aluminum value and 4.9:1 for the IC_{25} dissolved aluminum value. Interestingly, the IC_{50} ratios were 1:1 for total aluminum and 5.14:1 for dissolved aluminum. These ratios are very close to what was determined using the acute toxicity tests for Rainbow trout.

Since the water quality guideline for aluminum is currently expressed as dissolved aluminum, the resulting SSG for Pound Cove Brook was calculated by applying the geometric mean of the IC_{25} and IC_{50} data (5:1). Thus, using the WER, the SSG for Pound Cove Brook was calculated to be 0.025 mg/L. This SSG value was confirmed based on the toxicity data from this work. The lowest value showing an impact is the IC_{25} value for reproduction at 0.202 mg/L, while all survival data exceed 0.400 mg/L. Thus the calculated SSG seems to be reasonable considering the concentrations where effects were noted.

For Pinchgut Brook, the resulting SSG was calculated by applying the ratio for the IC_{25} value of 1.21:1. The geometric mean for the IC_{25} and IC_{50} in this case could not be used since no WER for the IC_{50} data could be calculated. Thus, using the WER, the calculated SSG would be 0.120 mg/L based on the generic guideline of 0.100 mg/L at pH levels > 6.5. This SSG was confirmed based on the toxicity data from this work. The lowest value showing an impact was the IC_{25} value for reproduction at 0.176 mg/L and all survival data were above 0.400 mg/L. Thus based on the toxicity data from this test, no adverse implications on either *Ceriodaphnia dubia* or rainbow trout would be expected from applying the proposed SSG.

It should be noted that while the laboratory test water had hardness adjusted to match the hardness in the water bodies; the pH in the laboratory waters was not adjusted. This could be an important factor in toxicities in laboratory waters, especially for Pound Cove Brook. It is suspected that if the pH had been adjusted downward in the laboratory water to more closely match Pound Cove Brook water, that the toxicity results would have been at lower concentrations and the resulting WER values may have been higher than reported. It is recommended that future testing programs where pH can be an important variable such as for aluminum ensure that the hardness (as was done for this testing) and the pH of the laboratory test waters be adjusted to match that of the water body.

1.4 Applying the Results to Newfoundland

In meetings in late 2008, a desire was expressed that if possible, it was desirable that the results from the testing be expanded to apply to all of Newfoundland and Labrador. This concept is examined in the report.

In 2009 testing was undertaken on two additional water bodies: the Virginia River in eastern Newfoundland (Figure 4) and the Northwest Gander River in central Newfoundland (Figure 5).

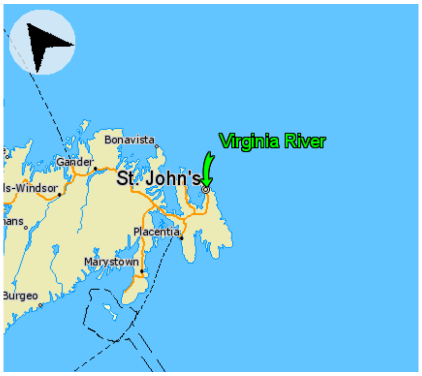


Figure 4: Location Map for Virginia River

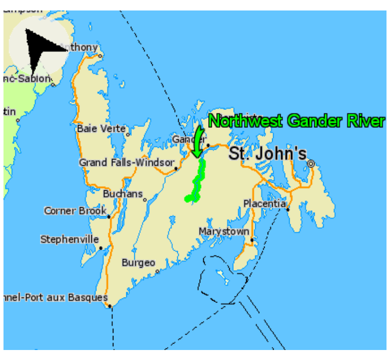


Figure 5: Location Map for Northwest Gander River

2. Discussion

2.1 General Principles of the Water Effects Ratio

The general principle behind the use of the WER is that the natural attribute of many systems will ameliorate toxic effects seen in testing in a laboratory, and that if side-by-side tests are performed using laboratory water and water from source water, that the amount of a contaminant (say a metal) can be increased in the natural source water. This was illustrated in Figure 1 for the Sumas River in British Columbia and has been discussed previously in support of this project (Tri-Star Environmental Consulting, 2008 a).

To generate these ratios, generally a vertebrate and an invertebrate are tested, with preference given to chronic tests and tests carried out during different seasons. Generally, only one test is needed for the vertebrate species (usually a fish). When all of this testing occurs, the results are then "averaged" using a geometric mean of the values to derive one WER. This then leads to one new guideline value, derived by multiplying the generic guideline by the WER.

To reduce the costs of this program and in order to look at more water bodies, it was decided that ratios would be developed at a "worst-case" time of year, producing the lowest possible ratio. This did not seem unreasonable since a geometric mean, used in guideline development when a multiple of many values is available, would tend to skew the result to the lower values. In a worst-case scenario, tests to generate WER would be performed for both vertebrate and invertebrate species when the lowest hardness and dissolved organic carbon are expected in a water body, thereby obtaining the lowest WER.

To define the "worst-case", the agency responsible for establishing the guideline could use one of three possible ratios: the lowest ratio derived (maximum safety factor), the ratio derived from the geometric mean of the two ratios, or finally the arithmetic average of the ratios. The latter two potentially reduce the available safety factor; however, it must be remembered that this might be compensated for at other times of year when higher concentrations of hardness or dissolved organic carbon might be present.

2.2 Water Bodies Tested in the 2009 Program

Sites were not considered in Labrador because of the lack of good long-term data sets and the difficulties in collecting samples. The former problem will be addressed through a concerted sampling program in future years.

Two water bodies were tested using the WER procedure in 2009: the Virginia River in eastern Newfoundland and the Northwest Gander River in central Newfoundland. The Virginia River was examined in order to have a water body from eastern Newfoundland, while the Northwest Gander River was tested due to concerns for results in 2008 for Pound Cove Brook. A decision was made to continue to examine aluminum concentrations using this procedure.

2.3 Evaluation of the Water Bodies

2.3.1 Northwest Gander River

The Northwest Gander River has been sampled since August 1986 at site NF02YQ0006 (latitude 48^o 58’ 11” N; longitude 55^o 50’ 29” W) on Route #360 which is 105 metres above sea level (Figure 6). It is located in the north-central sub-region of the central Newfoundland ecoregion with a drainage area of 1240 km^2. It has the highest summer temperatures and lowest winter temperatures. However, night frost can occur in any summer month. Due to the warm summer and high evapotranspiration losses, soils in the northern part of this ecoregion display soil moisture deficiency. The North-central Sub-region has higher summer maximum temperatures, lower rainfall and higher fire frequency than anywhere else in Newfoundland. The sub-region extends from Clarenville in the east to Deer Lake in the west and for the most part has a rolling topography below 200 m.

The headwaters of Gander River begin with Northwest and Southwest Gander rivers which lie inland in a southwest direction. These two major rivers, which are influenced by several smaller tributaries, empty into Gander Lake south from Appleton and Glenwood. The Gander River flows from the outlet of Gander Lake in a northeast direction toward Gander Bay.

Figure 6: Sampling Location on Northwest Gander River

2.3.1.1 Dissolved Organic Carbon and Hardness

These variables are the two that will most likely impact the toxicity of most metals in the environment. It is therefore important that testing be done using waters that represent the lowest concentrations of these two variables. Often, sacrifices need to be made in order that one or the other is at its lowest concentration, thereby resulting in higher than desired levels for the other variable.

There is a good long-term data set for Northwest Gander River. In the period between 1986 and 2008, 117 measurements were made of dissolved organic carbon. The fluctuation of the DOC values through that period is shown in Figure 7. Values ranged from 2 mg/L to 12.8 mg/L, with a mean value of 8.3 mg/L, with a 5th percentile value of 5.7 mg/L. The lowest values have typically been recorded during August of 1987, 1988, and 1990. Values since 1996 have generally been near or above 6 mg/L.

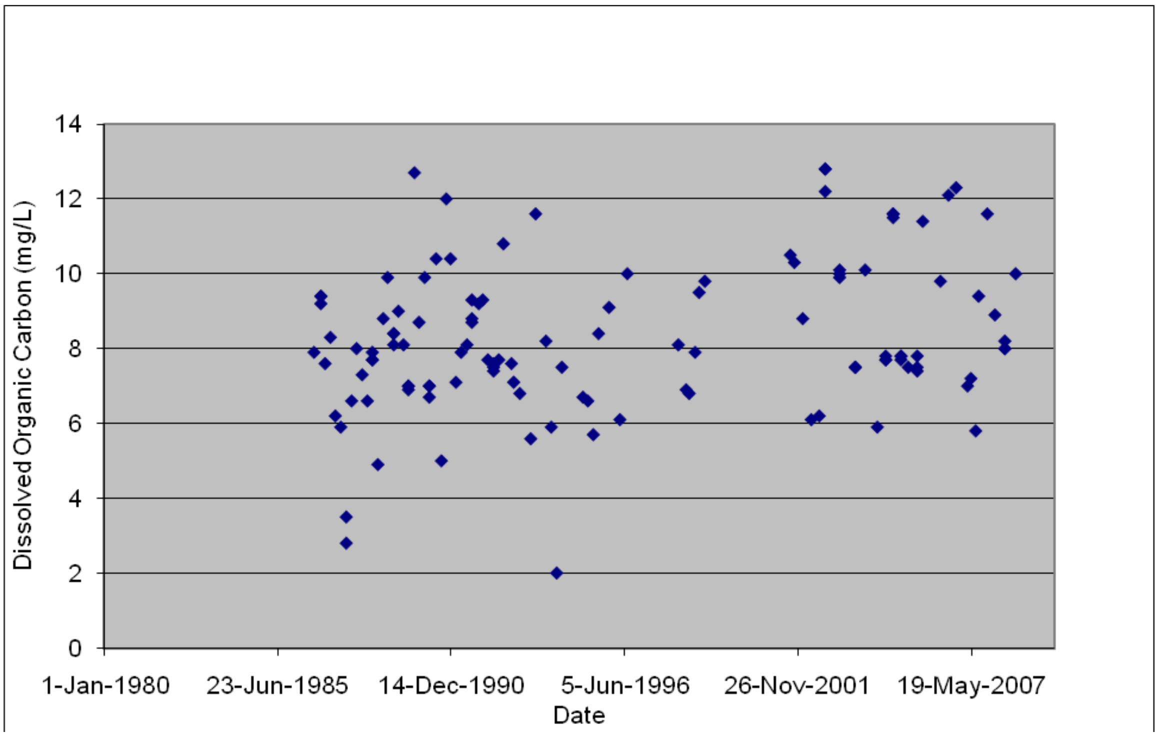


Figure 7: DOC Concentrations in the Northwest Gander River

Hardness values for Northwest Gander River (n = 118) have ranged from 2.9 mg/L to 14.9 mg/L, with a mean value of 7.6 mg/L and a 5th percentile value of 4.6 mg/L. The data are plotted in Figure 8. Low hardness values typically were in April; however, low concentrations can occur in any month. Values since 1990 have generally been 4 mg/L or greater.

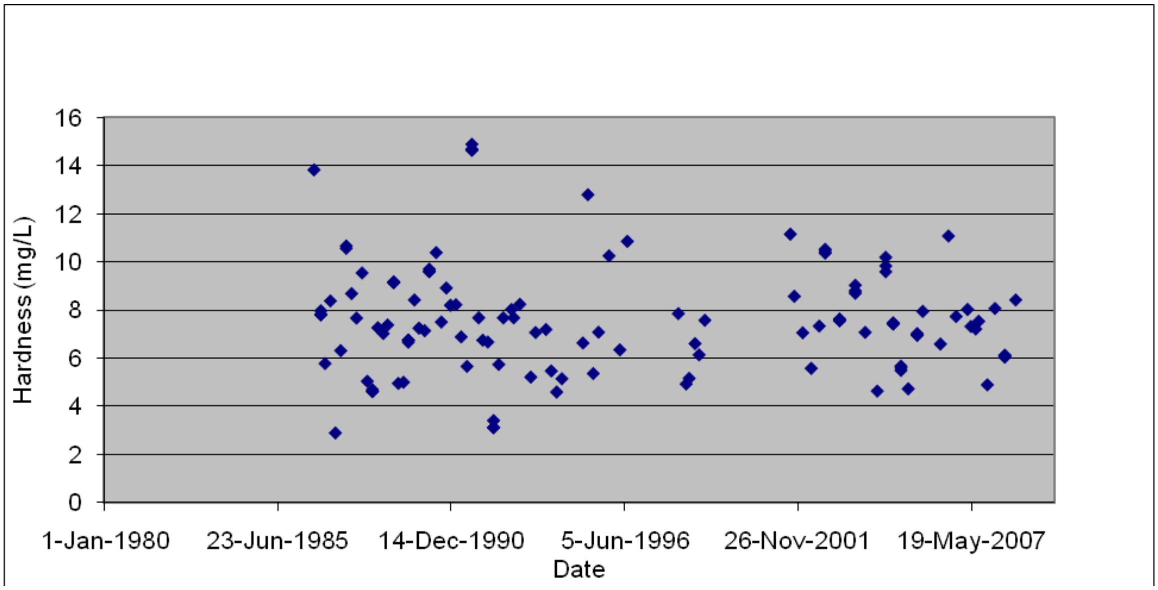


Figure 8: Hardness Concentrations in the Northwest Gander River

Based on this information, ideally samples would be collected in late August when the lowest DOC values have been measured or in the spring (April) when the lowest hardness values occurred. Due to the lack of a pattern with hardness, it is likely of more importance that sampling coincide with predicted low DOC timings.

The actual samples for testing were collected October 26, 2009 due to difficulties in shipment of the original samples. The hardness was measured as 9.0 mg/L and the TOC at 11.6 mg/L (DOC of 11.8 mg/L measured independently by Environment Canada), towards the higher end of the historic data set. These are higher than desired when the program was designed; however, the results from the test program will provide some indication of allowable levels of aluminum for the river.

2.3.1.2 Aluminum

As noted earlier, the CCME guideline for aluminum is being revised; however, there has not been a draft document produced since about 2005. The present CCME guideline value for waters with pH less than 6.5 is 5 µg/L as dissolved aluminum. The pH in the

Northwest Gander River ranged from 5.39 to 7.17 (Figure 9), with a median of 6.44. This means that the generic CCME 5 µg/L as dissolved aluminum guideline applies more than 50% of the time.

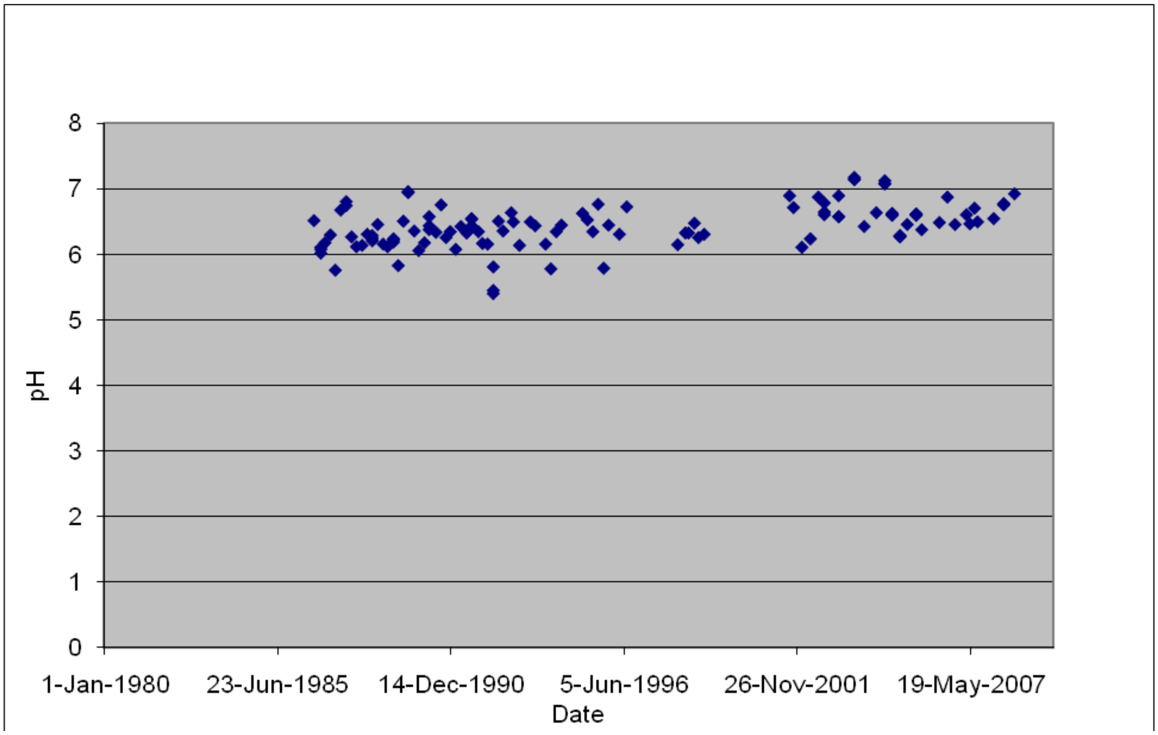


Figure 9: pH in the Northwest Gander River

This guideline is a value that is well below all total aluminum measurements in the Northwest Gander River where total aluminum concentrations were measured (Figure 10). Values ranged from 0.004 mg/L to 0.235 mg/L with a mean concentration of 0.12 mg/L. Aluminum concentrations in the Northwest Gander River do not appear to be increasing. The present CCME guideline value for waters with pH greater than 6.5 is 100 µg/L as dissolved aluminum. About 70% of measurements in the Northwest Gander River exceeded this value.

The sample submitted for toxicity testing had concentrations of 0.120 mg/L dissolved aluminum and 0.150 mg/L total aluminum, in the typical range of historic values.

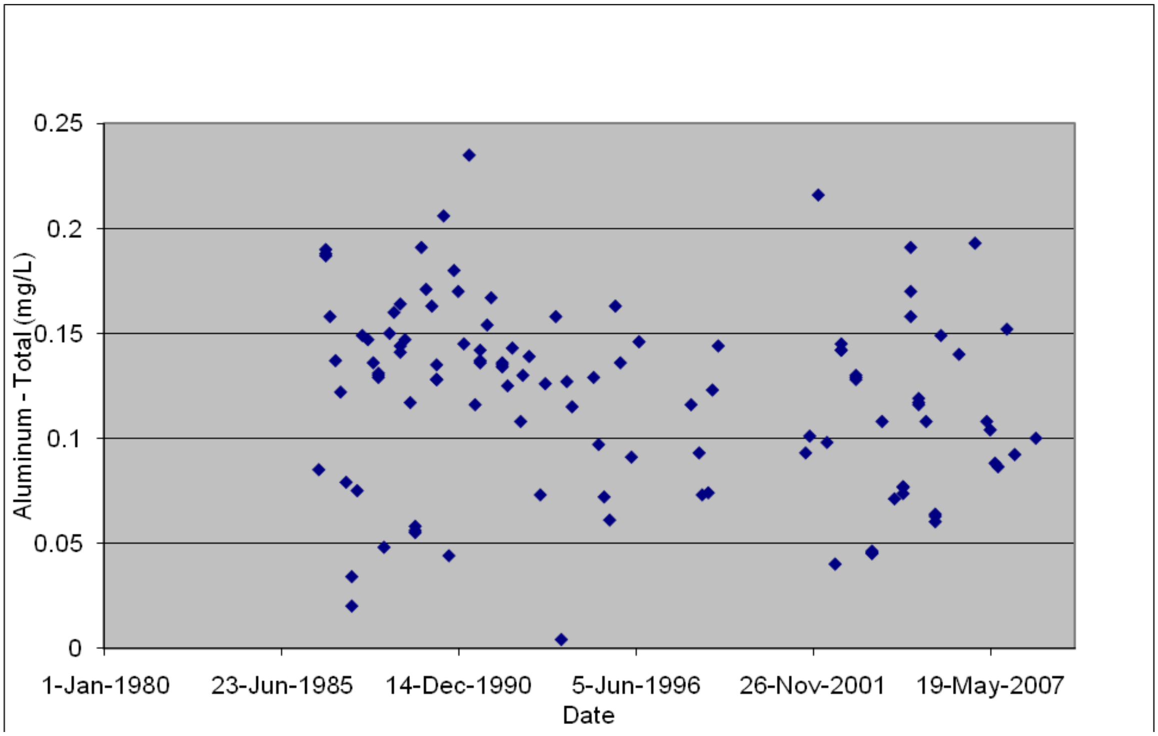


Figure 10: Aluminum Concentrations in the Northwest Gander River

2.3.2 Virginia River

The Virginia River at its headwaters site (NF02ZM0098) has been sampled since August 17, 1998 (Figure 11). It is located in St. John's at an elevation of 170 m and at Latitude: 47^{o} 35' 56" and Longitude: 52^{o} 45' 17". Development pressure at the site is considered to be low. The site is at the end of Firdale Place; approximately 50 m further alongside the fence toward the stream; and down a slight embankment; with sampling site located in centre of stream. The Virginia River is in the Maritime Barrens ecoregion.

The headwaters to Virginia River are marshes located near Penetanguishene in Airport Heights. The river runs southeast through some urban areas before draining into Virginia Lake. Virginia River continues from Virginia Lake and eventually drains into Quidi Vidi Lake and then into Quidi Vidi Harbour. The main channel length from the headwaters to the sampling site is 0.5 km and the length from the sampling site to the mouth of the river is 8.51 km.

Figure 11 – Looking Downstream at Virginia River at Headwaters Site

The drainage area is only 1.00 km^2 with a mean channel length of 0.50 km. The mean stream gradient: 2.00 %. The basin consists mostly of bedrock with little or no surficial sediment and a blanket of till (greater than 1.5 m) that lies over the bedrock. There is a small portion at the north of the basin where the veneer of till over the bedrock is less than 1.5 m. Till consists of a mixture of grain sizes from clay to boulders, and was deposited by glacial action.

The mean annual precipitation is 1400 mm with a mean annual runoff of 1200 mm. The river has ice for less than 55 days on average. Fish species present include Atlantic salmon, Brown Trout, Brook Trout, Rainbow Smelt and Stickleback. A 1981 study by fisheries biologists found a trout biomass of up to 50 g/m^2 in Virginia River.

The Water Survey of Canada operated a hydrometric station (02ZM019) from 1985-1998 on the Virginia River at Cartwright Place, 4.3 km further downstream. At that site (drainage area of 5.55 km^2), the mean daily discharge was 0.24 m^3/s, with a maximum daily discharge of 3.56 m^3/s in May 1985 and a minimum of 0.010 m^3/s in September 1988.

2.3.2.1 Dissolved Organic Carbon and Hardness

A limited number of data have been collected at the site. DOC values ranged from 3.1 mg/L to 9.8 mg/L (Mean 4.95 mg/L). DOC values are plotted in Figure 12. There does not appear to be any seasonal pattern to DOC concentrations. Most values were between 3 mg/L and 6 mg/L so that the timing of sampling is not a big concern for this site. Two samples were collected in August 2009: on August 12 and August 18. The DOC values were 13 mg/L and 6.5 mg/L, respectively.

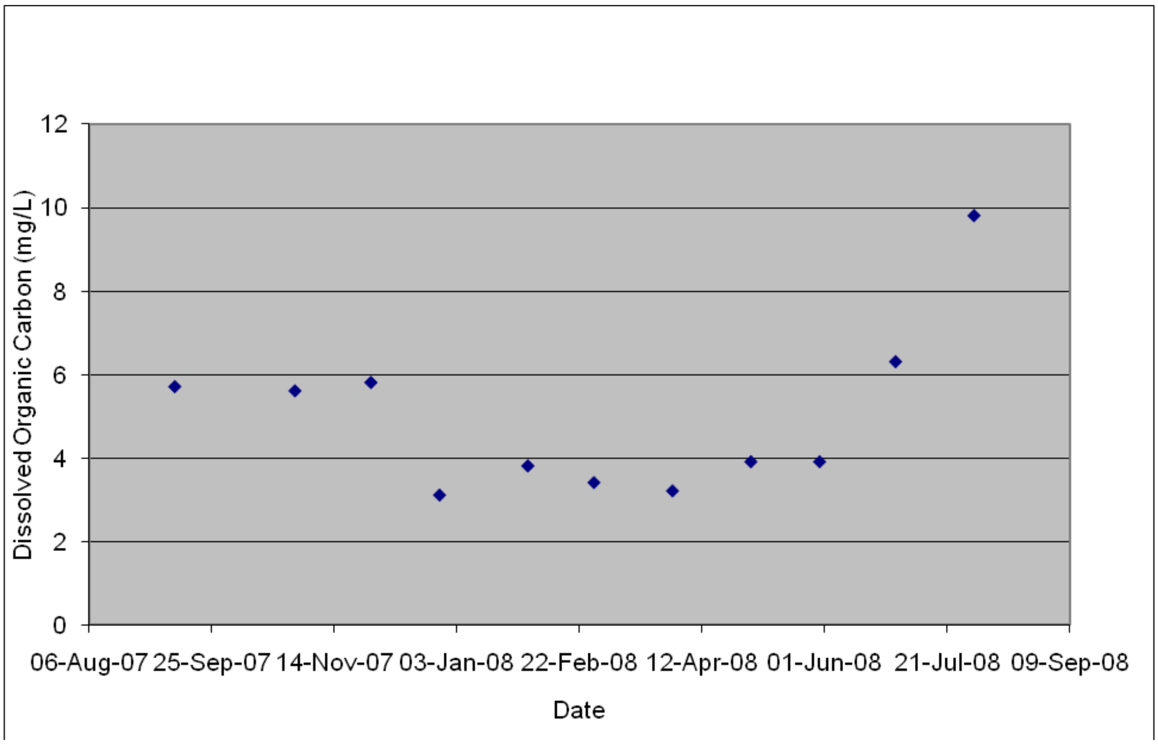


Figure 12: DOC Concentrations in the Virginia River at Headwaters Site

Hardness values at the site have ranged from 3 mg/L to 10 mg/L (mean 4.8 mg/L). The data have been plotted in Figure 13. The data show that hardness is usually between 4 mg/L and 6 mg/L, so that timing of sampling is not a big concern from the standpoint of hardness. The hardness values for the two samples collected were 7 mg/L for August 12 and 6 mg/L for the August 18, 2009 sample.

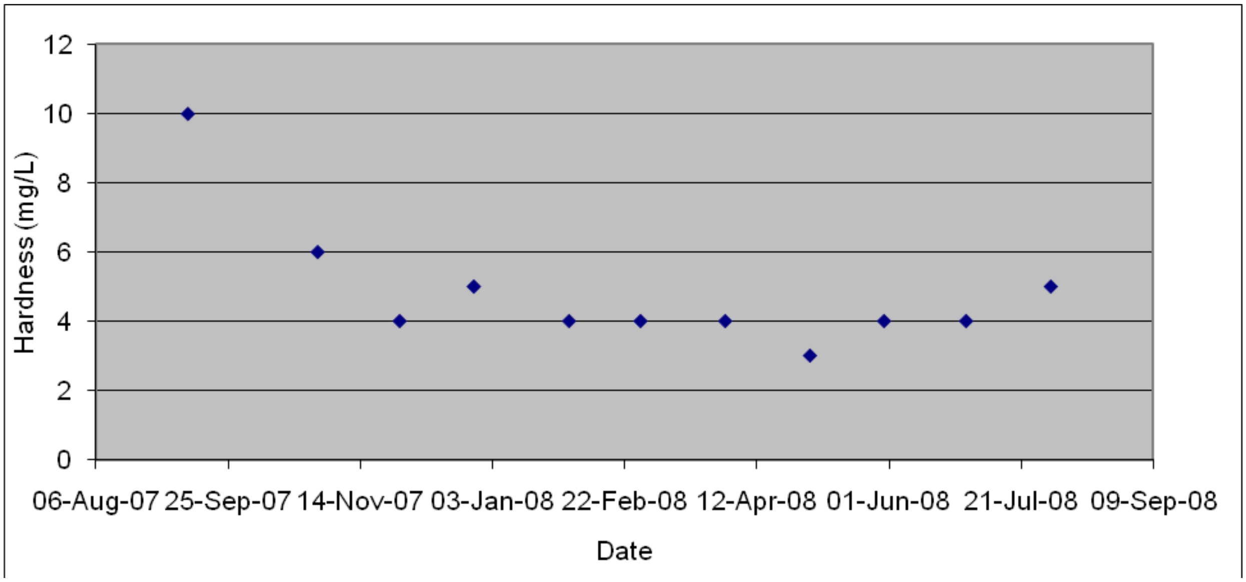


Figure 13: Hardness Concentrations in the Virginia River at Headwaters

2.3.2.2 Aluminum

The pH in the Virginia River ranged from 5.08 to 6.93, with most values between pH 5.0 and 6.0 (Figure 14). Field values in 2009 on August 12 and August 18 were 4.69 and 5.42, while laboratory results were 5.2 and 6.0, respectively.

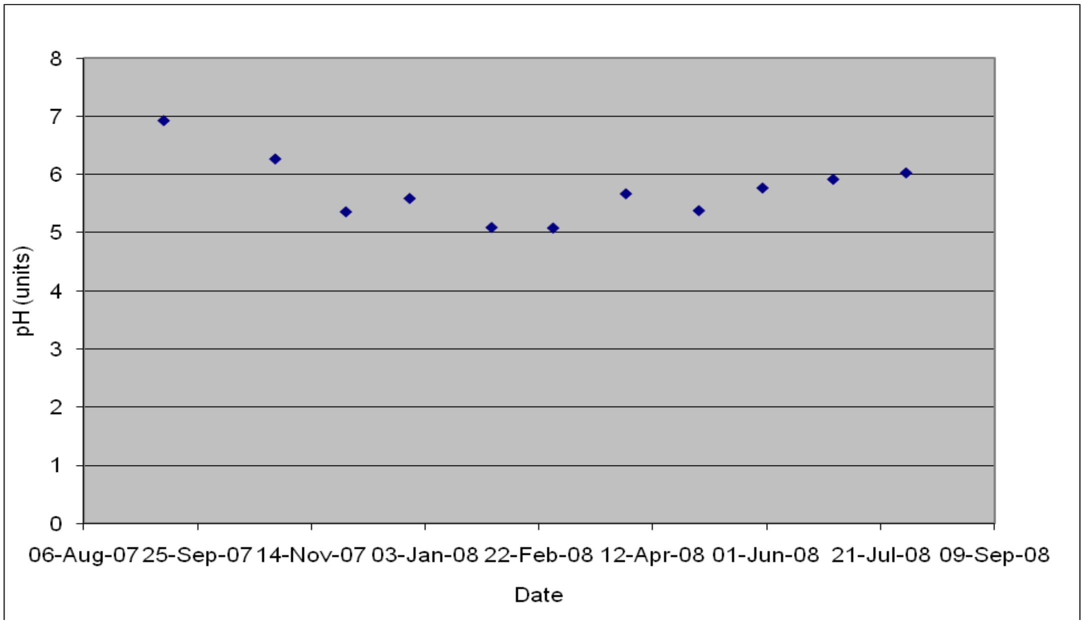


Figure 14: pH in the Virginia River

The present CCME guideline value for waters with pH less than 6.5 is a maximum of 0.005 mg/L, while for waters with pH greater than 6.5; it is 0.100 mg/L as dissolved aluminum. These guidelines are exceeded by all total aluminum measurements in the Virginia River. Aluminum concentrations are plotted in Figure 15.

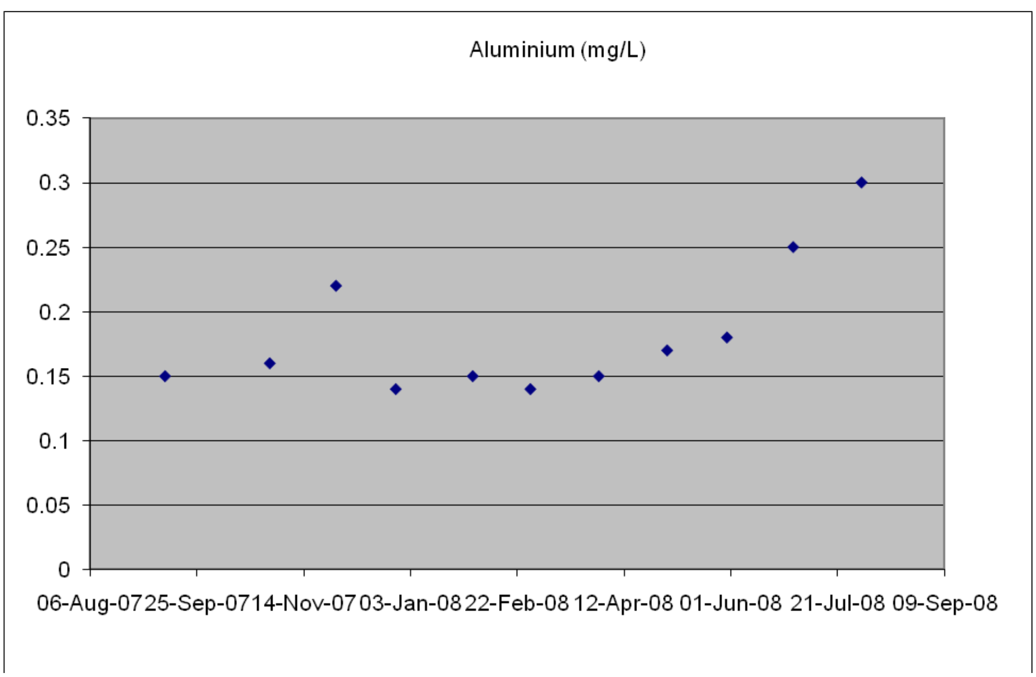


Figure 15: Aluminum Concentrations in the Virginia River at Headwaters

Aluminum concentrations in the 2009 samples used for toxicity testing were 0.190 mg/L dissolved and 0.280 mg/L total aluminum for the August 12 samples and 0.092 mg/L dissolved and 0.160 mg/L total aluminum for the August 18, 2009 sample.

3.0Results from the Water Effects Ratio Testing Program

The CCME (Canadian Council of Ministers of the Environment) guidelines for aluminum are expressed as dissolved aluminum and are based on the 1987 CCREM (Canadian Council of Resource and Environment Ministers) document. These guidelines are that dissolved aluminum concentrations should not exceed 0.005 mg/L at pH < 6.5 nor 0.100 mg/L at pH ≥6.5. The latter document cites higher toxicity at lower pH values although the "toxicity of aluminum is greatly reduced at circumneutral pH levels." More recently, CCME (2005 draft) have proposed draft guidelines for aluminum for pH <6.7, in terms preferably of monomeric aluminum (Table 1) although interim total aluminum guidelines (Table 2) are also cited. Aluminum is currently not on the work plan for updating by CCME[2].

Table 1: Draft CCME Water Quality Guidelines for Inorganic Monomeric Aluminum for the Protection of Aquatic Life

	pH Range		
	<5.7	**5.7 – 6.7**	**>6.7**
Al_{im} (mg/L)	0.0028	0.00018	N/A

N/A = not applicable

Since the existing guidelines are expressed as dissolved aluminum, toxicity tests that were conducted measured dissolved and total aluminum concentrations; however, Environment Canada also made some monomeric aluminum measurements. The fact that actual toxicity data were generated for the two water bodies means that actual SSGs can be developed for the water bodies with great confidence, since we are not using studies conducted by chance by other researchers who may have been performing tests for other purposes and under restrictive conditions with potentially arbitrary safety factors applied.

[2] Personal Communication. Susan Roe, National Guidelines and Standards Office, to L. Swain. August 28, 2008.

Table 2: Draft CCME Water Quality Guidelines for Total Aluminum (mg/L) for the Protection of Aquatic Life

	DOC (mg/L)				
pH	**0.5**	**2.5**	**5.0**	**7.5**	**10.0**
4.4	0.0061	0.0061	0.0063	0.0065	0.0067
4.8	0.0067	0.0072	0.0081	0.0096	0.0119
5.2	0.0084	0.0087	0.012	0.0154	0.0203
5.6	0.0098	0.0116	0.0149	0.0193	0.0252
6.0	0.0092	0.0108	0.0137	0.0178	0.0232
6.4	0.0074	0.0082	0.0097	0.0121	0.0156

As part of this project, samples were collected approximately quarterly from eight sites, with between two and nine samples being collected and measurements made by Environment Canada in Moncton for dissolved, extractable, complexed and free aluminum (assumed here to be monomeric). In Figure 16 the data for dissolved versus free aluminum are plotted (since free aluminum is a calculated value, negative values sometimes exist which has been removed). These data indicate that there is no relationship between the two forms of aluminum. This was also the case for individual water bodies (not reproduced here).

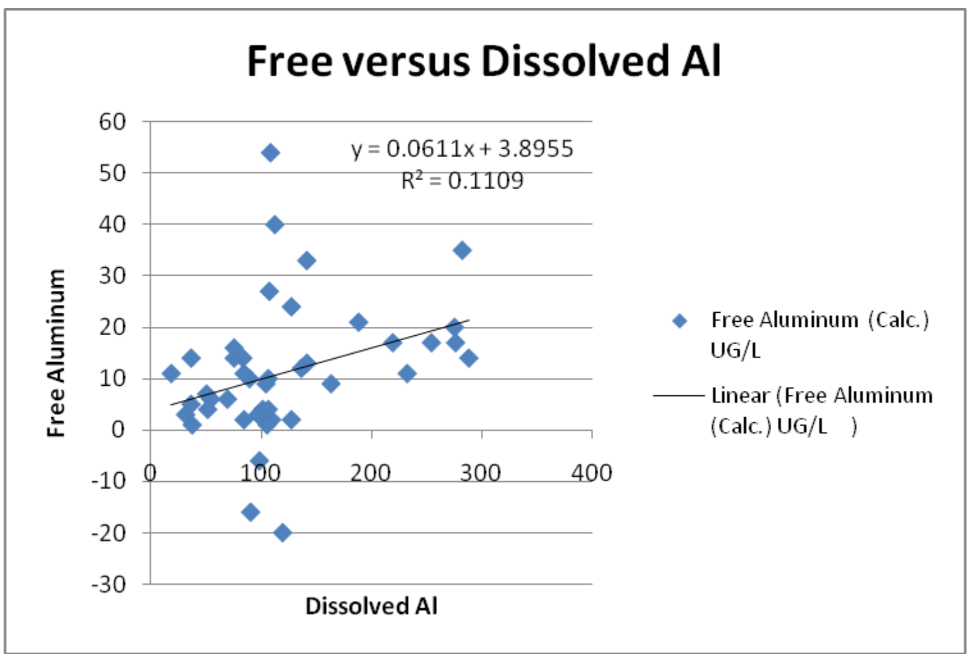


Figure 16: Free versus Dissolved Aluminum for All Sites

We also plotted the values for free aluminum versus the DOC concentrations in Figure 17. Interestingly, there seems to be a weak association between higher DOC and free aluminum concentrations. This was not the case for individual water bodies, especially Pound Cove Brook, the Virginia River, and Northwest Gander River.

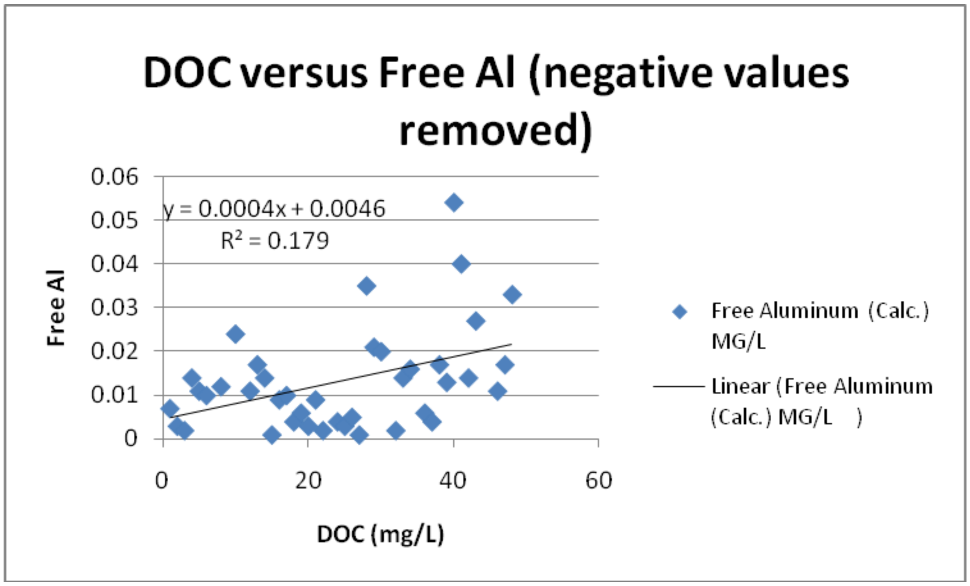


Figure 17: DOC versus Free Aluminum for All Sites

3.1 2009 Toxicity Testing Program

Tests performed for both the Virginia River and Northwest Gander River were acute toxicity tests using Rainbow trout (*Oncorhynchus mykiss*) with measurements after 24 hours and the standard 96 hours. In addition, reproduction and survival tests using the Cladoceran *Ceriodaphnia dubia* were measured with effects measured and reported for survival as LC50, NOEC, LOEC, and for reproduction as NOEC, LOEC, and IC_{25}. Tests were performed using laboratory water (hardness adjusted to match site water) as well as site waters. Results were reported both as total and dissolved concentrations. Results and methods are described in AquaTox (2010). It should be noted that LOEC and NOEC values are actual values that will depend on the dilutions selected, whereas IC_{25} values are determined statistically from the actual testing. Thus there can be situations where an IC_{25} might be higher than a LOEC.

In addition, it should be noted that where values for an endpoint have been reported as greater than a concentration, that a WER has not been calculated. Similarly, we have done the same for the reported NOEC concentrations since these could occur at any number of points in the continuum.

3.1.1 Virginia River

Virginia River water was sampled August 12 and 18, 2009 with testing initiated on August 18. Results are reported for the test endpoints in Tables 3 and 4 and water effects ratios are also calculated. The pH in the laboratory water was reduced using CO_2 injection to about 5.2 (based on the lab measurement on receipt) to match that in the Virginia River at the time of sampling.

Water effects ratios for the dissolved and total aluminum in the chronic tests were similar, being up to a ratio of 2.83:1 for the IC_{25} total value and 3.66:1 for the dissolved value. The LC_{50} values for rainbow trout were both reported as "greater than" certain concentrations and could not be used.

Table 3. Toxicity Testing Results for Virginia River –Total Aluminum (µg/L)

Test	**Virginia River**	**Laboratory Water**	**Water Effects Ratio (WER)**
Rainbow Trout			
96-hour (survival)	>756	66	>11.5:1
Ceriodaphnia dubia			
LC_{50} (survival)	>775	> 356	>2.18:1
NOEC (survival)	775	356	2.18:1
LOEC (survival)	> 775	> 356	>2.18:1
NOEC (reproduction)	479	77	6.22:1
LOEC (reproduction)	775	123	6.30:1
IC_{25} (reproduction)	328	116 (103 - 130)	2.83:1

Table 4. Toxicity Testing Results for Virginia River – Dissolved Aluminum (µg/L)

Test	Virginia River	Laboratory Water	Water Effects Ratio (WER)
Rainbow Trout			
96-hour (survival)	>324	43	>7.5:1
Ceriodaphnia dubia			
LC_{50} (survival)	>145	> 72	>2.01:1
NOEC (survival)	145	72	2.01:1
LOEC (survival)	> 145	> 72	>2.01:1
NOEC (reproduction)	145	32	3.59:1
LOEC (reproduction)	> 145	36	>3.19:1
IC_{25} (reproduction)	128 (112 - 140)	35 (34 - 37)	3.66:1 (3.29 – 3.78)

Since the water quality guideline for aluminum is currently expressed as dissolved aluminum, the resulting SSG from this work were calculated by applying the IC_{25} value to the dissolved aluminum concentration (3.66:1). The guideline for dissolved aluminum is 0.005 mg/L at pH <6.5. Thus, using the WER, the calculated SSG would be 0.0183 mg/L or could be rounded to 0.020 mg/L. The lowest concentration of dissolved aluminum tested that produced some toxicity was 0.112 mg/L at the IC_{25} level. This is about six times higher than the SSG suggested from our analysis, and is in the same order as the safety factors often applied (10:1). As well, all survival data exceed 0.145 mg/L. Thus it seems like a reasonable SSG.

3.1.2 Northwest Gander River

The Northwest Gander River water was sampled water October 26, 2009 with testing initiated on October 29, 2009. Results are reported for the test endpoints in Tables 5 and 6 and water effects ratios were also calculated. The pH in the laboratory water was reduced using CO_2 injection to about 6.8 (based on the lab measurement on receipt) to match that in the Northwest Gander River at the time of sampling. However, pH values during toxicity testing were from 6.3 to 7.0 in the river water and 6.2 to 7.1 in the lab test water.

Water effects ratios for the dissolved and total aluminum during the chronic tests were quite different, being up to a ratio of 2.8:1 for the IC_{25} total value and 21.4:1 for the dissolved aluminum value. The LC_{50} values for rainbow trout were both reported as "greater than" certain values and could not be used; however, these values did seem to confirm the wide range discrepancy between the total and dissolved WER values.

Table 5. Toxicity Testing Results for Northwest Gander River –Total Aluminum (µg/L)

Test	Northwest Gander River	Laboratory Water	Water Effects Ratio (WER)
Rainbow Trout			
96-hour (survival)	>1049	525	>2:1
Ceriodaphnia dubia			
LC_{50} (survival)	> 1020	> 833	>1.22:1
NOEC (survival)	1020	833	1.22:1
LOEC (survival)	> 1020	> 833	>1.22:1
NOEC (reproduction)	343	88	3.90:1
LOEC (reproduction)	472	140	3.37:1
IC_{25} (reproduction)	294 (236 - 343)	105 (72 - 142)	2.8:1 (2.42 – 3.28)

Table 6. Toxicity Testing Results for Northwest Gander River – Dissolved Aluminum (µg/L)

Test	Northwest Gander River	Laboratory Water	Water Effects Ratio (WER)
Rainbow Trout			
96-hour (survival)	>405	>24	16.9:1
Ceriodaphnia dubia			
LC_{50} (survival)	> 428	> 62	>6.90:1
NOEC (survival)	428	62	6.90:1
LOEC (survival)	> 428	> 62	>6.90:1
NOEC (reproduction)	281	30	9.37:1
LOEC (reproduction)	357	32	11.16:1
IC_{25} (reproduction)	257 (223 - 284)	12 (9 - 18)	21.4:1 (15.8 – 24.8)

Since the water quality guideline for aluminum is currently expressed as dissolved aluminum, the resulting SSG from this work would be calculated by applying the IC_{25} value to the dissolved aluminum concentration (21.4:1). The guideline for dissolved is

0.005 mg/L at pH <6.5 and 0.100 mg/L at pH $\geq$6.5. Thus, using the WER, the calculated SSG would be 0.107 mg/L at pH <6.5 and 2.140 mg/L at pH >6.5. We are concerned about the applicability of the results to the higher pH range, especially when the actual toxicity test data (pH in test varied between 6.3 and 7.0) are examined. The lowest concentration of dissolved aluminum tested that produced some toxicity was 0.223 mg/L at the IC_{25} level. This is only about two times higher than the SSG suggested from our analysis for pH <6.5, and is certainly below the SSG that would be recommended for pH>6.5. Thus it seems that the SSG should be a maximum dissolved aluminum concentration of 0.107 mg/L, or rounded to 0.110 mg/L. Chronic survival tests had LC_{50} values of >0.428 mg/L.

It should also be noted that due to test delays because of the shipping problems, these results do not represent the "worst-case" of the lowest DOC levels (and higher toxicities and resulting lower WER values) in the river water.

4.0 Applying the Data to Newfoundland and Labrador

Performing WER testing on every water body in Newfoundland would be an exhaustive program that also would be very costly. In British Columbia, one approach that is being used to reduce the level of effort while using site-specific guidelines on a larger scale is to extrapolate the findings to larger areas that are relatively homogeneous. These larger areas are called ecoregions.

Newfoundland has been divided into nine ecoregions (Figure 18). Work on the WER has resulted in work being completed in five of these ecoregions, and certainly the three largest on an area basis. The ecoregions where WER work has been completed are Western Forest (Pinchgut Brook – 2008), Central Forest (Northwest Gander River – 2009), North Shore Forest and Eastern Hyper-Oceanic Barrens (Pound Cove Brook – 2008), and the Maritime Barrens (Virginia River – 2009).

The following has been extracted largely from Tri-Star Environmental (2008 b). The plants and animals of a Province are affected by that environment and also by historic factors such as the position of glaciers or other barriers to dispersal and migration. An Ecoregion classification provides a systematic view of the small scale ecological relationships in the Province. This classification is based on climatic processes and landforms, and it brings into focus the extent of critical habitats and their relationship with adjacent areas.

The idea that water quality in nearby adjacent watersheds should be similar, assuming that all the factors cited for developing ecoregions apply, has been tested in several applications. A number of studies have shown that land-classification systems can be useful for identifying areas of relative homogeneity for water quality which varies according to predominant land type and present use.

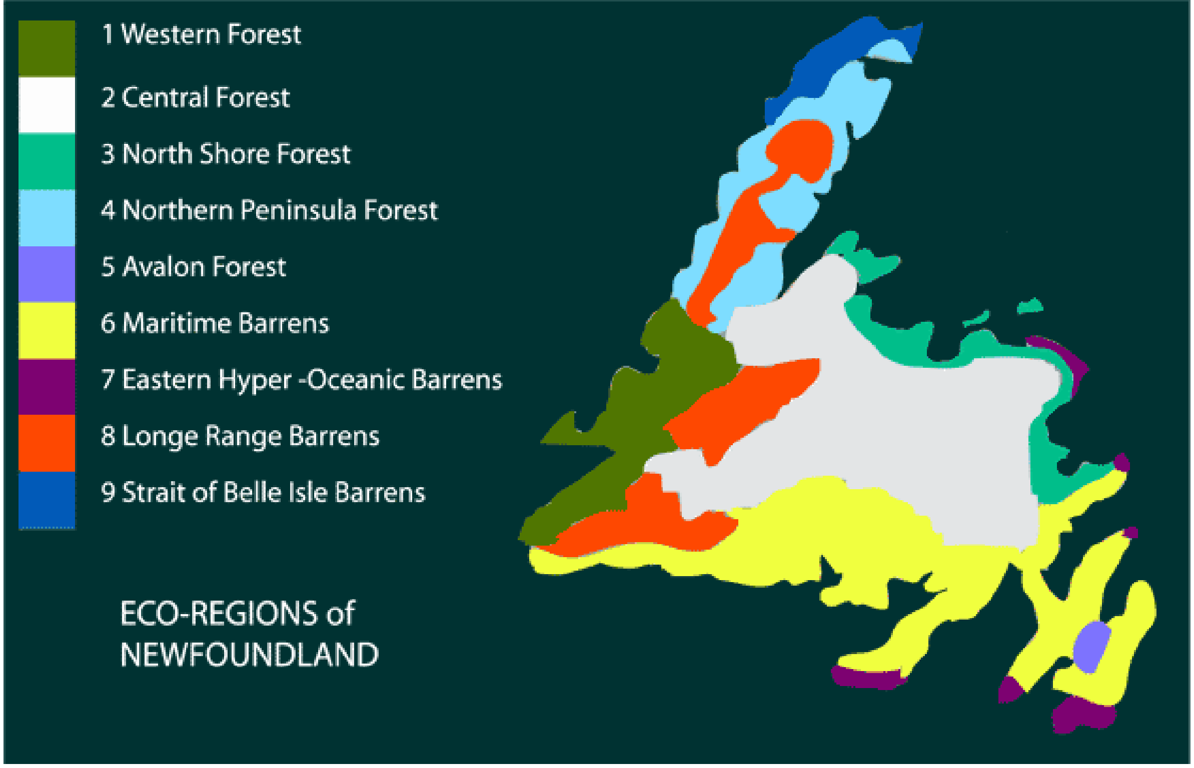


Figure 18: Ecoregions of Newfoundland (Source: http://wildnewfoundland.com/ecoregions.htm)

"Five ecological regions in Ohio were delineated to evaluate a framework for assessing attainable water quality in small streams. Streams in relatively un-impacted, representative watersheds were selected in each region. Various water-quality variables were sampled over a 16-month interval from July 1983 through November 1984" (Larsen *et al*. 1988). The authors found that the correspondence between spatial patterns in water-quality variables and the delineated regions, together with multivariate classification of the streams based on their major ion chemistry and nutrient richness, supported the hypothesis that regional differences in surface-water quality occur and that a land-classification system was useful for characterizing attainable water-quality goals. Variables measured by the researchers were total phosphorus, Kjeldahl nitrogen, nitrate, nitrite, ammonia, total organic carbon, specific conductivity, alkalinity, calcium, and magnesium.

Rohm *et al*. (1987) studied fish, physical habitat and water quality in 22 streams in Arkansas. Ordination analysis of the data showed greater similarity in streams within the same ecological region than in streams from different ecological regions. Water quality variables measured were ammonia, nitrate, nitrite, suspended solids, turbidity, ortho phosphate, total phosphorus, dissolved solids, chloride, hardness, sulphate, specific conductivity, alkalinity, biochemical oxygen demand, dissolved oxygen and temperature.

Newsom (1993) tested the water quality of relatively un-impacted rivers and streams in three ecoregions in the Southern Interior Ecoprovince of British Columbia. Data for dissolved solids, alkalinity, hardness, ammonia and total phosphorus from September and October 1973 and 1974 were used in the evaluation. It was determined that mean concentrations were fairly similar among ecoregions, although the greatest variation in mean concentrations was for total phosphorus and dissolved solids. The use of the Kruskal-Wallis test identified that one of the variables was significantly related at the 95% confidence level while the other four variables had significant relationship at the 85% confidence level. Finally, potential sources of error in this analysis were suggested to be the use of a limited number of sites due to the use of an existing data set, some sites may have been impacted by logging or farming, the frequency of some sample collections, and finally the age of the data and the fact that better analytical detection limits have been developed.

MacDonald (1997) provided evidence of using background concentrations in one watershed to that in a nearby watershed. The context was a contaminated watershed in Montana (Upper Fork River, a tributary to the Columbia River) and the desire to establish site-specific water quality objectives in that impacted watershed. This water body has had a great deal of historic mining activity. Because of this, copper concentrations were deemed to be higher than background. It was not possible to establish a monitoring station upstream on the river to determine background copper levels. In an attempt to estimate background concentrations, a nearby reference site was established in an area with similar mineralogy in order to establish background. Data from this site indicated that background dissolved copper concentrations (0.0012 mg/L) were in fact considerably lower than those in the Upper Fork River.

These studies illustrate that there is evidence that water quality in water bodies of similar mineralogy also can be similar, and that use of this scientific finding may be a useful and efficient means to develop site-specific water quality guidelines in relatively un-impacted water bodies in Newfoundland.

4.1 Applying WER Results to Newfoundland

Where large human developments such as mines are proposed or may currently be taking place, other more expensive but site-relevant procedures may need to be undertaken by proponents to develop defensible water quality guidelines. Even in those situations it may be possible to use more detailed results from one watershed to others in the same ecoregion. The ecoregion approach is a defensible first-estimate of a site-specific guideline that can be broadly applied.

The work in 2008 recommended dissolved aluminum site-specific guidelines of 0.025 mg/L for Pound Cove Brook and 0.120 mg/L for Pinchgut Brook. Thus, using the ecoregion approach, we recommend a maximum dissolved aluminum concentration of 0.120 mg/L in the Western Forest ecoregion of Newfoundland and a maximum dissolved aluminum concentration of 0.025 mg/L in the North Shore Forest ecoregion and the Eastern Hyper-Oceanic Barrens ecoregion.

Based on the 2009 WER testing, it is recommended that the maximum dissolved aluminum concentration of 0.110 mg/L apply in the Central Forest Ecoregion and a maximum dissolved aluminum concentration of 0.020 mg/L in the Maritime Barrens Ecoregion.

4.1.1 Uncertainties in Application

Interestingly, two of the four SSGs based on WER testing were between 110 and 120 µg/L. Further testing in other ecoregions may indicate that such a level is applicable in even a more widespread area. The two other water bodies had a SSG of between 0.020 and 0.025 mg/L. It should be remembered from Section 1.3 that it was suspected that in the 2008 test program, that if the pH had been adjusted downward in the laboratory water to more closely match Pound Cove Brook water, that the toxicity results would have been at lower concentrations and the resulting WER values may have been higher than reported.

5.0 Recommended Next Steps

There are a number of things that should be pursued prior to formally and fully adopting an ecoregion approach for the development of SSGs for all of Newfoundland and Labrador. These are:

1. At least one water body in Labrador needs to be tested using the WER for aluminum. Labrador ecoregions are displayed in Figure 19 as are water quality sampling sites. The largest ecoregions are the Kingurutik/Fraser Rivers, Smallwood Reservoir/Michikamau, and Mecatina River. There appear to be federal water quality sampling stations in all these. It is recommended that existing water quality data for aluminum be reviewed for these stations to determine whether one is a better candidate.

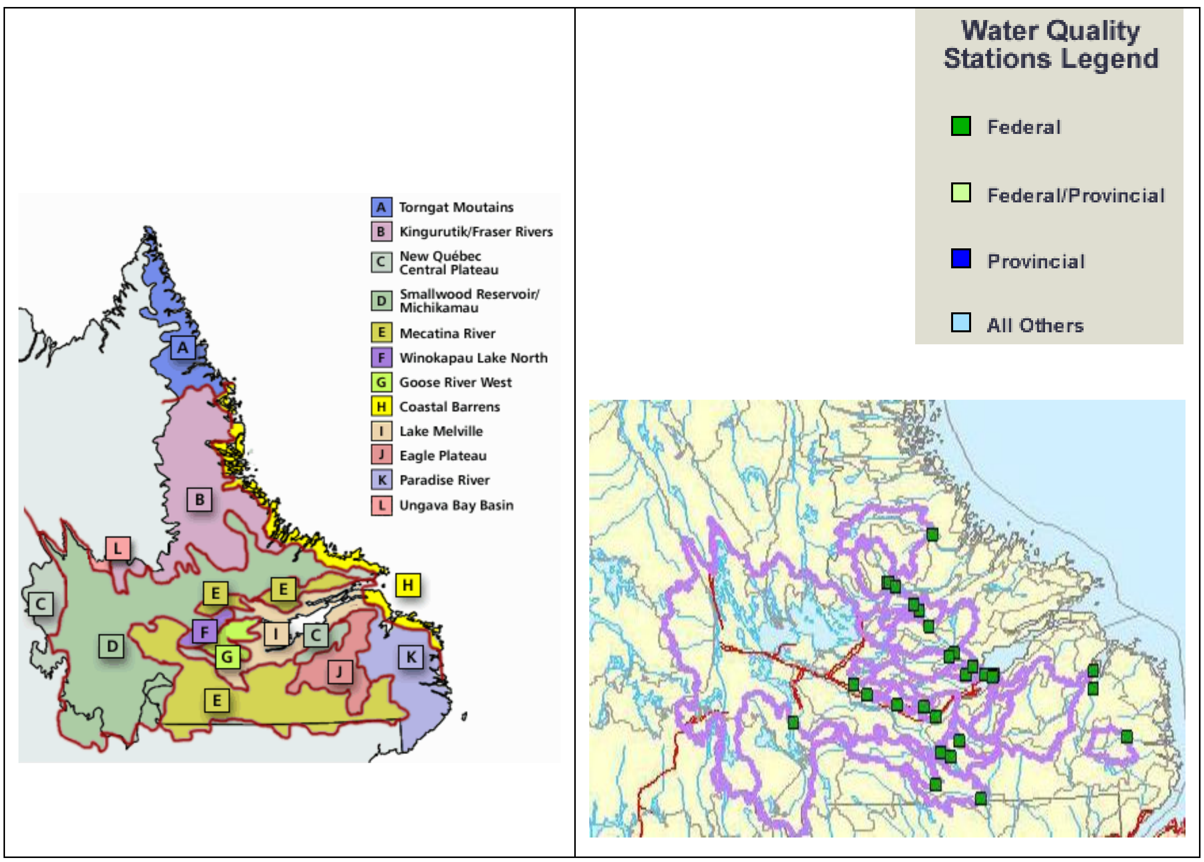


Figure 19: Ecoregions and Water Quality Sampling Stations in Labrador (Sources: http://www.heritage.nf.ca/environment/ecoregions_lab.html and CANAL web site)

2. If it is the desire of the Department to have SSGs for aluminum for all ecoregions, then there are five ecoregions remaining where SSGs for aluminum have not been developed. In our opinion, there is only one ecoregion large enough to warrant undertaking additional work for aluminum, and that is the Long Range Barrens ecoregion in western Newfoundland. Work should be undertaken in this ecoregion if there are good water quality data that can be reviewed to determine whether such work for aluminum is warranted in the ecoregion. Water quality stations in Newfoundland are shown in Figure 20.

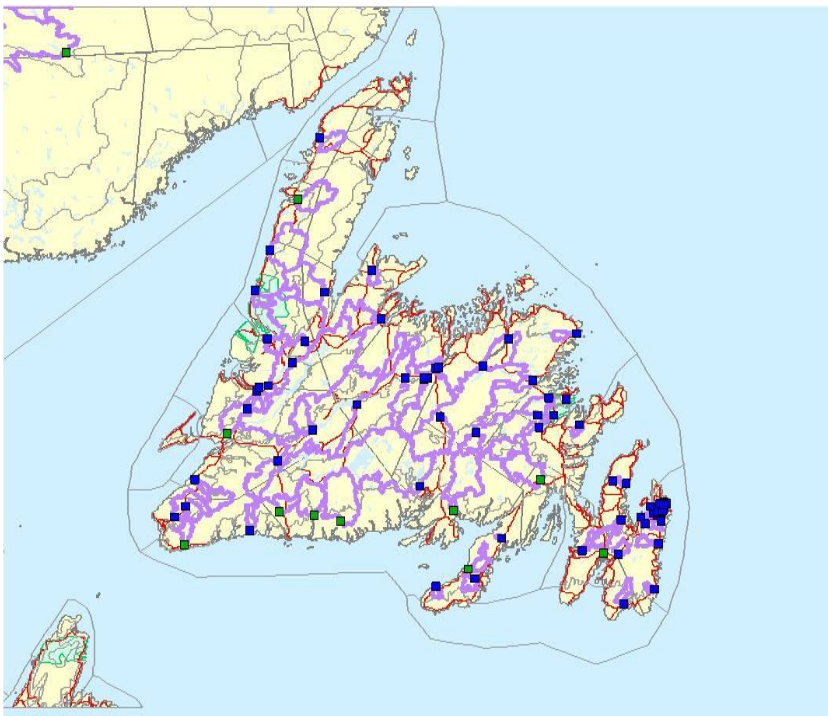


Figure 20: Water Quality Sampling Stations in Newfoundland (Source: CANAL web site)

3. The concept of the ecoregion approach needs to be developed more fully for Newfoundland and eventually for Labrador as it applies to the development of other SSGs. This involves the development of SSGs for variables other than aluminum for those ecoregions where SSGs for aluminum have been developed. This work need not be a hugely time-consuming process nor take significant resources, and can be undertaken most likely using the background concentration

approach to developing the SSGs for each ecoregion. This would use the water quality data collected to-date for the water bodies where sampling has taken place.

4. The focus of this work to-date has been on rivers and streams in Newfoundland. Water quality data for the lakes in each ecoregion needs to be examined to determine whether additional work needs to be completed or whether the information that has been developed for streams and rivers can be applied to lakes.
5. Finally, we recommend that where large ecoregions are present, that work be undertaken in selective sites to determine whether smaller areas such as eco-sections would be more appropriate units for the application of these results. Such a comparison initially could be based on existing water quality data that may exist at this scale.

References

AquaTox Testing and Consulting Inc. *Toxicity Testing in Support of a Site-specific Guideline for Aluminum Derived Using the Water Effects (WER) Ratio Method*. Draft Report. February 10, 2010.

CCME 1999. Canadian Environmental Quality Guidelines. *Water Quality Guidelines for the Protection of Aquatic Life. Aluminum*.

CCME 2005 Draft. *Water Quality Guidelines for the Protection of Aquatic Life. Aluminum.*

Environment Canada. Poster Presentation to the CCME WQI Workshop, Victoria, B.C. January 2006.

Larsen, D.P., D. R. Dudley, and R. M. Hughes. *An Approach for Assessing Attainable Water Quality: Ohio as a Case Study*. Journal of Soil and Water Conservation, 171-176(Mar-Apr 1988).

Macdonald, D. D. 1997. *Methods for Deriving Site-Specific Water Quality Objectives in British Columbia and Yukon*. Prepared for B.C. Ministry of Environment, Lands and Parks.

Newsom, D. 1993. *Evaluation of Water Quality Generalizations within Three Ecosections*. Department of Biology, University of Victoria. (Work term report in partial fulfillment of the requirements of the Biology Co-op Program)

Personal Communication. Susan Roe, National Guidelines and Standards Office, to L. Swain. August 28, 2008

Rohm, C.M., J.W. Giese, and C.C. Bennett. (1987). *Evaluation of an Aquatic Ecoregion Classification of Streams in Arkansas*. Journal of Freshwater Ecology.Volume 4: 127-40.

Tri-Star Environmental Consulting. 2008 (a). *A Comparative Study of Site-specific Guideline Methods: Results from the 2008 Testing Program*. Prepared for the Department of Environment and Labour for the Government of Newfoundland and Labrador and for Environment Canada. November 2008.

Tri-Star Environmental Consulting. 2008 (b). *The Use of the Ecoregion Approach to Setting Water Quality Objectives in the Vancouver Island Region*, B.C. Ministry of Environment. Prepared for the B.C. Ministry of Environment, Vancouver Island Region. March 2008.

Appendix 1: Descriptions of the Newfoundland Ecoregions

ECO-REGION 1

Western Newfoundland Forest

Characteristics

Mountainous terrain, most geologically diverse.
Heavily Forested, Most favourable climate for plant growth.
Longest growing season, Highest temperatures and humidity.
Greatest temperature variations due to changes in elevation.
Heaviest snowfalls, >4m annually.

Predominant tree types

Balsam Fir.

Noteworthy residents.

Eastern Chipmunk, Pine Marten, American Toad.

Serpentine River / "Lewis Hills"

Eco-Region 1a
Western Forest Serpentine Range - Subregion Geological Formations

The winding river has broken through it crescent shaped in the foreground. A fo and rubble, is visible on the mountainside in the background. The fa zone for springs along the stream bank.

ECO-REGION 2

Central Newfoundland Forest

Characteristics

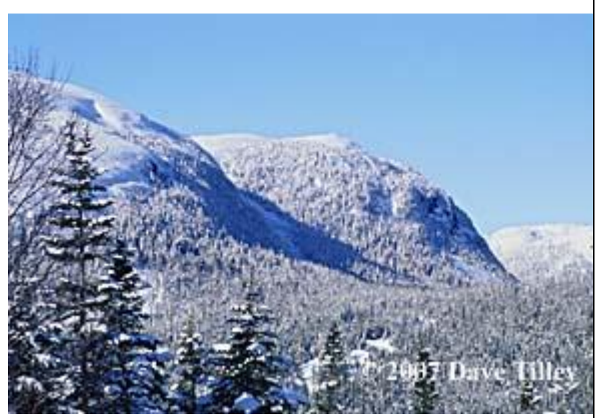
Gently rolling hills, greatest temperature range, dry in summer, lightest winds.
Heavily forested with black spruce/kalmia (goowitty).

Predominant tree types

Black Spruce, white birch & trembling

West Brook / "Red Pine Reserve"

aspen. **Rare tree types** Red Pine. **Noteworthy residents.** Eastern Chipmunk, Pine Marten, Northern Hawk Owl, Northern Flicker Green Winged Teal.	Pine clad hills... Most of the white pines were destroyed by a root killing disease brought over on early European vessels. Large pines prized for lumber and once harvested failed to return rare Red Pine grows in small stands. This one at the of the Topsail barrens as been designated as an ecolo reserve.

ECO-REGION 3 **North Shore Forest** **Characteristics** Irregular coastline, rolling hills, lowest rainfall, warmest coastal area in summer. **Predominant tree types** Black Spruce, balsam fir & white birch, less abundant white spruce & aspen. **Rare tree types** Red Pine. **Noteworthy residents.** Common Redpoll, Bald Eagle, Osprey.	**Crackerberries** 
ECO-REGION 4 **Northern Peninsula Forest** **Characteristics** Divided east from west by the Longe Range Mountains. Flat lowlands to the west, foothills to the east. Coolest climate, lowest precipitation/ low evapotranspiration. **Predominant tree types** Balsam fir, black spruce at high elevations. Past the northern limit for white birch & pine, red maple & trembling aspen. **Noteworthy residents.** Northern Harrier, American Bittern & Short-eared Owl in wetlands.	**Gros Morne** 
ECO-REGION 5 Avalon Forest **Characteristics** Low elevation, irregular low hills with steep	**Bull Moose**

sides. Scattered with small ponds and bogs. Cool summers, mild winters, frequent fog, high precipitation but little snowcover in winter. **Predominant tree types** Yellow Birch with spruce & fir. **Noteworthy residents.** Goshawk, American Bittern & Sharp Shinned Hawk.	

ECO-REGION 6

Maritime Barrens

Characteristics

Low, undulating, open country. Barren due to frequent fires.
Cool summers, mild winters, frequent fog, high precipitation with no permanent snowcover in coastal areas.

Predominant tree types
Some Balsam Fir & Yellow Birch in valleys.

Noteworthy residents.
Wintering grounds for large herds of caribou, 21 major seabird colonies offshore.
Rough Legged Hawk, Short-eared Owl, Sharp Shinned hawk, Belted Kingfisher.

Blue Flag Iris

ECO-REGION 7

Eastern Hyper-Oceanic Barrens

Characteristics

Flat to rolling, open country.
Most oceanic climate, very cool summers, mild winters, frequent fog,
high precipitation with variable snowcover.

Predominant tree types
Treeless coastal barren, fir tuckamoor.

Noteworthy residents.
Includes the largest seabird colonies. Rough Legged Hawk, Snowy Owl, Short-eared Owl,
Northern Gannet, Harlequinn Duck, Northern Harrier, Atlantic Puffin.

Cape St. Marys

ECO-REGION 8

Long Range Barrens

Grand Lake

Characteristics

Mountainous, highlands, plateaus.
Short cool summers, long cold winters, persistant snow cover.

Predominant tree types
Treeless highland barren, spruce tuckamoor, Balsam Fir in deep sheltered valleys.

Noteworthy residents.
Summer range for Humber caribou herd, year round for Northern Peninsula herd.
Arctic Hare, Rough Legged Hawk, Snowy Owl, Short-eared Owl, Northern Harrier.

ECO-REGION 9

Strait of Belle Isle Barrens

Characteristics

Flat & rocky along the western coast, hills to the east.
Short cool summers, long cold winters, lowest island temperatures.
Pack ice present until early summer, potential for frost year round.
Low precipitation, persistant fog.

Predominant tree types
Treeless barrens, tuckamoor & tundra.

Noteworthy residents.
Polar Bears drift ashore on the pack ice.
Peregrine Falcon, Gyrfalcon,
Red-throated Loon, Belted Kingfisher.

Rock Barrens

Appendix 2

Laboratory Test Results – Virginia River

Modified Lab Water (hardness 10) - Acute RBT - **25297**

Maxxam Data

0 h						
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
750	790	260	105.33%	32.91%	5.3	0
560	540	150	96.43%	27.78%	5.2	0
420	380	94	90.48%	24.74%	5.3	0
320	300	100	93.75%	33.33%	5.3	0
240	230	130	95.83%	56.52%	5.2	0
0	< 5	< 5			5.5	0

48 h old						
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
750	440	11	58.67%	2.50%	5.1	100
560	150	6	26.79%	4.00%	5.6	80
420	180	10	42.86%	5.56%	5.2	70 (10)
320	96	8	30.00%	8.33%	5.4	30 (20)
240	71	6	29.58%	8.45%	5.6	10 (20)
0	< 5	< 5			5.7	20

48 h fresh						
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
750	-	-	-	-		100
560	520	350	92.86%	67.31%	5.3	80
420	370	65	88.10%	17.57%	5.4	70 (10)
320	250	64	78.13%	25.60%	5.4	30 (20)
240	230	13	95.83%	5.65%	5.6	10 (20)
0	< 5	< 5			5.5	20

96 h old						
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
750	-	-	-	-		100
560	440	12	78.57%	2.73%	5.2	100
420	300	15	71.43%	5.00%	4.9	100
320	210	8	65.63%	3.81%	5.2	100
240	130	7	54.17%	5.38%	5.4	50
0	< 5	< 5			5.9	20

Notes: Target pH was 5.2 ± 0.2

pH control was established by continuous on-demand addition of CO_2

Samples for analysis collected at t= 0 h (start); 48 h old and fresh solutions (i.e., at time of renewal) and at t= 96 h (end)

Virginia River Water - Acute RBT - **25296**

Maxxam Data

0 h							
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
560	840	920	630	109.52%	68.48%	4.6	0
420	700	730	530	104.29%	72.60%	4.8	0
320	600	660	480	110.00%	72.73%	4.9	0
240	520	590	390	113.46%	66.10%	4.9	0
180	460	480	360	104.35%	75.00%	5.1	0
0	280	280	220	100.00%	78.57%	5.2	0

48 h old							
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
560	840	750	420	89.29%	56.00%	4.5	0 (10)
420	700	630	390	90.00%	61.90%	4.9	0
320	600	530	370	88.33%	69.81%	4.9	0
240	520	470	330	90.38%	70.21%	4.9	0
180	460	420	310	91.30%	73.81%	4.9	0
0	280	250	190	89.29%	76.00%	5.1	0

48 h fresh							
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
560	730	680	140	93.15%	20.59%	4.9	0 (10)
420	590	550	160	93.22%	29.09%	5	0
320	490	470	170	95.92%	36.17%	5.1	0
240	410	380	150	92.68%	39.47%	5.1	0
180	350	360	160	102.86%	44.44%	5.2	0
0	170	170	89	100.00%	52.35%	5.3	0

96 h old							
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
560	730	680	120	93.15%	17.65%	5.1	10
420	590	520	140	88.14%	26.92%	5.1	10 (10)
320	490	430	130	87.76%	30.23%	5.5	0
240	410	380	150	92.68%	39.47%	5	0
180	350	320	150	91.43%	46.88%	5.2	0
0	170	160	91	94.12%	56.88%	5.4	10

Virginia River Water - Acute RBT - **25296**

Environment Canada - Moncton

0 h				
Nominal	Extractable	Diss	Complexed	Free
560	817	597	418	179
420	664	519	405	114
320	587	460	387	73
240	499	404	359	45
180	439	366	326	40
0	249	212	197	15

48 h old				
Nominal	Extractable	Diss	Complexed	
560	712	426	379	47
420	601	388	381	7
320	521	407	350	57
240	477	345	311	34
180	396	294	277	17
0	239	199	183	16

Virginia River Water - Chronic Cd - 25336

0 h								
Nominal	Corrected Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
750	920	870	230	94.57%	26.44%	5.6		
375	545	510	190	93.58%	37.25%			
188	358	330	170	92.31%	51.52%			
94	264	240	150	91.00%	62.50%	5.9		
47	217	220	120	101.44%	54.55%			
23	193	180	110	93.05%	61.11%	6.0		
0	170	170	94	100.00%	55.29%	6.0		

24 h old								
Nominal	Corrected Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
750	920	730	90	79.35%	12.33%	6.6		
375	545	450	110	82.57%	24.44%			
188	358	280	100	78.32%	35.71%			
94	264	210	100	79.62%	47.62%	6.7		
47	217	170	89	78.39%	52.35%			
23	193	170	82	87.88%	48.24%	6.7		
0	170	150	76	88.24%	50.67%	6.8		

120 h fresh								
Nominal	Corrected Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
750	930	930	140	100.00%	15.05%			
375	555	530	170	95.50%	32.08%	5.7		
188	368	380	160	103.40%	42.11%			
94	274	300	130	109.59%	43.33%	6.1		
47	227	230	110	101.38%	47.83%			
23	203	200	100	98.31%	50.00%	6.1		
0	180	180	77	100.00%	42.78%	6.0		

144 h old								
Nominal	Corrected Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
750	930	600	99	64.52%	16.50%		0	4.1
375	555	430	120	77.48%	27.91%	6.7	10	12.6
188	368	250	100	68.03%	40.00%		0	18.3
94	274	180	100	65.75%	55.56%	6.8	0	18.2
47	227	170	86	74.93%	50.59%		0	15.5
23	203	150	79	73.73%	52.67%	6.8	0	21.5
0	180	140	77	77.78%	55.00%	6.8	0	16.8

Modified Lab Water (hardness 10) - Chronic Cd - 25337

0 h							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
750	760	220	101.33%	28.95%	5.8		
375	360	48	96.00%	13.33%			
188	180	30	96.00%	16.67%			
94	93	23	99.20%	24.73%	5.9		
47	47	30	100.27%	63.83%			
23	28	19	119.47%	67.86%	6.0		
0	< 5	< 5			5.9		
24 h old							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
750	140	49	18.67%	35.00%	7.2		
375	160	41	42.67%	25.63%			
188	130	40	69.33%	30.77%			
94	68	56	72.53%	82.35%	7.2		
47	36	28	76.80%	77.78%			
23	24	19	102.40%	79.17%	7.1		
0	7	< 5			7.1		
120 h fresh							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
750	690	19	92.00%	2.75%	6.1		
375	350	18	93.33%	5.14%			
188	180	13	96.00%	7.22%			
94	90	17	96.00%	18.89%	6.1		
47	48	17	102.40%	35.42%			
23	26	14	110.93%	53.85%	6.1		
0	6	35			6.1		
144 h old							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
750	140	47	18.67%	33.57%	7.4	0	2.9
375	160	39	42.67%	24.38%		0	16.6
188	130	52	69.33%	40.00%		0	25.2
94	63	40	67.20%	63.49%	7.1	0	23.9
47	35	24	74.67%	68.57%		0	22.1
23	20	13	85.33%	65.00%	7.1	0	25.4
0	6	< 5			7.2	0	23.2

Notes: Target pH was 6.0 ± 0.2
pH control was established by continuous on-demand addition of CO_2
Samples for analysis collected at t= 0 h (start) and; 24 h old solutions; at 120 h renewal (fresh and old solutions)

Appendix 3

Laboratory Test Results – Northwest Gander River

Modified Lab Water (hardness ~ 10 mg/L) - Acute RBT - **26086**
Maxxam Data

0 h						
Nominal (ug/L)	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
1000	840	11	84.0%	1.3%	6.3	0
560	480	20	85.7%	4.2%	6.5	0
320		29			6.5	0
180	160	33	88.9%	20.6%	6.5	0
100		30			6.6	0
0	6	< 5			6.5	0

48 h old						
Nominal (ug/L)	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
1000	690	9	69.0%	1.3%	6.3	70 (10)
560	330	8	58.9%	2.4%	6.6	10
420		14			6.5	0
320	63	29	19.7%	46.0%	6.6	0
240		26			6.7	0
0	6	< 5			6.7	0

48 h fresh						
Nominal (ug/L)	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
1000	920	6	92.0%	0.7%	6.2	70 (10)
560	530	14	94.6%	2.6%	6.6	10
420		26			6.7	0
320	150	25	46.9%	16.7%	6.7	0
240		36			6.8	0
0	9	< 5			6.9	0
			70.8%	9.7%		

96 h old						
Nominal (ug/L)	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
1000	660	< 5	66.0%	-	6.4	100
560	78	5	13.9%	6.4%	6.5	10
420		11			6.7	0
320	51	11	15.9%	21.6%	6.7	0
240		9			6.7	0
0	9	< 5			6.8	0

Modified lab water is prepared by treating well water by Reverse Osmosis and adding hardness chemicals to achieve ~ 10 mg/L as $CaCO_3$)

Samples are collected at start of testing (0 h), after 48 h testing (48 h old solutions), at test solution renewal (48 h fresh solution) and at the end of the test (96 h old solution)

Solutions are spiked with nominal aluminum concentrations as shown using Aluminum chloride

River water sample contains ~ 150 ug/L Al as background.

NW Gander River Water - (hardness ~ 10 mg/L) Acute RBT - **26085**
Maxxam Data

0 h							
Nominal (ug/L)	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort
1000	1150	1000	410	87.0%	41.0%	6.1	0
680	830	760	360	91.6%	47.4%	6.4	0
460	610		310			6.6	0
320	470	440	270	93.6%	61.4%	6.8	0
220	370		260			6.8	0
0	150	150	110	100.0%	73.3%	6.9	0

48 h old							
Nominal	Corrected Nom	Total	Dissolved			pH	% Mort
1000	1150	1100	380	95.7%	34.5%	6.3	0
680	830	800	370	96.4%	46.3%	6.5	0
460	610		330			6.7	0
320	470	460	290	97.9%	63.0%	6.7	0
220	370		270			6.9	0
0	150	140	120	93.3%	85.7%	7.0	0

48 h fresh							
Nominal	Corrected Nom	Total	Dissolved			pH	% Mort
1000	1150	1100	440	95.7%	40.0%	6.1	0
680	830	800	520	96.4%	65.0%	6.4	0
460	610		340			6.5	0
320	470	460	290	97.9%	63.0%	6.7	0
220	370		270			6.7	0
0	150	150	120	100.0%	80.0%	7.0	0

96 h old							
Nominal	Corrected Nom	Total	Dissolved			pH	% Mort
1000	1150	1000	390	87.0%	39.0%	6.3	0
680	830	790	540	95.2%	68.4%	6.6	0
460	610		310			6.6	0
320	470	460	290	97.9%		6.9	0
220	370		270			6.9	0
0	150	160	120	106.7%	75.0%	7.0	0

NW Gander River Water - Chronic Cd - 26085

0 h								
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	1150	1100	400	95.65%	36.36%	5.8		
630	780	770	440	98.72%	57.14%			
400	550		390	97.50%		6.4		
250	400		320	128.00%				
160	310			0.00%				
100	250					6.7		
0	150	150	120	100.00%	80.00%	6.7		

24 h old								
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	1150	940	410	81.74%	43.62%	6.4		
630	780	640	430	82.05%	67.19%			
400	550		350			6.7		
250	400		260					
160	310							
100	250					6.8		
0	150	120	110	80.00%	91.67%	6.7		

24 h fresh								
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	1150	1100	490	95.65%	44.55%	5.9		
630	780	700	150	89.74%	21.43%			
400	550		370			6.6		
250	400		300					
160	310							
100	250					6.7		
0	150	160	120	106.67%	75.00%	6.8		

48 h old								
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	1150	870	430	75.65%	49.43%	6.5		
630	780	610	430	78.21%	70.49%			
400	550		360			6.6		
250	400		280					
160	310							
100	250					6.7		
0	150	130	120	86.67%	92.31%	6.8		

NW Gander River Water - Chronic Cd - 26085

120 h fresh								
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	1150	1100	490	95.65%	44.55%	6.3		
630	780	300	260	38.46%	86.67%			
400	550		410			6.7		
250	400		310					
160	310							
100	250					6.8		
Modified Lab Water (hardness 10) - Chronic Cd - 26086 (test cancelled)	150	150	130	100.00%	86.67%	6.7		

144 h old								
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	1150	910	420	79.13%	46.15%	6.8		
630	780	270	240	34.62%	88.89%			
400	550		340			6.9		
250	400		270					
160	310							
100	250					7		
0	150	120	120	80.00%	100.00%	7		

144 h fresh								
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	1150	1200	420	104.35%	35.00%	6.3		
630	780	830	420	106.41%	50.60%			
400	550		340			6.8		
250	400		280					
160	310		240					
100	250		210			6.9		
0	150	150	120	100.00%	80.00%	6.9		

168 h old								
Nominal	Corrected Nom	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	1150	970	370	84.35%	38.14%	6.9	10	2.4
630	780	660	360	84.62%	54.55%		10	5.6
400	550		300			7	10	8.1
250	400		230				0	15.9
160	310		210				0	19.7
100	250		180			7	0	21.7
0	150	130	110	86.67%	84.62%	7	0	23.9

Modified Lab Water (hardness 10) - Chronic Cd - 26256 (repeated test)

0 h							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	910	450	91.00%	49.45%	6.0	0	0
630		110				0	0
400	350	18	87.50%	5.14%	6.1	0	0
250		9				0	0
160	150	10	93.75%	6.67%		0	0
100		9			6.4		
0		< 5			6.7	0	0

24 h old							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000		22			6.4		
630		31					
400		29			6.8		
250		49					
160		58					
100		53			7.1		
0		< 5			7.2		

72 h fresh							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	910	19	91.00%	2.09%	6.3		
630		12					
400	360	10	90.00%	2.78%	6.3		
250		13					
160	140	13	87.50%	9.29%			
100		19			6.7		
0		< 5			6.7		

96 h old							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000		34			7.0		
630		25					
400		27			7.0		
250		25					
160		50					
100		56			7.0		
0		< 5			7.1		

Modified Lab Water (hardness 10) - Chronic Cd - 26256 (repeated test)

120 h fresh							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	830	11	83.00%	1.33%	6.2		
630		13					
400	330	10	82.50%	3.03%	6.2		
250		13					
160	130	16	81.25%	12.31%			
100		17			6.6		
Modified Lab Water (hardness 10) - Chronic Cd - 26256 (repeated test)		< 5			6.7		

144 h old							
Nominal	Total	Dissolved	Tot as % of Nom	Diss as % of Tot	pH	% Mort	Reprod
1000	110	28			6.8	10	4.2
630		23				10	4.6
400	140	22			6.9	10	16.4
250		48				20	23.7
160	120	83				10	26.2
100		55			7.0	0	32.1
0		< 5			7.1	0	36.2