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Final Report

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Bosworth Creek Water Quality Data Study:

Final Report

Prepared for the Environmental Studies Research Funds (ESRF),
Department of Natural Resources, Government of Canada

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Executive Summary

Bosworth Creek drains a small watershed near the town of Norman Wells, in the Tulita District, Sahtu Settlement Area of the Northwest Territories. A weir was constructed on the Creek in 1960 by Imperial Oil Resources to create a small impoundment supplying drinking water to the town and process water to the nearby oil field and processing facility. Later abandoned by the town and no longer used following the closure of the refinery, the Government of the Northwest Territories requested the removal of the weir and the completion of stream rehabilitation measures. The weir removal, completed in 2005, also included stream bed reclamation work to improve fish habitat and spawning bed access as well as restoration of riparian vegetation. The removal of the impoundment after decades of alteration provided a unique opportunity for the monitoring of water quality and ecological changes associated with stream restoration. Additional anthropogenic influences upstream of the area of the impoundment include the Norman Wells Pipeline crossing, a winter road crossing, the creation of a fire fuel break in the vicinity of the Creek and ATV crossings. Potential future activities associated with aggregate removal to support the development of infrastructure along the Mackenzie Valley Pipeline are a noted concern in the region.

This water quality data report summarizes the existing water quality data that has been gathered on Bosworth Creek intermittently from 1953 to 2009. Historical data from water quality sampling for industrial development is included. The existing dataset is heavily weighted with data from recent years (2006-2009). Although there is a significant amount of water quality data for the stream, some parameters have been sampled sporadically, and there are numerous sampling points along the water course. Sample points were clustered into groups to allow for analysis of the associated water quality data.

Water samples from Bosworth Creek watershed have been collected and analyzed for a suite of water quality parameters. Inconsistencies in the location, frequency and timing of water quality samples throughout this period limited the information that could be gleaned from them. These data did not support robust analyses of differences in concentrations during periods pre, during and post impoundment, making analyses of trends difficult. Statistical testing independent of site grouping showed a significant seasonal effect on concentrations for a range of trace metals, major metals, routine samples and major ions; most often characterized by significantly higher winter values and lower spring values. These seasonal differences were attributed to characteristics of seasonal discharge for the Creek.

All water quality data were compared to established guideline values for drinking water and aquatic life. Exceedances of Guidelines for Canadian Drinking Water Quality (GCDWQ) and the Canadian Water Quality Guidelines for the Protection of Aquatic Live (GPAL) were noted for a small number of samples and parameters. Observed exceedances were generally infrequent; however, some sites were more prone to guideline exceedances.

The highest number of guideline exceedances were observed for aluminum, showing 34% of the total samples analyzed for the parameter exceeding the guidelines. Other parameters showing exceedances were generally below 20% of the total number of samples analyzed for that parameter and include selenium and iron. The majority of water quality parameters including major ions, nutrients, hydrocarbons and physical parameters were generally within acceptable water quality guidelines for both drinking water and protection of aquatic life.

The development of new groundwater springs has been documented in recent years in the vicinity of the Creek. One spring in particularly in the lower portion of the basin was shown to have high concentrations of numerous water quality trace metal parameters, some exceeding GCDWQ and the GPAL. Continued water quality sampling at these new points of groundwater discharge will determine if they impact overall water quality of Bosworth Creek over time.

Recommendations for a long-term water quality monitoring program are also presented. Existing sample groups are ranked for inclusion in a future long-term monitoring program for water quality.

Résumé

Le ruisseau Bosworth draine un petit bassin versant près de la ville de Norman Wells, dans le district Tulita de la zone désignée du Sahtu, dans les Territoires du Nord-Ouest. En 1960, la Pétrolière Impériale Ressources a construit un déversoir pour créer un petit bassin de retenue approvisionnant en eau potable la ville, ainsi qu'en eau de traitement le champ de pétrole et les installations de traitement à proximité. Ensuite abandonné par la ville et n'étant plus utilisé après la fermeture de la raffinerie, ce déversoir a été, à la demande du gouvernement des Territoires du Nord-Ouest, enlevé. Le gouvernement a aussi exigé la prise de mesures de rétablissement du ruisseau. L'enlèvement du déversoir, terminé en 2005, comprenait aussi des travaux de remise en état du lit du ruisseau pour améliorer l'habitat des poissons et l'accès aux frayères, ainsi que le rétablissement de la végétation riveraine. L'enlèvement du bassin de retenue après des décennies de modification offrait une occasion unique d'assurer la surveillance de la qualité de l'eau et des changements écologiques associés au rétablissement d'un cours d'eau. Parmi les influences anthropiques additionnelles en amont du bassin de retenue, il y a le croisement du pipeline de Norman Wells, une traversée routière hivernale, la création d'un coupe-feu à proximité du ruisseau et une traversée pour VTT. Dans la région, on est préoccupé par des activités futures éventuelles associées à l'extraction de granulats pour appuyer l'élaboration d'une infrastructure le long du pipeline de la vallée du Mackenzie.

Ce rapport sur la qualité de l'eau résume les données sur la qualité de l'eau existantes recueillies, par intermittence, au ruisseau Bosworth, entre 1953 et 2009. Elles comprennent des données historiques tirées des échantillons mesurant la qualité de l'eau pour le développement industriel. L'ensemble de données existant est fortement pondéré à l'aide des données des dernières années (de 2006 à 2009). Même s'il existe un grand nombre de données sur la qualité de l'eau du ruisseau, certains paramètres ont été mesurés ici et là. De plus, on trouve plusieurs points d'échantillonnage le long du cours d'eau. On a regroupé les points d'échantillonnage pour permettre l'analyse des données sur la qualité de l'eau.

On a recueilli et analysé des échantillons d'eau du bassin du ruisseau Bosworth en fonction d'un ensemble de paramètres relatifs à la qualité de l'eau. En raison

d’incohérences quant au lieu, à la fréquence et au moment où les échantillons ont été pris durant cette période, les données découlant de ceux-ci étaient limitées. Ces données n’appuient pas des analyses robustes des différences entre les concentrations durant les périodes avant, durant et après l’utilisation d’un déversoir, rendant l’analyse des tendances difficile. Selon des tests aléatoires sans égard au regroupement des lieux, il y avait un effet saisonnier important sur les concentrations d’un ensemble de métaux-traces, de métaux principaux, d’échantillons systématiques et d’ions principaux. La plupart était souvent caractérisée par des valeurs fortement supérieures l’hiver, et inférieures au printemps. On a attribué ces différences saisonnières aux caractéristiques des rejets saisonniers du ruisseau.

On a comparé toutes les données sur la qualité de l’eau aux valeurs définies recommandées pour l’eau potable et la vie aquatique. On a noté qu’un petit nombre d’échantillons et de paramètres dépassait les Recommandations pour la qualité de l'eau potable au Canada et les Recommandations canadiennes pour la qualité des eaux : protection de la vie aquatique. Habituellement, les excédents observés étaient peu fréquents. Cependant, certains endroits étaient plus portés à dépasser les valeurs recommandées.

On a observé le plus grand nombre d’excédents pour l’aluminium, soit 34 % du total des échantillons analysés en fonction des paramètres dépassant les recommandations. Les autres paramètres pour lesquels on a enregistré des excédents étaient, dans l’ensemble, inférieurs à 20 % du total des échantillons analysés en fonction des paramètres, et comprenaient le sélénium et le fer. En général, la majorité des paramètres relatifs à la qualité de l’eau, y compris les ions principaux, les nutriants et les hydrocarbures, et les paramètres physiques, respectaient les recommandations quant à la qualité de l’eau potable et de la vie aquatique.

Au cours des dernières années, on a documenté l’exploitation de nouvelles sources d’eau souterraine autour du ruisseau. Tout particulièrement, on a découvert qu’une source dans la partie inférieure du bassin affiche des concentrations élevées pour plusieurs paramètres mesurant les métaux-traces ayant un effet sur la qualité de l’eau, certains dépassant les normes énoncées dans les Recommandations pour la qualité de l'eau potable au Canada et les Recommandations canadiennes pour la qualité des eaux : protection de la vie aquatique. La prise d’échantillons constante pour mesurer la qualité de l’eau à ces nouveaux points de vidange de nappes souterraines déterminera si elles ont une incidence sur la qualité de l’eau du ruisseau Bosworth au fil du temps.

On présente aussi des recommandations relatives à un programme de surveillance de la qualité de l’eau à long terme. Des groupes échantillons existants sont classés pour les ajouter à un programme de surveillance à long terme futur de la qualité de l’eau.

1 Introduction

1.1 Historical Overview

Bosworth Creek (Tulita District, Sahtu Settlement Area, Northwest Territories) (65° 18’N 126 41’W) drains a small watershed of ~125 sq. km. and originates as the outlet of Jackfish (Hodgson) Lake. From Jackfish Lake the creek runs northwest for approximately 8 km, paralleling the base of Discovery Ridge in the Norman Range of the Franklin Mountains and turns sharply to run southeast toward the town of Norman Wells, NWT, draining into the Mackenzie River within the town boundaries (Figure 1).

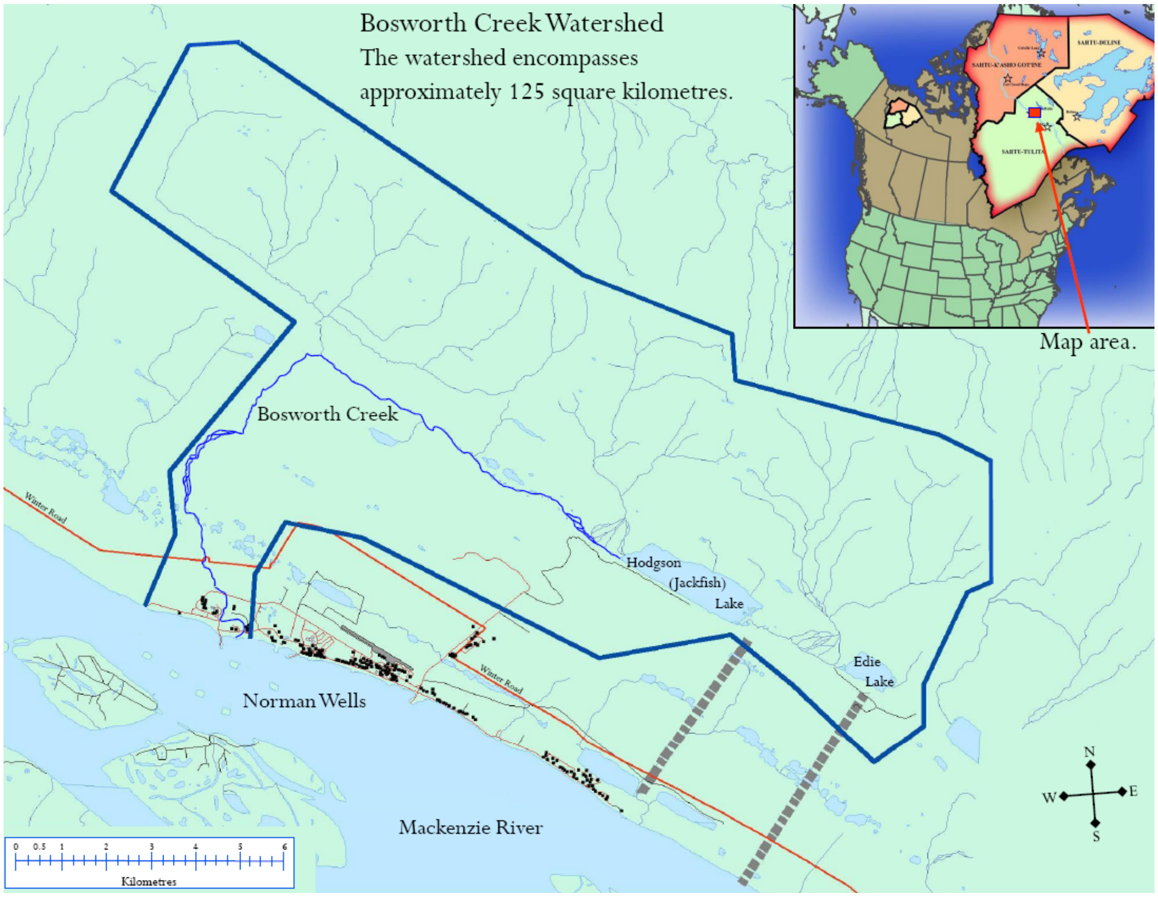

Figure 1. Bosworth Creek Watershed (Guthrie, 2009a)

The underlying geology of the ridge draining into Bosworth Creek is bedrock or bedrock overlaid by colluvial deposits. Below the ridge, the region, including the area of the town of Norman Wells is characterized by postglacial lacustrine plain deposits over bedrock that includes shale and limestone, as well as silt and clay ground moraine deposits. A depression between the existing Mackenzie River and the base of the ridge is characterized by an organic veneer and thick peat. Limestone is quarried in the area (Couture et. al, 2000). The creek underwent historic alteration with the construction of a weir in 1960 by Imperial Oil Resources approximately 250 metres upstream from the confluence with the Mackenzie River. The weir was installed to create a small impoundment for water supply to operate a nearby oil field and processing facility, and a source of drinking water for Norman Wells (Imperial Oil, 2005). The town abandoned the creek as a source of drinking water in 1991 and the closure of the existing refinery in 1996 prompted the Government of the Northwest Territories to request the removal of the weir, initiating stream restoration efforts (NWT Cumulative Impact Monitoring Program, 2009). Completion of the weir removal in 2005 included stream bed reclamation with rocks and boulders for fish habitat and access to spawning beds as well as stream bank vegetation restoration (Imperial Oil, 2005). The Sahtu Renewable Resources Board, in collaboration with a local high school (Mackenzie Mountain School) developed and implemented the Bosworth Creek Monitoring Project (BCMP) whereby local school students monitor the creek for hydrologic, aquatic water quality and ecosystem changes after restoration. The project has been running since 2006 and includes water quality testing, sediment and ice sampling, fish habitat analysis, and biological monitoring, including benthic sampling using the CABIN protocol (NWT Cumulative Impacts Monitoring Program, 2009). The BCMP was initiated over concerns about the reestablishment of historically occurring species of fish in the creek prior to the impoundment due to the weir (Bosworth Creek History Project, 2008). There is reference to the historic fishing for grayling (*Thymallus arcticus*) into Bosworth Creek through the Bosworth Creek History Project, and reference to a population of Lake whitefish (*Coregonus clupeaformis*) in Jackfish Lake. Recently, arctic grayling were observed above the weir site in 2006, indicating migration from the Mackenzie River shortly after stream reclamation efforts (Guthrie, 2007). The BCMP project team has been working in collaboration with DFO to monitor the creek for the potential reestablishment of natural spawning populations of several whitefish species. (http://www.dfo-mpo.gc.ca/dpr-rpp07-08/sect3j-eng.htm).

A long-term objective of the BCMP is to assess water quality during development and use of two Borrow Sites proposed by the Mackenzie Gas Project (Sahtu Settlement Area Crown Lands Application, 2005) and monitoring for possible contamination due to erosion that is occurring at a forest fire "fuel break" created in 1995 by the GNWT Forest Management Division (NWT Cumulative Impact Monitoring Program, 2008). The study aims to provide a long-term record of water chemistry by building upon previously collected data (NWT Cumulative Impacts Monitoring Program, 2009).

1.2 Objective of Current Water Quality Study

The aim of the current study is to consolidate existing water quality data from historic and recent sampling, and analyze this data to ascertain if there are changes to the water quality of the creek over the period of record. The scope of this report is limited to the analysis of data on the creek water, exclusive of ice and sediment samples collected during the BCMP. This report will outline key findings on the creed water quality of Bosworth Creek with respect to the 2010 Guidelines for Canadian Drinking Water Quality (GCWQ) and the 2007 Canadian Water Quality Guidelines for the Protection of Aquatic Life (GPAL), and recommend a water quality monitoring program for future monitoring efforts on Bosworth Creek. Water quality parameters that may have a significant impact on the ability of the creek to support aquatic life are identified.

2 Data Analysis Methods

The current study has consolidated the existing data from previous reports and studies into one spreadsheet document (Appendix 1) and builds on the literature review from October, 2009 (SENES Consultants Ltd. and Glen Guthrie, 2009). This water quality data report has identified previously unrecorded data on water quality for Bosworth Creek from years prior to the building of the weir. Comparison of data was not always possible due to lack of information on the sampling site and differences in the parameters that were collected and analyzed. For some historical data, the described locations cannot be identified or location data is missing from the record. Sample information from these historic records is not included in analyses where spatial information is required. These data are included in the analyses that do not require a spatial component, but give information on parameters over the period of record. Data points excluded from the analysis due to missing spatial information are shown in

Table 1.

Table 1: Data points excluded from statistical analysis

Reference	Description	Date of Sample
Francl, 1974	Unknown	02/06/1953
Thomas 1957	Station 64A	01/03/1956
Thomas 1957	Station 64A	11/10/1956
Francl, 1974	Unknown	12/03/1970
Francl, 1974	Unknown	13/11/1970
Francl, 1974	Unknown	19/07/1971
McCart et al, 1974	McCart 1	05/10/1972
McCart et al, 1974	McCart 2, B	12/11/1972
McCart et al, 1974	McCart 3, A	13/04/1973
McCart et al, 1974	McCart 5, B	05/06/1973
McCart et al, 1974	McCart 4, C	05/06/1973
McCart et al, 1974	McCart 6, A	04/10/1973

Water quality data were compiled in Microsoft Excel, and statistical analyses were conducted using SPSS® Inc. (V.17) statistical analysis software. Prior to conducting significance testing, initial data investigation included checks of normality; however, these were found to be problematic when many of the low values were found to be below the LOD. Fu and Wang (2011) have suggested that checks for normality are difficult under these circumstances. Therefore, to ensure robust statistical analyses and results, non-parametric tests were used for this data set, as they are consistently recommended over parametric tests for water quality data, due to an absence of any assumption of normality in the data (Helsel, 1987; Berryman et al., 1988).

All statistical analyses performed regardless of site group affiliation were inclusive of all Bosworth Creek water quality data, including samples from unknown locations. In circumstances where data were aggregated by site grouping, all sites with sufficient sample sizes to support analyses were included in statistical testing.

2.1 Grouping of Sites

A range of water quality parameters were collected at numerous monitoring sites in the Bosworth Creek watershed beginning in 1953. Geographic coordinates provided for a number of these sites identify spatial clusters where water quality samples were gathered in a non-continuous manner through the years. For analysis purposes, these clusters were amalgamated, such that sites within the vicinity were treated as one discrete location. This resulted in the identification of 26 separate sites containing from 1 to 17 separate water quality sampling locations. One additional group included sites of unknown location. Where appropriate, existing site-naming conventions were used for established sites (as in the case of the “Lower Bridge North” site). Caution was taken to avoid aggregating sites that were deemed to be sufficiently far from the site group, or those sites that were located close to or upstream or downstream of a feature (i.e. pipeline, ice road crossing, etc.) that could potentially impact water quality, and required discrete treatment.

2.2 Seasonal Grouping Methods

All water quality samples were classified into one of four seasons, relative to their month of collection. The distribution of the seasons and the months comprising the seasons are identified in Table 2. Month-by-month classification of seasons was undertaken by examining monthly average temperatures and hydrometric data summaries. Months characterized by average temperatures well below zero degrees Celsius were classified as winter. The decision to classify the months of May and June as ‘spring’ is corroborated by flow data from the Water Survey of Canada (WSC) HYDAT station (10KA007) on Bosworth Creek, which shows spring melt to occur during the months of May and June as observed in the mean and median hydrographs for the site (Figure 2).

Table 2. Months comprising seasonal groupings

Season	Months Included
Winter	November-April
Spring	May-June
Summer	July-August
Autumn	September - October

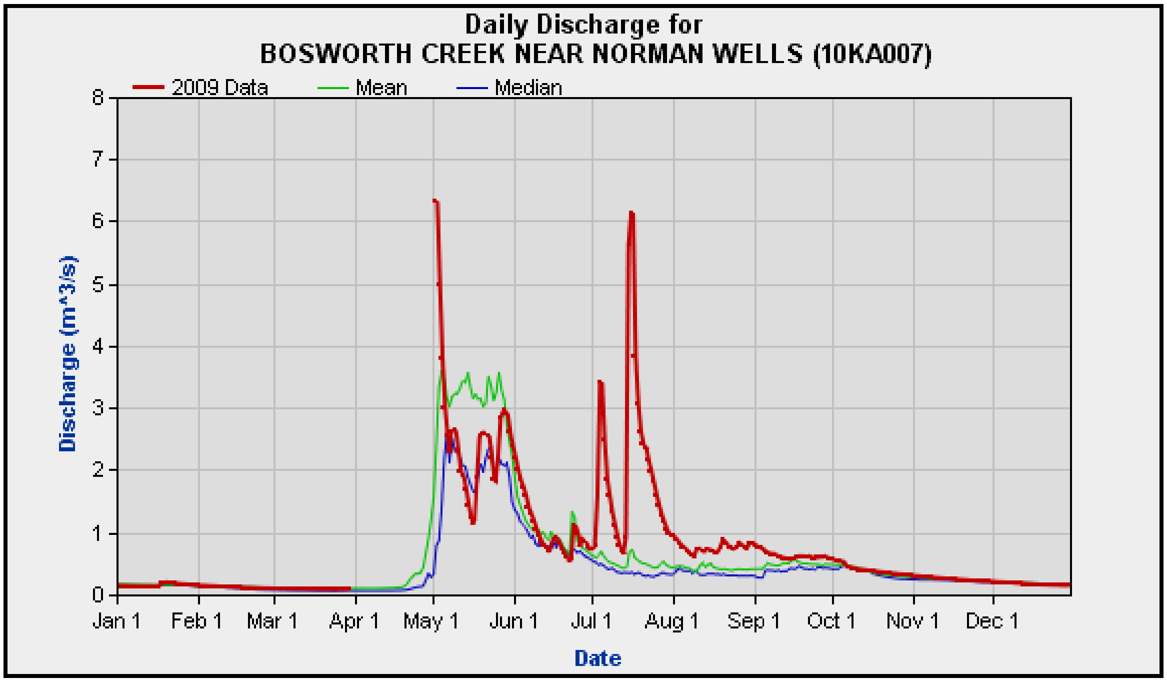

Figure 2. Daily discharge for Water Survey of Canada station on Bosworth Creek (Source: WSC, 2011)

2.3 Methods used to address left-censored (below Limit of Detection (LOD)) data

The detection limits of laboratory equipment used to analyze water quality parameters dictates that in some circumstances concentrations of a specific water quality parameter may occur at some concentrations less than the detection limit. In support of robust statistical analyses, these numbers, referred to as left-censored data, must not be omitted from testing (Helsel, 1990; Helsel, 2005). Many different methods are available to address data below the LOD to reduce censoring of data (Clarke, 1998; Helsel, 2005; Antweiler and Taylor, 2008). For the purposes of this study, a pseudo-random number generator was used to derive substitute values for below detection limit values using a method developed by Wichman and Hill (1982). This method has proven acceptable for addressing left-censored environmental data (Clarke, 1998; Antweiler and Taylor, 2008). The use of these substitute values for samples below the LOD was effective in increasing sample sizes on a parameter-by-parameter basis to support the use of statistical and significance testing. The effectiveness of this procedure was subject to limitations, such that under circumstances where >50% of any classified dataset was below LOD levels for any water quality parameter, statistical analyses were not undertaken for that parameter, as suggested by standard protocols (Helsel, 1990). At high degrees of censoring (50% or greater), findings indicate that no technique available for addressing below detection limit values can provide good estimates of summary statistics, or have sufficient power to detect differences in central values (Helsel, 1990; Antweiler and Taylor, 2008; Fu and Wang, 2011).

Non-uniform LOD, often referred to as *multiply censored data* (Lee and Helsel, 2007), were observed for a range of water quality parameters and were in many instances the result of changing analytical instrument resolution from the 1950's through to the present time for samples from Bosworth Creek. For some analytes, this translated into four to five different minimum LOD, several orders of magnitude in range. Issues in addressing left-censored environmental data with multiple LOD has been discussed by Fu and Wang (2011), where findings suggest that under such circumstances results can be biased if the censored rate is more than 10 to 30% (Lubin et al., 2004). For the purposes of the present study, water parameters with multiple LOD were evaluated on a case-by-case basis. Pseudo-random numbers were generated for these variables relative to the LOD value to derive a value between zero and the noted LOD. Where >50% of the values for any classified dataset was below LOD, the results of statistical analyses were not reported.

2.4 Statistical Significance Testing

Non-parametric tests of significance (Kruskal-Wallis, Mann-Whitney U) were performed to evaluate differences in similar water quality parameters between various data groupings (i.e. seasons, pre during and post weir, by site). This included examining differences in concentration of water quality parameters both dependent and independent of site groupings. Although statistically significant differences were identified in a number of these tests over a range of parameters, small sample sizes within test groups were found to limit the robustness of the tests in many instances. For this reason, the results of these analyses are not reported here.

2.5 Data Limitations

2.5.1 *Temporal bias of the data*

The existing database for Bosworth Creek, although comprised of a seemingly long period of record dating back to as early as 1953, is not continuous, having many years of missing data and being heavily weighted with data from more recent years, as shown in Table 3. Approximately 70% of the samples from the Bosworth Creek watershed were collected between 2006 and 2009. These recently weighted data points primarily monitor the post-weir period (for sites downstream of the Upper Bridge site). This, combined with inconsistencies in specific water quality parameters sampled between these dates, often leads to small samples sizes for like parameters through time.

Table 3. Percent Total Sample Points by Decade

Decade	No. of Samples	% Total by Decade
1950’s	7	7
1970’s	15	15
1980’s	8	8
2000’s	71	70

This bias towards data from recent years decreases the level of confidence in findings from statistical analyses due to considerable differences in sample sizes between the older and newer data collected. Improvements in analytical technologies over time have generally also contributed to lower LOD in more recent water quality samples. However, this was not consistently observed in analytes from Bosworth Creek. Rather, the LOD was often higher for more recent analyses than for older ones. For instance, the LOD for certain metals in 2009 was more than two orders of magnitude higher than those for values reported in 2007. The random nature of these differences in LOD was not considered to impart an appreciable bias on the analyses of these data, particularly when pseudo-random numbers were generated under these circumstances, as this number could potentially be any number greater than zero and less than the LOD. Therefore, multiple LOD for individual parameters were not found to limit comparisons among and between data.

2.5.2 *Irregularities in Sample Collection*

Data that were collected on Bosworth Creek vary in terms of the number and types of water quality parameters that were assessed. More recent samples are relatively consistent, although some parameters are not always reported for specific samples. Since the complete suite of analyses was not performed consistently over time, including for sites that are part of the BCMP program, finding data for corresponding analytes is difficult. Spatial inconsistencies in water quality monitoring locations over time hampers the utility of data collected as it is impossible to separate out any differences in concentrations from differences in sample collection location.

3 Relevant Findings

3.1 General trends in water quality data

Within Bosworth Creek watershed, a total of 101 samples were collected and analyzed for an array of 85 water quality parameters for the period of 1953 through to 2009. These data were analyzed for a range of trace and major metals, physical and routine and major ions, sporadically over time. Water quality from a select group of sites was also analyzed for benzene, toluene, ethylbenzene and xylene (BTEX), hydrocarbons, coliforms and chlorophyll A, on an infrequent basis.

The distribution of sample collection by site grouping is shown in Figure 3. Inequalities in the duration and frequency of water quality sampling are illustrated, as is the increase in the number of samples in years 2006 through 2009 (Figure 3). The most consistent, albeit sporadic, water quality monitoring was conducted for the site grouping “Lower Bridge North”, corresponding to the location of the now former impoundment above the removed weir (Figure 3). The ‘Unknown’ category of sites was comprised of samples for which no spatial information was available, despite these sites having the most consistent sampling record for the 1950’s through to the late 1970’s. While these samples were included for overall analyses independent of site group association, they were omitted for any site-related analyses.

Ranges of water quality parameters on a year-by-year basis were compared to assess general trends in the data for grouped sample points. Data aggregated by site grouping were plotted over time to assess trends for each parameter longitudinally from the headwaters towards the mouth of Bosworth Creek. This was intended to evaluate spatial patterns in water quality indices through the Creek network over time, and identify any potential source areas for specific parameters. Inconsistencies in the timing and location of sample collection interfered with such analyses. A general trend was observed for some trace and major metal parameters, which showed higher concentrations in lower reaches of the creek, compared to sample sites further upstream and often peaking at the “Upstream of Reservoir” and/or “Lower Bridge North” site groups. These findings were particularly notable for some metals, but were not consistent between sampling years and were most notable for samples collected from 2007 to 2009. Further investigation of the data (Section 3.2) has suggested that these inconsistencies may very well be artefacts of the season and/or flow condition during the time of sampling. Inconsistencies in the continuity and frequency of the sampling regime hinders interpretation of and renders definitive statements regarding trends in concentrations of water quality data over time inappropriate.

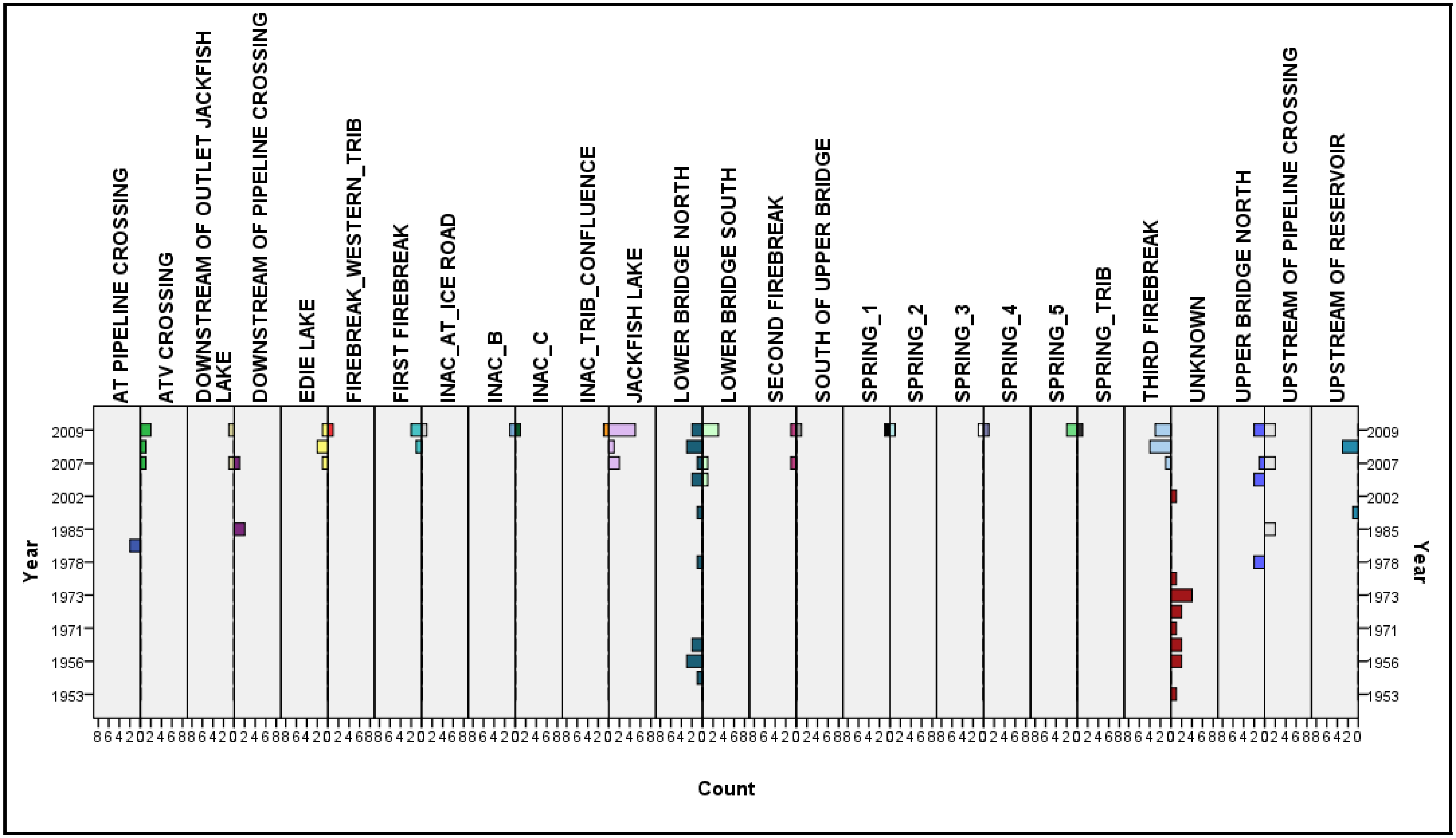

Figure 3. Distribution of water quality sampling through the period of record organised by site group

3.2 Assessment of Seasonal Trends in Water Quality

The distribution of data by season through the period of record, independent of site affiliation, is shown in Figure 4. . Overall, considerably more samples were collected in the summer and fall than for the other two seasons, as shown in Figure 4. . More samples were also collected in recent years relative to past years (Figure 4.). Overall, Figure 4. emphasizes the inconsistency in sampling to be representative of all four seasons through the period of record, but shows the benefit of increased sampling densities for the period 2007 to 2009.

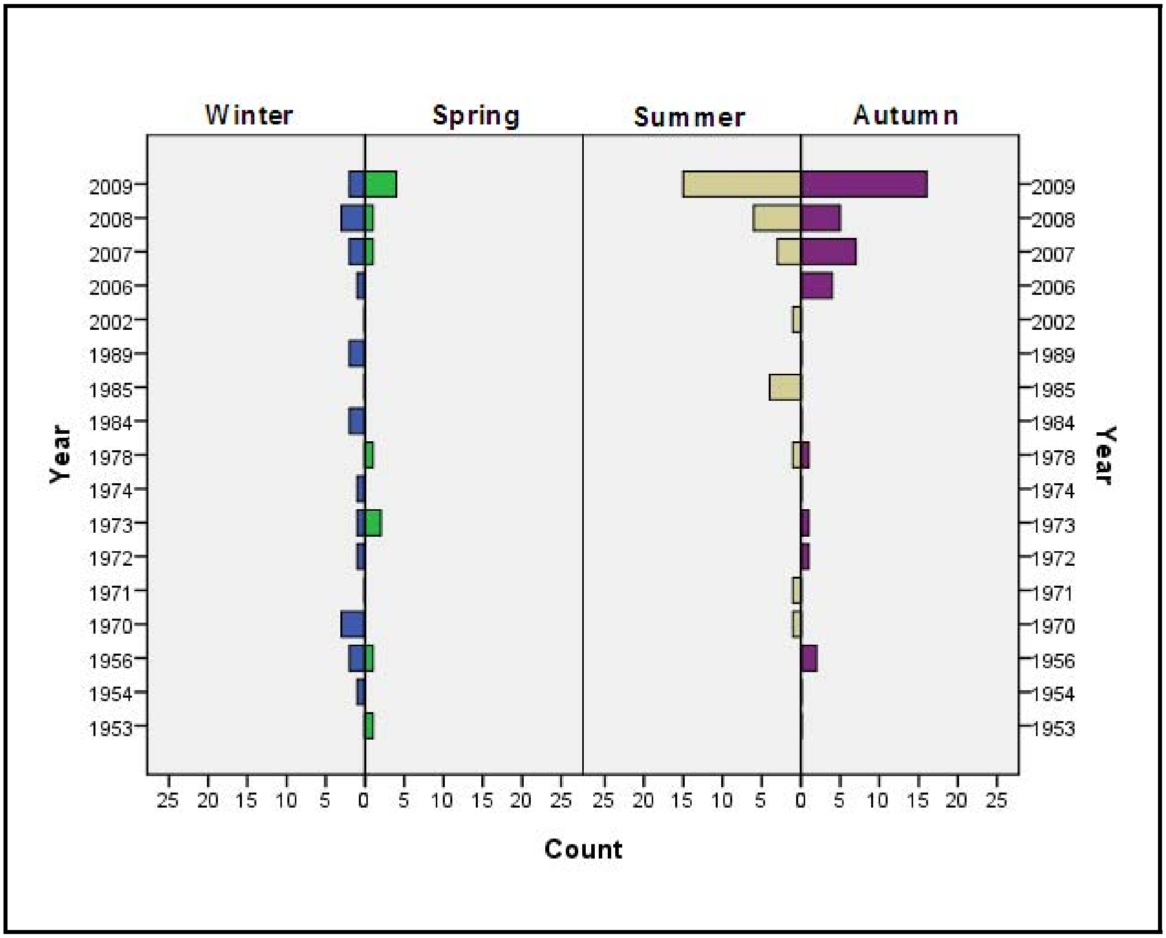

Figure 4. Distribution (count) of samples by season throughout the period of record (1953-2009), independent of sample site location

One of the original aims of the data analysis was to describe the seasonal variation and normal ranges of standard water quality parameters on a year-by-year basis, beginning in 1970. However, considerable constraints existed for undertaking a robust statistical analysis to achieve this goal, given the limitations presented by the available dataset.

The most consistent and comprehensive data were available for the site groupings referred to as "Lower Bridge North" and "Upper Bridge North." However, data for specific site groupings were not gathered consistently across the seasons or in sufficient numbers to warrant a description of seasonal variation, as often sample collection would occur in a different season for different years, rather than across all seasons within each year.

In an effort to complete some useful albeit perhaps less spatially relevant analyses of seasonal variation in water quality parameters, data were considered independent of the assigned site group affiliation (location) and year (time) for subsequent tests. Water quality data categorized by season were found to be distributed similarly between the summer and autumn seasons, at 32 and 36 samples, respectively. Fewer sites were sampled in winter and spring, represented by 21 and 11 sites, respectively. An assessment of the degree of seasonal variation in water quality parameters over the period of record was performed using nonparametric Kruskal-Wallis tests, while acknowledging inherent limitations in the data set. Subsequently, Mann-Whitney U tests were performed to evaluate differences between seasons in a pair-wise manner. Initial attempts at using site-by-site comparisons lacked statistical rigour due to the small sample sizes within site groups when compared by season. In addition, high percentages (>50%) of sites comprised of below LOD values for some water quality parameters meant that these parameters had to be omitted from further analyses, despite showing statistical significance ($p<0.05$).

Despite the above-noted limitations, a range of water quality parameters were found to differ significantly ($p \leq 0.05$) by season (Table 4) over the period of record regardless of site grouping affiliation. Findings indicate a general trend towards higher concentrations in winter, with lowest concentrations in spring for the majority of the parameters (Table 4). These findings suggest that the concentrations of many of the water quality parameters outlined in Table 4 are related to flow conditions in the Creek. During the winter months, baseflow is maintained by sources of storage, including lakes and groundwater, with Creek water chemistry reflective of concentrations from these sources. Lower concentrations in spring coincide with the period of highest streamflow, suggesting that affected water quality parameters (Table 4) are diluted by snowmelt and rainfall during springtime, associated with increased discharge in the Creek.

The trend towards higher winter and lower spring concentrations was not consistent across all water quality parameters showing seasonally significant differences. The lowest concentrations were observed for iron, manganese and potassium in the fall (Table 4). The season of highest concentrations differed between these analytes, however, with iron, manganese and potassium showing the highest concentrations in spring, summer and winter, respectively. Seasonal trends for pH were in contrast to the aforementioned water quality parameters, showing significantly higher ($p<0.001$) values in the fall, contrasted by lower winter values. It is well acknowledged that pH is considered the master variable for concentrations of aqueous manganese and other associated water quality parameters (Bourg et al., 2000). The season of lowest concentration for these parameters is often associated with higher pH values (Bourg et al., 2000), as was observed in Bosworth Creek. It is well established that the water solubility of some iron compounds decreases as pH increases (EMAN-North, 2005; vanLoon and Duffy, 2000). Observed correspondence between low manganese, iron and potassium in the fall and corresponding higher pH suggest that pH may also be seasonally mediating concentrations of these elements in Bosworth Creek.

The highest concentrations of barium occurred in the summer and the lowest in spring ($p<0.05$). These findings concur with others (Seyler and Boaventura, 2003) documenting barium concentrations associated with changes in stream stage, whereby maximum concentrations were documented during low water periods (summer) and lower concentrations during high water periods (spring). This emphasizes the importance of considering hydrometric factors when undertaking water quality sampling as concentrations can be significantly affected by hydrological conditions at the time of sampling.

Table 4. Results of Kruskal Wallis tests of statistical significance for seasonal differences in concentrations of all water quality parameters analyzed

Analyte / Sampling Category	Water Quality Parameter	Significance Level (*p*-value)	Season of Highest Concentration	Season of Lowest Concentration
Trace Metals	Barium	<0.05	Summer	Spring
	Uranium	<0.001	Winter	Spring
Major Metals	Calcium	<0.001	Winter	Spring
	Magnesium	<0.001	Winter	Spring
	Sodium	<0.01	Winter	Spring
	Iron	<0.05	Spring	Autumn
	Manganese	<0.01	Summer	Autumn
Physical Routine	pH	<0.001	Autumn	Winter
	Conductivity (Specific)	<0.001	Winter	Spring
	Dissolved (TDS)	<0.05	Winter	Spring
	TDS (Calculated)	<0.01	Winter	Spring
Major Ions	Fluoride	<0.05	Winter	Spring
	Chloride	<0.05	Winter	Spring
	Sulphate	<0.001	Winter	Spring
	Calcium	<0.001	Winter	Spring
	Magnesium	<0.001	Winter	Spring
	Sodium	<0.01	Winter	Spring
	Potassium	<0.01	Winter	Autumn
	Hardness (as $CaCO_3$	<0.001	Winter	Spring

3.3 Summary of Statistical Analyses of Water Quality Parameters

Sporadic collection of water samples across time and space in Bosworth Creek watershed has placed noteworthy limitations on the findings that can be gleaned from these data. Inconsistencies in the timing and suite of water quality parameters sampled throughout the period of record limits the potential of deriving a meaningful analysis of seasonal variation in concentrations for site groupings. For many site groupings, ‘normal ranges’ of individual water quality parameters reflect the values of one sample for one season within each year. These facts make it difficult to evaluate differences within and between sites when so few samples are available.

Acknowledging the statistically significant effect that seasonality was found to have on a range of water quality parameters further emphasizes the limitations of any attempt to statistically examine, with any degree of confidence, data on a year-by-year basis. This is particularly problematic for sites which have annual samples that reflect concentrations for one season in a year. The resulting water quality concentration is representative of one value in a potential range of values for a given season, and is correspondingly less capable of defining a meaningful yearly or annual value.

Statistically significant differences observed between seasons independent of site association may be related more to the hydrological conditions during sampling and the overall bias towards a higher number of samples in summer and fall, compared to winter and spring data. Notable improvements in overall data collection frequency have been noted from 2007 to present day. However, more spatial and temporally consistent sampling regimens would make appreciable advancements towards improving the statistical robustness of water quality analyses and improve overall confidence of results.

3.4 Comparison of Water Quality Parameters to Established Water Quality Guidelines

The analytical results of each sample taken from Bosworth Creek were compared to The Guidelines for Canadian Drinking Water Quality (GCDWQ) and The Canadian Water Quality Guidelines for the Protection of Aquatic Life (GPAL). These two guidelines are designed to establish benchmarks for the protection of human and aquatic health. The GCDWQ are developed by the Federal-Provincial-Territorial Committee on Drinking Water and published by Health Canada (Health Canada, 2009). These human health-based guidelines are developed for many chemicals, micro-organisms and physical substances. They are based on current published scientific research related to health effects, drinking water aesthetics, (taste and odour) and water treatment operational considerations (Health Canada, 2010). These guidelines are utilized across Canada as the foundation for establishing benchmarks for drinking water quality. Provinces and territories can adopt some or all of these guidelines as guidance documents or by regulation as enforceable drinking water standards. It must be emphasized that these standards are human health-based guidelines that have been established based on known human health effects related to exposure through drinking water.

The Canadian Water Quality Guidelines for the Protection of Aquatic Life were developed by the Canadian Council of Ministers of the Environment (CCME). These guidelines are intended to provide numerical limits for chemical and physical constituents of water based on current scientifically defendable toxicological data (CCME 2007). These guidelines are not restricted to a particular biotic species. They are designed to protect all forms of aquatic life and all aspects of aquatic life cycles, including the most sensitive life stage, and the most sensitive species over the long term (CCME 2007). Given that the GPAL were designed to protect the most sensitive species at their most sensitive stage of life, these guidelines are often much more stringent than the GCDWQ.

Both the GPAL and GCDWQ established benchmarks allow us to compare the analytical results from the Bosworth Creek sample data to determine which constituents of the creek water exceed recommended limits for drinking water quality and the protection of aquatic life. Table 5 lists all the physical and chemical parameters that were analyzed at Bosworth Creek, and reports the number of samples for which the parameter was measured, the number of samples that were below the detection limit, and the limits suggested by GPAL and GCDWQ. Exceedances of these limits are highlighted in bold for the GCDWQ and shaded cells for the GPAL.

Table 5. Physical and Chemical Parameters Measured for Bosworth Creek compared to the GCDWQ and GPAL

	N	**N Below LOD**	**Max. Value (in mg/L unless noted)**	**Avg Value (in mg/L unless noted)**	**GCDWQ**	**GPAL**
Aluminum (Al)	47	13	**76**	**3.00**	0.1 *	0.1
Antimony (Sb)	39	32	0.0007	0.0003	0.006	n/a
Arsenic (As)	45	23	**0.046**	0.0044	0.01	0.005
Barium (Ba)	43	0	**3.4200**	0.2064	1	n/a
Beryllium (Be)	42	42	n/a	n/a	n/a	n/a
Bismuth (Bi)	16	13	0.0006	0.0004	n/a	n/a
Boron (B)	42	22	0.585	0.1020	5	n/a
Cadmium (Cd)	45	43	0.0020	0.002	0.005	0.000017
Cesium (Cs)	18	17	0.0001	0.0001	10 Bq/L (not comparable)	n/a
Chromium (Cr)	44	36	**0.1600**	0.0204	0.05	0.0089
Cobalt (Co)	44	32	0.0900	0.0077	n/a	n/a
Copper (Cu)	50	30	0.1400	0.0139	≤1.0 *	0.004
Lead (Pb)	46	27	**0.85**	**0.0525**	0.01	0.007
Lithium (Li)	42	21	0.2000	0.01951	n/a	n/a
Mercury (Hg)	39	32	**0.002**	0.00030	0.001	0.000026
Molybdenum (Mo)	44	26	0.0226	0.0028	n/a	0.073
Nickel (Ni)	46	18	0.2700	0.0149	n/a	0.15
Rubidium (Rb)	17	0	0.0073	0.0012	n/a	n/a
Selenium (se)	42	28	**0.0100**	0.0029	0.01	0.001
Silver (Ag)	44	36	0.0013	0.0003	non-numerical	0.0001
Strontium (Sr)	19	1	3.9400	1.857	n/a	n/a
Thallium (Ti)	42	39	0.0030	0.0013	n/a	0.0008
Tin (sn)	40	32	0.383	00481	n/a	n/a
Titanium (Ti)	44	15	0.8400	0.0424	n/a	n/a
Uranium (U)	42	1	0.0050	0.0011	0.02	n/a
Vanadium (V)	44	24	0.2000	0.0144	n/a	n/a
Zinc (Zn)	46	31	1.7100	0.1796	≤5.0 *	0.03
Calcium (Ca)	33	0	524.0	96.4516	non-numerical	n/a
Potassium (K)	27	0	18.0000	2.1522	n/a	n/a
Magnesium (Mg)	32	0	170.0	32.219	non-numerical	n/a
Sodium (Na)	30	2	**518.0**	49.9679	≤200 *	n/a
Iron (Fe)	58	16	**202.0**	4.7152	≤0.3 *	0.3
Manganese (Mn)	44	10	**3.92**	0.2109	≤0.05 *	n/a
pH	69	0	8.6	8.1387	6.5 to 8.5 *	6.5 to 9.0
Conductivity, Specific	70	0	2890.0	48.2857	n/a	n/a
Temperature	22	0	**17° C**	7.8° C	≤15° C *	narrative
Oxygen, Dissolved	22	0	13.8	10.9	n/a	6.5 to 9.5
Turbidity	31	1	26.0	2.8247	varies	narrative
Solids, Total Suspended	26	6	35.6	7.95	n/a	n/a
Solids, Total Dissolved	19	0	837.0	518.9	n/a	n/a
Ion Balance	15	0	106	101.24	n/a	n/a
TDS (Calculated)	25	0	1620.0	430.848	n/a	n/a
Nitrate+Nitrite as Nitrogen	34		0.29	0.1248	n/a	n/a

Bicarbonate (HCO3)	34	0	1010.0	237.1	n/a	n/a
Carbonate (CO3)	31	21	6.5000	1.64	n/a	n/a
Hydroxide (OH)	16	16	n/a	n/a	n/a	n/a
Total Kjeldahl Nitrogen	13	1	1.65	0.8	n/a	n/a
Ammonia as N	24	16	1.2100	0.2438	non-numerical	see fact sheet
Phosphorous, Total	36	26	0.0600	0.0288	n/a	n/a
Phosphorous, Dissolved	15	13	0.01	0.008	n/a	n/a
Ortho-Phosphate as P	15	8	0.0500	0.0201	n/a	n/a
Organic Carbon, Total	18	0	28.5	7.4	n/a	n/a
Organic Carbon, Dissolved	15	0	28.0	5.4	n/a	n/a
Biochemical Oxygen Demand	10	8	3.0	2.6	n/a	n/a
Sulphide	19	9	**103.0**	**11.5346**	≤0.05 *	n/a
Fluoride	32	1	0.9000	0.3210	1.5	n/a
Chloride	48	0	**416.0**	34.9954	≤250 *	n/a
Nitrite as Nitrogen	30	29	0.1900	0.1900	n/a	0.06
Nitrate as Nitrogen	41	19	0.3	0.0993	45	13
Sulphate	56	0	363.0	167.373	≤500 *	n/a
Calcium	49	0	153.1	88.676	non-numerical	n/a
Magnesium	49	0	53.3	31.96	non-numerical	n/a
Sodium	51	0	**515.0**	35.11	≤200 *	n/a
Potassium	47	4	7.0	1.4	n/a	n/a
Hardness	54	0	583.0	321.3	non-numerical	n/a
Silica, Reactive	17	0	10.9	4.7	n/a	n/a
Total C11-C40+	1	1	n/a	n/a	n/a	n/a
Total Hydrocarbon (C6-C10)	1	1	n/a	n/a	n/a	n/a
F1(C6-C10)	5	5	n/a	n/a	n/a	n/a
F1-BTEX	5	5	n/a	n/a	n/a	n/a
F2 (>C10-C16)	9	9	n/a	n/a	n/a	n/a
2-Bromobenzotrifluoride	9	0	110.0	100.44	n/a	n/a
Benzene	9	9	n/a	n/a	0.005	0.37
Toluene	9	9	n/a	n/a	≤0.024 *	0.002
Xylene (m, p, o)	9	9	n/a	n/a	≤0.3 *	n/a
Hydrocarbons, total extractable	2	2	n/a	n/a	n/a	n/a
Hydrocarbons, total purgeable	1	1	n/a	n/a	n/a	n/a
Coliforms, Fecal	5	3	19 CFU/100ml	12 CFU	n/a	n/a
Coliforms, Total	7	0	**473 NPM/100ml**	**123.4 NPM/100ml**	0 NPM/100ml	n/a
Escherichia coli	6	1	**7.4 NPM/100ml**	**2.68 NPM/100ml**	0 NPM/100ml	n/a
Fecal Streptococcus	7	3	5.2 NPM/100ml	2.575 NPM/100ml	n/a	n/a
Chlorophyll A	5	2	0.110	0.047	n/a	n/a

*= Aesthetic Objectives or Operational Guidance Values
Exceedances of GCDWQ are highlighted
Exceedances of GPAL are bolded

The site groupings discussed in Section 2.1 allow us to analyze the exceedances of the GPAL and GCDWQ guidelines from a geographic perspective to determine if there are geographic trends to the exceedances, or sites that are of particular concern. There is not enough data from any of the sites to properly assess any changes over time. However, by comparing the water chemistry data at each site to the GPAL and GCDWQ guidelines, we can determine variables that may be of concern.

3.4.1 *Edie Lake*

Edie Lake is one of two headwater lakes for the Bosworth Creek Watershed. It is the uppermost water body in the watershed. The lake is situated at the base of the Discovery Ridge in the Norman Range. There are few streams providing direct input into the lake with a confluence of streams entering the watershed at the outlet of the lake. Groundwater flow into the lake has been reported in SENES and Guthrie (2009). This 2009 report indicates that the water quality of Edie Lake has undergone a drastic change in pH and water quality over the last 20 years. SENES and Guthrie (2009) report a change in pH from 10.2 to 7.8 over this time period. The pH value of 7.61 (March 6, 2008) from Edie Lake is the lowest reading recorded in the existing Bosworth Creek data. There are four samples in the data set from Edie Lake, from fall 2007, winter and fall 2008, and fall 2009 (Figure 5); however, there is inconsistent analysis for chemical and physical parameters. The changes in basic water chemistry that were noted over time, with the reported change in aquatic life, would make this site a priority for continued water quality monitoring in a long-term monitoring program.

Figure 5. Edie Lake site sample location (Image Source: Google Earth, 2011)

Table 6 shows the chemistry data from this site that exceeds either the GCDWQ or GPAL guidelines. The only water quality parameter that exceeds the GCDWQ at this group of sampling sites is sulphide. One sample taken from the middle of Edie Lake (PRO 26) on March 6, 2008 had a sulphide concentration of 2.64 mg/L, substantially higher than the ≤0.05 mg/L drinking water quality guideline. However, a sample taken six months later on September 6, 2008 on the northwest shore of Edie Lake (PRO 39) had a sulphide concentration of 0.003 mg/L, within acceptable standards for drinking water.

PRO 26, taken on March 6, 2008 from the middle of Edie Lake, has a high zinc value (0.276 mg/L) which exceeds the (0.03 mg/L) GPAL. The other two samples taken at Edie Lake that were analyzed for zinc were below the detection limits. However, these samples were taken on the northwest shore of Edie Lake, whereas PRO 26 was taken in the middle of the lake. Given the difference in zinc concentrations and sample locations, it is difficult to make general inferences about zinc at this site.

Table 6. Water chemistry variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Edie Lake sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Zinc	3	0.093	0.002	0.276
Sulphide	2	**1.322**	**1.322**	**2.640**

3.4.2 *Jackfish (Hodgson) Lake*

A total of eight samples were taken at Jackfish Lake, with the sample locations close to the outlet of Bosworth Creek (Figure 6). Jackfish Lake is downstream from Edie Lake and receives water from this water body as well as numerous tributaries that enter the watershed upstream, which drain through low, wetland type habitat. The eight samples from Jackfish Lake are recent samples from the years 2007-2009, with five samples for the year 2009. One of these samples was not part of the BCMP and was sampled by INAC in 2009 (Guthrie, pers. comm.). No exceedances of the GPAL and GCEWQ were noted at this site.

Figure 6. Jackfish Lake Sample locations (Image Source: Google Earth, 2011)

3.4.3 *Downstream of Jackfish Lake outlet*

There are two samples from downstream of Jackfish Lake (Figure 7). Sampling at this location was done for metals and basic physical parameters in September of 2007 and September of 2009 (PRO 22, PRO 55). This sampling location is located downstream of a large area of channels and gullies that drain the Discovery Ridge. Significant erosion from the ridge is apparent from the satellite image of this location (Figure 7).

Figure 7. Downstream of Jackfish Lake sample locations (Image Source: Google Earth 2011)

Table 7 shows the chemistry data from this site that exceeds either the GCDWQ or the GPAL. Sample PRO 22, taken on September 2, 2007, exceeds the GPAL for mercury, and equals the GPAL for silver. Mercury concentrations were 0.00004 mg/L, above the guideline of 0.000026 mg/L. The sample taken two years later at the same site (PRO 55) reported mercury at below the detection limit; however, the reported detection limit was much higher at 0.0001 mg/L. Silver concentrations in sample PRO 22 were 0.0001 mg/L, which is equal to the recommended GPAL. Sample PRO 55 that was taken two years later at the same site had silver concentrations below the detection limit.

Table 7. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Downstream of Outlet Jackfish Lake sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Mercury	2	0.000022	0.000022	0.000040
Silver	2	n/a	n/a	0.00010

3.4.4 *All Terrain Vehicle Crossing (Snowmobile Trail)*

There are a total of four samples taken from the All Terrain Vehicle Crossing site (Figure 8). Three of these samples are from the BCMP (PRO 23, PRO 36 and PRO 52) and one sample upstream of the actual crossing through INAC in 2009. All samples were taken between September 2007 and September 2009. Concern over bank erosion, alteration to the stream channel and destruction of habitat at this location are noted in SENES and Guthrie (2009) and Northern Cumulative Impact Monitoring Program (2008). Sampling at this site is also inconsistent for all metals and other physical and chemical parameters. There are no exceedances of the GCDWQ or GPAL at this site.

Figure 8. Terrain Vehicle Crossing sample locations (Image Source: Google Earth 2011)

3.4.5 *Tributary Confluence, Upper Creek*

INAC sampled one time in 2009 (Bos 19) at the confluence of the main channel of Bosworth Creek and the major unnamed tributary stream draining the ridge that joins Bosworth Creek at the base of the Discovery Ridge (Figure 9). Data from this site are included in the overall and longitudinal statistical analyses. However, within the limited data from this site, there are no exceedances of the GCDWQ or GPAL.

Figure 9. Tributary Confluence, Upper Creek sample location (Image Source: Google Earth 2011)

3.4.6 *Upper Creek Spring Sites*

The BCMP has sampled several "spring" sites upstream and downstream of the confluence of the main Bosworth Creek channel and the stream draining the ridge (Figure 10). There are only basic field measurements of temperature, dissolved oxygen and conductivity for these sites. These data were used to assess general trends to characterize these sites in the context of others in the watershed; however, since total water chemistry for these water sources was not measured, the samples are excluded from any statistical analysis of the creek water, and no comparison to the GPAL and GCDWQ is possible.

Figure 10. Upper Creek Spring Sites sample location (Image Source: Google Earth 2011)

3.4.7 *Upper Creek INAC sites*

INAC has several sites distributed along the creek channel from the confluence of the two creeks to the first firebreak site. These are not grouped with other sites for site specific analysis as they are removed from other clusters of BCMP sites (Figure 11). However, the data that is available is included in the overall statistical analysis of creek water throughout the channel.

Figure 11. Upper Creek INAC CIMP sites sample location (Image Source: Google Earth 2011)

3.4.8 *Third Firebreak*

Eight water samples were collected from the Third Firebreak site between 2007 and 2009 (PRO 13, PRO 27, PRO 28, PRO 29, PRO 35, PRO 43, PRO 46, PRO 59) (Figure 12). The site is located midway along the creek channel in a wooded valley section. The samples at this site are all part of the BCMP. This site had several exceedances of the GCDWQ and GPAL.

Figure 12. Third Firebreak site sample location (Image Source: Google Earth 2011)

Table 8 shows the chemistry data from this site that exceeds the GCDWQ and/or the GPAL. Two of seven samples that were analyzed for aluminum concentrations exceeded the 0.1 mg/L GPAL. Samples PRO 29 and PRO 46 had aluminum concentrations of 0.325 mg/L and 0.965 mg/L, respectively. Pro 29, one of the six samples that were analyzed for mercury, had a concentration of 0.002 mg/L, above the 0.000026 mg/L GPAL and the 0.001 mg/L GCDWQ. The other five samples had mercury concentrations below the detection limits. Two samples of seven, PRO 13 and PRO 29, had selenium concentrations higher than the 0.001 mg/L GPAL, with 0.003 mg/L and 0.0026 mg/L, respectively. Four of the seven samples analyzed for selenium had a concentration less than the detection limit, and therefore statistics such as mean and median could not be calculated. One of the seven samples tested for silver (PRO

29) had a concentration greater than the 0.0001 mg/L GPAL, with a concentration of 0.0013 mg/L. Five of the seven samples analyzed for silver had concentrations less than the detection limit, and therefore meaningful summary statistics could not be calculated. One sample of the seven that were analyzed for iron had concentrations higher than the 0.03 mg/L guideline for both drinking water quality and protection of aquatic life. The one sample that was analyzed for coliforms and *E. coli* tested positive for both, which exceeds the GCDWQ.

Table 8. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Third Fire Break sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Aluminum	7	**.1922**	0.0150	**0.9650**
Mercury	6	n/a	n/a	**0.002**
Selenium	7	n/a	n/a	0.0030
Silver	7	n/a	n/a	0.0013
Iron	6	**0.353**	0.055	**1.850**
Coliforms, Total	1	**9.7 NPM/100 ml**	**9.7 NPM/100 ml**	**9.7 NPM/100 ml**
E. coli	1	**0.40 NPM/100 ml**	**0.40 NPM/100 ml**	**0.40 NPM/100 ml**

3.4.9 *Second Fire Break*

There were two water samples collected at this site (Figure 13). Sample PRO 12 was taken in March of 2007 as part of the BCMP, and sample Bos 2 is an INAC sample taken in August of 2009. This area is located approximately 1.5 km downstream of the third firebreak site.

There is not enough data from this site to properly assess any changes over time at the site. However, by comparing the water chemistry data to the recommended guidelines for drinking water and aquatic life, we can determine variables that may be of concern.

Figure 13. Second Fire Break site sample locations (Image Source: Google Earth 2011)

Table 9 shows the chemistry data from this site that exceeds either Heath Canada's GCGDWQ or the GPAL. There was only one exceedance of the GPAL at this site. Sample PRO 12 had a selenium concentration of 0.0017 mg/L, above the 0.001 mg/L guideline. There were also two exceedances of the GCDWQ, as sample PRO 12 was positive for both coliforms and *E. coli.*

Table 9. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Second Fire Break sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Selenium	1	n/a	n/a	0.0017
Coliforms, Total	1	n/a	n/a	**9.8 NMP/100 ml**
E. coli	1	n/a	n/a	**1.0 NPM/100 ml**

3.4.10 *First Firebreak*

These samples are located approximately 1.3 km downstream from the second firebreak site. Sampling was done on September 1 in both 2008 and 2009 (PRO 34 and PRO 51, respectively). This site has been grouped with the INAC Bos 1 site as the two sites are in very close proximity to one another (Figure 14). Bos 1 sample is a fall sample taken in August 2009. This site is located in a region of the stream where the topography is flatter and the channel becomes braided. The limited data that is available from this site has no exceedances of the GCDWQ or GPAL.

Figure 14. First Firebreak site sample locations (Image Source: Google Earth 2011)

3.4.11 *Winter Road Crossing*

There are two distinct INAC sampling sites related to the winter road crossing on Bosworth Creek (Figure 15). The upstream INAC B site is located approximately 0.6 km upstream from the sampling site directly at the winter crossing. The sampling site at the winter road crossing is located at the point where the bridge and ice crossing are situated. These sites each have one sample from August 2009. There are no exceedances of any of the GPAL or GCDWQ at either of these sites.

Figure 15. Winter Road Crossing site sample locations (Image Source: Google Earth, 2011)

3.4.12 *Upstream of Pipeline*

There are six samples from sites upstream of the Norman Wells to Zama pipeline crossing (Figure 16). Historic samples with site descriptions only (no coordinates) taken by the Interprovincial Pipeline Limited Study (Interprovincial Pipeline (NW) Ltd. 1985) are included (IPLL NS US and IPLL SS US). One INAC site is located approx. 0.6 km downstream of the winter road site (Bos 23). This site has been included with three samples from the BCMP (PRO 18, PRO 25 and PRO 60) upstream of the Norman Wells to the Zama pipeline crossing. The IPLL sites are from August 1985, two BCMP samples are from fall of 2007 and 2009, and the INAC sample is from summer of 2009. They were considered together for statistical analysis.

Figure 16. Upstream of Pipeline site sample locations (Image Source: Google Earth, 2011)

Table 10 shows the chemistry data from this site that exceeds the GCDWQ. There were no exceedances at this site of the GPAL. There were two exceedances of the GCDWQ's microbial contaminants. Sample PRO 25 tested positive for both Total colifoms and *E. coli*.

Table 10. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Upstream of the Pipeline sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Coliform, Total	1	n/a	n/a	**148 NPM/100 ml**
E. Coli	1	n/a	n/a	**3 NPM/ 100ml**

3.4.13 *Pipeline Crossing*

Two historic sampling sites from the International Pipeline Project are described as being at the pipeline crossing (Figure 17). Samples IPLL 1 and IPLL 2 were collected in January 1984 and February 1984. They are considered separately from the samples from the same study described as being 30 metres upstream and 30 metres downstream of the pipeline. However, by comparing the water chemistry data against the recommended guidelines for drinking water and aquatic life, we can determine variables that may be of concern.

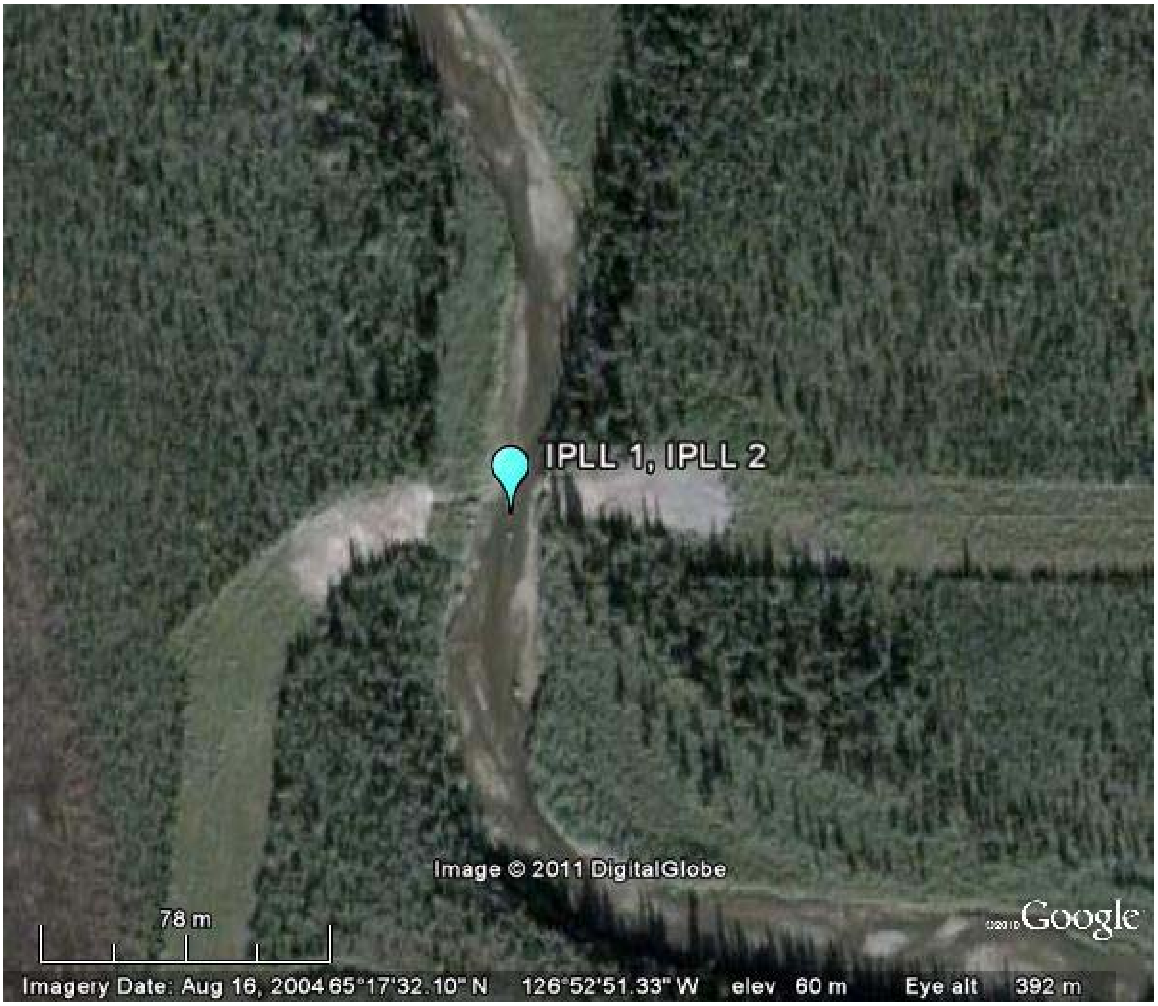

Figure 17. Pipeline Crossing site sample locations (Image Source: Google Earth 2011)

Table 11 shows the chemistry data from this site that exceeds GPAL and GCDWQ. Iron concentrations exceeded the 0.3 mg/L GPAL and GCDWQ. Both IPLL 1 and IPLL 2 samples were analyzed for iron, and had concentrations of 72 mg/L and 105 mg/L, respectively.

Table 11. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Upstream of the Pipeline sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Iron	2	**88.5**	**88.5**	**105**

3.4.14 *Downstream of Pipeline Crossing*

Four sample sites are located just downstream of the pipeline crossing (Figure 18). One of these samples (Unit 1) has been identified as being a sediment sample while labelled a water sample. The sample was removed from the water quality analysis. Of the three remaining samples, two are identified as being collected in August 1985 30 metres downstream of the pipeline for the IPLL study (IPLL NS DS and IPLL SS DS). One BCMP sample for this location is Pro 14, sampled in the summer of 2007.

Figure 18. Downstream of Pipeline Crossing site sample location (Image Source: Google Earth 2011)

Table 12 shows the chemistry data from this site that exceeds the GPAL. There were no exceedances of the GCDWQ at this site. Sample PRO 14, taken on June 30, 2007, had a selenium concentration of 0.0031 mg/L, which exceeded the selenium GPAL of 0.001 mg/L.

Table 12. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Downstream of Pipeline Crossing sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Selenium	1	n/a	n/a	0.0031

3.4.15 *Upper Bridge North*

There are a total of seven Upper Bridge North samples in the database (Figure 19). Samples are from the summer and fall of 1978 (Dillon 2, Dillon 3), fall of 2006 (U2-1, U2-2), and summer of 2007 and 2009 (PRO 15, PRO 49) and one INAC sample from summer 2009 (Bos 11). These samples are grouped together as they fall between the pipeline samples and the upper bridge.

Figure 19. Upper Bridge North site sample locations (Image Source: Google Earth 2011)

Table 13 shows the chemistry data from this site that exceeds the GCDWQ and/or the GPAL. The aluminum concentration in sample PRO 49 (0.203 mg/L) that was taken on July 24, 2009 exceeds the guidelines for both GCDWQ and GPAL, which are both set at 0.01 mg/L. The two other samples that were analyzed for aluminum in 1978 (Dillon 3) and 2007 (PRO 15) at the Upper Bridge North location did not exceed the detection limits. The Dillon 3 sample that was taken in September of 1978 has an arsenic concentration of 0.01 mg/L. This value is equal to the maximum allowable concentration for arsenic in the GCDWQ, and exceeds the 0.005 mg/L GPAL. Two other samples at this location were analyzed for arsenic (PRO 15 and PRO 49), but both were below the detection limits for this element.

One sample at this site exceeded the GPAL recommendation for copper concentrations. Sample Dillon 3 taken in August of 1978 had a copper concentration of 0.01 mg/L, which exceeds the 0.004 mg/L. Sample PRO 15 taken in July 2007 had a copper concentration of 0.0006 mg/L. PRO 49, the only other sample at this site that was analyzed for copper at this site, had a concentration below the 0.001 mg/L detection limit.

Three samples were analyzed for mercury. Dillon 3, and PRO 49 had concentrations below the detection limit for mercury, which was <0.02 mg/L and <0.0001 mg/L, respectively. It should be noted that the Dillon 3 sample detection limit exceeds the GPAL and GCDWQ limits for mercury, and the PRO 49 detection limit exceeds the GPAL limit for mercury. PRO 15 had a mercury concentration of 0.00003 mg/L, which exceeds GPAL but does not exceed the GCDWQ.

Three samples at this site were analyzed for selenium. Two of the three, Dillon 3 and PRO 15, exceeded the 0.001 mg/L GPAL for selenium, with concentrations of 0.01 mg/L and 0.002 mg/L. The Dillon 3 selenium concentration is also equal to the maximum allowable concentration of the GCDWQ. Sample PRO 49 is the only other sample that was analyzed for selenium at this site and tested below the 0.0004 mg/L detection limit.

One sample at this site exceeded the GPAL recommendation for silver concentrations. The PRO 15 sample had a silver concentration of 0.0003 mg/L, which exceeds the

0.0001 mg/L GPAL. The Dillon 3 and PRO 49 samples both had silver concentrations below the detection limits.

Sample PRO 49 exceeded the 0.3 mg/L GPAL and GCDWQ recommendations for iron with a concentration of 0.98 mg/L. Two other samples, Dillon 3 and PRO 15, had iron concentrations of 0.01 and below the detection limit, respectively.

The only sample at this site that was analyzed for coliforms, Dillon 2, taken in August of 1978, had coliform concentrations of 473 NPM/100 ml. This is the highest coliform count of any sample in the Bosworth Creek Database, much higher than the GCDWQ maximum allowable concentration of 0 NPM/100 ml.

Table 13. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Upper Bridge North sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Aluminum	3	n/a	n/a	**0.2030**
Arsenic	3	n/a	n/a	**0.0100**
Copper	3	0.0053	0.0053	0.0100
Mercury	3	n/a	n/a	0.00003
Selenium	3	0.0041	0.0020	**0.0100**
Silver	3	n/a	n/a	0.0003
Iron	3	**0.50**	**0.50**	**0.98**
Coliforms, Total	1	n/a	n/a	**473 NPM/100 ml**

3.4.16 *South of Upper Bridge*

One sample (Bos 10) was collected directly downstream of the upper bridge by INAC in the summer of 2009 (Figure 20). There is limited data from this site; however, there are no exceedances of the GPAL or GCDWQ.

Figure 20. South of Upper Bridge site sample location (Image Source: Google Earth 2011)

3.4.17 *Upstream of Reservoir*

There are four sample sites located upstream of the former reservoir that existed until the removal of the weir in 2005 (Figure 21). These sites include one sample from the period when the weir was in place (UMA 2) and three samples from the BCMP (PRO 32, SS-01-01, SS-01-02) from August 2008.

Figure 21. Upstream of Reservoir site sample location (Image Source: Google Earth 2011)

Table 14 shows the chemistry data from this site that exceeds either the GCDWQ or GPAL. Most of the exceedances of the guidelines for drinking water and protection of aquatic life at this location are caused by the impact of one sample, SS-01-01, taken on August 9, 2008. This site is a small spring on the north shore of Bosworth Creek (Figure 22), which was first identified in the summer of 2008 (Guthrie 2009). This sample has an extremely high aluminum concentration of 76 mg/L, much higher than the 0.1 mg/L GCDWQ and GPAL; cadmium concentrations are 0.002 mg/L, exceeding the 0.000017 mg/L GPAL; chromium concentrations of 0.16 mg/L exceed both the GCDWQ (0.05 mg/L), and GPAL (0.0089mg/L); copper at a concentration of 0.14 mg/L exceeds the 0.004 mg/L GPAL; the lead concentration of 0.107 mg/L is substantially higher than the 0.01 mg/L and 0.007 mg/L guidelines for water quality and protection of aquatic life, respectively; nickel concentrations of 0.27 mg/L are almost double the 0.15 mg/L guideline for the protection of aquatic life; selenium at 0.005 mg/L exceeds the guidelines for aquatic life (0.001 mg/L); the thallium concentration of 0.003 mg/L exceeds the 0.0008 mg/L guideline for protection of aquatic life; zinc at a concentration of 1.71 mg/L is greater than the guideline of 0.03 mg/L for the protection of aquatic life, and an iron concentration of 202 mg/L is many orders of magnitude greater than the 0.3 mg/L guideline for both drinking water quality and the protection of aquatic life. Of all the samples in the Bosworth Creek dataset, this sample has the highest concentration of aluminum, arsenic, barium, cadmium, chromium, cobalt, copper, lithium, nickel, thallium, titanium, uranium, vanadium, zinc, calcium, potassium, magnesium, and iron.

Figure 22. Site of Sample SS-01-01, a small spring on Bosworth Creek (Source: Guthrie, 2009)

With the exception of the SS-01-01 sample, the only other exceedances were aluminum and iron. The sample SS-01-02, another spring sample taken on August 20, 2008, exceeded the 0.1 mg/L guideline for both drinking water quality and the protection of aquatic life with a concentration of 0.49 mg/L. The PRO 32 sample taken the same day as the SS-01-02 sample had an aluminum concentration below the 0.01 mg/L detection limit. Iron concentrations in the SS-01-02 samples were 1.14 mg/L, greater than the 0.3 mg/L guidelines for both drinking water quality and the protection of aquatic life. The

PRO 32 and UMA 2 samples taken at this location were both below the guidelines, with concentrations of 0.025 and 0.038 mg/L, respectively.

Table 14. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Upstream of Reservoir sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Aluminum	3	**25.4984**	**0.4900**	**76.0000**
Arsenic	3	**0.0156**	0.0007	**0.0460**
Barium	3	**1.2263**	0.1960	**3.420**
Cadmium	3	n/a	n/a	0.002
Chromium	3	n/a	n/a	0.16000
Copper	3	0.0476	0.0020	0.1400
Lead	3	**0.0359**	0.0007	**0.1070**
Nickel	3	0.0913	0.0030	0.2700
Selenium	3	n/a	n/a	0.0050
Thallium	3	n/a	n/a	0.00300
Zinc	3	0.57343	0.01000	1.710000
Iron	4	**50.8**	**0.59**	**202**
Sulphide	1	n/a	n/a	**1.27**

3.4.18 *Lower Bridge North Sites*

There are a total of 16 samples for the area north of the lower bridge crossing Bosworth Creek (Francl 3, Francl 4, Thomas 1, Thomas 2, Thomas 3, Thomas 4, Dillon 1, UMA 1, U1-1, U1-2, PRO 17, PRO 31, PRO 33, PRO 50, SS-05-03 and SS-06-01) (Figure 23). Historical samples from the town tap (Canol Camp) from Thomas (1957) are included in this set of samples, although exact location data is not available. These samples are from winter of 1954, and winter, spring and fall of 1956. Frankl (1974) samples are from winter and summer of 1970. There is one sample from spring of 1978 (Dillon, 1978), one sample from winter 1989 (UMA, 1989), and 8 BCMP samples from summer, 2006, fall 2007, summer 2008, and summer and fall of 2009. Samples from this region are considered together for statistical analysis. This region is just upstream of the former dam created at the lower bridge by Imperial Oil in 1960. This area was heavily impacted by the blockage of the creek by the weir as it is directly upstream of this location.

Figure 23. Lower Bridge North site sample locations (Image Source: Google Earth, 2011)

Table 15 shows the chemistry data from this site that exceeds either GCDWQ and/or GPAL. Of the 11 samples from this location that were analyzed for aluminum, 73% of them exceeded the 0.1 mg/L GCDWQ and the GPAL. The results show aluminum concentrations that range from a maximum of 14 mg/L at PRO 31 in August 2008, to a low of 0.033 at PRO 17 in July 2007. The average aluminum concentration at this site is 2.03 mg/L.

Of the six samples at this site to be analyzed for arsenic, two samples exceed the 0.01 mg/L GCDWQ, and the 0.005 mg/L GPAL. PRO 31 and SS-05-03 had arsenic concentrations of 0.011 and 0.017 mg/L, respectively. The SS-05-03 sample with a 1.23 mg/L concentration of barium, taken in August of 2008, exceeds the GCDWQ of 1 mg/L. However, it was the only sample from this site that was in exceedance for barium. Six samples were analyzed for cadmium, and five had concentration lower than the detection limits (which ranged from 0.002 to 0.00005 mg/L). However, the one sample that registered above the detection limit for cadmium was SS-05-03, which exceeds the 0.000017 mg/L GPAL. Copper concentrations exceeded the 0.004 mg/L GPAL in three of the eight samples analyzed, Thomas 2 from February 1956 (0.06 mg/L), PRO 31 (0.03 mg/L), and SS-05-03 (0.02 mg/L); however, the median copper concentration of 0.0024 mg/L is below the guideline. Samples PRO 31 and SS-05-03 have a lead concentration 0.021 and 0.014 mg/L, respectively. Both of these values exceed the GCDWQ (0.01 mg/L) and the GPAL (0.007 mg/L). However, with the exception of these two samples, lead concentrations are well below the guidelines at this site. Two of the six samples at this site exceeded the 0.001 mg/L GPAL. These samples are SS-06-01 taken in July 2009, and PRO 17 in July 2007. Three of these samples resulted in concentrations below the detection limit for selenium, and as a result summary statistics such a mean and median are not valid. Two of the seven samples analyzed for zinc exceed the GPAL of 0.03 mg/L. These samples are PRO 31 and SS-05-03, with concentrations of 0.31 mg/L and 0.29 mg/L. The other samples were either below detection limits or of an order of magnitude lower than the guidelines. Two samples of 5 for which a sodium analysis was done exceed the GCDWQ (≤200 mg/L). These samples are SS-05-03 and SS-06-01 with concentrations of 390 and 518 mg/L. The other three samples have an average sodium concentration of 23 mg/L. The GCDWQ and GPAL are 0.3 mg/L for iron. Seven of the 11 samples for which iron was analyzed for at this site exceed this guideline. However, there are two extreme exceedances of 184 mg/L and 42.7 mg/L at sites SS-05-03 and PRO 31. The median iron concentration from the samples at this site is 0.57 mg/L, which still exceeds both guidelines. Two of the four samples analyzed for sulphide at this site exceed the GCDWQ of 0.05 mg/L. These samples are SS-05-03 and SS-06-01, with 8.3 and 0.12 mg/L, respectively. One sample of the 11 that were analyzed for chloride was greater than the 250 mg/L GCDWQ. The extreme concentration of 416 mg/L was found in sample SS-06-01. The average of the other 10 chloride samples is 24.5 mg/L, well below the guideline.

Of the 12 parameters that exceeded a GCDWQ or GPAL, two samples, PRO 31, and SS-05-01, accounted for 8 of the 12 maximum concentrations. These two samples skew the chemistry results at this site, and if they are not considered there would be only 5 of the 12 parameters listed in Table 15 that still exceeded any guidelines.

Table 15. Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Upstream of Reservoir sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Aluminum	11	**2.0274**	**0.1700**	**14.00**
Arsenic	6	0.0053	0.00196	**0.0170**
Barium	6	0.4399	0.3375	**1.23**
Cadmium	6	n/a	n/a	0.002
Copper	8	0.0145	0.0024	0.0600
Lead	7	0.0061	0.0002	**0.0210**
Selenium	6	n/a	n/a	0.0020
Zinc	7	n/a	n/a	0.3100
Sodium	5	195	40	518
Iron	10	**23**	**0.57**	**184**
Sulphide	4	**2.1058**	**0.0615**	**8.30**
Chloride	11	60.17	25.00	**416**

3.4.19 *Lower Bridge South Sites*

This area was sampled five times and includes samples from both the BCMP and INAC sites (PRO 1, PRO 16, PRO 45, PRO 48, Bos 9) (Figure 24). Sampling dates range from winter (December) 2006, summer 2007, and spring, summer and fall of 2009. This region of the Creek has undergone significant changes over time from pre- to post-weir removal, including stream restoration, engineering and re-vegetation.

Figure 24. Lower Bridge South site sample location (Image Source: Google Earth, 2011)

Table 16 shows the chemistry data from this site that exceeds either the GCDWQ or GPAL. Two samples exceed the 0.1 mg/L guidelines outlined by the GCDWQ and GPAL. Sample Pro 45 and PRO 48 had aluminum concentrations of 0.996 mg/L and 0.379 mg/L, respectively. These samples were taken in May and June of 2009. Samples taken in 2006 and 2007 had much lower aluminum values, with an average aluminum concentration of 0.022 mg/L. Sample PRO 45 had a copper concentration of 0.0067, which is above the 0.004 mg/L GPAL. The other three samples analyzed for copper were well below the guidelines. Only one sample out of four analyzed for mercury had a concentration greater than the detection limit. Sample PRO 16 taken in July 2007 had a mercury concentration of 0.00003 mg/L, above the 0.000017 mg/L GPAL. Selenium concentrations exceed the 0.001 mg/L GPAL in two of the three samples that were analyzed. The PRO 1 and PRO 16 samples taken in December 2006 and July 2007 had concentrations of 0.039 and 0.036 mg/L, respectively. The only other sample that was analyzed for selenium, PRO 48 from June 2009, had a concentration of 0.00042 mg/L. Two of the four samples that were analyzed for silver had concentrations below the detection limit of 0.001 mg/L. The other two, PRO 16 and PRO 45, had concentrations of 0.0004 mg/L and 0.00016 mg/L, respectively, both of which are above the 0.0001 mg/L for silver recommended in GPAL. Of the four samples that were analyzed for iron, two are above the 0.3 mg/L GCDWQ, and the GPAL. Samples PRO 45 and PRO 48 had iron concentrations of 1.91 and 0.693 mg/L, respectively. All three of the samples that were tested were positive for both coliforms and *E. coli* bacteria.

Table 16. Water Chemistry Variables that exceed Drinking Water Quality Guidelines (Bold) and/or Protection of Aquatic Life Guidelines (Shaded) at the Lower Bridge South sample site

	Number of Samples	Mean (mg/L, unless noted)	Median (mg/L, unless noted)	Maximum (mg/L, unless noted)
Aluminum	4	**0.3547**	**0.2052**	**0.9960**
Copper	4	0.0021	0.0006	0.0067
Mercury	4	n/a	n/a	0.000057
Selenium	3	0.0026	0.0036	0.0039
Silver	4	n/a	n/a	0.0004
Iron	4	**0.7258**	**0.4635**	**1.9100**
Coliforms, Total	3	**74.6**	**39.9**	**160.0**
E. coli	3	**3.1**	**1.0**	**7.4**

3.4.20 *Summary of Comparison of Water Quality Parameters to Established Water Quality Guidelines*

Table 17 shows each parameter that had exceedances of the GCDWQ and GPAL, and the percentage of samples that exceeded the GCDWQ and GPAL. It must be noted that for mercury, the detection limits are often higher than the extremely low GPAL of the 0.000026 mg/L recommendation. The microbial parameters of total coliforms and *E. coli* had the highest percentage of exceedences of GCDWQ guidelines (100% and 83%, respectively). The parameter that most often exceeds the GCDWQ and GPAL is aluminum. 34% of the 47 samples had aluminum concentrations that exceeded the 0.1 mg/L GCDWQ and GPAL. 26% of the samples that were analyzed for iron exceeded the GCDWQ and GPAL 0.3 mg/L recommendation. The 0.001 mg/L GPAL for selenium was exceeded in 26% of the samples for which it was analyzed. Sulphide exceeded the

0.05 mg/L GCDWQ in 26% of the samples for which it was analyzed (however, note that this is an aesthetic objective based on disagreeable taste and odour). None of the other parameters had exceedence frequencies of >20%.

Table 17. Summary of Exceedances of GCDWQ and GPAL from Bosworth Creek Water Quality Data

	N	**N Below LOD**	**Max. Value (in mg/L, unless noted)**	**Avg Value (in mg/L, unless noted)**	**GCDWQ**	**Exceedances of GCDWQ (%)**	**GPAL**	**Exceedances of GPAL (%)**
Aluminum (Al)	47	13	**76**	**3.00**	0.1 *	34	0.1	34
Arsenic (As)	45	23	**0.046**	0.0044	0.01	9	0.005	9
Barium (Ba)	43	0	**3.4200**	0.2064	1	5	n/a	n/a
Cadmium (Cd)	45	43	0.0020	0.002	0.005	0	0.000017	4
Chromium (Cr)	44	36	**0.1600**	0.0204	0.05	2	0.0089	2
Copper (Cu)	50	30	0.1400	0.0139	≤1.0 *	0	0.004	4
Lead (Pb)	46	27	**0.85**	**0.0525**	0.01	9	0.007	9
Mercury (Hg)	39	32	**0.002**	0.00030	0.001	3	0.000026	18
Nickel (Ni)	46	18	0.2700	0.0149	n/a	n/a	0.15	2
Selenium (se)	42	28	**0.0100**	0.0029	0.01	2	0.001	26
Silver (Ag)	44	36	0.0013	0.0003	non-numerical	n/a	0.0001	16
Zinc (Zn)	46	31	1.7100	0.1796	≤5.0 *	0	0.03	9
Sodium (Na)	30	2	**518.0**	49.9679	≤200 *	7	n/a	n/a
Iron (Fe)	58	16	**202.0**	4.7152	≤0.3 *	26	0.3	26
Manganese (Mn)	44	10	**3.92**	0.2109	≤0.05 *	16	n/a	n/a
Sulphide	19	9	**103.0**	**11.5346**	≤0.05 *	26	n/a	n/a
Chloride	48	0	**416.0**	34.9954	≤250 *	2	n/a	n/a
Nitrite as Nitrogen	30	29	0.1900	0.1900	n/a	n/a	0.06	3
Sodium	51	0	**515.0**	35.11	≤200 *	2	n/a	n/a
Coliforms, Total	7	0	**473 NPM/100ml**	**123.4 NPM/100 ml**	0 NPM/100 ml	100	n/a	n/a
E. coli	6	1	**7.4 NPM/100ml**	**2.68 NPM/100 ml**	0 NPM/100 ml	83	n/a	n/a

4 Recommendations for a Long-Term Water Quality Monitoring Program

4.1 Overview

The BCMP was initiated to provide for educational opportunities for local school students to gain experience in environmental science. The water chemistry data collected to date on Bosworth Creek is substantial for a small watershed in the Northwest Territories and is now considered baseline data for a future long-term monitoring program for this creek (SENES and Guthrie, 2009). The data on water quality is part of the overall monitoring program which includes the collection and identification of benthic macro-invertebrates, aquatic plant life, fish species, amphibians and birds (Guthrie, 2009). The SRRB intends to use this baseline water quality data as the basis for the development of a long-term monitoring program that may contribute to the knowledge of climate change impacts and cumulative effects in the Norman Wells region and on the Bosworth Creek ecosystem in particular. The Mackenzie Valley Pipeline project has proposed two future “Borrow Sites” in proximity to the creek. The impact from these sites as well as concerns over erosion from the fire fuel break and ATV use across and in the creek are both identified by the BCMP as activities that require long-term monitoring for creek health and aquatic habitat, including potential spawning areas for local species of fish.

4.2 General Considerations for Monitoring Program Design and Implementation

Long-term monitoring programs (LTMPs) are those that are in place over a period of years or decades and require substantial commitment of both personnel and funding. Environmental monitoring programs are in place across Canada and monitoring of water quality in natural waters is important to ascertain whether the water body in question is able to support a healthy ecosystem, or some other purpose such as use for drinking water. The SRRB and Mackenzie Mountain School developed the BCMP to include monitoring by students from grades 6-12 as part of their science curriculum, under the direction of expert personnel (Guthrie, 2009). An important consideration for any LTMP that is developed as part of this curriculum program is that consistency can be ensured for field sites and collection techniques. The Bosworth Creek Monitoring Program has been identified as a baseline dataset for the development of a long-term monitoring program able to support regional data on environmental changes from changing climate and impacts from development of natural resources. To ensure that the monitoring program will operate effectively over the long term, there should be formal documentation of the scope and design of the project so that changes in both senior personnel and students do not affect the quality of data collected. This documentation should include information on the rationale and scope of the program and clearly outline the questions that the program is intended to answer, such as whether water quality is being impacted by changes in groundwater inputs, or whether erosion from the fuel fire break is contributing to increased sediment loading. Collection techniques, rate of sampling, water quality parameters being sampled, and reporting techniques should also be clearly documented. For the BCMP to effectively track changes to Bosworth Creek water quality over time, an LTMP must be designed to include a suite of parameters that are consistently measured from specific sampling points. The BCMP currently includes a large suite of measured parameters Table 5. For consistency of information, the administrators of the long-term program should decide on a regular suite of water chemistry parameters that should be measured at all sites to allow for a robust statistical analysis over time and within the watershed.

Information regarding the design and sampling for water quality can be found in two documents “Northern Waters: A Guide to Designing and Conducting Water Quality Monitoring in Northern Canada” by the Northern Ecological Monitoring and Assessment Network (EMAN-North) 2005, and “A Canada-wide Framework for Water Quality Monitoring, 2006.” These documents should be used as reference documents for the development of a long-term monitoring program for Bosworth Creek. Generally the long-term monitoring program should ensure that:

- Sampling locations are consistent
- All sampling sites are physically identified with some form of marking to ensure consistency of sampling points
- Sampling methods are consistent, including analytical methods and laboratories, if possible
- Sample analysis is consistent for all samples collected at each point and throughout the watershed
- Sample data entry is done in a consistent format in a monitoring program database

For tracking variations by season, samples should be taken at least once each season at the specified sample locations. Short-term changes in water quality by season cannot be considered accurate at this low sampling frequency; however, long-term changes may be represented (EMAN-North, 2005). Whenever possible, the samples should be collected on or about the same date for each season and each year.

The suite of parameters measured by the BCMP includes a large number of parameters that are often below detection limits for all the samples. For a long-term monitoring program, some of these parameters may not be required and care should be taken to ensure that monitoring parameters are meaningful for the intentions of the LTMP. This may be limited by the methodology of the analytical laboratory, especially for parameters such as trace metals. Since erosional changes are of concern in a number of sites of the watershed, it is recommended that a measure of total suspended sediment be added to the water quality analysis for all the sites.

The BCMP has monitoring stations across the length of the watershed. It is recommended that the program endeavor to collect samples from all the stations each time that sampling is done. This may be impractical or not possible considering that some sampling for the program is run through the local school; however, sampling on the same date would allow for less variability in differences in ambient conditions in the watershed, including precipitation, temperature, and stream flow characteristics. Ambient conditions, including hydrological stages, can impact the measured values of some parameters.

For all the water samples, it is recommended that the sample be taken midstream in flowing water. If safety concerns preclude this, sampling as close to midstream as possible is recommended and care should be taken that water samples are not from still water regions or back eddies. Midstream sampling will give accurate results of changes in water chemistry along the channel and uniform mixing concentrations. Sampling in back eddies or quiet water may give erroneous results for the overall chemistry of the stream section sampled. Sites considered for long-term monitoring are based on the existing set of BCMP and INAC sites identified in this report. It is assumed that these sites are accessible safely at all times of year; however, if safety is a concern for sample collection, these may require modification for inclusion in a long-term program.

4.3 LTMP Sample Locations

Currently, the baseline data for the BCMP has combined data collected through a number of industry and government agencies and the local school program, from both historic and recent sampling activities. These data are not from consistent locations and reflect sites that relate to specific activities or locations of interest for studies being conducted by the collector. For instance, the INAC sampling sites are not always in the same locations as many of the BCMP sites, although the goals of the Cumulative Impacts Monitoring Program fit in well with the purpose of the BCMP (NWT CIMP, 2009).

The existing sample locations for the BCMP in this report are ranked for inclusion in an LTMP, with a rank of 1 considered of most importance to maintain, to a rank of 4 meaning “not required.” This ranking is based on the site locations within the watershed and the goals of the LTMP for monitoring the creek water quality for impacts of future activities and environmental change. Table 18 indicates the ranking of the existing sampling sites for inclusion in an LTMP. Each aggregate site name used for analysis has a recommended site name for an LTMP. Future samples taken at a site should be designated by a sample name-date combination for data records. The recommended names in this report are for illustrative purposes only for all the existing sites, as only those sites designated in a new LTMP should be named and numbered. These sites are listed from the mouth of the creek upstream to the top of the watershed.

Table 18. Ranking of samples sites for inclusion in a long-term monitoring program. Green: top priority; Turquoise and Yellow: potentially useful for local issues; Red: not necessary

Aggregate Sample site name	Recommended Site Name	Existing Samples at location	Rank
Lower Bridge South	BCMP-1	BCMP INAC	1
Lower Bridge North	BCMP-2	Thomas 1957 Francl 1974 Dillon 1978 UMA 1989 BCMP	1
Upstream of Reservoir	BCMP-3	UMA 1990 BCMP	1
Upper Bridge South	BCMP-4	INAC	4
Upper Bridge North	BCMP-5	Dillon 1978 BCMP INAC	1
Downstream of Pipeline Crossing	BCMP-6	Interprovincial Pipe Line Ltd. BCMP	2
At Pipeline Crossing	BCMP-7	Interprovincial Pipe Line Ltd.	4
Upstream of Pipeline	BCMP-8	Interprovincial Pipe Line Ltd. BCMP INAC	1
Winter Road Crossing sites	BCMP-9	INAC B	1
	BCMP-10	INAC at Ice Road	1
First Firebreak	BCMP-11	BCMP INAC	1
Second Firebreak area	BCMP-12	BCMP INAC	3
Third Firebreak area	BCMP-13	BCMP INAC	1
Confluence with Tributary	BCMP-14	INAC	4
ATV crossing	BMCP-15	BCMP	2
Downstream of Jackfish Lake	BCMP-16	BCMP	1
Jackfish Lake	BCMP-17	BCMP at outlet INAC at outlet	1
Edie Lake	BCMP-18	BCMP -shoreline area INAC mid lake	2
Firebreak -Tributary on Ridge	BCMP-19	BCMP	4

4.3.1 *BCMP -1 (Lower Bridge South) – Rank 1*

This site includes samples taken by the BCMP and INAC. The site should be maintained for an LTMP. The mouth of the stream has undergone considerable change since the removal of the weir in 2005, with stream reclamation and re-vegetation. Sampling should continue at a single marked location for this site for an LTMP. This location at the mouth of the creek can indicate whether there are cumulative impacts from activities or environmental changes upstream. As can be seen from the results of BCMP monitoring, several metals are above the maximum values allowed for protection of aquatic life at this location, whereas further upstream they are not in exceedance. Long-term monitoring of stream water at this site will indicate whether these issues are of a long-term nature.

4.3.2 *BCMP-2 (Lower Bridge North) –Rank 1*

This general sample location is the site of the former reservoir created by the Imperial Oil weir located at the lower bridge. The general site location includes several historic and recent sample points. It is recommended that a single sample point be identified at this location, midstream in the new stream channel. This site has historically been altered with the creation of the impoundment behind the weir in 1960, the subsequent removal of the weir, and engineered rechanneling of the former reservoir site. Potential impacts on downstream water quality from erosion of deposits of sediment from the former impoundment are cited as a concern in this region of the stream (Guthrie, 2007). The new sample site should be upstream from the existing bridge and downstream of the newly identified springs on the south bank. A comparison of water chemistry at this site with that from upstream of the former reservoir may indicate local water quality impacts from sediment erosion and/or the identified spring sites. Like the former site at the mouth of the stream, there are currently indications of water quality exceedances for several metals.

4.3.3 *BCMP-3 (Upstream of reservoir) – Rank 1*

This site is the location of a new spring that has a distinct chemistry far different than the water samples from the actual creek, and exceeds the water quality guidelines for the protection of aquatic life for a number of metals. A sample point directly downstream of this site will provide information on the dilution of these metals below the spring site.

The impact of inputs from this water source to the overall quality of the creek water downstream of this site is uncertain and requires monitoring. The development of springs in this region with distinct water chemistry may be influencing water quality downstream. A long-term monitoring program may include monitoring specifically for this spring water; however, direct measurement of these water sources requires a separate monitoring method. Measurement of these water sources using seepage meters would more accurately sample water from springs, particularly under circumstances where springs are innundated by creek water. This would be done based on the methods of Lee (1977), Lee and Cherry (1978) and Rosenberry (2008) adapted for flowing waters.

4.3.4 *BCMP-4 (South of Upper Bridge) – Rank 4*

This site was sampled by INAC in 2009. Potential changes to water quality due to the presence of the road crossing can be monitored. There are no BCMP data for this point so inclusion in a long-term monitoring program would not have baseline data associated with it for all metals or BTEX and other hydrocarbons. It is not recommended for an LTMP.

4.3.5 *BCMP-5 (Upper Bridge North) – Rank 1*

There are a number of locations in this region of the stream that have been sampled both historically and recently as part of industry, INAC and BCMP programs. These sites are all upstream of the upper bridge and south of the Norman Wells-Zama pipeline crossing. One site from this location is recommended (PRO 15, 49 sampling site). BCMP sample data indicates that there are a number of exceedances for metals in this region of the stream and contamination with coliform bacteria. Continued monitoring at this site will indicate whether these are long-term issues.

4.3.6 *BCMP-6 (Dowstream of Pipeline) – Rank 2*

The current BCMP site at this location (PRO 14) is located just downstream of the Norman Well-Zama pipeline crossing. Impacts of bank erosion or site disturbance by vehicle traffic at the pipeline site or changes in water chemistry and sediment load due the altered local environment at this crossing can be compared with the upstream sites to discern any effect of the pipeline crossing on the overall water quality of the stream.

4.3.7 *BCMP-7 (at pipeline) – Rank 4*

There are sampling points both directly upstream and downstream of the actual pipeline crossing. This point was sampled by INAC in 2009 for basic water quality parameters only. Long-term monitoring of water quality directly at this site may not give significant data, and any impacts from site disturbance can be ascertained by comparison of the upstream and downstream sampling data. There is no baseline data on the full suite of BCMP parameters. However, if direct local impacts from vehicle use at the crossing to the creek bed and bank are of concern, the site could be monitored for local impacts to sediment and aquatic life parameters of an LTMP. However, it is not essential for long-term monitoring of water chemistry.

4.3.8 *BCMP-8 (Upstream of pipeline) –Rank 1*

One sampling site from this group of historic sample points is useful for detecting local stream impacts downstream of the winter road crossing, located upstream from this site. One of the concerns expressed by the Sahtu Renewable Resources Board is the impact of the ice and bridge at the road crossing and their effect on winter water flow (Guthrie, 2008). Documented ATV and other vehicle use of the crossing in other seasons may produce sedimentation detrimental to water quality and stream habitat. An LTMP site should be located here to monitor for potential adverse effects and to address local concerns about this site. It should include sampling in all seasons for total suspended sediments as well as the regular suite of water quality parameters. Although there are currently no metal or chemical exceedances at this site, potential future alteration in the ice road configuration (Guthrie, 2008) and continued erosion at the site may impact water quality downstream in the long term.

4.3.9 *BCMP-9 and 10 (Winter Road Crossing) – Rank 1*

INAC had two sites from their 2009 sampling: one located at the winter road crossing and one upstream from the winter road crossing. These sites are discussed together, although the statistical analysis was done separately. Impacts from ice damming and constriction of water flow upstream results in overflow and pressure ridge formation at the road crossing site. Although the existing samples in this area do not currently indicate any exceeded values for the GPAL or the CGDWQ, water quality sampling at one permanent BCMP LTMP site upstream of the road crossing could detect potential detrimental impacts to water quality upstream of the winter road. Inflow of groundwater with different water chemistry from spring sites that provide baseflow during the winter may influence water chemistry over the long term, as indications of spring water with distinct water chemistry have been documented to be developing on the stream (Guthrie, pers. comm.). Direct impacts of vehicle traffic, winter ice road stream bed impacts and water flow restriction at the winter road crossing can be monitored for direct impacts on local water quality.

4.3.10 *BCMP-11 (First Firebreak site) - Rank 1*

There are a number of sample sites located upstream of the winter road crossing that are in an area of the creek where there are concerns about erosion from the forest fire fuel break. The most downstream of these sites are in an area where the topography is flat and streamflow slows and spreads into a more braided channel, while the uppermost site is located in a steep-sided valley with a defined stream channel. There are both BCMP and an INAC sampling site from 2009 in this area. The WSC gauge is located in the mid-area of these sample points (from coordinates from a WSC web site). A long-term monitoring site should be established at the most downstream of these sites (PRO 34 site) for analysis. Proximity to the WSC gauge is recommended as the hydrologic data from the gauge can be used to coordinate streamflow data with water analysis results. Monitoring at this site may indicate water chemistry impacts from the fire fuel break. These concerns have been noted in previous reports.

4.3.11 *BCMP- 12 (Second Firebreak site) – Rank 3*

The need for a long-term site within the area of the “Second Firebreak” site may not be required unless there are significant local impacts in this region that the BCMP would be interested in monitoring.

4.3.12 *BCMP 13 (Third Firebreak site) – Rank 1*

There are a number of samples from the area designated as the “Third Firebreak” site. This site is downstream of a number of springs that provide groundwater flow to Bosworth Creek and are located upstream both within the main channel of the creek and on the large tributary confluence with the channel draining the Discovery Ridge. A long-term monitoring site for this area that is located midstream will incorporate water chemistry from upstream groundwater inputs and water quality influences due to inputs from the unnamed Discovery Ridge stream. Water quality data from this region of the creek indicates a number of metal exceedances. Long-term monitoring of this site will determine if this is a long-term issue.

4.3.13 *BCMP-14 (Tributary Confluence) – Rank 4*

INAC sampled a site located in proximity to the confluence of Bosworth Creek and the main channel draining the ridge. This site data could be used for the BCMP long-term monitoring program if desired. It may be useful to indicate direct impacts to stream water quality from the inputs of the stream tributary flowing in from the ridge. However, the implementation of an LTMP site at this location is not considered necessary.

4.3.14 *BCMP-15 (ATV crossing) – Rank 2*

Concern over local stream channel and habitat impacts from a trail crossing for ATVs was documented by the Sahtu Renewable Resources Board. A BCMP monitoring site at this location was initiated. Water quality impacts from vehicle crossings at this location may include increased loads of suspended solids and potential fuel impacts, although there are no current water quality exceedances. Impact to overall creek water quality downstream is unknown; however, due to the concern over local impact, a long-term monitoring site may be desired for this location.

4.3.15 *BCMP-16 (Downstream from outlet from Jackfish Lake) – Rank 1*

This site is recommended as part of the overall long-term monitoring program. This is the beginning of the creek proper and will provide water quality data that can be compared to sites further downstream. Changes in water quality upstream to either the headwater lakes or increased erosion inputs from the large complex of gullies and channels draining the ridge adjacent to this site would be indicated through long-term monitoring at this location. Although there is indication of some metal exceedance for mercury and silver at this site from the data provided, long-term monitoring will indicate if this is a continuing issue.

4.3.16 *BCMP-17 (Jackfish Lake) – Rank 1*

There are both BCMP and INAC samples from the shoreline of Jackfish (Hodgson) Lake adjacent to the outlet to Bosworth Creek. Although there are no current exceedances in water quality at this time, this site should be part of the long-term monitoring program. If possible, water should be taken from a point mid-channel at the outlet to Bosworth Creek. This would give a sample where no impacts from disturbances to the shoreline would be introduced.

4.3.17 *BCMP-18 (Edie Lake) – Rank 2*

The existing data set has sampling points from mid-lake and the shoreline. One sampling point on Edie Lake should be established for long-term monitoring of this water body as it is undergoing significant change, as documented over the last 15 years. The inclusion of this site into a long-term monitoring program for Bosworth Creek water chemistry is not strictly necessary as the chemical changes in this water body currently do not appear to have affected the overall water chemistry of the actual creek. However, the interesting changes that have been documented to have occurred over the last several years are of interest for changes in aquatic biota that may have an impact to the overall Bosworth Creek ecosystem over time.

5 Summary and Conclusions

5.1 Summary

The BCMP was initiated to monitor changes to the ecological state of Bosworth Creek after the removal of a weir that had been installed to create a reservoir in 1960. Stream reclamation provided for educational opportunities for local school students to gain field experience and education in environmental science, as part of their school curriculum. This monitoring program has been collecting data since 2006.

This water quality data report summarizes the existing water quality data gathered on Bosworth Creek from the 1950's to 2009. Historical data from water quality sampling for industrial development is included. The existing dataset is heavily weighted with data from recent years (2006-2009). Although there is a significant amount of water quality data for the stream, some parameters have been sampled sporadically, and there are numerous sampling points along the water course. Sample points were clustered into groups to allow for analysis of the associated water quality data.

Due to the inconsistencies in the frequency, timing, and location of water quality sampling, in addition to variability in the specific water quality parameters analyzed for the period of record (1953 to 2009), there were significant difficulties in analyzing trends in data collected from Bosworth Creek. To date, water sampling efforts on the creek have not been conducted in an intensive or consistent enough manner to support analyses of change in water quality through time, with any acceptable degree of confidence.

Seasonal analyses independent of site grouping or year-by-year variation showed significant (p<0.05) differences in concentrations for trace and major metals, routine parameters and major ion analytes. The data show a general trend towards higher concentrations during winter and lowest concentrations in spring. This trend was observed for the majority of parameters, suggesting that concentrations may be associated with stream discharge magnitude. Findings also suggest that pH may be influencing the concentration of associated water quality parameters.

5.2 Overview of Water Quality for Bosworth Creek

Through most of the watershed, the measured parameters for water quality fall within the acceptable standards for both the GPAL and the GCDWQ. Bosworth Creek receives water from both Edie and Jackfish Lakes as well as contributions from runoff and gullies draining from the Discovery Ridge. Previous reports also indicate that there are significant groundwater inputs to the creek in all seasons, with the groundwater component providing base flow throughout the winter months (Guthrie, 2007). Data do not show a marked change to the pH values of Bosworth Creek over the period of record; however, SENES and Guthrie (2009) report that the water quality of Edie Lake has undergone a drastic change in pH and water quality over the last 20 years. The pH of Bosworth Creek is heavily influenced by the geology of the surrounding landscape but is considered normal for freshwater ecosystems where the average pH is usually in the range of 6-8. The GPAL state that pH in the range 6.5 to 9 is considered acceptable for healthy aquatic ecosystems for the protection of aquatic life.

The underlying geology of the ridge draining into Bosworth Creek is bedrock or bedrock overlaid by colluvial deposits. Below this ridge, Bosworth Creek runs through a region consisting of bedrock that includes shale and limestone, and silt and clay ground moraine deposits. A depression between the existing Mackenzie River and the base of the Ridge is characterized by an organic veneer and thick peat. The limestone and shale rock formations are most likely the contributing factors to the high average pH of the water in Bosworth Creek through inputs of both groundwater and surface water sources. Alkalinity in the form of bicarbonate ions (HCO_3) reflects the local conditions and provides excellent buffering capacity for the creek. The pH of creek water has not varied over the period of record regardless of the change in pH in Edie Lake over the same period of time.

Several of the samples in the existing database show exceedances in metals at six different locations, all below the confluence of Bosworth Creek and the unnamed major tributary entering from Discovery Ridge. Groundwater inputs below this confluence through a series of springs may account for the higher values in these metals as compared to upstream values. Several newly documented springs occurring in the lower creek on the Imperial Oil leased property (Upper Bridge North, Lower Bridge North and Lower Bridge south sites) are documented as having altered water chemistry and being higher in metals and ions (Guthrie, 2009), and these point sources could be contributing to higher metal and ion values in the water samples in these areas. Overall, the water samples from the described groundwater sources show higher metal and ion values as compared to other creek water samples. Water samples from other locations of the Creek often do not have the same metal values and do not show exceedances in these metals. The intermittent nature of the exceeded values for a small number of metals, along with the fact that they are often based on one sample does not allow for any conclusions about their impact on water quality or protection of aquatic life in the Creek ecosystem.

Documented oil seeps are most prevalent near the mouth of Bosworth Creek (Esso Resources Canada Ltd., 1980). New sources of groundwater seepage are also reported. The water quality measurements in the existing data do not show any exceedance values for hydrocarbon parameters. However there has been sporadic sampling for hydrocarbons and no measurement of these parameters at newly documented sources of groundwater discharge. Existing data shows that hydrocarbon impacts are not presently of concern for Bosworth Creek.

The SRRB has expressed concern over increased sediment loading in the Creek through the crossing and in stream riding of ATV vehicles and potential bank erosion. Short-term increases in turbidity from these activities could affect the amount of suspended sediment transported downstream and influence channel erosion and sedimentation.

Turbidity values for Bosworth Creek for the recorded dates are low throughout the period of record, ranging from 0 to 16.5 NTU. The maximum turbidity value acceptable for finished drinking water under the CGDWQ is 1 NTU (GCDWG, 2010); however, the Creek is not used as a source of drinking water. Water quality guidelines for the protection of aquatic life state that for clear flow, the reading should not exceed an increase of 8 NTU over the background level for a period of 24 hours. During high flow, the maximum acceptable increase is 8 NTUs from background levels at any one time, when background levels are between 8 and 80 NTUs, and should not increase more than 10% of background levels when background is under 80 NTUs. Since the readings for Bosworth creek are well below these values, it does not appear that turbidity in the creek over the long term is of concern for aquatic organisms. However, it is not known what the ambient conditions were at the time of testing or whether any of the sampling dates follow a precipitation event. Turbidity values can rise sharply in areas experiencing erosion after rain event, during spring freshet, and if there are areas of slope slumping of the creek banks. In these cases, excess turbidity, depending on the timing of the event, may have water quality impacts that cause negative effects to aquatic life. Excess turbidity in the water column is known to cause a rise in water temperature (GPAL).

Bacterial contamination is often linked with turbidity for water quality testing for drinking water. Testing for total coliform and fecal coliform bacteria has been sporadic over the period of record. In total there are only seven recorded measurements, beginning with 08/08/1978 to 04/06/2009. The location of water sampling is also not consistent, with samples taken from the WSC gauge site in 1978 and the Lower and Upper Bridge sites more recently (2006, 2007, 2009). *E. coli* and faecal *streptococcus* were also present in the samples. Although these results show the presence of some faecal contamination from warm-blooded animals (and potentially human waste), the water does not serve as a source of drinking water and therefore does not pose a risk to human health for residents of Norman Wells who use the municipal water system. Coliform bacteria are not considered in the GPAL.

Future monitoring efforts as part of an LTMP will provide the SRRB with more comprehensive data on the overall water quality of Bosworth Creek. The continued collection of water quality data will allow for analysis of changes that may occur due to resource development activities. This continued data collection will contribute to knowledge on short- and long-term trends in water quality related to climate change in the Northwest Territories and in the Norman Wells region in particular.

6 References

Antweiler, R.C. and Taylor, H.E. 2008. Evaluation of statistical treatments of left-censored environmental data using coincident uncensored data sets: I. Summary statistics. Environmental Science and Technology, 42: 3732-3738.

Aquatic Environments Ltd. for Northern Engineering Services Co. Ltd. 1973. Data Report. Late Winter Surveys of Lakes and Streams in Canada and Alaska Along the Gas Pipeline Routes Under Consideration by Canadian Arctic Gas Study Limited.

Bourg, A.C.M., Kedziorek, M.A.M., Crouzet, C. 2000. Seasonal cycles of dissolved Cd, Mn and Zn in river water caused by variations in pH induced by biological activity. Aquatic Geochemistry, 6: 461-471.

CCME 2007. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Summary Table. 2007. Canadian Environmental Quality Guidelines.

Clarke, J.U. 1998. Evaluation of censored data methods to allow statistical comparisons among very small samples with below detection limit observations. Environmental Science and Technology, 32: 177-183.

Couture, R., S.D. Robinson, and M.M. Burgess. 2000. Climate change, permafrost degradation, and infrastructure adaptation: Preliminary results from a pilot community case study in the Mackenzie valley. Geological Survey of Canada, Current Research 2000-B2 9 p. (online: http://www.nrcan.gc.ca/gsc/bookstore).

Dillon Consulting Engineers & Planners. 1976. Norman Wells, NWT Water Supply study and extension of services to new subdivision. Government of the Northwest Territories.

Dillon Consulting Engineers & Planners. 1978. Norman Wells, N.W.T. Water Supply Study – 1978. Government of the Northwest Territories, Department of Public Works.

EIS for Mackenzie Gas Project. 2004. Volume 3: Biophysical Baseline. Section 6: Water Quality. August 2004.

Esso Resources Canada Limited. 1980. Norman Wells Oilfield Expansion. Environmental Impact Statement Oilfield Development, Vol. 2 of 4., 204 p.

Franckl, W. J. 1974. Development Plan, Norman Wells, N.W.T. Report No. 74-28 Env.-Soc. Committee Northern Pipelines Task Force on Northern Oil Development.

Fu, L and Wang, Y-G. 2011. Nonparametric rank regression for analyzing water quality concentration data for multiple regression limits. Environmental Science and Technology, 45(4): 1481-1489.

Guidelines for Canadian Drinking Water Quality.
http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/2010-sum_guide-res_recom/index-eng.php

Guthrie, G. 2007. Bosworth Creek Monitoring Project 2006/2007 Annual Summary Report. Sahtu Renewable Resources Board. March 31, 2007.

Guthrie, G. 2008. Bosworth Creek Winter Road Crossing, Negative Impacts and a Possible Solution. Report to MLA, June 2008.

Guthrie, G. 2009a. Bosworth Creek Monitoring Project. Canadian Lightsource Saskatoon Presentation. August 10-14, 2009.

Guthrie, G. 2009b. Bosworth Creek Monitoring Project Near Norman Wells. N.W.T. Journal of the Northern Territories Water and Waste Association. September 2009.

Health Canada. 2009. Drinking Water. http://www.hc-sc.gc.ca/ewh-semt/water-eau/drink-potab/index-eng.php

Health Canada, 2010. Guidelines for Canadian Drinking Water Quality. http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/2010-sum_guide-res_recom/index-eng.php

Helsel, D.R. 1987. Advantages of nonparametric procedures for analysis of water quality data. Hydrological Sciences Journal, 32(2): 179-190.

Helsel, D.R. 1990. Less than obvious: statistical treatment of data below the detection limit. Environmental Science and Technology, 24(12): 1766-1774.

Helsel, D.R., 2005. More than obvious: Better methods for interpreting nondetect data. Environmental Science and Technology, 39(20): 419A-423A.

Imperial Oil Resources. 2005. Corporate Citizenship Report. http://www.imperialoil.ca/Canada-English/Files/Corporate_Citizenship/2005citizenship.pdf

Intraprovincial Pipeline (NW) Ltd. Water quality monitoring in relation to 1985 pipeline construction and operation. Edmonton. AB. 8 p. +app.

Lee, D. R. 1977. A device for measuring seepage flux in lakes and estuaries. Limnology and Oceanography 22:140-147.

Lee, D.R. and Cherry, J.A. 1978. A field exercise on groundwater flow using seepage meters and mini-piezometers. Journal of Geol. Educ. 27: 6-10.

Lee, L. and Helsel, D. 2007. Statistical analysis of water-quality data containing multiple detection limits II: S-language software for nonparametric distribution modeling and hypothesis testing. Computers and Geosciences, 33: 696-704.

Lubin, J. H., Colt, J. S., Camann, D., Davis, S., Cerhan, J. R., Severson, R. K. 2004. Epidemiologic evaluation of measurement data in presence of detection limits. Environmental Health Perspectives, 112: 1691–1696.

Morgan, J.D., G.A. Vigers, P.G. Nix. E.V.S. Consultants Ltd.. 1986. Assessment of Freshwater Impacts from the Norman Wells Oilfield Development Part II. Field and Laboratory Studies. Environmental Protection Service, Environment Canada.

Northern Ecological Monitoring and Assessment Network (EMAN-North).
2005. Northern Waters: A Guide to Designing and Conducting Water Quality Monitoring in Northern Canada. Northern Ecological Monitoring and Assessment Network (EMAN-North).

Northwest Territories Cumulative Impact Monitoring Program: Capacity Building & Monitoring Projects 2007-2008. Bosworth Creek Monitoring Project. March, 2008.

Northwest Territories Cumulative Impact Monitoring Program: Capacity Building & Monitoring Projects 2008-2009: Bosworth Creek Monitoring Project. March 30, 2009.

Rosenberry, D.O. 2008. A seepage meter designed for use in flowing water. Journal of Hydrology, 359(1-2): 118-130.

Sahtu Settlement Area Crown Lands Application for a type A Land Use Permit. Section 5. Borrow Sites. Subject 11. Borrow sites 7.054P. Northern Gas Project Secretariat. October 2005. pp5-177.

SENES Consultants. Bosworth Creek History Project Report. 2008.

SENES Consultants Ltd., and G. Guthrie. 2009. Bosworth Creek (NWT) Literature Review. Environmental Studies Research Funds Report No. 174. Yellowknife, NT. 28 p.

Seyler, P.T. and Boaventura, G.R. 2003. Distribution and partition of trace metals in the Amazon basin. Hydrological Processes, 17: 1345-1361.

Thomas, J.F.J. 1957. Industrial Water Resources of Canada. Water Survey Report No. 8. Mackenzie River and Yukon River Drainage Basins in Canada, 1952-1953. No. 856. Dept. of Mines and Technical Surveys. Government of Canada.

VanGerwen-Toyne, M.,and R.F. Tallman. Department of Fisheries and Oceans. 2006. Mackenzie River Fish Tagging Study 2005/2006. Department of Fisheries and Oceans, Winnipeg, 2006.

vanLoon, G.W. and Duffy, S.J. 2000. Environmental Chemistry – A Global Perspective. Oxford University Press. Toronto.

Water Survey of Canada (WSC). 2001. Archived hydrometric data:
http://www.wsc.ec.gc.ca/applications/H2O/graph-eng.cfm?station=10KA007&report=daily&data=flow&year=2009

Wichman, B.A. and Hill, I.D. 1982. Algorithm AS 183: An efficient and portable pseudo-random number generator. Applied Statistics, 31:188-190.