City of Yellowknife

Potable Water Source Selection Study

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December 6, 2017

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Dear Dennis:

Project No: **60541637**

Regarding: **Potable Water Source Selection Study**

We are pleased to provide the final report for the Yellowknife Potable Water Source Selection Study. If you have any further questions, please do not hesitate to contact us.

Sincerely,
AECOM Canada Ltd.

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Executive Summary

The City of Yellowknife has retained AECOM to evaluate its potable water supply options. Currently the City obtains its drinking water from the Yellowknife River through an eight-kilometre submarine pipeline that carries water from Pumphouse 2 at the river, through Yellowknife Bay, to Pumphouse 1 in the city. However, the submarine pipeline is reaching the end of its useful life, so the City needs to either replace the pipeline, or use the alternate water source of Yellowknife Bay.

Prior to 1968, the City of Yellowknife obtained its drinking water from Yellowknife Bay, which is connected to Great Slave Lake. The City's water source was switched from Yellowknife Bay to the Yellowknife River in 1968/69 over concerns about arsenic contamination from the Giant and Con mines. Currently, the levels of total arsenic in Yellowknife Bay water are below 4.5 µg/L, which meets the drinking water limit of 10 µg/L. However, it is possible that a catastrophic loss of containment of a surface pond at the Giant Mine remediation site could result in increased arsenic concentrations at the City's Yellowknife Bay intake location. Estimates of the arsenic concentration at the Pumphouse 1 intake immediately following this failure range from approximately 190 µg/L to 4,600 µg/L total arsenic. The hypothetical high-arsenic raw water conditions following a Giant Mine containment failure are referred to as Upset Conditions for this study.

Water treatment options exist to remove arsenic from water. Reverse osmosis (RO) is expected to be the most effective at removing arsenic, but this treatment process is not considered feasible for Yellowknife WTP because of residuals disposal issues and high operation and maintenance costs. An adsorptive media system would provide some removal of arsenic, but may have difficulty removing enough arsenic to meet drinking water quality guidelines at some of the high arsenic concentrations estimated to occur during Upset Conditions.

A matrix-style decision model was developed to evaluate two options: Yellowknife River with a new submarine pipeline, or Yellowknife Bay with a new adsorptive media treatment system. The Yellowknife River option has a Total Score of 65.2 and the Yellowknife Bay option has a Total Score of 54.5, indicating that the Yellowknife River is the preferred option. The River option has a higher estimated life cycle cost (LCC) of $33.0 million compared to the Bay option estimated LCC of $18.2 million. The total scores reflect the importance placed on qualitative criteria such as reliability of the water supply. The Bay option received a lower score for reliability because the arsenic removal treatment process may not be able to consistently meet the drinking water quality standards in the wake of a major Upset Condition due to a berm failure at Giant Mine.

Overall, the Yellowknife River source with a new submarine pipeline has a higher capital cost, but has less risk of arsenic contamination. Arsenic contamination of the Yellowknife Bay source water due to a major failure at Giant Mine has a low probability of occurring but is considered plausible. Note that this "short-term" risk only exists until the end of the remediation phase of the Giant Mine project. In the long-term care and maintenance phase after remediation, any failures at Giant Mine are not expected to affect water quality at the City's Pumphouse 1 intake, because plausible failures during the long-term operation phase would only release a small amount of waste to the Bay.

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1. Introduction

The City of Yellowknife has retained AECOM to evaluate its potable water supply options. Currently the City obtains its drinking water from the Yellowknife River through an eight-kilometre submarine pipeline that carries water from Pumphouse 2 at the river, through Yellowknife Bay, to Pumphouse 1 in the city. However, the submarine pipeline is reaching the end of its useful life. Submarine (diver) inspections completed in 2016 found leakage occurring in the pipeline. In addition, the capacity of the existing pipeline is limited due to pipe size, the effective pressure rating of the aging pipe, and the pumping infrastructure in Pumphouse 2. The need to either replace the pipeline or use an alternate source will become more urgent with each passing year, as the pipeline condition continues to deteriorate and potable water demands increase.

1.1 History

Prior to 1968, the City of Yellowknife obtained its drinking water from Yellowknife Bay, which is connected to Great Slave Lake. The City's water source was switched from Yellowknife Bay to the Yellowknife River in 1968/69 over concerns about arsenic contamination from the Giant and Con mines. The City is currently still using the original eight-kilometre submarine pipeline that carries water from Pumphouse 2 at the river, through Yellowknife Bay, to Pumphouse 1 in the city.

The Giant and Con gold mines released arsenic into the air around Yellowknife for decades, starting in 1938 (Con) and 1948 (Giant). In the 1950's the mines made process changes to reduce the airborne emissions. In 1999, Giant Mine stopped producing gold, and Con Mine shut down in 2003. Around 1999, the Government of Canada began planning how to manage the arsenic trioxide waste from Giant Mine. Giant Mine remediation is currently underway, and includes freezing arsenic trioxide underground; surface remediation; and water treatment. When remediation is complete the site will need to be maintained and monitored permanently to protect human health and the environment[1]. Giant Mine is of primary concern to the City because it is located upstream of the existing emergency Bay water intake.

1.2 Previous Source Selection Studies

From 2009 to 2011, AECOM completed several tasks related to source water selection during design of the City's new Water Treatment Plant (WTP):

- Evaluation of water source alternatives, including decision modeling and life cycle costs (as part of the Water Treatment Plant Preliminary Design Report, May 2009)
- Literature review to assess the extent of arsenic in Yellowknife Bay water and sediments (Technical Memorandum, May 5, 2010)
- Water and soil sampling at four locations around the Pumphouse 1 intake (August 2010)
- Monte Carlo modeling of arsenic in Yellowknife Bay water (Technical Memorandum, December 2, 2010)
- Water source selection summary and recommendation (Letter, February 25, 2011)

[1] *INAC & GNWT, Giant Mine Remediation Project: Developer's Assessment Report, EA0809-001, October 2010*

In 2009 (WTP Predesign Report) and 2011 (source selection letter) AECOM recommended that the City use Yellowknife Bay as the raw water source, with the addition of an arsenic treatment system to address the risk that arsenic concentrations in the water could increase. A major reason for the recommendation was that estimated life cycle costs for the Bay source option were significantly lower than the River source option with pipeline replacement.

Following public consultation in 2011, the City decided to continue using the Yellowknife River source with emergency supply from the Bay, with the understanding that the issue would need to be revisited before the pipeline reached the end of its lifespan, which was estimated to occur around 2020.

1.3 This Study

Now in 2017, the pipeline is leaking and approaching the end of its useful life. The key objective of this study is to provide an updated recommendation for the City's potable water source, based on new arsenic data and current cost information. The options have been evaluated using a matrix decision model to provide City Council with the information necessary to make a well-founded and defensible decision about the potable water source.

This study evaluates two water source options:

- Option 1: Yellowknife River through a new submarine pipeline
- Option 2: Yellowknife Bay with a new treatment process for arsenic removal in case arsenic levels increase

2. Arsenic Risk Assessment

To evaluate the Bay supply option, AECOM needed to determine the expected arsenic concentrations at Pumphouse 1. To meet this objective, AECOM obtained available surface water dissolved and total arsenic data from a variety of sources. These data were then used to characterize upper bound estimates for arsenic in the surface water of Yellowknife Bay near Pumphouse 1 for a variety of situations, including for Normal Conditions, Storm Conditions, and defined Upset Conditions (i.e., short-term and long-term failure events associated with Giant Mine). The full analysis is presented in a separate technical memorandum attached to this report as Appendix A.

The key conclusions are as follows:

1. For Normal Conditions, the upper bound estimates for total and dissolved arsenic (total arsenic is virtually entirely associated with the dissolved form) in surface waters ranged from 1.7 ug/L to 4.5 µg/L, and therefore met the Health Canada drinking water quality guideline for arsenic of 10 µg/L without the requirement for further treatment. These values are likely over-estimates of the upper bound of arsenic concentration under Normal Condition because of an observed significant decreasing temporal trend in arsenic within the period of record (2005 to 2017).
2. Storm Conditions that were observed during the period of record did not measurably affect water column arsenic concentration, and therefore it was concluded that upper bound estimates developed for Normal Conditions were also applicable to Storm Conditions.
3. Upset Conditions for the *short-term* scenario (i.e., catastrophic loss of containment at the Giant Mine treatment pond) resulted in estimates of the arsenic concentration at the Pumphouse 1 intake ranging from approximately 190 µg/L to 4,600 µg/L total arsenic.
4. For the Upset Condition *long-term* scenario (i.e., Giant Mine water treatment pipe failure), it was concluded that there would be no measurable increase in arsenic at the Pumphouse 1 intake.

The key recommendations in the memo were as follows:

1. Provide public access to the arsenic data collected from Pumphouse 1 on a website so that the public could look at the actual data as it is collected and compare the data with the federal drinking water quality guideline for arsenic of 10 µg/L.
2. Continue to collect water samples for dissolved and total arsenic determination on a regular basis from the Pumphouse 1 wet well, whether that is monthly or at some shorter interval going forward.
3. Begin collection of turbidity and Total Suspended Solids (TSS) data from samples collected at the same location (Pumphouse 1 wet well) and in conjunction with the arsenic data.
4. Discard oldest year of arsenic data as new data are collected to gradually lessen the effect of observed temporal trends in arsenic concentration on upper bound estimates of normal range.
5. Continuously monitor turbidity at the water intake during storm conditions. If a spike in turbidity occurs, then take a sample for determination of TSS and total and dissolved arsenic.
6. Re-evaluate the short-term ‘Upset Conditions’ if an appropriate hydrodynamic model is developed that includes the area of Yellowknife Bay near the Pumphouse 1 intake.

3. Arsenic Treatment Options

3.1 Raw Water Quality

3.1.1 Normal Raw Water Quality

In general, both water source options (Yellowknife River and Yellowknife Bay) have good quality water with similar turbidity (around 2 NTU) and Total Organic Carbon (average 4.7 mg/L), as summarized in the City of Yellowknife Water Treatment Plant Preliminary Design Report, AECOM, May 2009. The water treatment process uses microfiltration membranes to remove turbidity and large pathogens, and chlorine (sodium hypochlorite) disinfection to inactivate smaller pathogens (bacteria and viruses). Because the normal water quality of both sources is similar, the existing water treatment plant is expected to be capable of effectively treating either source under normal conditions.

3.1.2 Upset Conditions

Giant Mine is located at the north end of Yellowknife Bay. It is possible that untreated mine contact water could be released into Yellowknife Bay following a catastrophic failure of the perimeter dam for the Northwest Pond, which currently stores untreated mine contact water. As discussed in Section 2 and Appendix A, this catastrophic failure could seriously affect the raw water quality at the City's emergency intake at Pumphouse 1. This failure is not expected to affect the River intake which is located upstream of the Mine. The estimated water quality at the Bay intake following this hypothetical failure will be referred to as "Upset Conditions" for the remainder of this report.

Note that this failure event could only occur in the short-term prior to completion of the remediation phase of the Giant Mine project. In the long-term care and maintenance phase, the Northwest Pond will not be used for storage. Other failures at Giant Mine are not expected to impact the raw water quality at the Pumphouse 1 intake.

Based on the Giant Mine "Pilot Plant Options Analysis" draft report (AECOM, June 16, 2017, Draft Revision 3), the untreated mine contact water contains various metals and other contaminants besides arsenic. However, the only parameters identified in that draft report as being above the limits in the Guidelines for Canadian Drinking Water Quality (GCDWQ) are arsenic and antimony.

3.1.3 Arsenic

The Guidelines for Canadian Drinking Water Quality describe arsenic as "a natural element that is widely distributed throughout the Earth's crust". Water sources, especially groundwater, often contain arsenic that has eroded naturally from minerals containing arsenic. Arsenic compounds are used to make products such as semiconductors; arsenic can also be a waste product from other industrial activities such as gold mining. Arsenic is a human carcinogen, and there are many other adverse toxic effects associated with arsenic exposure.

As described in Section 2 and Appendix A, arsenic concentrations in Yellowknife Bay water are normally below the allowed limit of 10 µg/L for drinking water in Canada. Under “short-term Upset Conditions” (i.e., catastrophic loss of containment at the Giant Mine treatment pond), arsenic concentrations at the Pumphouse 1 intake are estimated to range from approximately 190 µg/L to 4,600 µg/L total arsenic.
Arsenic speciation during the hypothetical Upset Condition is unknown. For this evaluation we have assumed arsenic speciation during the Upset Condition would be similar to existing arsenic speciation in Yellowknife Bay. Yellowknife Bay surface water sampling in September 2014 and August 2015 (from Chetelat *et al.*, *Arsenic, Antimony and Metal Concentrations in Water and Sediment of Yellowknife Bay*. NWT Geological Survey, 2017 draft version June 19, 2017) found that on average:

- Dissolved arsenic was 88±8% of total arsenic
- Inorganic arsenic was 77±19% of dissolved arsenic. The remaining 23% of dissolved arsenic was presumed to be organo-arsenic compounds.
- Arsenite (As^{+3}) was 38±15% of inorganic arsenic.

As^{+3} was therefore 88% x 77% x 38% = 26% of the total arsenic. Organo-arsenic compounds were 88% x 23% = 20% of total arsenic. Using these proportions, the Upper Limit of 4,600 μg/L during Upset Conditions would include 1190 μg/L of As^{+3} and 920 μg/L of organo-arsenic compounds.

3.1.4 Antimony

Antimony, like arsenic, is an element that is found throughout the Earth’s crust. It is present in some water sources due to natural erosion. Antimony and its compounds are used to make various products such as semiconductors and paints. Antimony can also be released as a waste product from industrial processes. Exposure to antimony is associated with heart problems, cancer, and various other toxic effects.

The metal antimony has a Maximum Acceptable Concentration of 6 μg/L in the Guidelines for Canadian Drinking Water Quality (GCDWQ). Normal concentrations in both the Bay and River water are below this limit. Total antimony in River water is typically 5 μg/L (based on 6 samples from 1998-2000 in the GNWT Drinking Water Quality Database). Total antimony in Bay water is typically 0.4 μg/L (based on 8 samples taken by AECOM from May – October 2010 for Yellowknife WTP design).

During Upset Conditions, the antimony concentrations at the Pumphouse 1 intake may exceed the GCDWQ limit. The antimony concentrations are estimated in **Table 1** below using the same assumptions and calculation as for arsenic in Appendix A. Giant Mine contact water concentrations of antimony from the Pilot Plant Options Analysis draft report are 1814 μg/L (SNP 43-21 95%ile) and 946 μg/L (SNP 43-21 average).

Table 1. Catastrophic Failure of the Northwest Pond Retaining Dam: Estimate of Antimony Concentration at the Pumphouse 1 Intake

Item	Parameters		Data Estimate
1	Estimated Upper Yellowknife Bay Water Volume*		7.4×10^7 m^3
2	Northwest Pond Maximum Yearly Volume of Contact Water**		7.0×10^5 m^3
3	Antimony concentration (g/m^3 antimony) in Northwest Pond (Site SWP4)	Average	0.946
		95%ile	1.814
4	Total estimated antimony load (g antimony) in Northwest Pond	2 x 3 (average)	1.3×10^6
		2 x 3 (95%ile)	6.6×10^5
5	Estimated antimony concentration (g/m^3 antimony) at Pumphouse 1 intake assuming full dilution with upper Yellowknife Bay water	4/1 (average)	0.009
		4/1 (95%ile)	0.017
6	Estimated antimony concentration (g/m^3 antimony) at Pumphouse 1 intake assuming dilution with 25% of upper Yellowknife Bay water	4/1/25% (average)	0.036
		4/1/25% (95%ile)	0.069

**Area = $13.4 \times 10^6 m^2$, Average Depth = 5.5m*
*** Based on pumping volumes monitored between 2010 and 2015*

3.2 Treatment Options Comparison

3.2.1 High Level Treatment Options Comparison

Table 2 presents a high-level comparison of five arsenic removal treatment options. Only ferric (iron oxide/hydroxide) adsorptive media was selected to carry forward for the detailed water source options evaluation.

3.2.2 Adsorptive Media

Adsorption is a process where substances are removed from a liquid when they accumulate onto the surface of a solid material. Various special adsorptive materials are used in water treatment to remove contaminants such as pesticides or arsenic.

The ferric adsorptive media option developed for this study is based on Bayoxide E33 media. Similar types of media have achieved arsenic removal up to 97% (influent concentration of 300 µg/L reduced to below the GCDWQ limit of 10 µg/L) based on available literature[2]. Typically, raw water arsenic concentrations at municipal water treatment plants are below 50 µg/L[3].

However, information is not available on the performance of the media for influent concentrations of arsenic as high as some of those projected for Yellowknife WTP at the beginning of Upset Conditions. From Section 2 and Appendix A, the estimated concentrations of total arsenic at the Pumphouse 1 intake at the start of Upset

[2] United States Environmental Protection Agency (USEPA), Arsenic Treatment Technologies for Soil, Waste, and Water, EPA-542-R-02-004, September 2002
[3] USEPA Demonstration Project reports for Goffstown NH, Queen Anne's County MD, and Wellman TX

Conditions range from 190 µg/L to 4,600 µg/L. Therefore, there is a risk that adsorptive media would not be able to reliably remove enough arsenic to meet drinking water standards at all times during an Upset Condition.

3.2.3 Reverse Osmosis

A reverse osmosis treatment system uses a semi-permeable membrane to separate solids and dissolved ions from water. Feed water is pumped to the membrane unit, and the pressure differential forces some of the water (between 50-90%) across the membrane while a concentrated stream of solids and ions is wasted (also called the reject water). The RO process is used in water treatment for desalination (removing salt from seawater) and for removing various other contaminants.

An RO system produces a significant volume of reject brine for disposal. In general, RO brine disposal options are

- **Discharge to a brackish/saline water source.** This is mainly applicable to coastal sites and not possible for Yellowknife.
- **Municipal sewer discharge**. Adding approximately 30% of the City's entire water demand to the sanitary sewer system would reduce the lifespan of the sanitary lagoon, potentially affect the performance of the lagoon (the high salt content in reject brine is not good for biological activity in the lagoon), increase lift station pumping costs and possibly require lift station upgrades or replacement. This is not considered feasible for Yellowknife.
- **Evaporation/crystallization**. An evaporator or crystallizer can be used to reduce the volume of brine, so that final disposal is only required for a small amount of highly concentrated brine or solid crystals. In some climates solar energy can be used but solar evaporation is not suitable for Yellowknife for most of the year. The fuel oil requirements make this option unfeasible for Yellowknife, as approximately 57,000 L/day of oil would be required for average flows in the winter (two truckloads per day for 9,000 usg / 34,000 L tanker trucks).
- **Deep well injection**. At some WTP's, RO reject is injected into a brackish or saline aquifer with no connection to shallower, fresh water aquifers. The only site that could possibly be used for this near Yellowknife WTP is the Giant Mine, because in Upset Conditions, the RO reject could contain high concentrations of arsenic which could not be disposed of at most sites. However, it is unlikely that municipal brine disposal at the Giant Mine remediation site would be approved by the Government of Canada. Further, the cost of transportation to the Giant Mine site would be substantial and carry a risk of spillage for either buried lines or in-lake lines.

There are other significant operation & maintenance (O&M) costs associated with an RO system besides residuals disposal. A conceptual, order-of-magnitude cost estimate for RO O&M at Yellowknife WTP is $1.5 million per year, including pumping power, chemicals, and membrane replacement.

Due to the high O&M cost and lack of a feasible method to dispose of residuals, reverse osmosis is not considered further for this study.

Table 2. Arsenic Treatment Options Comparison

Name of Process		Coagulation	Ion Exchange	Adsorptive Media Filtration - Granular Ferric Media	Adsorptive Media Filtration - Activated Alumina	Reverse Osmosis
Ranked Low to High	Process Complexity	High	Moderate	Low	Moderate	High
	Mechanical Complexity	Low	Moderate	Moderate	Moderate	High
	Relative Capital Cost	Low	Moderate	Moderate	Moderate	High
	Relative O&M Cost	Moderate	Moderate	Low	Moderate	High
1 to 5 Ranked Efficacy for Reduction/Treatment of… (1 = minimal effect, 5 = very effective)	Particulate Arsenic	3 (Note 1)	1 (Note 1)	2 (Note 1)	2 (Note 1)	2 (Note 1)
	Dissolved Arsenic (III)	1 or 2 with oxidation (Note 2)	2 or 4 with oxidation (Note 2)	3 or 4 with oxidation (Note 2)	2 or 4 with oxidation (Note 2)	4
	Dissolved Arsenic (V)	2	4	4	4	5
	Organo-arsenic	2	unknown	unknown	unknown	5
Ability to Handle Rapid Changes in Arsenic Concentration (storm or upset)		Poor. Operator required to adjust chemical dosages	Moderate. Operator required to adjust oxidant dosage if As(III) present	Moderate. Operator required to adjust oxidant dosage if As(III) present	Moderate. Operator required to adjust oxidant dosage if As(III) present	Good
Residuals		Membrane backwash waste and thickener sludge volumes would increase compared to no coagulation. If high arsenic is present then the sludge would need to be sent to a hazardous waste facility.	Brine from regeneration would need to be concentrated and sent to a hazardous waste facility.	Adsorptive system backwash waste would be combined with membrane backwash waste for treatment. Spent adsorptive media would be sent to landfill.	Adsorptive system backwash waste would be combined with membrane backwash waste for treatment. Spent adsorptive media would be sent to landfill.	Large volumes of reject brine would need to be concentrated and sent to a hazardous waste disposal facility.
Distribution System Effects			pH adjustment chemicals would likely be needed after ion exchange. Could increase corrosion in distribution if pH adjustment not done properly.	Potential to release fines from the media, i.e. adding iron particulates and potentially arsenic to the distribution system. Iron in distribution system could increase microbial activity.	Potential to release fines from the media, i.e. adding aluminum to the distribution system. Could increase corrosion in distribution if pH adjustment is not done properly.	Could increase corrosion in distribution system if filtered water is not properly stabilized (for example adding lime or soda ash to increase hardness, pH and alkalinity)
Other Comments		* Requires jar testing to determine optimal chemistry and confirm removal efficacy. Complex chemistry required (coagulant, oxidant, alkalinity addition and pH adjustment) * High coagulant doses may foul membranes and/or affect cleaning schedule	* An arsenic-selective resin could be used to target arsenic specifically, to increase media life. However, antimony is also a concern. * Potential for arsenic 'dumping' (arsenic released from resin) if regeneration is not done at the right time. * Need to accurately dose oxidant if As(III) is present	* Not as selective as ion exchange so media life might be shorter; however ferric media will also remove other contaminants besides Arsenic * Will remove some As(III) without oxidant, but for best performance need to dose oxidant	* Requires pH control as this process performs best at pH 5.5-6.0; performance drops above 7.0. * Need to accurately dose oxidant if As(III) is present	* Requires chemical pretreatment to control scaling and post-treatment to avoid corrosion * Overall WTP capacity would be reduced by 10 - 50% (depending on RO system design) since some of the existing MF membrane production would be wasted as RO concentrate/reject
Considered viable for Yellowknife?		No	No	Yes	No	No
Rationale		Historical difficulties with coagulation process at Yellowknife WTP. Expect operational difficulty especially if this process is only used rarely for extreme arsenic concentrations (upset event).	Targeted resin would not remove antimony or other contaminants. Risk of arsenic "dumping" into treated water. Expensive residuals disposal.	Simple and inexpensive residuals disposal (landfill). Simple operation. Not expected to require pH adjustment.	Expected to be similar to ferric media but pH adjustment would be required. Note that pilot testing would normally be used to choose between different media, but for Yellowknife we cannot pilot test with hypothetical water (upset condition).	Would remove arsenic reliably. However, very expensive (including residuals disposal) and complex (including chemical pre and post treatment). Also would need to add more MF membranes or accept lower water production when RO is in use.

Note 1: Particulate arsenic would be removed by existing MF membrane filters at Yellowknife WTP

Note 2: Pre-oxidation requires adding an oxidant such as chlorine, potassium permanganate or ozone

4. Water Source Options

4.1 Existing System

The Yellowknife River is the City's current raw water source. Duty/standby pumps at Pumphouse 2 pump water through the submarine pipeline to Pumphouse 1 and the Water Treatment Plant (WTP) in Yellowknife. **Figure 1** below is a schematic showing the existing water supply and treatment system.

The City also has the ability to pump raw water from Yellowknife Bay at Pumphouse 1. This intake is used for emergency back-up water supply in the event that the normal water supply from Pumphouse 2 is unavailable.

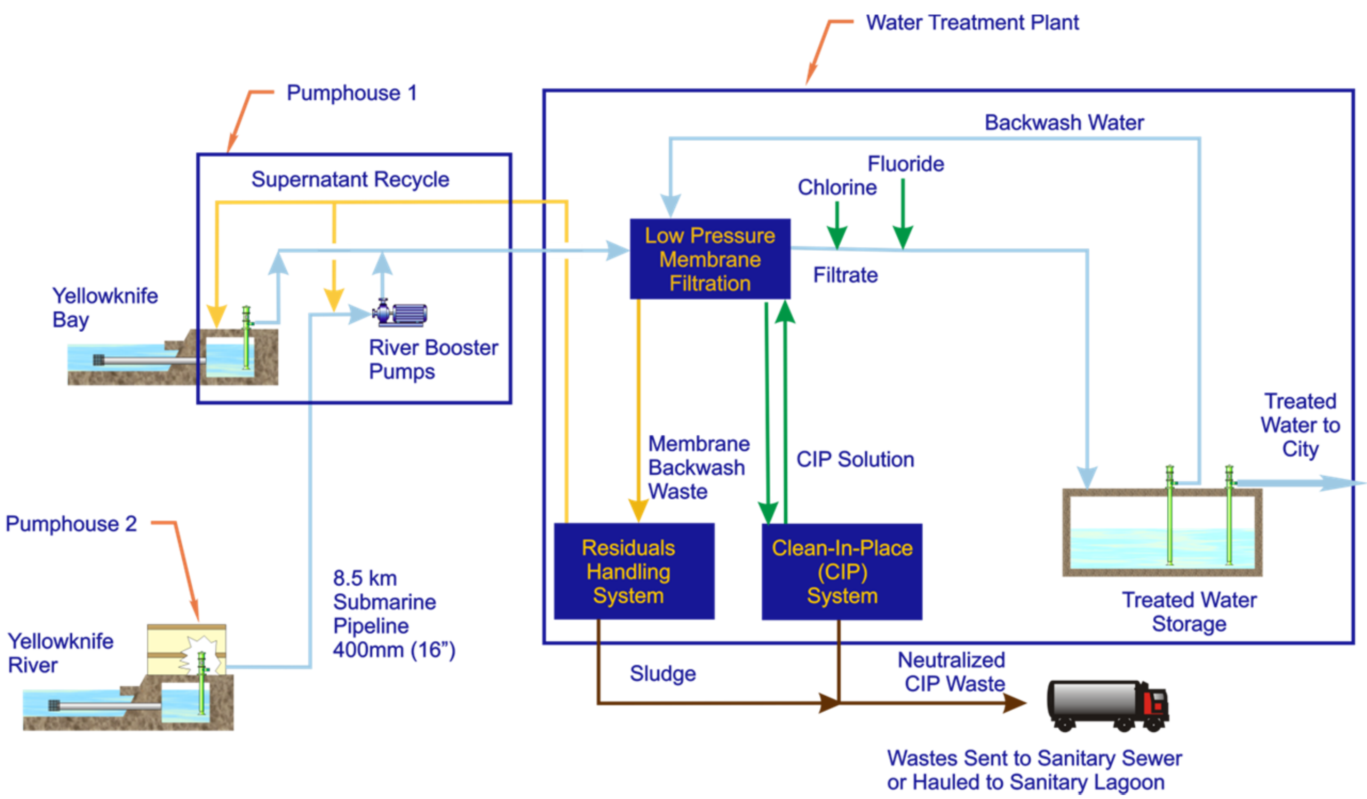


Figure 1. Existing Water System Schematic

4.2 Option 1 – River Source

Option 1 is to continue to use the Yellowknife River water source, and replace infrastructure such as the pipeline that is reaching the end of its service life. The main differences between the upgraded system and the existing system are a larger submarine pipeline, and some pumping changes in Pumphouse 1, as shown in **Figure 2**. The following sections describe the upgrades and work required for Option 1.

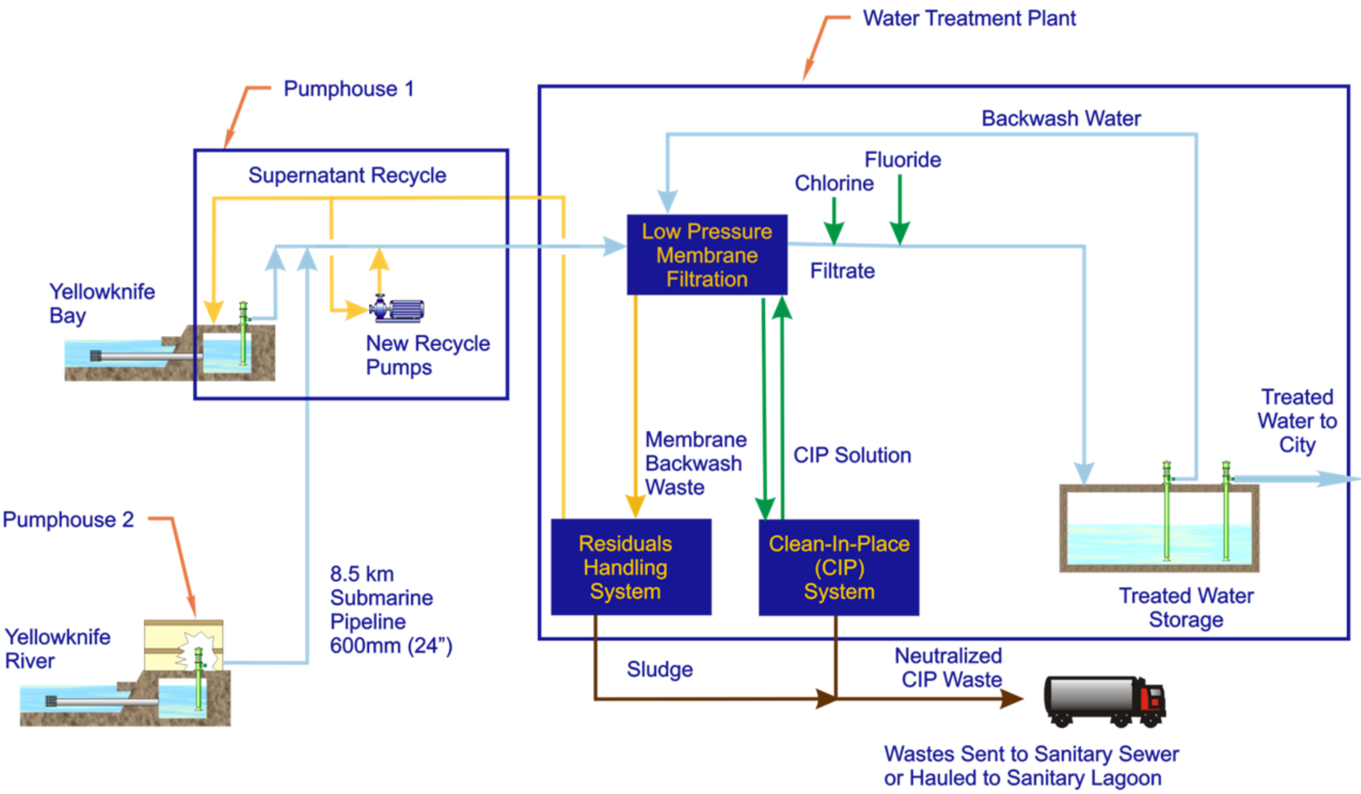


Figure 2. Option 1 River Source System Schematic

4.2.1 Surveys

Bathymetric survey and side-scan sonar survey would be needed along the pipeline route to facilitate design and installation.

4.2.2 Intake and Pumphouse 2

There are two existing intake lines from the Yellowknife River to the wetwell in Pumphouse 2. For this study we have assumed that as part of upgrades to Pumphouse 2, the existing intakes would need new screens that meet the Department of Fisheries and Oceans (DFO) guidelines to avoid entraining fish.

The existing pumps and piping in Pumphouse 2 would be replaced. Two new raw water pumps would each have a capacity of 165 L/s at 82m (307hp). No backup pumping (genset or diesel engine pump) at Pumphouse 2 is included in this option since the impact of a short-term power outage at Pumphouse 2 is minimal (because there is significant treated water storage in reservoirs in the city).

Electrical upgrades at Pumphouse 2 would include VFD drives for the new pumps, a new MCC, and associated electrical equipment and wiring. The existing transformer would also need to be upgraded; this would be done by the power utility but there may be a customer contribution cost required from the City of Yellowknife. An allowance of $100,000 has been included in the cost estimate for upgrading the transformer and power supply line.

4.2.3 Pipeline

The existing 8.5 km of 400 mm (16”) steel submarine pipeline would be replaced with 8.5 km of new 600 mm (24”) steel pipeline. The pipe would be cement-mortar lined and polyurethane coated for protection against corrosion and abrasion. The pipeline would follow roughly the same route as the existing pipeline through Yellowknife Bay (see **Figure 3**).

We have assumed the new pipeline would be installed during the winter when Yellowknife Bay is frozen (January – March), by welding the pipe on the ice, cutting the ice and lowering the pipe into the water through the cut. The pipeline installation would also require excavation to replace 82 metres of pipe between Pumphouse 2 and the River, 670 metres of pipe in a shallow area at the north end of the Bay, and 15 metres of pipe between Pumphouse 1 and the Bay.

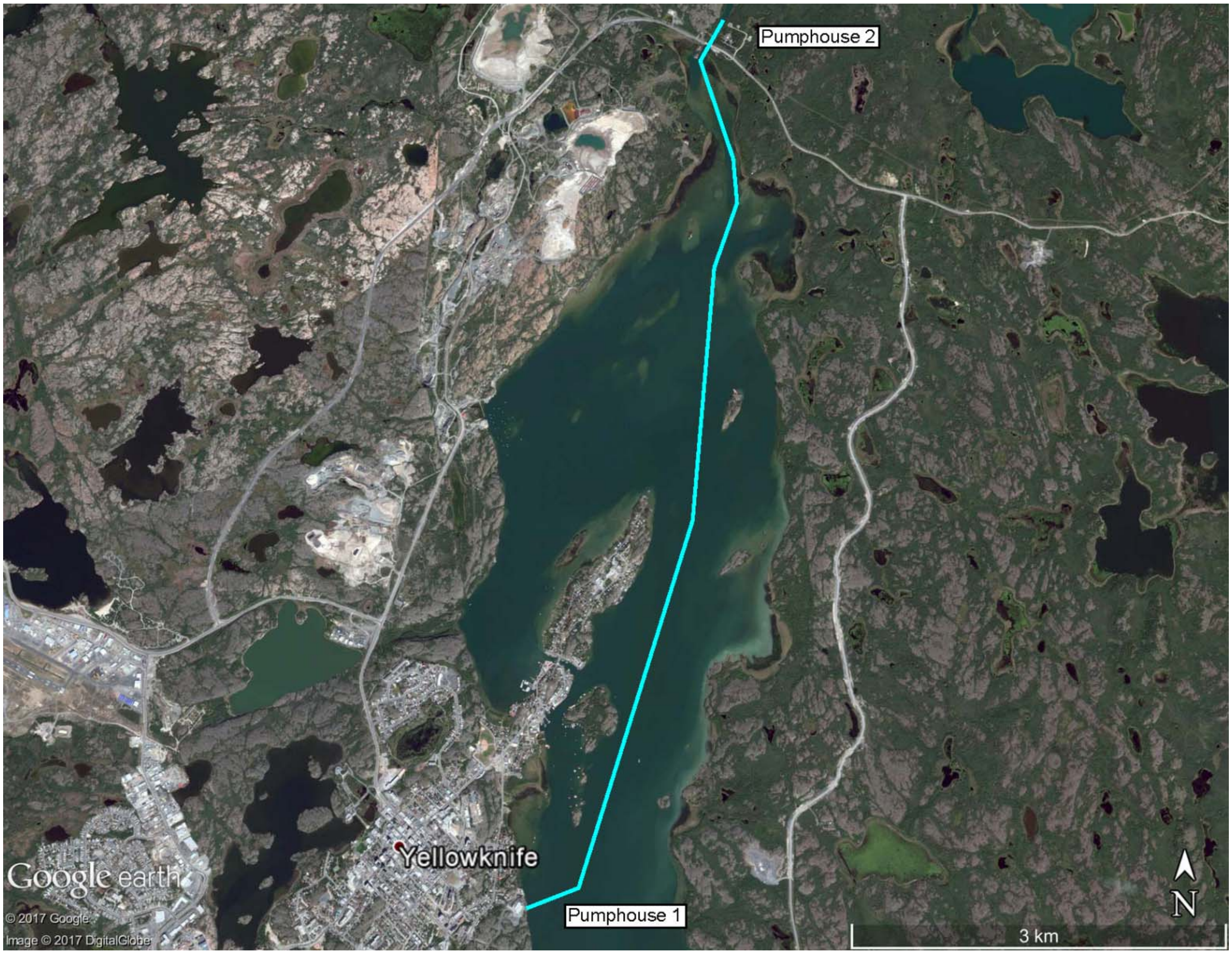


Figure 3. Pipeline from Pumphouse 2 to Pumphouse 1

For this study we have selected steel pipe as the design basis. **Table 3** presents a high-level comparison of steel and HDPE pipe materials for this application.

Table 3. Pipeline Material Comparison

Material	Advantages	Disadvantages
Steel	• Steel is a strong material that can handle minor irregularities in the lake bottom (i.e. rocks)	• Susceptible to corrosion; lining and coating required for long-term service
HDPE	• Not susceptible to corrosion	• Requires concrete weights to avoid flotation. Weights may suffer from differential settlement or degradation • Requires careful route selection and lake bed preparation to provide adequate support

4.2.4 Pumphouse 1 and WTP

Currently the WTP controls a set of booster pumps in Pumphouse 1, and the pumps at Pumphouse 2 are either operated at a fixed speed or are controlled indirectly based on the pressure in the submarine pipeline. This control strategy is used because communications between the WTP and Pumphouse 2 are not reliable enough to directly control the pumps in Pumphouse 2 from the WTP. However, both of these methods wastes energy; the pumps run at a higher speed than necessary, and excess pressure is reduced through an automated control valve at Pumphouse 1.

The long-term control strategy for Pumphouse 2 is to improve communications so that the WTP can directly control the river pump VFDs to minimize energy use. For this study we have assumed a new radio tower would be built at Pumphouse 2. Other communications options should be considered in preliminary design to determine the most suitable method.

The existing booster pumps in Pumphouse 1 would be demolished, and the WTP programming would be changed to include direct control of the River pumps. With the booster pumps gone, a new, smaller set of pumps would be needed at Pumphouse 1 to pump recycle water into the raw water piping. Recycle water is a combination of excess recirculation from the membrane process, and treated backwash wastewater from the gravity thickener process.

4.2.5 Permitting Requirements

The water supply pipeline and intake are permitted as a Type A Water Licence under the *Northwest Territories Water Act* (NWTWA) by the Mackenzie Valley Land and Water Board (MVLWB). The NWTWA was repealed in 2014, and replaced by the *Waters Act* (2014). As per Section 100, this Act will apply to all matters respecting waters under the administration and control of the Commissioner that were governed by the Northwest Territories Water Act before the coming into force of this Act. The current Water Licence (MV2009L3-0007) was granted May 31, 2010 and expires May 30, 2022. This licence limits water withdrawals to 3.6 million m^3/year and / or 575,000 m^3/month. Modifications to the Water Supply Facilities, as defined by the Water Licence, are allowed under specified conditions as outlined in Part E, Section E1 of the current Water Licence. This provision of the Water Licence allows for modifications to the Water Supply Facilities where the conditions in Section E1 have been met, specifically notification to the Board, the proposed changes do not place the Licence holder in contravention of the Water Licence or the Act, and the Board has no objections to the proposed modifications.

The proposed modification for Option 1 includes a new pipeline along the same alignment as the current 400mm welded steel submarine pipeline below Yellowknife Bay. It is AECOM's perspective that a new pipeline along the same alignment from Pumphouse #2 to Pumphouse #1 as the current primary source for potable water and the continued use of the emergency intake at Pumphouse #1 does not constitute a material change to the Water Supply Facilities. Furthermore, there are no anticipated changes to the water withdrawal parameters of the current licence. Typically, a Type A Water Licence renewal and/or amendment might require a Public Hearing. Such a Public Hearing was conducted for the renewal application in 2009-2010. AECOM is of the opinion that a Public Hearing is not likely required for modifications that do not change the intent or nature of the activity. The Public Hearing requirement should be confirmed with the Board in advance of an application process. Having said this, AECOM expects that a detailed construction and operations plan with all the requisite environmental protection mitigation and monitoring should be clearly defined and outlined in the documentation that is submitted to the MVWB.

Based on the above, the process should be relatively simple and straight-forward. The Proponent will file a notification with the Board a minimum of 60 days in advance of the construction of the modifications. This notification is intended to provide the specifics of the modification in sufficient detail to understand how the project will be built and monitored in the post construction and operations period. The proposed modifications cannot contravene the existing Water Licence or the Act. The Board has 60 days to provide their feedback on the proposed development plan, though they may also extend that period by another 60 days if necessary. The Board is required to notify the Proponent of the additional review time in advance of the expiry of the first 60 day period. Construction may proceed after expiry of the 60 days with no comments from the Board or on expiry of the second 60 day period.

Upon completion of the modifications as outlined in the notification to the Board, the Proponent will provide the Board with as-built plans and Record Drawings signed and stamped by an Engineer within 90 days of completion of the modifications.

Alternately, the modifications can also be approved by written approval from the Board where these modifications do not meet the conditions outlined in Section E1.

The regulatory review process will include other agencies and government departments besides the MVLWB. AECOM expects that the documentation submitted to the MVLWB will be circulated as referrals to other agencies and government departments that may hold an interest in the project. As such, AECOM recommends that early in the process, the Proponent should engage some of these authorities in advance of submitting their application. This approach can lead to a more collaborative resolution of potential issues for these groups. For example, the Department of Fisheries and Oceans, and the appropriate staff in Environment and Natural Resources, Government of the Northwest Territories, should be brought into the conversation early to confirm their perspective and expectations as it relates to these modifications. Similarly, NavCan should be notified and consulted for compliance with the requirements under the Navigation Protection Act.

In the Public Registry files, there is a DRAFT Timeline that was developed for the 2009 renewal application. AECOM has used this template and revised the content to reflect the current understanding and expectations as outlined for Option 1 and Option 2 (**Table 4**). The permitting process for Option 1 from the time of submission of documentation to the Board is estimated between 60-120 days.

Table 4. Estimated Permitting Timeline for Options 1 and 2

TASK	Option 1	Option 2
	Duration	Duration
Application Received	milestone	milestone
Application Sent for Review	milestone	milestone

TASK	Option 1	Option 2
	Duration	Duration
Notification of Modification review period	60 days	n/a
Work Plan sent out for review	n/a	2-3 weeks
Comments issued to Proponent	milestone	milestone
Proponent reply to comments	2 weeks	2 weeks
Technical Meeting	n/a	1-2 days
Written Interventions Due	n/a	2 weeks (start approx. 45 days in advance of hearing
Pre-Hearing Conference	n/a	Approx. 30 days before hearing
Intervention IRs – if required	n/a	10 days before presentations
Proponent's Response to interventions	n/a	15 days prior to hearing
Hearing presentations and Intervention IRs due	n/a	10 days prior to hearing
First Public Hearing	n/a	2-3 days
Undertakings Due	n/a	1 week after hearing
Final Arguments Due - Intervenor	n/a	320 days after hearing
Final Arguments Due - Proponent	n/a	320 days after hearing
Notification of Modification additional 60 day period	60 days	n/a
DRAFT Water Licence sent for review	n/a	21 days for review
FINAL Water Licence and Reasons for Decision presented to the Board	n/a	1 day
Water Licence sent to the Minister for review and approval	n/a	60 days
Cumulative duration	**60-120 days**	**485 +/- days**

Note1: Public consultation process is assumed to include all items from "Written Interventions Due" to "Final Arguments Due"

4.2.6 Environmental Protection

Environmental requirements will need to be evaluated during design of whichever raw water supply upgrade option is selected. There is the potential for several species at risk to be present in the work areas.

For Option 1, major mitigation activities that may be required include:

- Timing of work to protect specific fish, birds or other organisms, particularly for work in water
- Contaminant and spill management
- Erosion and sediment control, including measures such as silt booms/silt curtains
- Stabilizing disturbed shorelines through re-vegetation
- Rehabilitation/restoration of disturbed habitat

4.2.7 Redundancy

This option includes a single pipeline from Pumphouse 2 to Pumphouse 1, which is a potential point of failure. The Yellowknife Bay intake at Pumphouse 1 would continue to be used as an emergency back-up water source in the event of pipeline failure. An online arsenic analyzer would be added at Pumphouse 1 to monitor arsenic concentrations in the Bay source.

The new raw water pumps in Pumphouse 2 would each provide 50% of the design maximum day flow. If a raw water pump failed, the emergency back-up water source could be used to provide additional water.

4.3 Option 2 – Bay Source

Option 2 is to switch to using the Yellowknife Bay intake as the City's primary raw water source, instead of using this intake only as emergency back-up supply.

There is concern about the quality of Yellowknife Bay water due to its location downstream of Giant Mine. As discussed in Section 3, the Bay source option includes an arsenic treatment system capable of removing arsenic and antimony from the water before it enters the potable water distribution system, in order to address the risk of increased arsenic and antimony concentrations at the Pumphouse 1 intake following a short-term upset event at Giant Mine. The adsorptive media treatment system in this option would reduce the risk of high arsenic in the City's drinking water, but would not remove this risk entirely, as discussed in section 3.2.2.

Figure 4 gives an overview of the water supply and treatment system for Option 2. The following sections describe the upgrades and work required for Option 2.

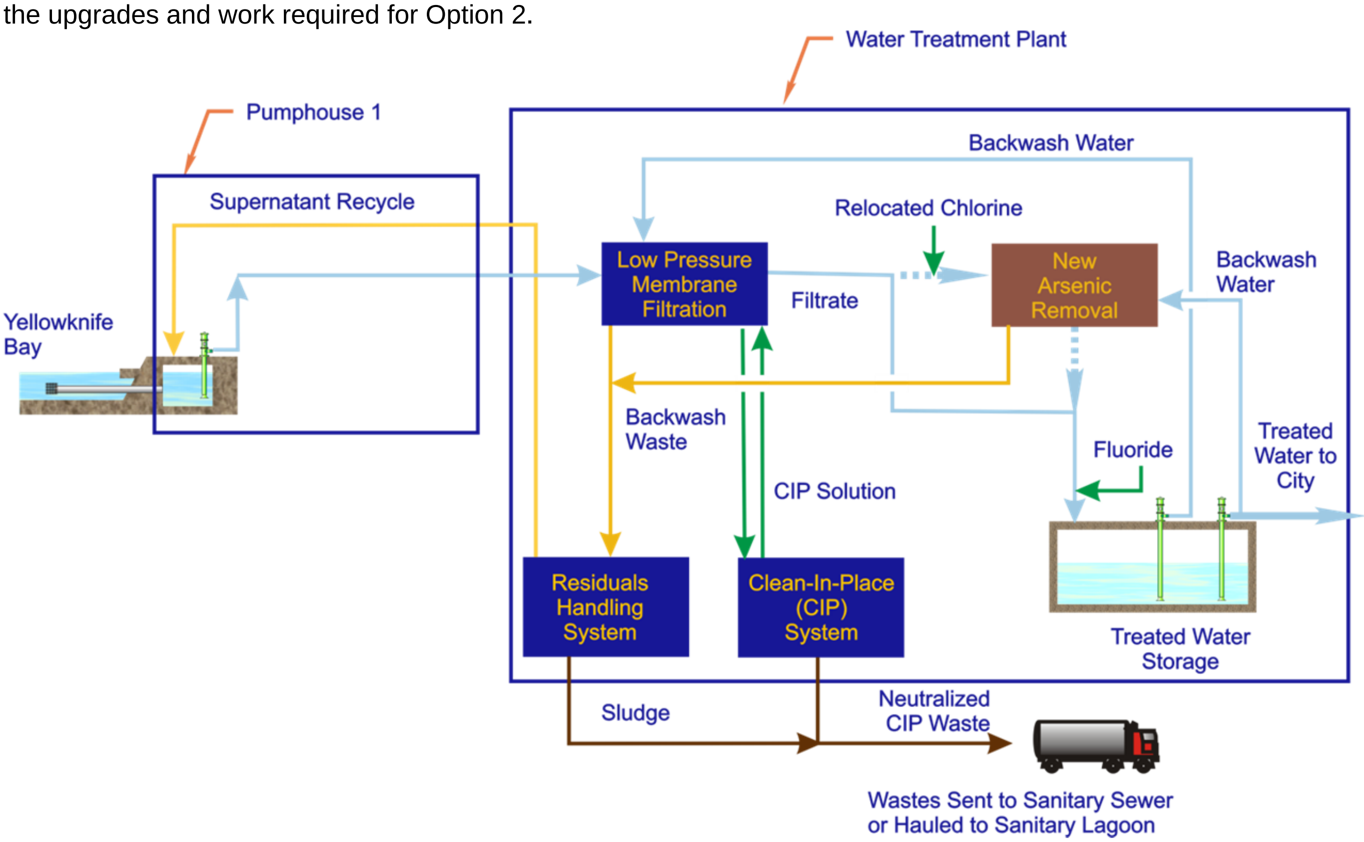


Figure 4. Option 2 Bay Source System Schematic

4.3.1 Intake and Pumphouse 1

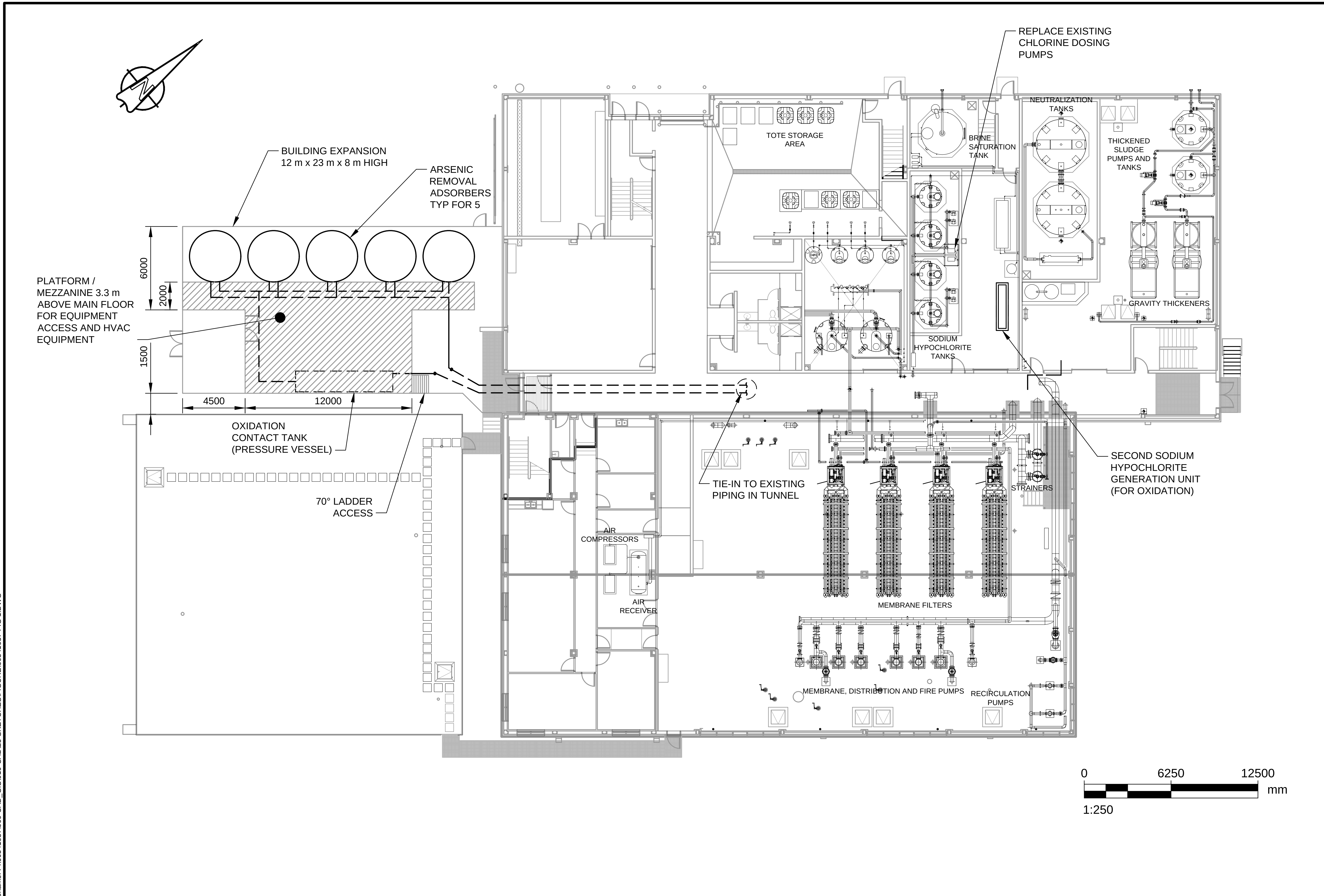
The existing raw water intake screen would need to be replaced with a new screen that meets the Department of Fisheries and Oceans (DFO) guidelines to avoid entraining fish.

The existing emergency raw water pumps in Pumphouse 1 would need to be replaced with larger pumps in order to supply enough pressure for the new arsenic treatment system.

The river water booster pumps in Pumphouse 1 would no longer be needed in this Option, so the pump room and unused chlorine/fluoride room could be demolished. Demolishing this building (which is the oldest part of Pumphouse 1) saves annual heating costs and removes a potential fire hazard.

4.3.2 Water Treatment Plant Expansion

The WTP building would need to be expanded to provide space for the arsenic treatment equipment. **Figure 5** shows the conceptual layout of this building expansion.



AECOM

Figure 5

YELLOWKNIFE
WATER TREATMENT PLANT
THE CITY OF YELLOWKNIFE
Project No.: 60541637 Date: 2017-07-27

ANSI B 279.4mm x 431.8mm

Approved: ____ Checked: ____ Designer: ____ Project Management Initials: ____

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It is assumed the proposed building extension will match the existing building in appearance and general structural form. The building extension is preliminarily sized to be 12 m wide x 23 m long x 8 m tall. The height of the existing building is approximately 8.5 m.

The superstructure is assumed to be flat roof supported on 38mm deep steel deck on OWSJ on wide flanged steel beams and HSS columns down to the concrete foundations. Lateral stability to be provided by steel angle cross bracing or HSS ‘K’ bracing. The new roof and wall construction is assumed to be similar to the existing work carried out in 2015.

Structural live loads for the proposed extension are assumed to be:

- Main floor slab: 6.0 kPa minimum.
- Main floor live load to be increased to allow for the filters and tanks as required.
- Platforms and stairs: 2.4 kPa minimum.
- Main floor slab superimposed dead load of 0.5 kPa for mechanical and electrical (combined) and a superimposed dead load of 1.0 kPa for partitions.

Loading for Snow and Wind is from NBC 2010 (National Building Code) of Canada and NBC 2010 Structural Commentaries (Part 4 of Division B).

The site is located on a NBC 2010 seismic site classification ‘A’ and therefore seismic loading need not be considered further.

The substructure is assumed to be structural suspended slab supported on grade beams. Grade beams to be founded on bedrock or if bedrock is located at some depth rock socketed piles will be used. General use GU concrete is assumed suitable for the slab and grade beams. It is understood that the geotechnical condition of the site is shallow overburden to the bedrock to be removed and the void between the structural slab and bedrock to be filled with compacted gravel. No void-form is expected to be required.

The new structure may need to support the roof and main floor loads. Careful consideration of the existing structure’s capacity to support the proposed extension would be required during design.

A mezzanine (partial second floor) will be required for mechanical equipment. There will also be equipment platforms for accessing the top of the adsorptive media filters to inspect and replace the media.

4.3.3 Building Mechanical

The new building expansion would require its own heating and ventilation equipment.

For this study we have assumed a single Make-up Air Unit (MAU) with built-in heat recovery ventilator would be installed on a mezzanine level in the building extension. Four new glycol unit heaters would be used to heat the new room. One new glycol pump would be added in the existing boiler room. No additional boilers would be needed.

4.3.4 Electrical

Electrical upgrades would be required at Pumphouse 1 in order to run larger (250hp) motors with VFDs for new raw water pumps in Pumphouse 1. We have assumed the utility service can be upgraded from 400 amp to 800 amp. The trip unit on the main breaker would need to be changed. The new 250hp motors/drives would be fed from the existing 1200 amp rated main service CDP directly, and not from the current 400 amp MCC's.

The existing genset should be able to carry the two new 250 hp motors, with monitoring and depending on what other loads are operating.

4.3.5 Arsenic Treatment Process

As discussed in Section 3, the recommended treatment process for the Bay water source option is ferric oxide/hydroxide adsorptive media. See **Appendix B** for the most recent vendor data from DeNora for a system using Bayoxide E33 media. This system would have five units operating in parallel, each 12' in diameter. Backwash water would be provided through a takeoff from the treated water pipeline in the basement before it leaves the WTP to distribution.

The ferric media may provide some removal of arsenite (As^{+3}), but the vendor recommends oxidizing As^{+3} to arsenate (As^{+5}) for the best media performance. Sodium hypochlorite (i.e. chlorine), which is currently used for disinfection, could also be used to oxidize arsenic in an Upset Condition. The existing sodium hypochlorite dosing point in the WTP tunnel would need to be relocated to somewhere on the new arsenic system supply piping. Alternatively, the tunnel piping could be modified to add takeoffs to and from the arsenic system downstream of the existing hypochlorite dosing point, but then the fluoride dosing point would need to be relocated to avoid having the adsorptive media remove the fluoride. The Bayoxide E33 media is not expected to remove chlorine residual from the water.

Assuming there is up to 1190 μg/L of As^{+3} in the raw water as discussed in Section 3, additional free chlorine (in addition to the amount normally required for disinfection) of up to 1.1 mg/L would be required to oxidize the As^{+3} to As^{+5}.

For this evaluation we have assumed that a second on-site sodium hypochlorite generation skid would be installed to provide additional capacity for higher chlorine doses. The second generation unit would be connected to the existing brine tank and hypochlorite storage tanks. Alternatively, the City could choose to use totes of 12% sodium hypochlorite (diluted using the existing dilution panel) to supplement the existing generation capacity during Upset Conditions, instead of installing a second generation skid. A pressurized oxidation tank should be installed to provide at least 1 minute of holding time to ensure that As^{+3} is oxidized prior to the adsorptive media process.

Online arsenic analyzers would be installed upstream and downstream of the arsenic treatment system to monitor arsenic concentrations. WTP operators would also take regular weekly grab samples for laboratory analysis to confirm the online analyzer readings.

4.3.6 Permitting Requirements

Section 4.2.5 Permitting Requirements provides the details to permitting for Option 1 (a new pipeline along the same alignment as the existing with the same intent, purpose, terms and conditions as the existing system). In this case, the modifications as considered under Part E, Section E1 of the Water Licence are considered to fall within the scope of allowable modifications that do not contravene the Water Licence or the Act. For Option 2, a change to the emergency intake to be repurposed as the primary water supply is considered a more significant, possibly a material, change to the Water Supply Facilities as defined by the Water Licence and may require additional effort and information.

The current Water Licence was issued May 31, 2010 on the basis of the supporting documentation, including the Water Licence Renewal Application Supplementary Report (June 2009). The fresh water intake at Pumphouse #1 has served the function of emergency intake, and was not intended for use as the primary source. Before using the existing intake as the primary water source, the City should evaluate the potential effects this change would have on the biophysical environment and related aspects of the design, construction and operation of this component of the Water Supply Facilities. Early guidance from a conversation with the Board suggests that this change would be an amendment to the licence and thus a Public Hearing would probably be required (pers. comm. Erica Janes, MVLWB).

Specifically, Option 2 could require additional effort to confirm that the change in operations will not result in impacts that were not considered when evaluated as only an emergency intake. It should be confirmed whether or not the original design and operation expectations as an emergency intake are still suited to primary source operations. It is not clear from the available documentation what constitutes an emergency, or what specific operating parameters or limits for the emergency intake were considered in the original evaluation and assessment.

There has also been considerable discussion and public debate regarding the water quality and particularly arsenic in Yellowknife Bay. This report addresses some of that discussion in Section 2.

As noted in the Water Licence and the Act, modifications require an approval by the Board regardless of their type, nature or specifics. Similar to Option 1, the Proponent would file notification of the proposed amendments. The schedule and tasks / activities will be the same with one significant change. The circumstances for Option 2, namely a change in use of the emergency intake to be repurposed as the primary source as noted, forms the basis to AECOM's perspective that this modification may require a public hearing. The specific steps are provided in **Table 4**. The Public Hearing can involve a tremendous amount of effort and activity related to the administrative process. Based on the City of Yellowknife's discussions with the Water Board, the public consultation process for changing the water source is expected to take one full year. The balance of the process will remain similar if not identical to the process for Option 1, with the added elements of re-drafting new Terms and Conditions for the Water Licence. This step alone could add another 60+ days to the schedule.

As noted for Option 1, in the Public Registry files, there is a DRAFT Timeline that was developed for the 2009 renewal application. AECOM has used this template and revised the content to reflect the current understanding and expectations as outlined for Option 1 and Option 2 (**Table 4**). The permitting process for Option 2 from the time of submission of documentation to the Board is estimated at approximately 485 days.

4.3.7 Environmental Protection

Environmental requirements will need to be evaluated during design of whichever raw water supply upgrade option is selected. There is the potential for several species at risk to be present in the work areas.

For Option 2, major mitigation activities that may be required include:

- Timing of work to protect specific fish, birds or other organisms (for new intake screen)

4.3.8 Redundancy

The single intake line into Pumphouse 1 is a potential point of failure (for example by a pipeline break or screen plugging). However, this is a short length of pipe located close to the Pumphouse, so damage from impact to this line is unlikely. The new intake screen should be designed to minimize the potential for frazil ice buildup, for example limiting the approach velocity.

The new (higher head) raw water pumps in Pumphouse 1 would each provide 50% of the design maximum day flow. A shelf spare pump could be installed if one of the raw water pumps failed.

The new adsorptive media system would have five (5) adsorber vessels. While one vessel is out of service for media replacement, equipment repair, etc., the other four would continue to operate, and the WTP capacity would be temporarily reduced to 4/5 of the design maximum flow.

4.4 Cost Estimates

Conceptual cost estimates for each option are shown in **Table 5**, in 2017 dollars. See Appendix C for details.

The capital costs include engineering fees and 30% construction contingency. The River capital cost includes additional contingency for the submarine pipeline work, to address the risks associated with working on ice.

Operation and maintenance (O&M) costs in the table are incremental costs which only include items that vary between the two options (in other words this is not the total O&M cost for the City's water supply). These O&M estimates include the costs for raw water pumping, diver inspections of the submarine pipeline, building HVAC for Pumphouse 2 and the new WTP expansion, adsorptive media replacement and disposal of old media, incremental operational labour and a 20% contingency. The O&M costs were calculated based on projected flows for the 13-year Average Day Demand of 10.4 ML/d potable water.

The life cycle costs were calculated using a 25-year period and an annual discount rate of 3%.

Table 5. Conceptual Cost Estimates

	Option 1 – River Source	Option 2 – Bay Source
Total Estimated Capital Cost	**$27,790,000**	**$9,340,000**
Annual Estimated O&M Cost	**$300,000**	**$510,000**
25-year Life Cycle Cost (Net Present Value)	**$33,000,000**	**$18,200,000**

5. Options Evaluation

5.1 Decision Model Basis

The two raw water source options are being evaluated in this study using a matrix-type decision model. In this approach the project team identifies all of the criteria that will affect the decision; assigns a weight to each criteria based on its relative importance; and determines a numeric rating for each criteria and each option. This generates a score for each option.

The criteria and weightings developed for this study are shown in **Table 7** along with the ratings and total scores. The weights in the second column were reviewed and approved by Yellowknife City Council.

5.2 Qualitative Evaluation (Ratings)

5.2.1 Susceptibility to Raw Water Quality Changes

"Susceptibility to Raw Water Changes" items are rated based on how a change in raw water quality (within expected range for each source) would affect WTP operation. A rating of 100 means the treatment process is expected to handle raw water changes without any additional operational time, increased residuals production, etc. A low rating means raw water changes would have a major impact on WTP operation.

5.2.1.1 Arsenic

The life cycle cost estimate in Section 4 for the Bay option assumes that the arsenic treatment media is replaced every ten years, although the raw water arsenic levels are currently low enough that theoretically the media could last even longer than ten years. However, if short-term "Upset Conditions" as described in Section 2 were to occur, where a disaster at Giant Mine would release a large amount of arsenic into Yellowknife Bay, then the adsorptive media at the WTP might need to be replaced more frequently. This means there is the potential for very high operation and maintenance costs during "Upset Conditions".

The actual replacement frequency and cost in Upset Conditions is impossible to accurately predict since it depends on unknowns such as the amount of arsenic released, mixing/dilution patterns in the Bay, and performance of the media. The cost of one catastrophic failure of the Northwest Pond is estimated to range from $0 to $10 million, depending on the arsenic concentrations at the intake and the performance of the media. The media life will depend on the concentrations of other competing ions in the raw water, as well as arsenic concentrations and speciation. As discussed in section 3, we expect that the adsorptive media may need to remove antimony as well as arsenic in "Upset Conditions".

Given the potential for severe impacts on WTP operation and costs, the Bay option receives a low rating for this item. However, the rating also needs to consider the likelihood of arsenic "Upset Conditions" occurring.

The River source is not expected to experience any notable changes in arsenic concentrations and is therefore rated higher.

Ratings:

Option 1 – River Source: 90/100

Option 2 – Bay Source: 20/100

5.2.1.2 Organics

Naturally occurring organic matter, measured as Total Organic Carbon (TOC), can impact WTP operation by increasing fouling of the membrane filters. Waters with higher organic concentrations also tend to have higher concentrations of disinfection by-products in the treated water. However, the average organics concentrations are similar for both the Yellowknife River (average TOC of 5.8 mg/L from 2 samples in 2000-2002) and Yellowknife Bay (average TOC of 5.5 mg/L from 8 samples in 2010), so both options are rated similarly. The River option is rated slightly lower because the River water quality is expected to have more variation throughout the year, potentially requiring more adjustments to chlorine dosages or membrane cleaning schedules.

Ratings:

Option 1 – River Source: 70/100

Option 2 – Bay Source: 80/100

5.2.2 Constructability

5.2.2.1 Schedule

For this item, faster projects are generally rated higher. Schedule is affected by factors including environmental permitting, construction season, and material/equipment lead times.

Table 6 shows an initial estimate of the project schedule for each option. For the River option, construction would occur from January to April 2020. For the Bay option, construction would occur from May 2020 to January 2021, following a water licence amendment and public consultation process in 2019 to early 2020. Therefore the Bay option is rated lower for the decision evaluation.

Table 6. Conceptual Project Schedules

Task	Option 1 – River Source		Option 2 – Bay Source	
	Duration	Completed Date	Duration	Completed Date
Site Surveys and Predesign	8 weeks[1]	July 2, 2018	8 weeks	July 2, 2018
Detailed Design	16 weeks	October 22, 2018	22 weeks	December 3, 2018
Water Licence Notification of Modification	60 – 120 days	February 18, 2019	n/a	n/a
Water Licence Amendment with Public Hearing	n/a	n/a	485 days	March 30, 2020
Construction Tender	6 weeks	April 1, 2019	6 weeks	May 11, 2020
Shop Drawings and Equipment Supply	16 – 20 weeks[2]	August 19, 2019	20 - 26 weeks	November 9, 2020
Construction and Commissioning	15 weeks[3]	April 14, 2020	35 weeks[4]	January 11, 2021

[1] *Bathymetric and sonar surveys need to occur in open-water season*
[2] *Until start of delivery. For delivery of 132m of pipe per day, delivery duration would be another 65 days (10 weeks)*
[3] *Limited construction window from January 1 – March 31 (possibly into April)*
[4] *Building construction and shop drawings/equipment supply assumed to start at the same time*

Ratings:

Option 1 – River Source: 70/100

Option 2 – Bay Source: 40/100

5.2.2.2 Ease of Construction

This rates the risk of construction issues leading to schedule and/or cost overrun above and beyond that covered in cost estimate contingency.

The River option is rated lower than the Bay option because construction of the pipeline requires working on ice above cold water (which carries risks to personnel and equipment) in a limited timeframe (from January to mid-April, when the ice is thick enough to support vehicles). This risk has been partially addressed in the cost estimates as well by including a contingency cost.

The Bay option has minor risks due to working in and connecting to the existing WTP building.

Ratings:

Option 1 – River Source: 40/100

Option 2 – Bay Source: 80/100

5.2.2.3 Impact on Existing Operation

This rates construction impacts on operation, i.e. equipment shutdowns for tie-ins to the existing water supply system. Both options will require brief shutdowns of equipment upstream of the treated water storage reservoirs for tie-ins.

Ratings:

Option 1 – River Source: 80/100

Option 2 – Bay Source: 80/100

5.2.3 Reliability of Water Supply

5.2.3.1 Infrastructure Failure

This rates the risk of infrastructure failure leading to not enough water available to meet the City's demands.

For the River option, the risk of pipeline failure is mitigated by having the emergency pumps capable of drawing water from the Bay. There is still a risk that the pipeline could fail at the same time as a catastrophic failure at Giant Mine leads to elevated arsenic levels at the Bay intake; however, this would require two unlikely events to happen simultaneously. If both events occurred simultaneously, a new online analyzer at Pumphouse 1 would detect elevated arsenic levels and the City would have no acceptable water supply until the pipeline repair is completed.

The primary risk with the Bay option is that in a short-term "Upset Condition", the adsorptive media may not be able to fully treat the potentially very high influent concentrations of arsenic to drinking water standards, as discussed in section 3.2.2. If the treatment process cannot adequately treat the water then the City would have no acceptable water supply until the raw water concentrations have reached a treatable level due to natural flows in the Bay. Based on the assumptions in Appendix A for arsenic concentration decline in Upset Conditions, this could take up to approximately 80 days.

Also for the Bay option, as noted in Section 4.3.8, the WTP capacity would be temporarily reduced to 4/5 of the maximum design flow whenever one of the adsorber vessels is offline for maintenance. Maintenance is not expected to be needed often and can likely be timed to coincide with periods of low water demand.

The Bay option is rated lower than the River for this item because the existing River pipeline has operated for decades with failure, while historically some water from Giant Mine has been released into Baker Creek[4],[5].

Ratings:

Option 1 – River Source: 70/100

Option 2 – Bay Source: 50/100

5.2.3.2 Process/Operation/Monitoring Failure

This rates the risk of treatment process, operational or monitoring failures leading to potable water quality problems such as exceeding the allowed limit for turbidity or arsenic.

The River option has typical WTP operation and monitoring requirements, including monitoring pH, temperature, turbidity, and free chlorine. Arsenic monitoring is required at the Bay wetwell because this is the emergency water supply. This option has a risk of high arsenic concentrations entering the potable water distribution system if a monitoring failure and two infrastructure failures occurred simultaneously: Giant Mine tailings pond containment

[4] *Yellowknifer Volume 44 Issue 54, Wednesday September 23, 2015: article mentions an event in 2011 where Baker Creek overflowed into an arsenic-contaminated tailings pond at the mine.*

[5] *CBC News online article, May 7, 2013: surface meltwater from Giant Mine spilled through a berm into Baker Creek*

failure leading to short-term arsenic “Upset Condition”, a submarine pipeline failure, and failure of a new online arsenic analyzer at Pumphouse 1.

The primary risk with the Bay option is that in a short-term “Upset Conditions”, the adsorptive media may not be able to fully treat the potentially very high influent concentrations of arsenic to drinking water standards, as discussed in section 3.2.2. If this process failure occurred and the treated water arsenic analyzer also failed (without providing an error message), then high concentrations of arsenic could enter the potable water distribution system.

The Bay option also requires the same raw water quality monitoring as the River option. If an arsenic “Upset Condition” occurred, then there would be a risk of arsenic breakthrough (arsenic passing through the adsorptive media process in concentrations higher than the allowed limit) if the media is not replaced at the right time. Therefore this option has a risk of high arsenic and/or antimony concentrations entering the potable water distribution system if three monitoring/operation failures and one infrastructure failure occurred simultaneously: Giant Mine tailings pond containment failure leading to short-term arsenic “Upset Condition”, failure of a new online arsenic analyzer monitoring treated water downstream of the adsorptive media in the WTP, and failure to replace the media when it is nearing contaminant breakthrough, leading to arsenic and/or antimony passing through exhausted adsorptive media.

The Bay option is rated lower than the River option for this item because the drinking water arsenic limit could be exceeded if two failures occurred simultaneously for the Bay option, or if three failures occurred for the River options.

Ratings:

Option 1 – River Source: 80/100

Option 2 – Bay Source: 60/100

5.2.4 Ease of Operation

Ease of operation is partially addressed in O&M costs but this item gives more weight to operation time, and includes items not reflected in costs like frustration troubleshooting a new treatment process or desirability of driving to a remote site.

The upgraded River supply pumping would be simpler to control than the existing system, as the upgraded system would include direct control of Pumphouse 2 pumps instead of the current strategy of using a control valve and booster pumps in Pumphouse 1. No new treatment processes would be needed.

For the Bay option, Pumphouse 2 would no longer be needed, so City staff would have one less remote site to visit, monitor and maintain. The new arsenic removal process is relatively simple with few operational requirements as long as arsenic concentrations are low or stable. In the event of an “Upset Condition” with elevated and variable arsenic levels in the raw water, this process would require additional operator attention for monitoring arsenic levels and replacing media as needed. However this risk of additional operational requirements is addressed in the “Susceptibility to Raw Water Changes” criteria.

Ratings:

Option 1 – River Source: 70/100

Option 2 – Bay Source: 70/100

5.2.5 Life Cycle Cost

As shown in Section 4.4, the estimated 25-year net present value is $33.0 million for the River option and $18.2 million for the Bay option. For the decision model evaluation, net present value costs are scored from 0 – 100 where 100 is a cost of $10 million and 0 is a cost of $35 million.

Ratings:

Option 1 – River Source: 8/100

Option 2 – Bay Source: 67/100

5.3 Evaluation Results

Table 7 shows the matrix decision model, including criteria weightings and option scores. **Figure 6** illustrates the same results graphically, to show the contribution of each major criteria to the overall score.

Table 7. Decision Model Evaluation

					Ratings		Weighted Scores	
Criteria	**Weight**	**Sub-criteria**	**Sub-weight**	**Overall Weight**	**Option 1 - River**	**Option 2 - Bay**	**Option 1 - River**	**Option 2 - Bay**
Susceptibility to Raw Water Quality Changes	20%	Arsenic	80%	16%	90	20	14.4	3.2
		Organics	20%	4%	70	80	2.8	3.2
Constructability	10%	Schedule	25%	2.5%	70	40	1.8	1.0
		Ease of Construction	50%	5%	40	80	2.0	4.0
		Impact on Existing Operation	25%	2.5%	80	80	2.0	2.0
Reliability of Water Supply	50%	Infrastructure Failure	50%	25%	70	50	17.5	12.5
		Process / Operation / Monitoring Failure	50%	25%	80	60	20.0	15.0
Ease of Operation	5%	Ease of Operation	100%	5%	70	70	3.5	3.5
25-year Life Cycle Cost	15%	20-year Life Cycle Cost	100%	15%	8	67	1.2	10.1
						Total Score	65.2	54.5

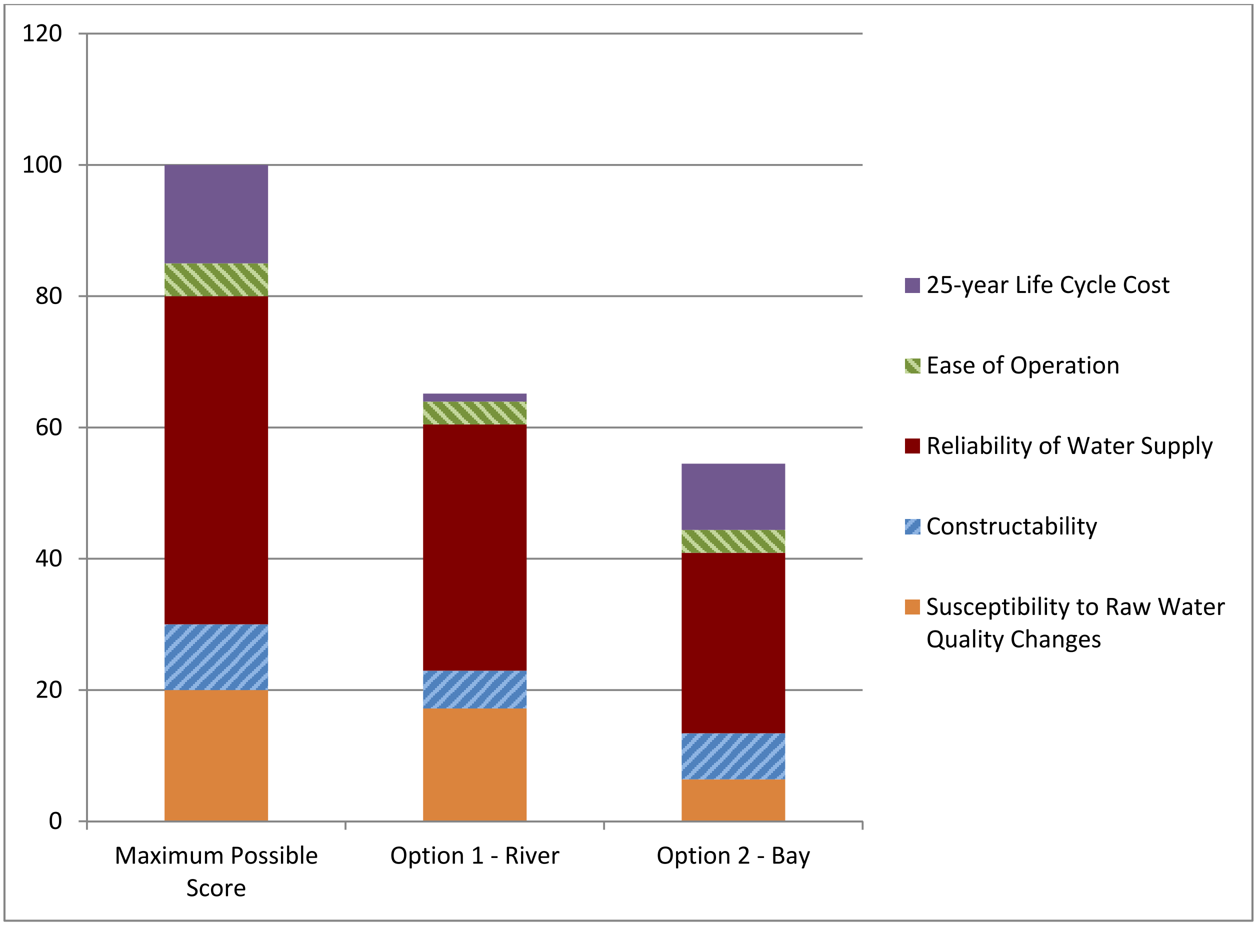

Figure 6. Decision Model Evaluation

5.4 Sensitivity Analysis

Sensitivity analysis is intended to evaluate the robustness of a model given that there is typically uncertainty associated with some of the inputs. For this study, we have considered how the overall scores and recommendation would change if various criteria weightings, ratings, or cost estimates varied. Option scores were calculated for the following alternative conditions:

1) Base Model (the ratings presented in Table 7).

2) Alternative weights: Susceptibility to Raw Water Changes 15%, Constructability 5%, Reliability of Water Supply 20%, Ease of Operation 0% and Life Cycle Costs 60%. This demonstrates the effect of making cost more important to the decision.

3) Alternative weights: Susceptibility to Raw Water Changes 50%, Constructability 10%, Reliability of Water Supply 20%, Ease of Operation 5% and Life Cycle Costs 15%. This places more emphasis on the operational impacts associated with treating an arsenic Upset Condition (including costs in a qualitative sense) and less emphasis on the water supply and water quality risks associated with both options.

4) Rating of 0 instead of 20 for Bay option, Susceptibility to Raw Water Changes – Arsenic.

5) Rating of 30 instead of 70 for River option, Reliability of Water Supply – Infrastructure Failure. A score of 70 was selected because the existing pipeline has operated reliably for decades. However, a lower score may be appropriate because the City would have no acceptable water supply in the unlikely event of simultaneous pipeline break and Upset Conditions.

6) Rating of 90 instead of 50 for Bay option, Reliability of Water Supply – Infrastructure Failure. A score of 90 could be appropriate if data were available supporting the ability of an adsorptive media system to reliably handle arsenic concentrations up to 4,600 µg/L, especially during a sudden increase from very low background concentrations.

7) Rating of 0 for both Bay and River options, Reliability of Water Supply – Operational/Monitoring Failure. The selected ratings of 80 (River) and 60 (Bay) reflect the low likelihood of the operational/monitoring failures discussed for this item. However, a lower score could be considered for both options due to the severe consequences of a water quality failure during Upset Conditions, including possible fatalities.

8) Using a range of $18.2 - $33.0 million for calculating the Life Cycle Cost ratings, instead of $10 - $35 million. This means the lowest cost option (Bay) receives a rating of 100/100 and the highest cost option (River) receives a rating of 0/100.

9) Using a scoring range of $0 - $45 million for calculating the Life Cycle Cost ratings.

10) Life Cycle Cost 30% higher than the Base Model estimate for the River option (and scoring range of $10 - $45 million).

11) Life Cycle Cost 30% lower than the Base Model estimate for the River option (and scoring range of $10 - $45 million).

12) Life Cycle Cost 30% higher than the Base Model estimate for the Bay option (and scoring range of $10 - $45 million).

13) Life Cycle Cost $10 million higher than the Base Model estimate for the Bay option (and scoring range of $10 - $45 million), and rating of 60 for Susceptibility to Raw Water Changes for the Bay option. This moves the major cost impacts of an Upset Condition from the “Susceptibility” criterion to the “Life Cycle Cost” criterion. The “Susceptibility” score still needs to consider additional operational labour, monitoring, and other operational impacts of an Upset Condition besides media replacement. $10 million is the high end of the range of estimated O&M costs potentially associated with Upset Conditions, as noted in Section 5.2.1.1.

14) Life Cycle Cost 30% lower than the Base Model estimate for the Bay option (and scoring range of $10 - $45 million).

The alternative total scores are shown in **Figure 7**. Of the thirteen alternative conditions considered here, three resulted in similar scores for both the River and Bay options (less than 5/100 points difference between the two options). Nine alternate conditions showed a better score (with over 5 points difference) for the River option. The only alternate condition that resulted in a higher score for the Bay option is #2, which applied a higher weight to project cost. Most of the alternate scores agree with the Base Model in that the overall score for the River option is higher than for the Bay option.

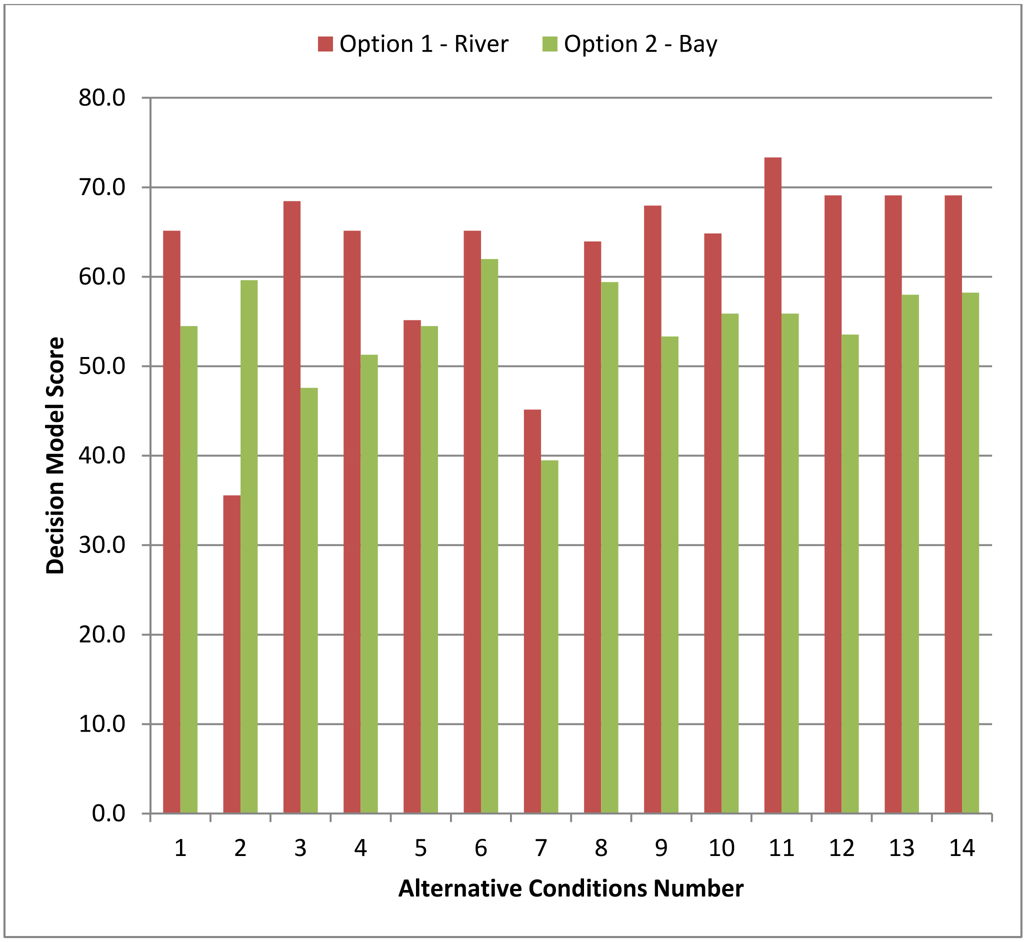

Figure 7. Alternative Decision Model Scores for Sensitivity Analysis

6. Recommendation

In this evaluation the Yellowknife River option has a Total Score of 65.2 and the Yellowknife Bay option has a Total Score of 54.5, suggesting that the Yellowknife River is the preferred option. The River option has a higher estimated life cycle cost (LCC) of $33.0 million compared to the Bay option estimated LCC of $18.2 million. The total scores reflect the importance placed on qualitative criteria such as reliability of the water supply. The Bay option received a lower score for reliability because the arsenic removal treatment process may not be able to consistently meet the drinking water quality standards in the wake of a major Upset Condition due to a berm failure at Giant Mine.

Overall, the Yellowknife River source with a new submarine pipeline has a higher capital cost, but has less risk of arsenic contamination. Arsenic contamination of the Yellowknife Bay source water due to a major failure at Giant Mine has a low probability of occurring but is considered plausible. Note that this “short-term” risk only exists until the end of the remediation phase of the Giant Mine project. In the long-term care and maintenance phase after remediation, any failures at Giant Mine are not expected to affect water quality at the City’s Pumphouse 1 intake, because plausible failures during the long-term operation phase would only release a small amount of waste to the Bay.

AECOM

Appendix A

Technical Memorandum: Arsenic Water Chemistry

AECOM

Technical Memo

City of Yellowknife Potable Water Source Selection-
Definition of Arsenic Water Chemistry at Pump House #1

Project Number: 60541637

July 24, 2017

Quality information

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1. Executive Summary

The City of Yellowknife currently obtains its drinking water from the Yellowknife River via an eight-kilometre submarine pipeline. The submarine pipeline, however, is reaching the end of its useful life and will need to be replaced. One replacement option that has been put forward is to use Yellowknife Bay via Pump House #1 as the primary source of drinking water for the City of Yellowknife.

In 2017, as part of the larger City of Yellowknife investigation of replacement options, AECOM was retained to determine the technical feasibility of achieving the federal drinking water guideline for arsenic at Pump House #1. To meet this objective, AECOM obtained available surface water dissolved and total arsenic data from a variety of sources. These data were then used to characterize upper bound estimates for arsenic in the surface water of Yellowknife Bay near Pump House #1 for a variety of situations, including for Normal Conditions, Storm Conditions, and defined Upset Conditions (i.e., short-term and long-term failure events associated with Giant Mine).

The key conclusions are as follows;

1. For Normal Conditions, the upper bound estimates for total and dissolved arsenic (total arsenic is virtually entirely associated with the dissolved form) in surface waters ranged from 1.7 ug/L to 4.5 µg/L, and therefore met the Health Canada drinking water quality guideline for arsenic of 10 µg/L without the requirement for further treatment. These values are likely over-estimates of the upper bound of arsenic concentration under Normal Condition because of an observed significant decreasing temporal trend in arsenic within the period of record (2005 to 2017).
2. Storm Conditions that were observed during the period of record did not measurably affect water column arsenic concentration, and therefore it was concluded that upper bound estimates developed for Normal Conditions were also applicable to Storm Conditions.
3. Upset Conditions for the *short-term* scenario (i.e., catastrophic loss of containment at the Giant Mine treatment pond) resulted in estimates of the arsenic concentration at the Pump House #1 intake ranging from approximately 190 µg/L to 4,600 µg/L total arsenic.
4. For the Upset Condition *long-term* scenario (i.e., Giant Mine water treatment pipe failure), it was concluded that there would be no measurable increase in arsenic at the Pump House #1 intake.

The key recommendations are as follows;

1. Provide public access to the arsenic data collected from Pump House #1 on a website so that the public could look at the actual data as it is collected and compare the data with the federal drinking water quality guideline for arsenic of 10 µg/L.
2. Continue to collect water samples for dissolved and total arsenic determination on a regular basis from the Pump House #1 wet well, whether that is monthly or at some shorter interval going forward.
3. Begin collection of turbidity and Total Suspended Solids (TSS) data from samples collected at the same location (Pump House #1 wet well) and in conjunction with the arsenic data.
4. Discard oldest year of arsenic data as new data are collected to gradually lessen the effect of observed temporal trends in arsenic concentration on upper bound estimates of normal range.
5. Continuously monitor turbidity at the water intake during storm conditions. If a spike in turbidity occurs, then take a sample for determination of TSS and total and dissolved arsenic.
6. Re-evaluate the short-term ‘Upset Conditions’ if an appropriate hydrodynamic model is developed that includes the area of Yellowknife Bay near the Pump House #1 intake.

2. Introduction

The City of Yellowknife currently obtains its drinking water from the Yellowknife River via an eight-kilometre submarine pipeline. The pipeline carries water from Pump House #2, which is located upstream of the City on the shores of the Yellowknife River, through Yellowknife Bay to Pump House #1, which is located in the City of Yellowknife itself (Figure 2-1).

The submarine pipeline, however, is reaching the end of its useful life. Submarine inspections completed in 2016 found leakage occurring in the pipeline. In addition, the capacity of the existing pipeline is limited due to pipe size, the effective pressure rating of the aging pipe, and the pumping infrastructure in Pump House #2.

One option that has been put forward is to use Yellowknife Bay via Pump House #1 as the primary source of drinking water for the City of Yellowknife. The main concern of this option is the level of arsenic in the water and sediment in Yellowknife Bay, and in the soil in the surrounding watershed, all as a result of decades of gold mining activity, primarily at the Giant Mine.

The Giant Mine produced gold from 1948 until 1999, and ore for off-site processing from 2000 to 2004. Gold in Giant Mine ore was associated with an arsenic-bearing mineral known as arsenopyrite (AsFeS), which released arsenic-rich gas as a by-product of gold extraction. From 1951 to 1999, this gas was captured in the form of arsenic trioxide (As_2O_3) dust and stored underground. Other sources of arsenic to the surrounding environment included mine tailings and contact water from the underground and surface mine works and tailings ponds. The result of the decades of mining activity is soil contamination in the watershed, elevated arsenic levels in Yellowknife Bay water, and highly contaminated sediments (including the presence of tailings material) in Yellowknife Bay.

The purpose of this technical memo is to provide a basis for deciding whether Pump House #1 is a viable option as the primary water intake structure for the City of Yellowknife. The objective of this report is to characterize arsenic in the water column near the existing intake near Pump House #1 to assist in determination of the technical feasibility of achieving the federal drinking water guideline for arsenic of 10 µg/L (Health Canada 2017), while recognizing that arsenic is a contaminant for which, '*Every effort should be made to maintain arsenic levels in drinking water as low as reasonably achievable*." (Health Canada 2006).

Specifically, the key questions related to this objective are;

- What are the 'upper bound estimates' for total arsenic, dissolved arsenic, and total suspended solids (TSS) in the water column at the proposed water intake now and in the future under:
    - Natural Conditions
    - Storm Conditions
    - Upset Conditions associated with the Giant Mine

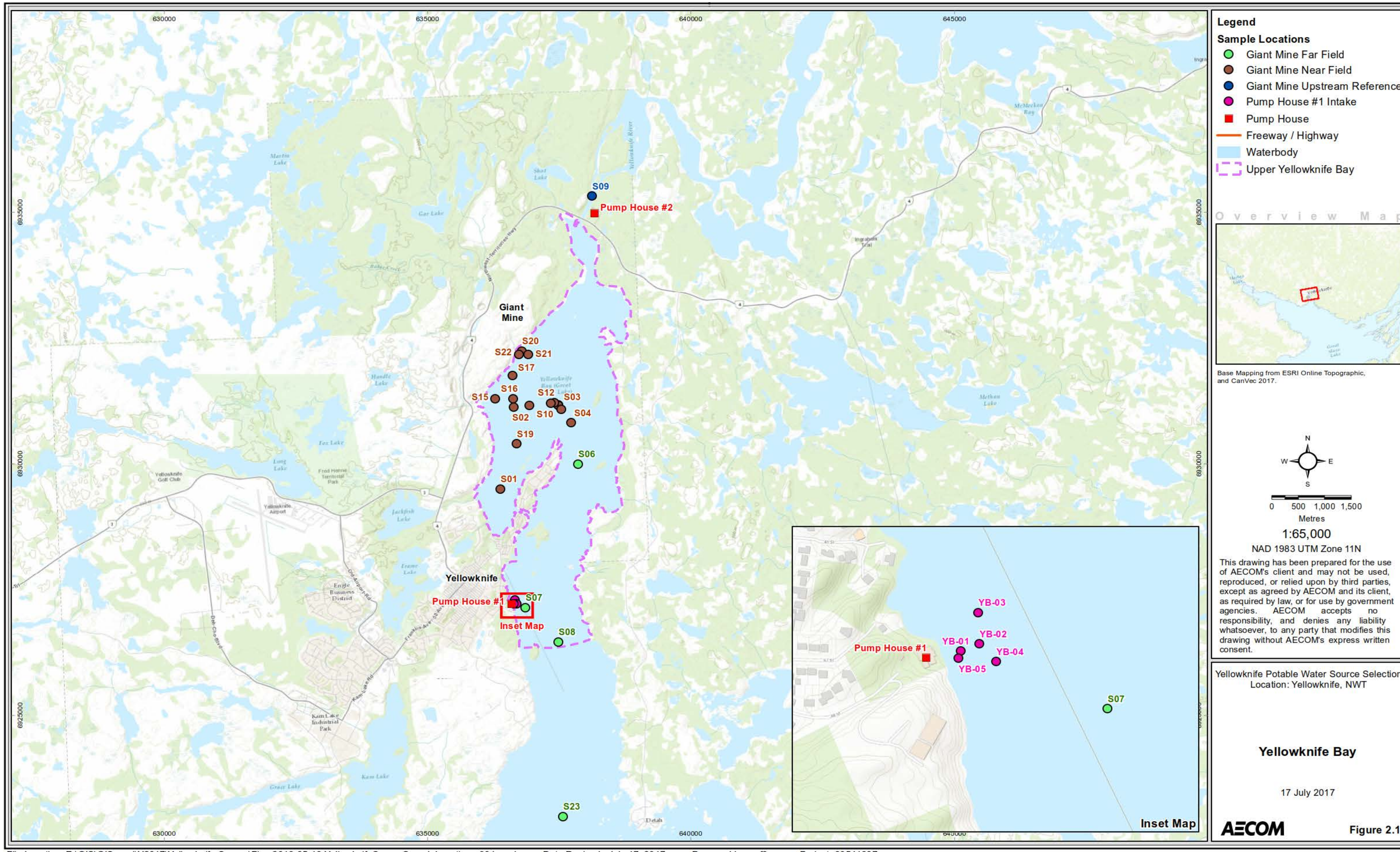

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Figure 2-1: Yellowknife Source Selection Study Area and Sampling Locations (See Appendix A: Table A 4 for site coordinates)

3. Methods

Pursuant to the key questions stated in the objective, AECOM obtained the requisite water chemistry data and completed the analyses to yield the required upper bound estimates of waterborne arsenic and TSS at Pump House #1.

The data required for the analyses included:

- Total Arsenic (water & sediment)
- Dissolved Arsenic (water only)
- Total Suspended Solids (TSS) (water only)

To the extent possible, upper bound estimates for following conditions were developed:

- 'Normal Conditions', which are those that generally occur in the absence of storms or catastrophic events.
- 'Storm Conditions', which are those that occur under unusual weather patterns (i.e. related to wind speed and direction, or heavy runoff related to either spring freshet or heavy rainfall).
- 'Upset Conditions', which are anthropogenic in origin and defined as occurring after a catastrophic release of arsenic from a major source related to activities at the Giant Mine.

Pursuant to the key questions, the upper bound estimates that were required to be calculated for total arsenic, dissolved arsenic, and TSS included:

- The 95th%ile of the data
- The 99th%ile of the data
- The 95% Upper Tolerance Limit (95%UTL)

3.1 Data Acquisition

Based on the proposal requirements listed above, environmental data were acquired from the following sources:

- **City of Yellowknife (Excel format):** Water column dissolved arsenic and total arsenic. The water samples have been collected approximately monthly from the Pump House # 1 wet well starting from 2005 and continuing to the present day (Appendix ATable A 3). These water samples are currently being analyzed for arsenic by Taiga Environmental Laboratories, which is a Canadian Association for Laboratory Accreditation Inc. (CALA) accredited laboratory located in Yellowknife, NWT. Total Suspended Solids (TSS) data were not available from the City of Yellowknife.
- **Indigenous and Northern Affairs Canada (INAC) (Excel format):** Water column total arsenic and TSS from the Giant Mine Phase 4 EEM program (Golder 2013). The total arsenic and TSS data from the Phase 4 EEM program (Appendix A:Table A 3) were collected at 17 sites in Yellowknife Bay (Figure 2-1, Appendix A: Table A 4) spread over three seasons (Feb/Mar, Jun/Jul, Sep/Oct) during the years 2012 and 2013.
- **Indigenous and Northern Affairs Canada (INAC):** Water column total arsenic and dissolved arsenic data from the Giant Mine Aquatics Baseline Study (Stantec 2014b). The arsenic data from the Aquatics Baseline Study were collected October 2012, February 2013, and June 2013 from 23 sites, from one reference site, and from both near-field and far-field sites spread throughout Yellowknife Bay (Figure 2-1).
- **Northwest Territories Geological Survey (Chetalat et al. in press):** Water column total arsenic, dissolved arsenic and arsenic speciation data. The samples were collected in September 2014, August 2015 and August 2016 at a total of 19 sites scattered throughout Yellowknife Bay, including eight near-field sites and ten sites located increasing distance from the Giant Mine.

- **Environment Canada (http://weather.gc.ca/index_e.html):** Rainfall, and wind speed and wind direction data for dates relevant to previous water column sampling to resolve whether prevailing meteorological conditions were normal or storm conditions for any given sampling event. Hydrometric data for the Yellowknife River; monthly means from 1987 to 2015.
- **Andrade (2006), Stantec (2014), Chetalat et al. (in press):** Sediment chemistry surface (0-5 cm) and depth profile data collected for sites in Yellowknife Bay.
- **AECOM 2011:** Surficial sediment chemistry samples collected near Pump House #1 (Figure 2-1).
- **INAC & GNWT (2010) and Communication with the Giant Mine Remediation Team:** Identification and characterization of upset scenarios related to credible accidents and malfunctions at Giant Mine causing catastrophic release of arsenic and related tailings metals to Back Bay. Load calculations (based on arsenic concentration and volume) for the most credible upset scenario were obtained from the Giant Mine Remediation Team.

3.2 Preliminary and Exploratory Data Analysis

Exploratory data analysis was undertaken to provide a preliminary understanding of the characteristics of the water chemistry data and to refine further analyses. The exploratory analysis included examination of the following:

- Presence of non-detect (i.e. censored) data
- Identification of outliers
- Seasonality
- Temporal trends
- Data distribution
- Definition of storm conditions

3.2.1 Censored Data

The presence and proportion of censored data are of critical importance, because censored data cannot be used in the calculation of the required upper bound estimates. Censored data that were identified in the data set from Pump House #1 were therefore assigned estimated values using ProUCL software (Singh & Singh 2015).

3.2.2 Outliers

Outliers are almost inevitable in sets of environmental data, and can profoundly affect calculation of parametric statistics, such as the 95%UTL (Singh & Singh 2015). ProUCL suggests that multiple decision statistics be calculated with and without outliers; the most defensible is then selected based largely on site understanding and best professional judgment (Singh and Singh 2015). Based on this guidance, extreme outliers in the arsenic data set from Pump House #1 were identified using box and whisker plots and then the required upper bound estimates were calculated with and without the outliers.

3.2.3 Seasonal Effects

Water chemistry data were sorted by season to improve calculation of the upper bound estimates. If seasonally distinct data were not separated, then the upper bound estimates could be potentially compromised by the presence of multiple distributions in the data set as a whole.

Two seasons were defined for Great Slave Lake, including a long ice-covered season and a shorter open-water season. Although ice cover is variable from year-to-year, it was assumed that the ice-covered period started in mid-October and ended in mid-May.

Based on this assumption, the arsenic data from Pump House #1 were separated by Julian Date into ice-covered and open-water datasets, and then seasonality was tested as a determinant of the water column arsenic concentration (i.e. do arsenic concentrations vary through the seasons?) using boxplot analysis and a two-tailed Student's t-test.

3.2.4 Assessment of Temporal Trends

After the data were separated by season, an assessment of temporal trends in the Pump House #1 arsenic data was undertaken separately for each season. The assessment was undertaken because the Giant Mine has been closed since 2004 and remediation of the site has been ongoing since then. These factors suggested that gradual improvement in water quality within Yellowknife Bay was a possibility. Monthly arsenic data were averaged for each year, season and form of arsenic (Appendix A: Table A 6). It was recognized that the sample size was variable for any given year because of missing monthly data (Appendix A: Table A 1); however, it was considered that this variability would not invalidate the trends test because there was at least one value for each time interval.

The temporal trends were examined visually and tested using a Mann-Kendall trends test. The Mann-Kendall trends test is a non-parametric test that makes no assumptions regarding data distribution, although it does require that the trend (if any) be monotonic (Meals et al. 2011). The data record was also visually inspected for any break points, which might be observed if a specific event resulted in a significant alteration of arsenic chemistry at the site.

3.2.5 Data Distribution

Calculation of the upper bound estimates using ProUCL requires an understanding of the underlying distribution of the data being explored. The dissolved and total arsenic concentration data represents a reasonably large dataset, with a very small degree of censoring (2 observations reported below analytical limits of detection). Summary statistics were selected based on the observed distribution of the data as indicated by goodness of fit statistical tests conducted automatically as part of the calculation of background threshold values in ProUCL. If more than one distribution (often gamma and lognormal distributions are observed together, with ProUCL unable to distinguish the two at the 5% confidence level) the distribution with the greatest correlation coefficient was selected. If no discernible distribution was identified, then a nonparametric statistic was selected.

3.2.6 Definition of Storm Conditions

Data reflective of 'Storm Conditions', were evaluated to address potential that turbulence in the water column could entrain sediment and result in elevated TSS and total arsenic in the intake water. The concern arose because the bottom of the intake structure at Pump House #1 is currently only approximately 0.75m above the surface of the sediment and is located in water approximately 5.5m in depth. The intake is therefore close to the sediment surface, and water at the intake is relatively shallow.

The meteorological data that were used for definition of Storm Conditions were precipitation, and wind speed and direction. The following were considered for the analysis of storm conditions:

- Analysis was restricted to the open-water season.
- Total arsenic would primarily be affected because of sediment mobilization and because of the high partition coefficient for arsenic in surface waters (see Glossary).
- Storm conditions that could affect total arsenic would likely develop and occur during the week prior to sample collection.
- It was assumed that onshore winds were required for development of storm conditions, which because of the position of Pump House #1 (Figure 2-1), occurred between approximately 45 degrees (NE) and 180 degrees (S). Of particular interest were sustained south winds that could produce a storm surge as waters from Great Slave Lake piled into Yellowknife Bay.

Water column data for total arsenic from the open-water season were initially sorted by wind direction, and only those within the selected direction range were brought forward in the analysis. To explore trends and correlations, total arsenic was then plotted against the following parameters reported for the week prior to sampling, including:

- Total precipitation
- Mean wind speed
- Speed of the maximum wind gust
- A combination of precipitation and wind speed developed by ordering and summing both precipitation and wind speed

In addition to the meteorological data, arsenic content of surface sediments was characterized and arsenic profiles in the sediment were plotted to illustrate the change in arsenic with depth. The purpose was to understand the arsenic content in the surficial sediments and to determine whether contaminated sediments that resulted from mining activity have been buried over time. This understanding was required for determination of the potential for arsenic mobilization from the surficial sediment during extreme storm conditions. All sediment profile samples were collected in near-field areas (i.e. close to the Giant Mine), which means that the analysis and interpretation of the sediment arsenic profile data provides a worst-case scenario and is therefore highly conservative. Surficial arsenic sediment content was also summarized in the far-field (relative to Giant Mine) area of Pump House #1.

3.3 Arsenic Characterization under Normal and Storm Conditions

Characterization of dissolved and total arsenic was developed for 'Normal Conditions' and 'Storm Conditions' for all seasons through the entire period of record (2005 – 2017). The analyses define the standard normal and storm operational conditions at Pump House #1.

The software package ProUCL (Singh & Singh 2015) was used to define the 95%ile, 99%ile, and the 95% UTL as required in the proposal. These three metrics were calculated using assumptions regarding the data distribution, identification and disposition of outliers, and estimation of values for censored data. Upper tolerance limits were calculated using ProUCL v5.0 (Singh and Singh 2015). The threshold value selected for comparison to water quality data was the upper tolerance limit. The UTL95-95 (i.e. a 95% UTL with 95% coverage) is designed to provide coverage for 95% of all observations potentially coming from the background or comparable to background population(s) with a confidence coefficient of 0.95 (Singh & Singh 2015), or in other words a value that will be greater than 95% of all future observations with 95% confidence. As such, it is a useful and conservative statistic for water resource planning, as it is intended to provide an upper bound on the population of data being considered.

Box and whisker plots (see Glossary) were used to define the median, 25th%ile, 75th%ile, and limits of the 'whiskers'. These data provided definition of the normal range of the data and of 'outliers' in the set of data from Pump House #1 independent of the distribution of the data. These data were also compared with three additional arsenic data sets (Chetalat et al. in press; Stantec 2014b: Golder 2013) to provide an understanding of whether arsenic concentrations at the intake were comparable with those in other areas within Yellowknife Bay.

Calculation of the 'Return Period' to define potential water column arsenic concentrations in the future under Normal Conditions was also undertaken using a Gumbel distribution (see Glossary). There was uncertainty regarding the requisite assumptions of this analytical approach, but nevertheless it was considered that estimation of a return period would provide useful information of potential future upper arsenic concentrations in the water column. Confidence in the results, however, was less than for the preceding analyses (box and whisker plots, 95%ile, 99%ile, and the 95% UTL).

The various upper bound estimates discussed above were presented on a graph with the individual data points to illustrate the current relationship between the existing data and the limits calculated from those data.

3.4 Arsenic Characterization under Upset Conditions

Credible scenarios for 'Upset Conditions' (i.e., catastrophic release of arsenic from the Giant Mine site), were drawn from a three-day workshop conducted by the Giant Mine Remediation Project Team on accidents and malfunctions (29 September to 1 October 2009; INAC & GNWT 2010). The workshop identified five potential initiating events that could result in the release of arsenic-contaminated water, sludge or tailings (Table 3-1). The workshop assessment process concluded that the two most credible malfunction scenarios involved release of arsenic trioxide slurry into the lower mine workings due to a bulkhead failure during the remediation phase (Initiating Event #1), or release of untreated mine water due to a pipe rupture under the long-term care and maintenance phase (Initiating Event #2) (INAC & GNWT2010). However, because of the use of Northwest Pond during the remediation phase to store mine contact water prior to treatment, failure of the perimeter dam for Northwest Pond (Initiating Event #3) was also considered a credible event for the present evaluation (Table 3-1).

Initiating Event #1: The primary consequence of a lower bulkhead failure would be an increase in the arsenic concentration in mine contact water, potentially to the approximate solubility limit for arsenic trioxide. Such a release would result in a requirement for prolonged water treatment prior to release to Yellowknife Bay. However, because this scenario would occur underground, the contaminated mine contact water would only reach the surface via the mine contact water collection system and would therefore be treated prior to release. The contact water would only be released to Yellowknife Bay if a pipeline rupture occurred immediately subsequent to a bulkhead failure, which would require two highly unlikely events to occur at approximately the same time. *This scenario is therefore not discussed further*.

Initiating Events #2 and #3: The primary consequence of a pipeline rupture or a dam failure would be release of mine contact water directly into Yellowknife Bay or the surrounding watershed. The pipeline rupture could potentially occur during the long-term care and maintenance phase, and the dam failure could be of consequence in the short-term during the remediation phase prior to completion of the remediation project. The two events were retained to cover potential catastrophic events for both the short-term and long-term in Yellowknife Bay.

Table 3-1: Credible Accidents and Malfunctions for the Giant Mine Remediation Project as Determined by the Giant Mine Remediation Team

Initiating Event	Evaluation
1. Bulkhead Failure: A lower mine bulkhead fails, resulting in the release of arsenic trioxide slurry to deeper underground mine workings.	Physical stability of the dust storage areas is of concern, with failure most likely to occur early in the remediation process prior to freezing. A bulkhead failure is considered to be a credible event.
2. Pipe Failure: Human error or failure of a mine water pipe on the surface leads to the discharge of untreated mine water above allowable discharge criteria into Yellowknife Bay.	A water treatment plant will be constructed as part of the remediation project to treat mine contact water. A rupture of collection and intake pipes and consequent release untreated mine water is determined to be a credible event.
3. NW Dam Failure: A prolonged period of precipitation causes erosion of the tailings cover and/or perimeter dams leading to the discharge of tailings and tailings pond contact water into Yellowknife Bay.	The cover and perimeter dams will be monitored and maintained as defined by regulatory authorizations. No further assessment was deemed necessary (However, this scenario was carried forward in the current study).

Initiating Event	Evaluation
4. Baker Creek: Flooding of the mine with water through the collapse of Baker Creek or heavy rainfall results in contaminated water being released to the environment.	The risk of Baker Creek quickly inundating the mine in the event of a failure was reduced in 2006 by the relocation of Reach 4 of Baker Creek. All water flowing into the mine is collected through an underground drainage and dewatering system to prevent release to the environment without treatment and testing. The system is designed to handle a flow rate of 4,000 m^3/day. No further assessment is required.
5. Sludge Release: Accidental release of sludge from the water treatment plant occurs during handling and disposal, either by a pipe rupture or vehicle accident during transport.	Pipes will have secondary containment and will be inspected regularly. Emergency response will be in place during sludge transport: given the chemical stability and semi-solid composition of the sludge, it is expected that complete remediation of a spill would be possible. No further assessment is required.

Source: Adapted from Tables 10.3.1 and 10.4.1 in INAC & GNWT (2010)

To develop these two malfunction scenarios further, arsenic concentration in the mine contact water, storage capacity of Northwest Pond, and pipeline capacity and maximum flow rate were used to calculate the total amount of arsenic that could be released into Yellowknife Bay for both the pipeline rupture and Northwest Pond dam failure. The assumption was that a pipeline rupture would occur for a maximum of approximately 1 hour. This timeframe was used because it was recognized that regular maintenance and inspection, combined with automatic pressure and flow sensors, would quickly identify a pipeline rupture and allow for a rapid shutdown. The assumption was also made that if the perimeter dam failed for the Northwest Pond, the pond would be completely and quickly drained and the maximum amount of water would be released.

Dilution of the potential plume of arsenic-contaminated water was estimated using the volume of upper Yellowknife Bay. The approach was to assume the arsenic-contaminated water from a Northwest Pond dam failure or pipeline rupture was discharged into Yellowknife Bay via Baker Creek as a slug of contaminated water that was either fully mixed with the water in upper Yellowknife Bay (as outlined in Figure 2-1), or mixed with 25% of the volume. After mixing, it was then assumed a slug of water from upper Yellowknife Bay was released to the proposed intake at Pump House #1 with no further dilution. No modeling was undertaken to support these assumptions, although existing hydrodynamic modelling results for upper Yellowknife Bay (Stantec 2014c) were examined when mixing proportions were considered.

Once the dilution ratios and loading rates were estimated, the total arsenic concentration was recalculated at the intake based on the addition of the arsenic from the mine water release to the ambient arsenic in Yellowknife Bay at the intake. Using these data, and the mean flow rate for the Yellowknife River (Environment Canada 2017b), the residence time in Yellowknife Bay was estimated and used to determine the attenuation of total arsenic over time.

(Note: A hydrodynamic model of Yellowknife Bay to beyond Pump House #1 intake is currently being developed by Golder Associates, and may be available in the future to refine the assessment of Upset Conditions.)

For definition of Upset Conditions, the following limitations were in place;

- Dissolved and sorbed arsenic were not separately identified because only total arsenic data were available for the Northwest Pond (SWP4: Stantec 2014d).
- Increases in TSS were considered as arising from measured TSS concentrations in the Northwest Pond only (Stantec 2014d). Modelling of tailings mobilization from the Northwest Pond, or movement of tailings in Yellowknife Bay, was beyond the scope of this report.

- Storm surges in Yellowknife Bay and reactive arsenic transport were not considered for estimation of arsenic attenuation.

4. Results

4.1 Exploratory Data Analysis

The following exploratory data analyses were undertaken for the set of total and dissolved arsenic data collected from the wet well in Pump House #1 approximately monthly between 2005 and 2017 and obtained from the City of Yellowknife, and for the TSS data collected from the Phase 4 EEM program (Golder 2013).

4.1.1 Censored Data

There were two non-detect results for total and dissolved arsenic returned through the period of record (2005-2017): 4 November 2008 and 8 January 2015 (Appendix A: Table A 1). This represents less than 1% of the set of arsenic data, which means that data analyses were not negatively affected by the presence of censored data. For exploratory data analysis, the censored arsenic data were assigned a value at the detection limit (0.2 µg/L As). For calculation of the required metrics using ProUCL, the censored data were assigned values based on characteristics of the data distribution (Singh and Singh 2015).

For the TSS data, there were 143 non-detect (<3.0 mg/L) results out of the 146 samples (Appendix A: Table A 3). These results indicated that TSS was relatively and consistently low in Yellowknife Bay: even the few recorded values were only slightly above the detection limit (Appendix A: Table A 3). The high proportion of censored data meant that further analysis of the TSS data for definition of Normal Condition and Storm Condition was not possible.

4.1.2 Outliers

Two extreme outliers were identified in the arsenic data collected at Pump House #1 (Figure 4-1): 1 May 2007 and 31 October 2012 (Appendix A: Table A 1). Both results occurred in the ice-covered season for total arsenic and as such were primarily caused by elevated particulate arsenic (Appendix A: Table A 1). The values were considered extreme because the distance from the outliers to the third quartile of the data was greater than three times the interquartile range (see Glossary). The two outliers were high enough that the mean of the total arsenic data was greater than the third quartile of the data (Figure 4-1). Brief discussion with City of Yellowknife staff could not identify a specific cause of the anomalous values, so they were retained in the set of data. Because these were considered extreme outliers, however, upper bound estimates (95^{th}%ile, 99^{th}%ile, 95%UTL) were calculated with and without these two values (Singh and Singh 2015).

Despite the fact that these two values were considered extreme outliers in comparison with the entire set of arsenic data, it is important to recognize that these two values were still below the Health Canada drinking water guideline of 10 µg/L (Figure 4-1).

Examination of the other sets of arsenic data also indicated that on rare occasion, arsenic concentration in the water column did spike to beyond normal limits (Chetalat et al. in press: Stantec 2014b: Golder 2013). The elevated concentrations, however, were relatively rare and transient, and considered extreme outliers in comparison with the entire set of data.

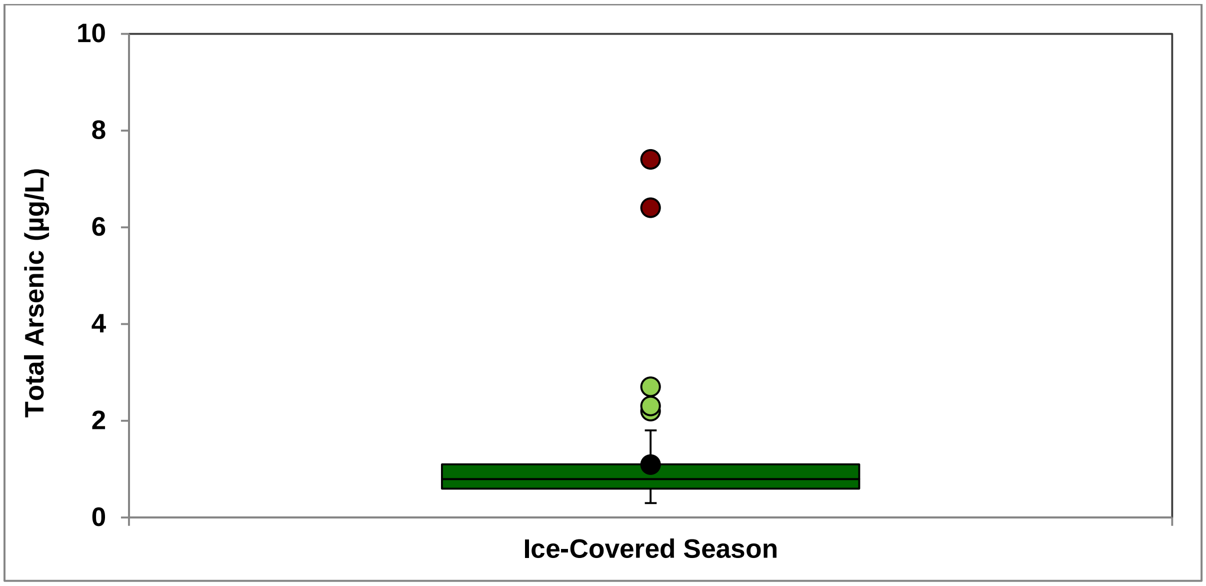

Figure 4-1: Total Arsenic at Pump House #1 for Samples Collected during the Ice-Covered Season through the Period of Record (2005-2017)

Notes: Green dots are outliers, red dots are extreme outliers, black dot is the mean (see Glossary).Health Canada Maximum Acceptable Concentration (MAC) is 10 µg/L.

4.1.3 Seasonal Effects

Seasonal separation of the Pump House #1 arsenic data through the period of record (2005 – 2017) indicated a highly significant difference (p<<< 0.001) in arsenic concentration between ice-covered and open-water seasons for both dissolved arsenic and total arsenic, with the higher concentrations occurring during the open-water season (Figure 4-2; Table 4-1). The increased arsenic concentration in the open-water season could be attributed to several factors, including increased runoff from the watershed, increased turbulence from wind and wave action, increased dust deposition due to wind action, and/or increased diffusion of arsenic from the sediment as a result of increased microbial metabolic activity during the warmer months (Chetalat et al. in press, Andrade 2006).

Table 4-1: Arsenic Concentration (µg/L) in Yellowknife Bay Water Collected Approximately Monthly from Pump House #1 between 2005 and 2017

Parameter	Dissolved Arsenic (µg/L)		Total Arsenic (µg/L)	
	Ice-Covered	Open-Water	*Ice-Covered	Open-Water
N	68	48	67	49
Median	0.70	1.40	0.80	1.40
Mean	0.78	1.32	0.92	1.41
STD	0.47	0.74	0.50	0.73
CV (%)	60	56	54	52
t-test p-value	$6.2X10^{-06}$		$3.6X10^{-05}$	

**Arsenic concentration and statistical testing calculated without two extreme outliers*

Because there was a significant difference in both total and dissolved arsenic concentration between seasons, data analysis and calculation of all upper bound estimates was undertaken separately for both the ice-covered and open-water seasons.

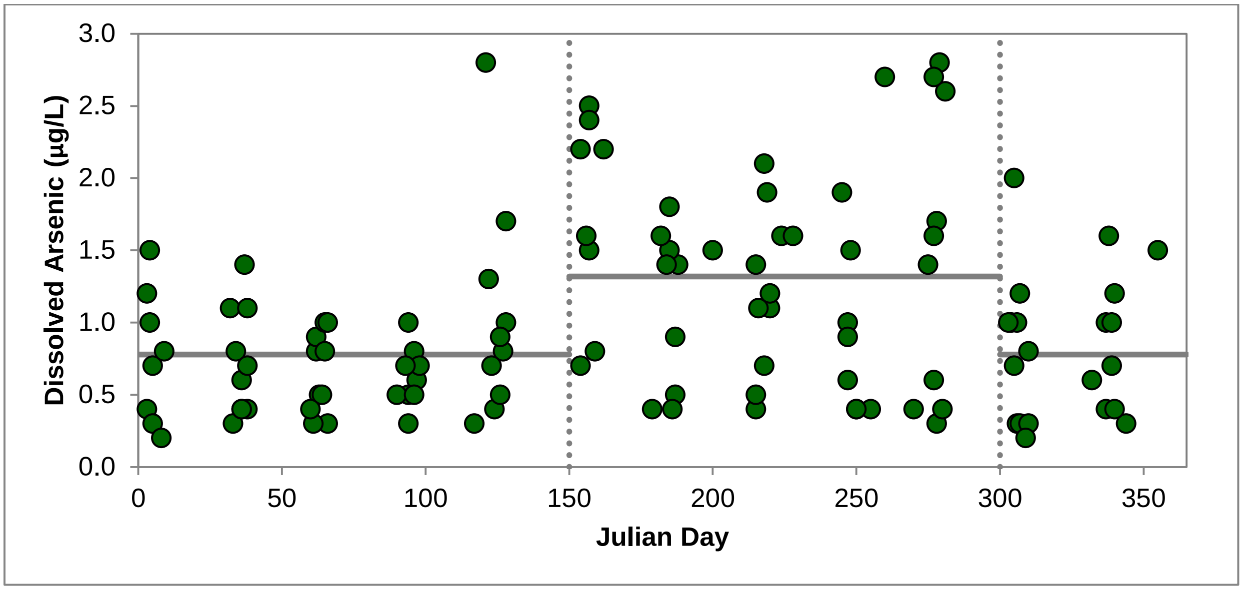

Figure 4-2: Dissolved Arsenic Concentrations during the Ice-Covered and Open-Water Seasons

Notes: Horizontal grey lines indicate the mean concentration. Vertical dotted grey lines separate the ice-covered season from the open-water season.

4.1.4 Temporal trends

Visual examination of the arsenic data from Pump House #1 indicated decreasing concentrations of both total and dissolved arsenic through the period of record (2005-2017) during both the ice-covered and open-water seasons (Figure 4-3, Figure 4-4). Furthermore, arsenic concentrations for the most recent samples (2016 and 2017) are now comparable with the estimated natural background concentration for Yellowknife Bay, estimated at <0.6 µg/L (Chetalat et al. in press).

The temporal variability during the open-water season, however, was noticeably greater than during the ice-covered season. The difference was likely due to the relatively dynamic conditions that existed during the open-water season, including deposition of wind-borne particles; watershed runoff associated with spring freshet and summer precipitation, wind-driven turbulence of surface waters, and increased biological activity in the sediments of Yellowknife Bay.

Statistical analysis of the yearly data (Appendix A: Table A 6) indicated:

- Highly significant decreasing trends for both dissolved and total arsenic concentration during the ice-covered season
- A marginally significant decreasing trend for dissolved arsenic in the open-water season, and
- No significant trend for total arsenic in the open-water season.

These results suggest that since the Giant Mine closed in 2004, there has been gradual improvement in the arsenic concentration in the water column in Yellowknife Bay. The lack of a trend in total arsenic during the open-water season again highlights the relatively dynamic environment during the open-water season, likely resulting in increased mobilization of both soil particles from the watershed, and particulates and pore water from Yellowknife Bay sediments.

The decreasing trend in water-column arsenic at the Pump House #1 intake complicates calculation of the required upper bound estimates, because the data distribution is changing over time and the required statistical metrics assume a single distribution of the data. Violation of this assumption will result in increased uncertainty in the results. However, because the arsenic concentrations have decreased over time, calculation of the 95[th]%ile, 99[th]%ile and 95%UTL will in all cases be over-estimates of the value going forward, and will therefore be conservative and over-predictive.

Continued collection of monthly arsenic data from Pump House #1 should allow for recalculation of the upper bound estimates over time. It is recommended that as new data are collected and yearly averages calculated, the oldest year of data be discarded and the decision metrics be recalculated. Ten years of data should be sufficient for calculation of upper bound estimates.

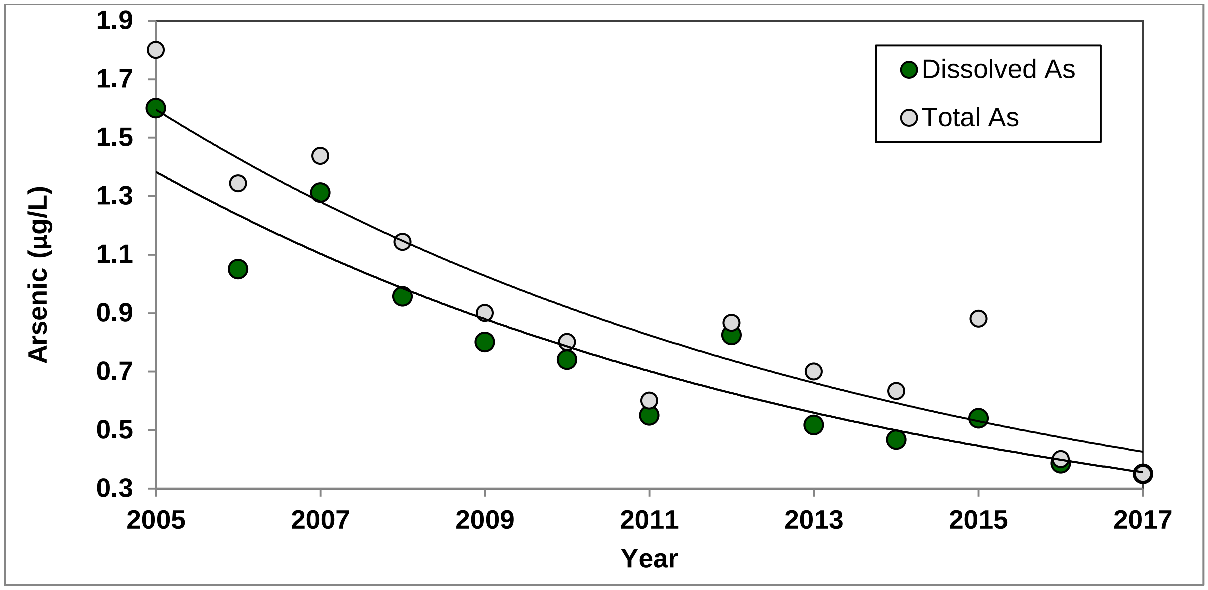

Figure 4-3: Mean Yearly Dissolved and Total Arsenic Concentration for the Ice-Covered Season

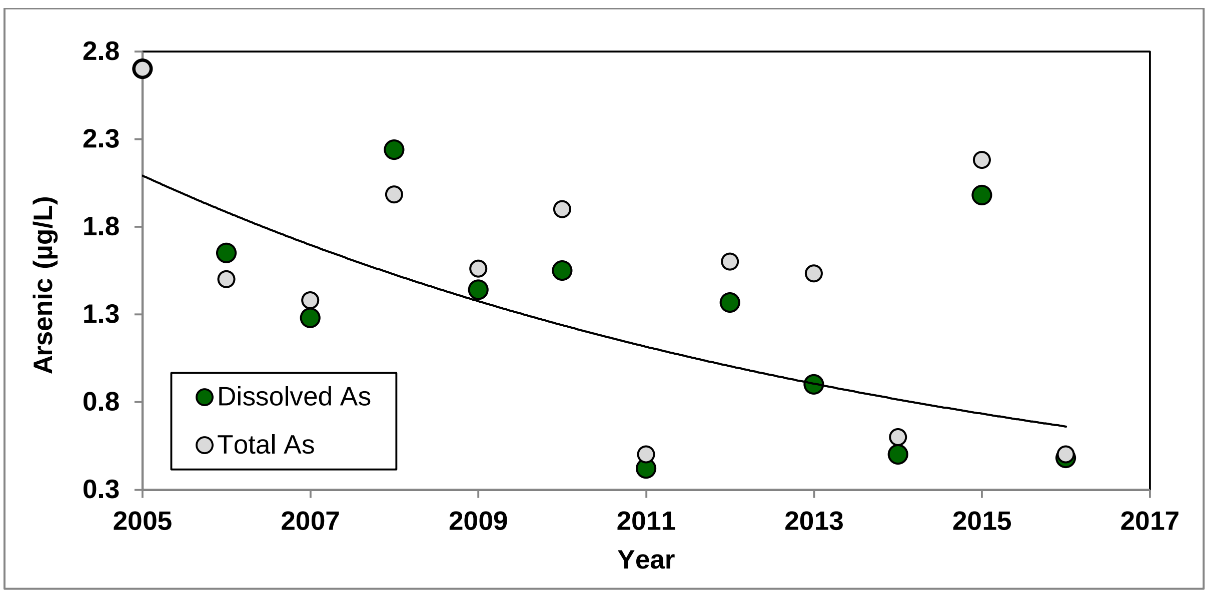

Figure 4-4: Mean Yearly Dissolved and Total Arsenic Concentration for the Open-Water Season

4.1.5 Data Distribution

Calculation of the required upper bound estimates in ProUCL (Singh and Singh 2015) requires definition of the distribution of the data, and assumes that the data being analyzed are from a single distribution.

Based on the cumulative distribution (Figure 4-5) and the frequency distribution (Figure 4-6), the arsenic data from Pump House #1 appeared to be approximately lognormally distributed. However, once the data were separated by season, the data distributions were variable for the different data sets and required a variety of analytical approaches for calculation of the required upper bound estimates (see Section 3.2.1 below).

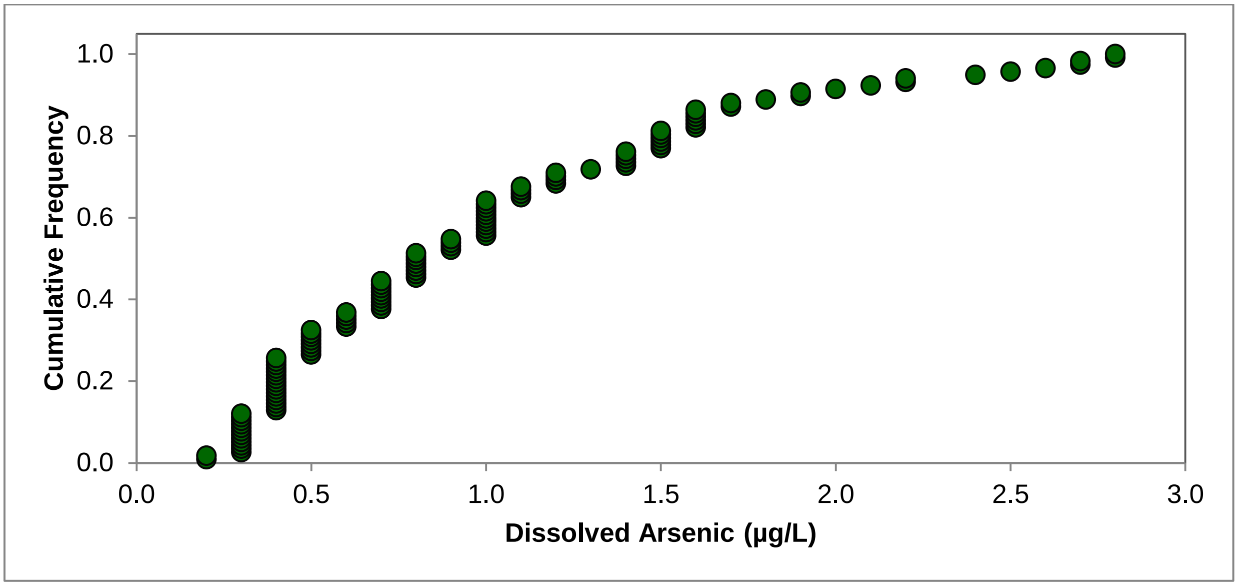

Figure 4-5: Cumulative Frequency of Dissolved Arsenic at Pump House #1 Intake (2005 to 2017)

Note: Because of the low As concentrations, there are insufficient significant digits as seen by the vertical clusters of data.

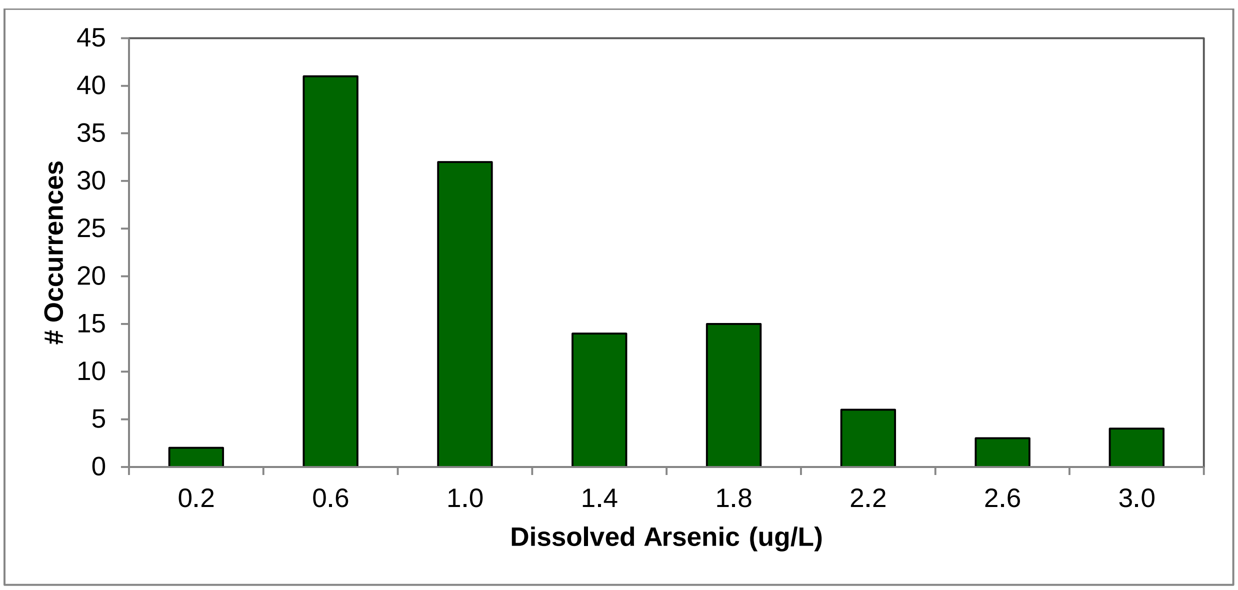

Figure 4-6: Frequency Distribution of Dissolved Arsenic at Pump House #1 Intake (2005-2017)

4.1.6 Definition of Storm Conditions

4.1.6.1 Observed Relationship between Weather and Arsenic

Annual precipitation in Yellowknife during the open-water season (May to October) averages approximately 168 mm with a maximum weekly rainfall within the period of record of approximately 68 mm (Environment Canada 2017). For each water sampling event at Pump House #1, weekly total precipitation prior to collection of water samples varied from 0 mm to 39 mm (Table A 5). The precipitation data collected prior to sample collection therefore provided a range of total precipitation, but did not provide data for extreme precipitation events beyond what has historically been observed in Yellowknife.

Examination of the Yellowknife wind rose indicated that during the period of record (2005-2017) the prevailing wind direction was from the east to south during the open water period and that wind speed greater than approximately 32 kph (8.8 m/s) was uncommon (Figure 4-7). For each water sampling event at Pump House #1, mean weekly wind speed prior to collection of the sample varied from 5 kph (~1.5 m/s) to 19 kph (~5.3 m/s) (Appendix A: Table A 5), which was within common wind speeds in Yellowknife (Figure 4-7). During the same time periods, maximum wind gusts the week prior to collection of samples ranged from 10 kph (~2.8 m/s) to 29 kph (~8.0 m/s), which again were within the range of common wind speeds in Yellowknife (Figure 4-7). Sustained southern winds, which have the potential to produce storm surges into Yellowknife Bay, were also common (Appendix A: Table A 5). The meteorological data collected prior to sample collection therefore provided a range of wind speeds, but did not provide data for extreme wind events beyond what has historically been observed in Yellowknife.

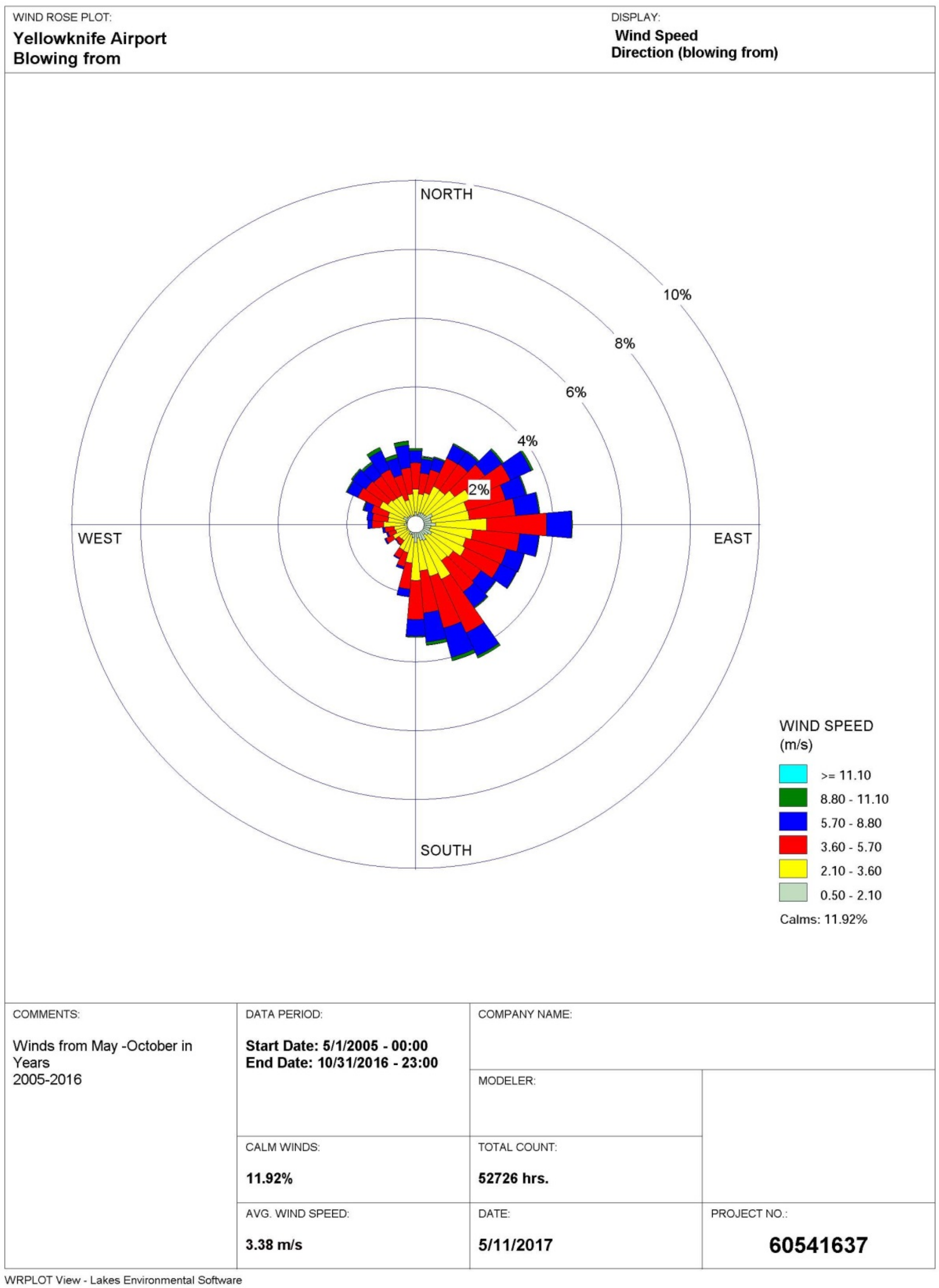

Figure 4-7: Yellowknife Wind Rose

Within the range of precipitation and wind speed that was recorded, there was no correlation with total arsenic concentration, and no threshold of meteorological conditions that resulted in a spike in arsenic concentration (e.g. Figure 4-8). These data indicated that the concentration of total arsenic in the water column at the Pump House #1 water intake structure was not measurably affected by wind speed or precipitation conditions commonly encountered in Yellowknife. The lack of correlation is possibly the result of ongoing sorting of sediment at the relatively shallow, high energy intake site due to wave and wind action, such that sediment susceptible to movement and resuspension (i.e. fines) has long ago been transported to deeper, relatively low energy depositional environments and is therefore not influenced by storm conditions.

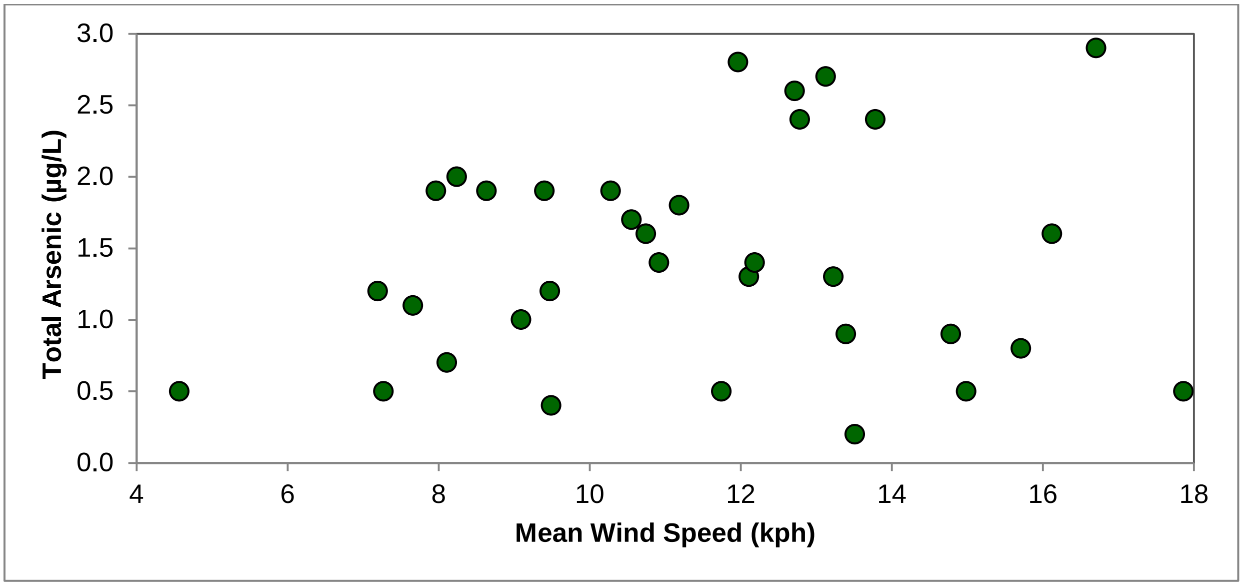

Figure 4-8: Mean Weekly Wind Speed Correlated with Total Arsenic in the Water Column

4.1.6.2 Potential for Arsenic Release from Sediment

The lack of *extreme* weather events within the period of record, beyond what has historically been observed, necessarily constrained interpretation of arsenic concentrations that might develop within the entire scope of what could be considered 'Storm Conditions'. Modelling to examine extreme storm conditions in greater detail, however, was beyond the scope of this study, except to state that a water velocity of approximately 50 cm/s or greater would be required to mobilize sediment (Hjulstrom 1939).

Because storm conditions were not fully realized within the period of record, it was considered that the potential for mobilization of sediment contaminated with arsenic existed under extreme conditions, and so sediment arsenic content of surficial sediment was also examined.

Sediment vertical profile data from upper Yellowknife Bay indicated that arsenic is mobilized at depth in the sediment (due to redox conditions) and precipitated at the sediment surface (Figure 4-9). These data indicate that surficial sediment in depositional areas is contaminated (i.e. exceeds the CCME Probable Effects Level) with arsenic and will likely continue to be contaminated into the future (Andrade 2006; Chetalat et al. in press). That is, it is unlikely that ongoing sediment deposition will bury arsenic contaminated sediment in the short term with a newly deposited clean layer of sediment (Andrade 2006) and therefore, "*Yellowknife Bay sediments are a large and potentially leaky reservoir of legacy arsenic pollution*." (Chetalat et al. in press).

What this means is that entrainment of surface sediment into the water column due to wave-induced turbulence has the potential to mobilize considerable amounts of particle-bound and/or porewater arsenic into the water column, even though there are no data to indicate this has happened during the period of record. However, it is expected that particle-bound arsenic would not dissolve into surface waters because of the high sediment:water partition coefficient for arsenic (see Glossary), and therefore that dissolved arsenic concentrations would remain relatively low under Storm Conditions.

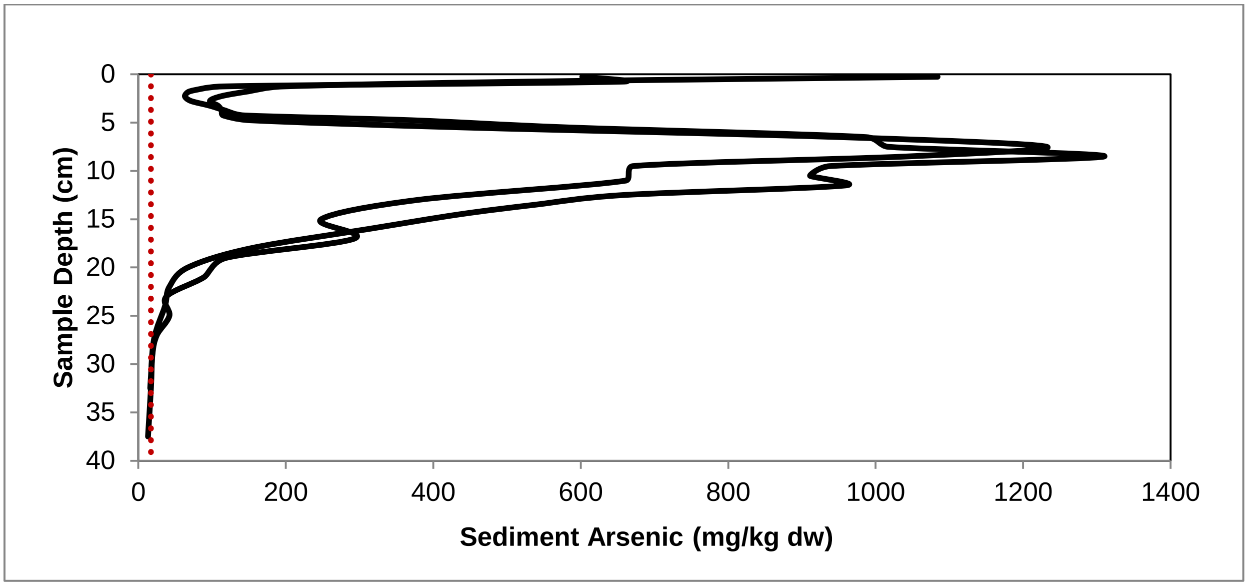

Figure 4-9: Sediment Arsenic Content in Deep (13m water depth) Depositional Sediments in Upper Yellowknife Bay

Notes: Red dotted line is the CCME Probable Effect Level Sediment Quality Guideline (17 mg/kg dw).
Source: Sites YKBS-03 and YKBW-04 (Andrade 2006)

Characterization of surface sediments in depositional near-field areas (i.e. close to Giant Mine) in Yellowknife Bay (Figure 2-1) indicated that the surficial sediments were highly contaminated, with mean arsenic content in surficial sediments (by Site) ranging from 426 mg/kg dw to 1733 mg/kg dw at (Table 4-2). These sediments are also composed primarily of fines (silt and clay) and are therefore also considered relatively mobile.

Table 4-2: Arsenic and Sediment Particle Size in Surficial Sediments (0-5cm) in Sites Located in Near-Field Areas (Close to Giant Mine) of Yellowknife Bay

Site	Coordinates*		Arsenic (mg/kg dw)		Sediment Fines (%)	
	Easting	Northing	Mean**	STD	Mean	STD
S2	636642	6931127	827	85	94	6
S3	637488	6931174	663	16	78	24
S11	637536	6931086	627	69	77	25
S12	637404	6931215	726	104	92	9
S13	637340	6931205	426	126	93	7
S14	636932	6931155	769	91	88	17
S15	636289	6931287	1733	255	94	6
S16	636632	6931296	1690	180	92	8
S17	636615	6931757	796	116	90	10
Summary			**917**	**466**	**89**	**7**

*Source: Stantec (2014b), *UTM Zone 11, 1983 NAD Datum, **N=3, 5 for S11*

In contrast, relatively limited surficial sediment data were available for areas adjacent to Pump House #1 (Table 4-3). The Pump House #1 intake site is a considerable distance from the Giant Mine, and surficial sediment arsenic concentrations, while still above the CCME PEL criteria (17 mg/kg dw) and the estimated background concentration for the Yellowknife Bay area (25 ± 10 mg/kg dw: Chetalat et al (in press)), were less than 10% of those observed closer to the Giant Mine (Table 4-2 vs Table 4-3). Analysis of the potential risk of mobilization of arsenic from sediment material adjacent to the Giant Mine (see Section 3.2.2 below) therefore provides a worst-case scenario and is highly conservative.

Table 4-3: Arsenic in Surficial Sediments at Sites Located near the Pump House #1 Intake

Site	Coordinates		Arsenic (mg/kg DW)
	Northing	Easting	
YB-01	6927234	636640	----*
YB-02	6927245	636667	102
YB-03	6927293	636665	47
YB-04	6927218	636691	140
YB-05	6927223	636636	81
YB-05(DUP)	6927223	636636	22
Mean ± Std			**78 ± 46**

Source: Data collected August 11, 2010 (AECOM 2011): See Figure 1.1 for locations
**Sediment sample was not collected at this site because the site was composed entirely of large rock and boulders*

4.2 Arsenic Characterization

4.2.1 Arsenic Characterization under Normal Conditions

4.2.1.1 Calculation of 95%ile, 99%ile, and 95%UTL

Given the evidence for seasonal differences between open-water and ice-covered conditions (see Section 2.2.3) as well as the presence of outlier values in the total arsenic dataset (see Section 2.2.2), summary statistics were calculated for the complete dataset for open-water, ice-covered, and full-year periods (Table 4-4). In addition, similar statistics were calculated for the dataset with the outlier values removed from the dataset. The 95%UTL ranged from 2.1 µg/L to 2.9 µg/L for the various categories, with values of up to 6.4 µg/L with the two extreme outliers included in the data (Table 4-4). These values are all considerably below the Health Canada drinking water guideline of 10 µg/L arsenic, and indicate that under Normal Conditions, the water in Yellowknife Bay in the vicinity of Pump House #1 is potable (i.e. below the Health Canada guideline) without the requirement for additional treatment to remove arsenic.

Table 4-4: Calculated Percentiles and Baseline Threshold Values for Dissolved and Total Arsenic Data (µg/L) from Pump House #1 (2005 and 2017)

Parameter	Open-Water		Ice-Covered[1]		Complete Dataset	
	Dissolved	Total	Dissolved	Total	Dissolved	Total
95%ile	2.7	2.7	1.6	2.3 (1.8)	2.4	2.6 (2.5)
99%ile	2.8	2.8	2.3	6.7 (2.4)	2.8	5.8 (2.8)
95%UTL	2.8[a]	2.9[a]	2.1[b]	6.4[c] (2.7)[d]	2.8[d]	3.5[b] (2.7)[e]

Notes:

1. *Dissolved arsenic dataset for ice-covered months included 2 non-detect values. Summary statistics were calculated based on a dataset with non-detect values estimated using Ln-ROS methods (Helsel 2012)*

a. Data approximates a normal distribution. Statistic presented is the 95% UTL with 95% Coverage assuming normal distribution.

b. Data approximate a lognormal distribution. Statistic presented is the 95% UTL with 95% coverage assuming a lognormal distribution.

c. Data do not follow a discernible distribution. Statistic presented is the non-parametric 95% UTL with 95% Coverage.

d. Values in parenthesis have extreme outliers omitted from analysis. Data do not follow a discernible distribution. 95% UTL with 95% coverage fails to meet confidence coefficient (i.e. the confidence coefficient achieved by the UTL is <0.95). Statistic presented is the 95% Upper Simultaneous Limit (USL). The 95% ULS represents a threshold on the maximum value which will be greater than all future observations with a confidence coefficient of 0.95 (Singh and Singh 2015).

e. Values in parenthesis have extreme outliers omitted from analysis. *Data appear gamma distributed. Statistic presented is the 95% WH Gamma UTL with 95% Coverage.*

4.2.1.2 Boxplot Analysis

Characterization of Arsenic Data Collected at Pump House #1

Because of the temporal trend in the data, and the multiple and at times undefined data distributions contained within the data, it was considered prudent to also develop upper bound estimates for normal conditions based on non-parametric boxplot analysis. These metrics are not dependent on assumptions regarding the distribution of the data, and are resistant to the effects of outliers and non-detect data. The following key observations were developed:

- **Seasonal Variatio**n: Arsenic concentrations were lower during the ice-covered season (as per Section 3.1.3 above), with median values of 0.7 µg/L to 0.8 µg/L during the ice-covered season and 1.4 µg/L in the open-water season (Figure 4-10, Table 4-5:). In addition, the interquartile range (IQR) was greater during the open-water season than during the ice-covered season. The increased variability in arsenic concentration, as discussed, likely reflects the relatively dynamic conditions present during the summer months.
- **Normal Range**: The upper bound estimate, as defined using these boxplots, was defined by the 'high limit', which is the highest arsenic concentration in the existing set of data within 1.5xIQR (see Glossary). The high limit ranged from 1.7 µg/L to 2.9 µg/L, depending on season and arsenic speciation (Figure 4-10, Table 4-5:). These are the values approximately comparable to the 95th%ile as calculated using ProUCL (Table 4-4), and provide an independent check on the reliability of those limits using a completely different approach and assumptions.
- **Dissolved:Total Ratio:** For the period of record, dissolved arsenic was the dominant form of arsenic in the water column, with dissolved arsenic 90% to 100% of total arsenic (Appendix A: Table A 1, Table A 2, Table 4-5:). This is consistent with the low TSS content of surface waters within Yellowknife Bay and comparable with results from other studies (Stantec 2014b: Chetalat et al. in press).

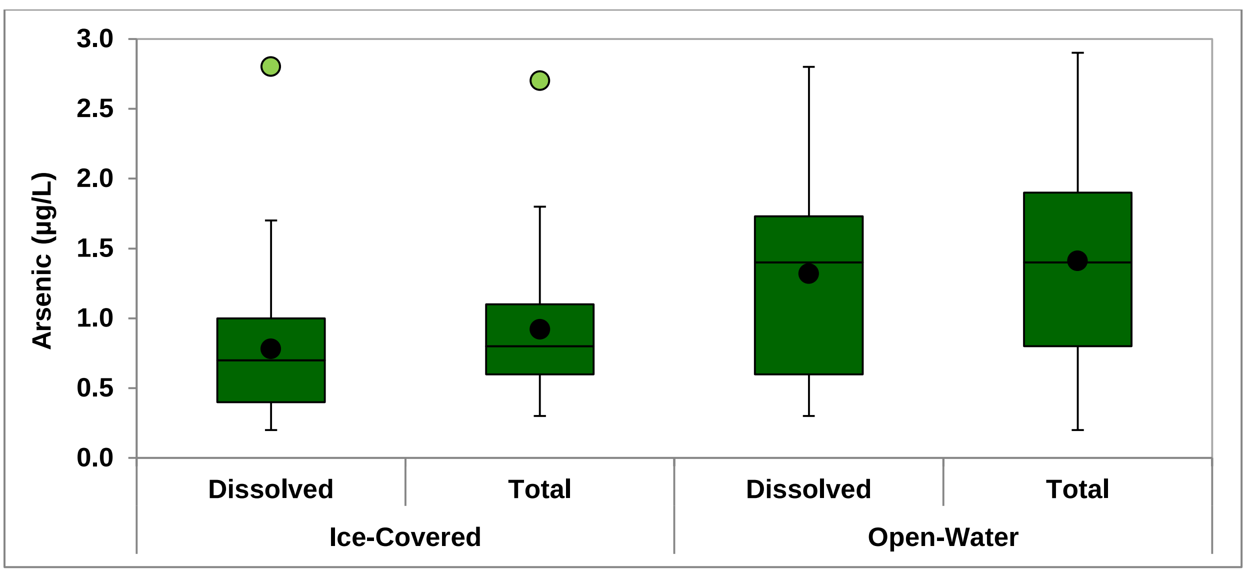

Figure 4-10: Dissolved and Total Arsenic Data Collected at Pump House #1 (2005-2017)

Notes: Extreme outliers (6.4 and 7.4 µg/L As) for total arsenic in the ice-covered season have been omitted from this figure.

Characterization of Arsenic Data Collected at Far-Field vs Near-Field Locations

The arsenic data collected at Pump House #1 were collected regularly over a long time period, but at only the one location. To examine whether the arsenic concentrations measured at Pump House #1 were comparable with those throughout the entire Yellowknife Bay, they were compared with data collected as part of the Phase 4 EEM program (Table 4-5:), which were collected from 17 sites scattered throughout Yellowknife Bay (Figure 2-1), and with data from Stantec (2014b) as part of baseline studies for the Giant Mine remediation project. The comparison was considered important because it provided information on whether water-column arsenic concentrations were higher in areas nearer the Giant Mine. If they were, then there was the potential for increased risk under certain meteorological conditions that might accelerate the movement of water from upper Yellowknife Bay to the area around Pump House #1. Arsenic concentrations measured for the Phase 4 EEM program and for background characterization, however, were comparable with those measured at Pump House #1, although the high limit was 3.7 µg/L for the Phase 4 EEM data, and 3.2 µg/L for the Stantec (2014b) data (Table 4-5:). These results indicated that arsenic concentrations in both near-field and far-field areas (related to the location of the Giant Mine) within Yellowknife Bay were comparable, although slightly higher in near-field areas.

Recently published data by the Northwest Territories Geological Survey confirmed these results (Chetalat et al. in press). They sampled 19 sites spread throughout Yellowknife Bay on three occasions during the open-water season, with a calculated median dissolved arsenic concentration of 1.7 µg/L (n=55), and a mean total arsenic concentration of 1.9 µg/L (n=77) (Chetalat et al. in press).

The 19 sites were located between 1.3 km and 22.9 km from the Giant Mine roaster, and based on the range in distance, a regression of total arsenic vs distance was developed. Using this regression, the mean total arsenic concentration at the Pump House #1 intake was estimated to be 1.9 µg/L with a high limit of approximately 3 µg/L to 4 µg/L (Chetalat et al. in press).

Table 4-5: Boxplot Analysis of Dissolved and Total Arsenic Data (µg/L) Collected from Pump House #1 between 2005 and 2017, from the Phase 4 EEM Program (2012-2013), and from Aquatic Baseline Studies for the Giant Mine Remediation Project (2012-2013)

Parameter	Open-Water		Ice-Covered		Stantec (2014b)		Phase 4 EEM
	Dissolved	Total	Dissolved	Total	Dissolved	Total	Total
N	48	49	68	69	125	125	146
Low Value	0.3	0.2	<0.2	0.3	0.2	0.4	0.1
Low Limit	0.3	0.2	<0.2	0.3	0.2	0.4	0.1
25% (Q1)	0.6	0.8	0.4	0.6	1.1	1.1	0.8
50% (Median)	1.4	1.4	0.7	0.8	1.6	1.7	1.6
75% (Q3)	1.7	1.9	1.0	1.1	1.9	2.0	2.0
High Limit	2.8	2.9	1.7	1.8	3.0	3.2	3.7
High Value	2.8	2.9	2.8	7.4	9.5	10.4	6.5
1.5XIQR	1.69	1.65	0.90	0.75	1.2	1.4	1.8
Skewness	-0.42	-0.09	0.00	0.20	-0.25	-0.33	-0.33
Dispersion	0.48	0.41	0.43	0.29	0.27	0.29	0.44

Notes: see Glossary for definition of terms. Shaded values define the upper bound estimates of normal conditions in Yellowknife Bay. Data source for Phase 4 Environmental Effects Monitoring (EEM) data was Golder (2013).Stantec (2014b) summary is for all sites, including historically contaminated, near-field and far-field sites.

4.2.1.3 Return Period

As an additional check on the upper bound estimates, return period (see Glossary) was calculated for both dissolved and total arsenic for both open-water and ice-covered seasons.

The arsenic concentration at the 20-year return period (5% probability per year) ranged from 2.4 to 3.5 µg/L arsenic, and at the 100-year return period (1% probability per year) ranged from 3.3 to 4.5 µg/L arsenic, depending on season and arsenic form (Table 4-6:). In contrast, the arsenic concentration at the return period was considerably higher when the extreme outliers were included in the analysis. However, even with the outliers included, the concentration of total arsenic was still below the Health Canada drinking water guideline of 10 µg/L arsenic (Figure 4-11).

Table 4-6: Return Period Calculated for Seasonal Maximum Dissolved and Total Arsenic Data (µg/L) collected from Pump House #1 (2005 to 2017)

Return Period	Open-Water		Ice-Covered		
	Dissolved	Total	Dissolved	Total	Total (Outliers)
N	12	12	13	13	13
20 year (5%)	3.3	3.4	2.4	2.6	6.3
100 year (1%)	4.4	4.5	3.3	3.6	9.1

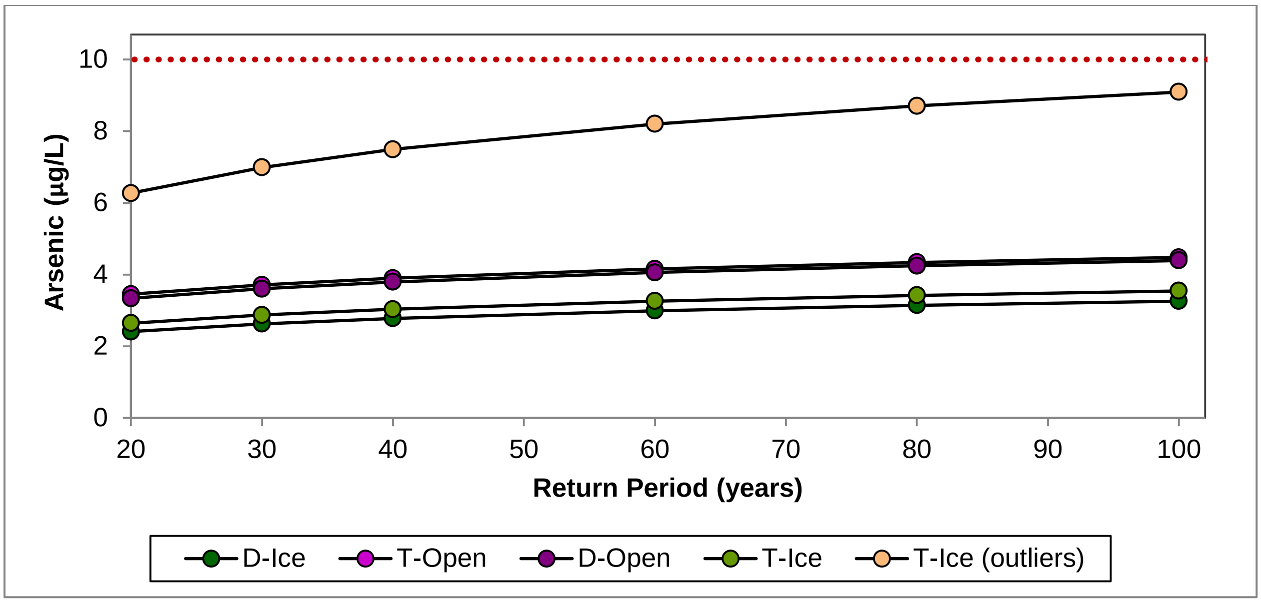

Figure 4-11: Arsenic concentration vs Return Period using Pump House #1 Maximal Seasonal Total and Dissolved Arsenic Data (2005-2017)

Notes: Red dotted line = Health Canada drinking water standard. See Table A.4 for input data. D-Ice = dissolved arsenic in the ice-covered season, T-Open = total arsenic in the open-water season, D-Open = dissolved arsenic in the open-water season, T-Ice = total arsenic in the ice-covered season with and without extreme outliers.

4.2.1.4 Ongoing Arsenic Monitoring

With definition of the upper bound estimate for arsenic using ProUCL, boxplot analysis, and return period, it is possible to compare the individual arsenic concentration data from Pump House #1 with the upper bound for both dissolved and total arsenic (Figure 4-12 and Figure 4-13). These comparisons provide an ongoing understanding of the relationship between individual data both with the defined limits and with the Health Canada drinking water guideline. They also provide a visual indication of the magnitude of the extreme outliers that were measured for total arsenic during the ice-covered season (Figure 4-13).

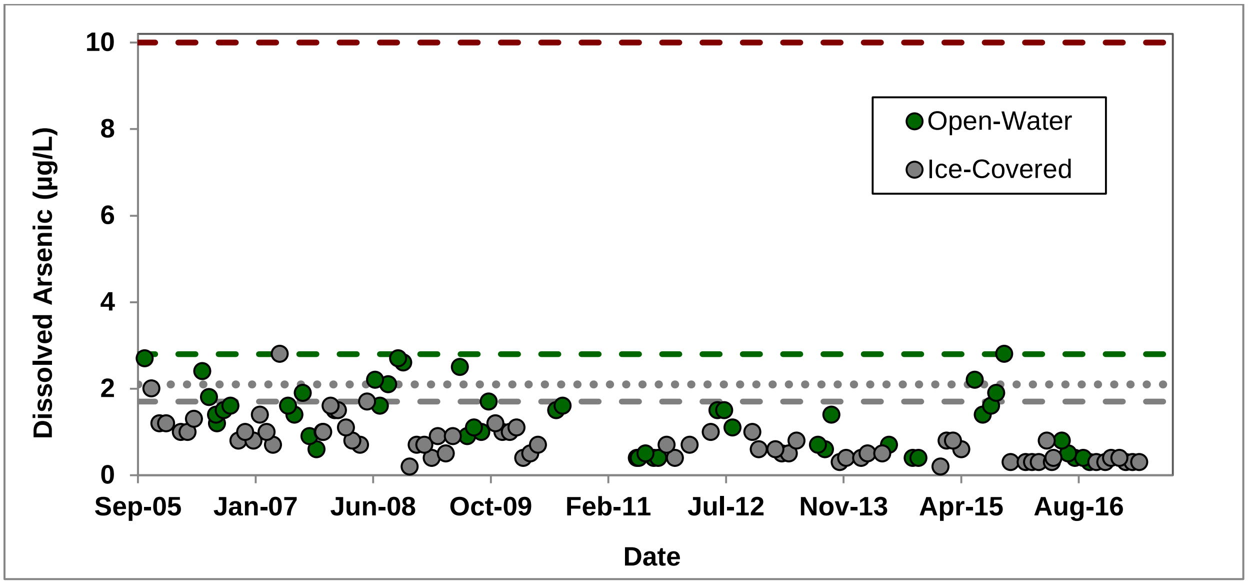

Figure 4-12: Normal Range of Dissolved Arsenic at Pump House #1 (2005-2017)

Notes: Dashed green lines are the upper high limit and 95%UTL of normal conditions for the open-water season, dashed grey line is the upper high limit of normal conditions and dotted grey line is the 95%UTL for the ice-covered season. All calculations are based on the collected Pump House #1 data (see Table 3.5). Red dotted line is the Health Canada drinking water-quality guideline (Health Canada 2017).

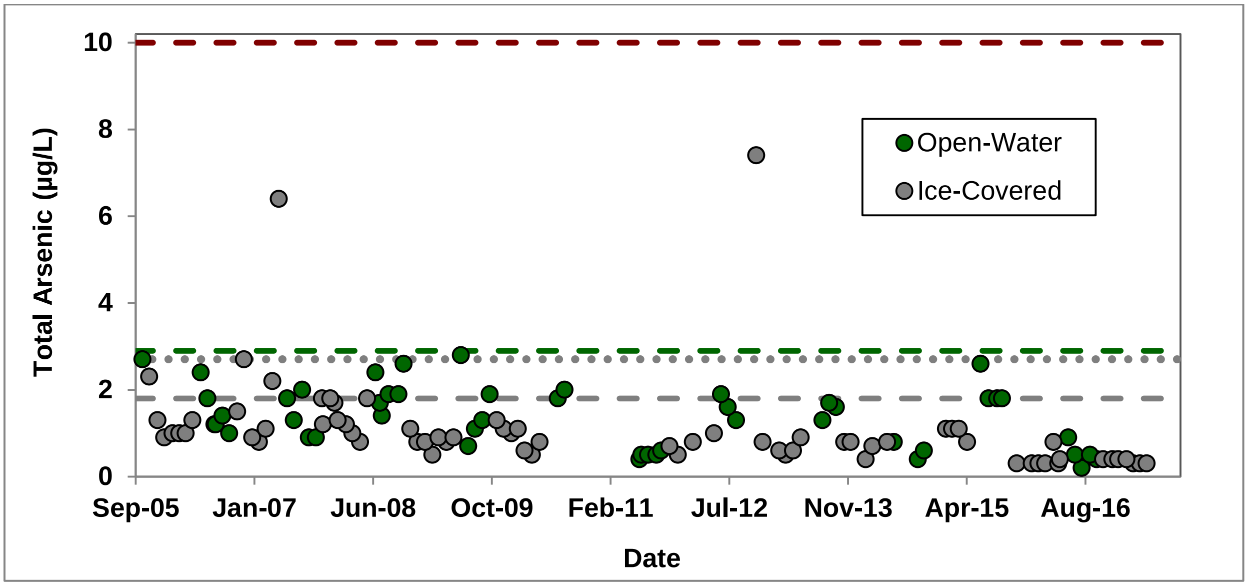

Figure 4-13: Normal Range of Total Arsenic at Pump House #1 (2005-2017)

Notes: Dashed green lines are the upper high limit and 95%UTL of normal conditions for the open-water season, dashed grey line is the upper high limit of normal conditions and dotted grey line is the 95%UTL for the ice-covered season. All calculations are based on the collected Pump House #1 data (see Table 3.5). Red dotted line is the Health Canada drinking water-quality guideline (Health Canada 2017).

4.2.2 Arsenic Characterization under Storm Conditions

Despite not being observed during the period of record, extreme storms could entrain considerable amounts of surficial sediment.

Under these conditions, there is the potential for sediment particles with arsenic content potentially up to 900 mg/kg dw or more (Table 4-2; Figure 4-8) to be entrained in the water column and migrate towards the water supply intake at Pump House #1. If surficial sediments containing 900 mg/kg dw were mobilized into the water column, then the Health Canada arsenic drinking water guideline would be exceeded with the addition of approximately 10 mg/L TSS (originating from near the Giant Mine) into the water column. In contrast, it would require greater than 100 mg/L TSS for sediments originating from the vicinity of the Pump House #1 intake structure. However, because of the high partition coefficient for arsenic in surface waters (see Glossary), it is not expected that arsenic sorbed to particulates would dissolve into the water.

4.3 Arsenic Characterization under Upset Conditions

4.3.1 Short-term Scenario

A catastrophic failure of the retaining dam for the Northwest Pond and subsequent release of contaminated contact water was assessed as a credible, although extremely low risk, short-term scenario for ‘Upset Conditions.’ If the contact water were to be discharged via Baker Creek into upper Yellowknife Bay (see Figure 2-1), it is estimated that the median total load of arsenic from the Northwest Pond to Yellowknife Bay could potentially be 2.9×10^7 g (Table 4-7). If the contact water were fully mixed with water in upper Yellowknife Bay, the median concentration in upper Yellowknife Bay and therefore at Pump House #1 could reach 0.39 g/m^3 (~390 µg/L) at equilibrium (Table 4-7). Higher estimates of discharge suggest arsenic concentrations at Pump House #1 could potentially reach approximately to 4.6 g/m^3 (4,600 µg/L) (Table 4-7). The concentration of arsenic could therefore be substantially (i.e. orders of magnitude) above the arsenic concentration under normal and storm conditions. Because of this, the 95%ile, 99%ile and 95%UTL arsenic concentrations were not separately calculated for the Upset Condition.

Based on an average monthly flow rate in the Yellowknife River of approximately 39 m^3/s (Environment Canada 2017b), it was determined that the residence time for the area of Yellowknife Bay from the Yellowknife River to Pump House #1 (Figure 2-1) was approximately 22 days under average river flow conditions. Based on these estimates, the total arsenic concentration in Yellowknife Bay was estimated to decline exponentially over time and meet the Health Canada guideline in approximately three to four months after a catastrophic failure of the Northwest dam (assuming an initial median Upset Condition concentration of 390 ug/L (Table 4-7)).

The maximum TSS concentration in the Northwest Pond (Site SWP4: Stantec 2014d) was measured at approximately 39 mg/L. This would result in a negligible increase (i.e. below detection limit) in TSS concentration at the Pump House #1 intake under fully-mixed conditions.

Table 4-7: Catastrophic Failure of the Northwest Pond Retaining Dam: Estimate of Arsenic Concentration at the Pump House #1 Intake Exposure Point.

Item	Parameters		Data Estimate
1	Estimated Upper Yellowknife Bay Water Volume*		7.4×10^7 m^3
2	Northwest Pond Maximum Yearly Volume of Contact Water**		7.0×10^5 m^3
3	Arsenic concentration (g/m^3 arsenic) in Northwest Pond (Site SWP4)***	25%ile	20
		50%ile (median)	41
		75%ile	60
		Upper Limit	120
4	Total estimated arsenic load (g arsenic) in Northwest Pond	2 x 3 (25%ile)	1.4×10^7
		2 x 3 (median)	2.9×10^7
		2 x 3 (75%ile)	4.2×10^7
		2 x 3 (Upper Limit)	8.4×10^7
5	Estimated arsenic concentration (g/m^3 arsenic) at Pump House #1 intake assuming full dilution with upper Yellowknife Bay water (see Figure 2-1)	4/1 (25%ile)	0.19
		4/1(median)	0.39
		4/1(75%ile)	0.57
		4/1(Upper Limit)	1.1
6	Estimated arsenic concentration (g/m^3 arsenic) at Pump House #1 intake assuming dilution with 25% of upper Yellowknife Bay water (see Figure 2-1)	4/1 (25%ile)	0.8
		4/1(median)	1.6
		4/1(75%ile)	2.3
		4/1(Upper Limit)	4.6

**Area = 13.4x10^{6}m^2 (see Figure 1.1), Average Depth = 5.5m*
*** Based on pumping volumes monitored between 2010 and 2015 (AECOM 2016)*
***Based on data collected between 2007 and 2013 (Stantec 2014a, 2014d)
Shaded cell is considered a reasonable estimate for Upset Condition

4.3.2 Long-term Scenario

A rupture of the pipeline transporting water from the mine to the treatment plant and subsequent release of contaminated contact water was assessed as a credible long-term scenario for ‘Upset Conditions.’ If water continued to flow from the ruptured pipe, it was estimated that approximately 290 m^3/hour of contact water would be released (Stantec 2014a). If it took approximately one hour to repair or shut down the pipeline, it is estimated that 290 m^3 could potentially be released into Yellowknife Bay, which is a negligible amount of water in comparison with the volume of Yellowknife Bay (cf Table 4-7). It is therefore concluded that a pipeline rupture, promptly repaired, would have an unmeasurable effect on arsenic concentration at the Pump House #1intake.

5. Conclusions

This objective of this report was to develop upper bound estimates for TSS, and dissolved and total arsenic concentration near the existing intake at Pump House #1 for specifically defined Normal Conditions, Storm Conditions, and Upset Conditions now and into the future.

The key findings include the following:

1. For TSS, it was determined that almost all data were below detection limit (3 mg/L) and that TSS in the water column was therefore extremely low. No further characterization of TSS to define Normal Condition or Storm Condition was possible.
2. Under Normal Conditions, the upper bound estimate for water column arsenic ranged from 1.7 ug/L to 4.5 µg/L for the various statistical approaches and conditions (Table 5-1).

- These values are likely over-estimates of the upper bound of arsenic concentration under Normal Condition because of an observed significant decreasing temporal trend in arsenic within the period of record (2005 to 2017).

- The upper bound estimates for the Pump House #1 arsenic data were confirmed as reasonable through comparison with analytical results from three separate and independent studies (Golder 2013; Stantec 2014b; Chetalat et al. in press).

- On two occasions, extreme arsenic outliers were recorded at Pump House #1, although in both instances the surface water arsenic concentration was below the Health Canada drinking water guideline.

3. Storm Conditions that were observed during the period of record did not measurably affect water column arsenic concentration, and therefore it was concluded that upper bound estimates developed for Normal Condition (Table 5-1) were also applicable to Storm Conditions.

Table 5-1: Characterization of Arsenic Concentration (µg/L) for Normal Conditions and Storm Conditions at Pump House #1 Intake

Parameter	Open-Water		Ice-Covered	
	Dissolved	Total	Dissolved	Total
95%ile	2.7	2.7	1.6	1.8*
99%ile	2.8	2.8	2.3	2.4*
95%UTL	2.8	2.9	2.1	2.7*
High Limit	2.8	2.9	1.7	1.8
20 year return (5%/year)	3.3	3.4	2.4	2.6*
100 year return (1%/year)	4.4	4.5	3.3	3.6*

**Extreme outliers excluded from data analysis*

- However, the lack of correlation between meteorological conditions and water chemistry data may also be a reflection of data inadequacies in that not all storm conditions were observed during the period of record and no modelling was undertaken. There is, therefore, some uncertainty in the conclusions for Storm Conditions.

4. Upset Conditions for the *short-term* scenario (i.e., catastrophic loss of treatment pond containment) resulted in estimates of the arsenic concentration at the Pump House #1 intake ranging from approximately 190 µg/L to 4,600 µg/L arsenic (Table 5-2).

   - Attenuation of the arsenic concentration to baseline was estimated at 3-4 months.

5. For Upset Conditions for the *short-term* scenario, it was determined that release of water-column particulates from Northwest Pond would result in a negligible increase in TSS at Pump House #1.

   - This determination did not include modelling of potential mobilization of tailings material into Yellowknife Bay.

6. For the Upset Condition *long-term* scenario (i.e., Giant Mine water treatment human error or pipe failure), it was concluded that there would be no measurable increase in arsenic at the Pump House #1 intake.

Table 5-2: Characterization of Short-Term Upset Conditions for Arsenic Input Concentration at Pump House #1 Intake

Parameter	Total Arsenic (µg/L)*	
	Fully Mixed	25% Mixed
25%ile	190	800
50%ile	390	1,600
75%ile	570	2,300
Upper Limit	1,100	4,600

Note: Upper bound estimates required by the proposal (95%ile, 99%ile, 95%UTL) were not calculated because the amount of arsenic from the upset scenario was orders of magnitude higher than the arsenic concentration under normal conditions.

**For upset conditions dissolved and sorbed arsenic were not separately identified*.

6. Recommendations for Future Monitoring

The City should continue to monitor arsenic concentrations in Yellowknife Bay water at the Pump House #1 intake, whether the intake is used for emergency water supply only or if it is changed to be the primary water source. For this ongoing data collection, we recommend the following:

1. Provide public access to the arsenic data collected from Pump House #1 on a website so that the public could look at the actual data as it is collected and compare with the federal drinking water quality guideline.
2. Continue to collect water samples for dissolved and total arsenic determination on a regular basis from the Pump House #1 wet well, whether that is monthly or at some shorter interval going forward.
3. Continue to run the small circulation pump that brings water into the Pump House #1 wet well continuously, to ensure that fresh lake water is being sampled.
4. Avoid collecting samples for arsenic analysis while recycle water from the Water Treatment Plant is being discharged into the Pump House #1 wet well (if the treatment process is paused for a set time, drain pump P-106 will start draining the recycle water pipe to avoid freezing).
5. Begin collection of turbidity and Total Suspended Solids (TSS) data from samples collected at the same location (Pump House #1 wet well) and in conjunction with the arsenic data.
6. Discard oldest year of arsenic data as new data are collected to gradually lessen the effect of observed temporal trends in arsenic concentration on upper estimates of normal range. A minimum of 10 years of monthly data should be retained.
7. Continuously monitor turbidity at the water intake during storm conditions. If a spike in turbidity occurs, then take a sample for determination of TSS and total and dissolved arsenic.
8. Re-evaluate the short-term ‘Upset Conditions’ if an appropriate hydrodynamic model is developed that includes the area of Yellowknife Bay near the Pump House #1 intake.

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Glossary

Return Period

The inverse of probability, the return period gives the estimated time interval between events of a similar size or intensity. For example, if the return period for dissolved arsenic at a concentration of 4.5 µg/L is estimated to be 100 years (at Pump House #1 intake based on monitoring data), then its probability of occurring is 1/100, or 1% in any one year. This does not mean that if such an arsenic concentration occurs, then the next will occur in about one hundred years' time - instead, it means that, in any given year, there is a 1% chance that it will happen, regardless of when the last similar event was. Or, put differently, it is 10 times less likely to occur than a concentration with a return period of 10 years (i.e. a probability of 10%).

The return period is calculated using the maximum value for each time period (see Table A 7) in the existing set of data, in this case the water chemistry monitoring data collected monthly at Pump House #1 between 2005 and 2017. The return period can be calculated using any number of distributions, but in this case the Gumbel distribution was selected as follows:

$$F(x) = \exp\{-\exp\left[-\frac{x-\beta}{\alpha}\right]\}$$

Where:

$\beta = \text{mean} - 0.577\alpha$, and

$$\alpha = \frac{\sqrt{6} * \text{std}}{\pi}$$

The Gumbel distribution assumes the following:

- The highest value for a given period is selected – the highest seasonal concentration was selected (Appendix A: Table A 7), although there were missing monthly data for some years and seasons.
- The data are independent of each other – yearly data points were separated enough that they could likely be considered independent, although the monthly data may not have been.
- The data are from a single distribution – this is uncertain due to the temporal trend in both the total and dissolved arsenic data (see Results section).
- The distribution of data is comparable to the assumed distribution – this is uncertain because there were only 12 or 13 data points for each set of data, which is not enough to confidently predict the data distribution.

Boxplot Analysis

Baseline conditions can be defined using boxplot analysis (Figure G 1), which is a type of exploratory data analysis that is non-parametric and makes no assumptions regarding normality of the data, is resistant to outliers, and can accommodate up to 25% non-detect data without compromising the analysis of the data. Analysis of associated box and whisker plots and data provides information on data location, spread, skewness, tail length, and separately identifies outliers in the data. The location is represented as the median, or 50^{th} percentile, of the data. The spread, or dispersion, is the distance between the 25^{th} and 75^{th} percentile of the data, and can be described by the quartile coefficient of dispersal, which is computed using the first (Q_1) and third (Q_3) quartiles of the data. The quartile coefficient of dispersion is calculated as;

$$\frac{Q3 - Q1}{Q3 + Q1}$$

Skewness is the difference in distances of the upper and lower quartiles from the median, divided by the IQR (Q3 – Q1) and can be calculated as;

$$\frac{(Q3 - Median) - (Median - Q1)}{Q3 - Q1}$$

If the third quartile is larger than the second quartile, then the data is said to be positively skewed, with a greater number of large values. If the third quartile is less than the second quartile, then the data are said to be negatively skewed. If both quartiles are similar, then the data are close to being normally distributed. Finally, the tail length describes the outer bounds of the data and provides for a precise definition of an outlier, or unusual value. An extreme outlier is greater than 2x the length of the whisker (3x IQR) from the 75th%ile of the data.

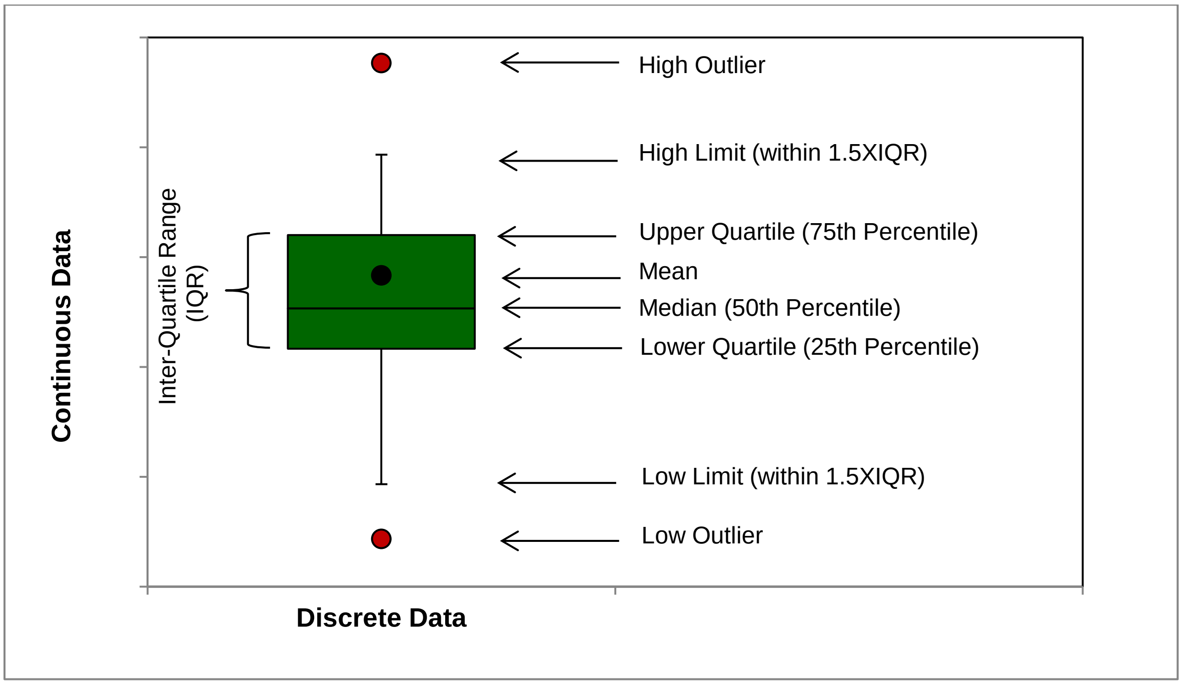


Figure G 1: Explanation of the information contained in box and whisker plots

Metal Partition Coefficients

In aquatic environments, dissolved metals react with suspended solids and sediment surfaces. These reactions are called sorption reactions and a metal that is bound to particulates is said to be sorbed. The metal partition coefficient (also known as the sorption distribution coefficient) is the ratio of the sorbed metal concentration (as mg/kg) to the dissolved metal concentration (mg/L) at equilibrium.

$$Kd = \frac{sorbed\ metal\ concentration\ (\frac{mg}{kg})}{dissolved\ metal\ concentration\ (\frac{mg}{L})}$$

Partition coefficients are reported as Log Kd with units of L/kg. For arsenic, a literature search found numerous reported Kd values, ranging from 1.6 to 6.0 (Table G 1). The Kd depends on specific characteristics of the particulate material, but the data do indicate that arsenic preferentially binds to particulate material in surface waters.

Table G 1: Arsenic Partition Coefficients (L/kg)

Parameter	**TSS:Water**	**Sediment:Water**
Median	4.0	2.5
Range	2.0 – 6.0	1.6 – 4.3
N	25	18

Source: Allison and Allison (2005)

For upper Yellowknife Bay, the partition coefficient (based on surficial sediment arsenic concentration (Table 4-2) and Phase 4 EEM median arsenic concentration (Table 4-5) is calculated as follows:

$$Kd = \log \frac{917\ (\frac{mg}{kg})}{0.0016\ (\frac{mg}{L})} = 5.8$$

Appendix A – Data Tables

Table A 1: Arsenic Concentration (µg/L) in Water Samples Collected from the Wet Well at Pump House #1 in Yellowknife, NWT, during the Ice-Covered Season

Julian Day	Date	Dissolved Arsenic (µg/L)	Total Arsenic (µg/L)	Ratio
305	1-Nov-05	2.0	2.3	0.87
340	6-Dec-05	1.2	1.3	0.92
3	3-Jan-06	1.2	0.9	1.33
38	7-Feb-06		1.0	
66	7-Mar-06	1.0	1.0	1.00
94	4-Apr-06	1.0	1.0	1.00
122	2-May-06	1.3	1.3	1.00
310	6-Nov-06	0.8	1.5	0.53
339	5-Dec-06	1.0	2.7	0.37
9	9-Jan-07	0.8	0.9	0.89
37	6-Feb-07	1.4	0.8	1.75
65	6-Mar-07	1.0	1.1	0.91
93	3-Apr-07	0.7	2.2	0.32
121	1-May-07	2.8	6.4	0.44
303	30-Oct-07	1.0	1.8	0.56
306	2-Nov-07	1.0	1.2	0.83
338	4-Dec-07	1.6	1.8	0.89
355	21-Dec-07	1.5	1.7	0.88
4	4-Jan-08	1.5	1.3	1.15
38	7-Feb-08	1.1	1.2	0.92
65	5-Mar-08	0.8	1.0	0.80
98	7-Apr-08	0.7	0.8	0.88
128	7-May-08	1.7	1.8	0.94
309	4-Nov-08	<0.2	1.1	
339	4-Dec-08	0.7	0.8	0.88
5	5-Jan-09	0.7	0.8	0.88
36	5-Feb-09	0.4	0.5	0.80
62	3-Mar-09	0.9	0.9	1.00
96	6-Apr-09	0.5	0.8	0.63
126	6-May-09	0.9	0.9	1.00
307	3-Nov-09	1.2	1.3	0.92
337	3-Dec-09	1.0	1.1	0.91
4	4-Jan-10	1.0	1.0	1.00
32	1-Feb-10	1.1	1.1	1.00
60	1-Mar-10	0.4	0.6	0.67
90	31-Mar-10	0.5	0.5	1.00

Julian Day	Date	Dissolved Arsenic (µg/L)	Total Arsenic (µg/L)	Ratio
123	3-May-10	0.7	0.8	0.88
305	01-Nov-11	0.7	0.7	1.00
340	06-Dec-11	0.4	0.5	0.80
38	07-Feb-12	0.7	0.8	0.88
128	07-May-12	1.0	1.0	1.00
304	31-Oct-12	1.0	7.4	0.14
332	27-Nov-12	0.6	0.8	0.75
36	05-Feb-13	0.6	0.6	1.00
64	05-Mar-13	0.5	0.5	1.00
94	04-Apr-13	0.5	0.6	0.83
127	07-May-13	0.8	0.9	0.89
310	06-Nov-13	0.3	0.8	0.38
337	03-Dec-13	0.4	0.8	0.50
36	05-Feb-14	0.4	0.4	1.00
63	04-Mar-14	0.5	0.7	0.71
126	06-May-14	0.5	0.8	0.63
8	08-Jan-15	<0.2	1.1	
34	03-Feb-15	0.8	1.1	0.73
62	03-Mar-15	0.8	1.1	0.73
97	07-Apr-15	0.6	0.8	0.75
307	03-Nov-15	0.3	0.3	1.00
5	05-Jan-16	0.3	0.3	1.00
33	02-Feb-16	0.3	0.3	1.00
61	01-Mar-16	0.3	0.3	1.00
96	05-Apr-16	0.8	0.8	1.00
117	26-Apr-16	0.3	0.3	1.00
124	03-May-16	0.4	0.4	1.00
306	01-Nov-16	0.3	0.4	0.75
344	09-Dec-16	0.3	0.4	0.75
3	03-Jan-17	0.4	0.4	1.00
38	07-Feb-17	0.4	0.4	1.00
66	07-Mar-17	0.3	0.3	1.00
94	04-Apr-17	0.3	0.3	1.00
122	02-May-17	0.3	0.3	1.00
(yellow)	Extra Monthly Samples			
(green)	Below Detection or High Outlier			
(orange)	Dissolved:Total Arsenic Ratio >>1.0			

Table A 2: Arsenic Concentration (µg/L) in Water Samples Collected from the Wet Well at Pump House #1 in Yellowknife, NWT, during the Open-Water Season

Julian Day	Date	Dissolved Arsenic (µg/L)	Total Arsenic (µg/L)	Ratio
277	4-Oct-05	2.7	2.7	1.00
157	6-Jun-06	2.4	2.4	1.00
185	4-Jul-06	1.8	1.8	1.00
215	3-Aug-06	1.4	1.2	1.17
220	8-Aug-06	1.2	1.2	1.00
248	5-Sep-06	1.5	1.4	1.07
277	4-Oct-06	1.6	1.0	1.60
156	5-Jun-07	1.6	1.8	0.89
184	3-Jul-07	1.4	1.3	1.08
219	7-Aug-07	1.9	2.0	0.95
247	4-Sep-07	0.9	0.9	1.00
277	4-Oct-07	0.6	0.9	0.67
162	10-Jun-08	2.2	2.4	0.92
182	30-Jun-08	1.6	1.7	0.94
190	8-Jul-08		1.4	
218	5-Aug-08	2.1	1.9	1.11
260	16-Sep-08	2.7	1.9	1.42
281	7-Oct-08	2.6	2.6	1.00
157	5-Jun-09	2.5	2.8	0.89
187	6-Jul-09	0.9	0.7	1.29
216	4-Aug-09	1.1	1.1	1.00
247	4-Sep-09	1.0	1.3	0.77
278	5-Oct-09	1.7	1.9	0.89
200	19-Jul-10	1.5	1.8	0.83
228	16-Aug-10	1.6	2.0	0.80
179	28-Jun-11	0.4	0.4	1.00
186	05-Jul-11	0.4	0.5	0.80
215	03-Aug-11	0.5	0.5	1.00
250	07-Sep-11	0.4	0.5	0.80
270	27-Sep-11	0.4	0.6	0.67
157	05-Jun-12	1.5	1.9	0.79
185	03-Jul-12	1.5	1.6	0.94
220	07-Aug-12	1.1	1.3	0.85
218	06-Aug-13	0.7	1.3	0.54
247	04-Sep-13	0.6	1.7	0.35
275	02-Oct-13	1.4	1.6	0.88
154	03-Jun-14	0.7	0.8	0.88

Julian Day	Date	Dissolved Arsenic (µg/L)	Total Arsenic (µg/L)	Ratio
255	12-Sep-14	0.4	0.4	1.00
280	07-Oct-14	0.4	0.6	0.67
154	03-Jun-15	2.2	2.6	0.85
188	07-Jul-15	1.4	1.8	0.78
224	12-Aug-15	1.6	1.8	0.89
245	02-Sep-15	1.9	1.8	1.06
279	06-Oct-15	2.8	2.9	0.97
159	07-Jun-16	0.8	0.9	0.89
187	05-Jul-16	0.5	0.5	1.00
215	02-Aug-16	0.4	0.2	2.00
250	06-Sep-16	0.4	0.5	0.80
278	04-Oct-16	0.3	0.4	0.75
(yellow)	Extra Monthly Samples			
(green)	Below Detection or High Outlier			
(orange)	Dissolved:Total Arsenic Ratio >>1.0			

Table A 3: Total Suspended Solids (TSS) and Total Arsenic in Yellowknife Bay Collected in 2012/2013 as part of the Giant Mine Phase 4 Environmental Effects Monitoring Program

Group	Location	Sample Name	Sample Date	TSS (mg/L)	Total Arsenic (µg/L)
YK Bay NF	S02	S2-S	3/26/2012	< 3.0	0.38
YK Bay NF	S01	S1-S	3/26/2012	< 3.0	0.40
YK Bay NF	S03	S3-B	3/27/2012	< 3.0	2.11
YK Bay NF	S03	S3-S	3/27/2012	< 3.0	0.36
YK Bay NF	S04	S4-B	3/27/2012	< 3.0	1.85
YK Bay NF	S04	S4-S	3/27/2012	< 3.0	0.41
YK Bay FF	S06	S6-B	3/27/2012	< 3.0	3.32
YK Bay FF	S06	S6-S	3/27/2012	< 3.0	0.37
YK Bay FF	S07	S7-S	3/27/2012	< 3.0	0.60
YK Bay FF	S08	S8-S	3/27/2012	< 3.0	0.40
YK Bay NF	S01	S1-1	7/18/2012	< 3.0	1.83
YK Bay NF	S01	S1-2	7/18/2012	< 3.0	2.10
YK Bay NF	S19	S19-1	7/18/2012	< 3.0	1.71
YK Bay NF	S19	S19-2	7/18/2012	< 3.0	3.09
YK Bay NF	S03	S3-1	7/21/2012	< 3.0	1.46
YK Bay NF	S03	S3-2	7/21/2012	< 3.0	1.31
YK Bay FF	S06	S6-1	7/21/2012	< 3.0	1.53
YK Bay FF	S06	S6-2	7/21/2012	< 3.0	1.03
YK Bay NF	S12	S12-1	7/21/2012	< 3.0	1.33
YK Bay NF	S12	S12-2	7/21/2012	< 3.0	1.44
YK Bay FF	S23	S23-1	7/21/2012	< 3.0	0.54
YK Bay FF	S23	S23-2	7/21/2012	4.0	0.64
YK Bay FF	S08	S8-1	7/22/2012	< 3.0	0.75
YK Bay FF	S08	S8-2	7/22/2012	< 3.0	0.68
YK Bay NF	S04	S4-1	7/22/2012	< 3.0	1.14
YK Bay NF	S04	S4-2	7/22/2012	< 3.0	1.05
YK Bay NF	S04	S4-3	7/22/2012	< 3.0	1.32
YK Bay NF	S17	S17-1	7/22/2012	< 3.0	1.45
YK Bay NF	S17	S17-2	7/22/2012	< 3.0	3.51
YK Bay NF	S16	S16-1	7/22/2012	< 3.0	1.84
YK Bay NF	S16	S16-2	7/22/2012	< 3.0	1.97
YK Bay NF	S16	S16-3	7/22/2012	< 3.0	0.10
YK Bay NF	S15	S15-1	7/22/2012	4.0	3.35
YK Bay NF	S15	S15-2	7/22/2012	< 3.0	3.72
YK Bay NF	S02	S2-1	7/22/2012	< 3.0	1.33
YK Bay NF	S02	S2-2	7/22/2012	< 3.0	2.09
YK Bay NF	S14	S14-1	7/23/2012	< 3.0	1.86
YK Bay NF	S14	S14-2	7/23/2012	< 3.0	1.65

Group	Location	Sample Name	Sample Date	TSS (mg/L)	Total Arsenic (µg/L)
YK Bay NF	S13	S13-2	7/23/2012	< 3.0	1.49
YK Bay NF	S13	S13-3	7/23/2012	< 3.0	0.10
YK Bay NF	S10	S10-1	7/23/2012	< 3.0	0.78
YK Bay NF	S10	S10-2	7/23/2012	< 3.0	1.56
YK Bay NF	S10	S10-3	7/23/2012	< 3.0	1.70
YK Bay NF	S11	S11-1	7/23/2012	< 3.0	1.07
YK Bay NF	S11	S11-2	7/23/2012	< 3.0	1.16
YK Bay FF	S23	S23-1	10/15/2012	< 3.0	0.43
YK Bay FF	S23	S23-2	10/15/2012	< 3.0	0.58
YK Bay FF	S08	S8-1	10/15/2012	< 3.0	0.85
YK Bay FF	S08	S8-2	10/15/2012	< 3.0	0.85
YK Bay FF	S06	S6-1	10/15/2012	< 3.0	1.79
YK Bay FF	S06	S6-2	10/15/2012	< 3.0	1.86
YK Bay FF	S07	S7-1	10/16/2012	< 3.0	1.63
YK Bay FF	S07	S7-2	10/16/2012	< 3.0	1.91
YK Bay NF	S19	S19-1	10/16/2012	< 3.0	1.52
YK Bay NF	S19	S19-2	10/16/2012	< 3.0	1.71
YK Bay NF	S04	S4-1	10/16/2012	< 3.0	1.74
YK Bay NF	S04	S4-2	10/16/2012	< 3.0	1.74
YK Bay NF	S10	S10-1	10/17/2012	< 3.0	1.35
YK Bay NF	S10	S10-2	10/17/2012	< 3.0	2.08
YK Bay NF	S01	S1-1	10/17/2012	< 3.0	1.36
YK Bay NF	S01	S1-2	10/17/2012	< 3.0	1.45
YK Bay NF	S03	S3-1	10/18/2012	< 3.0	1.58
YK Bay NF	S03	S3-2	10/18/2012	< 3.0	1.74
YK Bay NF	S11	S11-1	10/18/2012	< 3.0	1.82
YK Bay NF	S11	S11-3	10/18/2012	< 3.0	1.58
YK Bay NF	S11	S11-2	10/18/2012	< 3.0	1.81
YK Bay NF	S16	S16-1	10/18/2012	< 3.0	1.57
YK Bay NF	S16	S16-2	10/18/2012	< 3.0	1.78
YK Bay NF	S17	S17-1	10/18/2012	< 3.0	0.90
YK Bay NF	S17	S17-2	10/18/2012	< 3.0	0.86
YK Bay NF	S17	S17-1B	10/18/2012	< 3.0	0.70
YK Bay NF	S12	S12-1	10/18/2012	< 3.0	1.73
YK Bay NF	S12	S12-2	10/18/2012	< 3.0	1.85
YK Bay NF	S15	S15-1	10/20/2012	< 3.0	1.24
YK Bay NF	S15	S15-2	10/20/2012	< 3.0	1.68
YK Bay NF	S02	S2-1	10/20/2012	< 3.0	1.40
YK Bay NF	S02	S2-2	10/20/2012	< 3.0	1.34
YK Bay NF	S14	S14-1	10/20/2012	< 3.0	1.48

Group	Location	Sample Name	Sample Date	TSS (mg/L)	Total Arsenic (µg/L)
YK Bay NF	S13	S13-1	10/20/2012	< 3.0	1.23
YK Bay NF	S13	S13-2	10/20/2012	< 3.0	1.12
YK Bay NF	S19	S19-1	2/6/2013	< 3.0	0.33
YK Bay NF	S19	S19-2	2/6/2013	< 3.0	4.05
YK Bay NF	S12	S12-1	2/7/2013	< 3.0	0.39
YK Bay NF	S13	S13-1	2/7/2013	< 3.0	0.35
YK Bay NF	S13	S13-2	2/7/2013	< 3.0	1.75
YK Bay NF	S11	S11-1	2/7/2013	< 3.0	0.34
YK Bay NF	S11	S11-3	2/7/2013	< 3.0	0.76
YK Bay NF	S11	S11-2	2/7/2013	< 3.0	2.25
YK Bay NF	S14	S14-1	2/7/2013	< 3.0	0.31
YK Bay NF	S14	S14-2	2/7/2013	< 3.0	2.86
YK Bay NF	S16	S16-2	2/8/2013	< 3.0	1.40
YK Bay NF	S15	S15-1	2/8/2013	< 3.0	0.34
YK Bay NF	S15	S15-2	2/8/2013	< 3.0	6.48
YK Bay NF	S16	S16-1	2/8/2013	< 3.0	0.33
YK Bay NF	S03	S3-1	2/8/2013	< 3.0	0.31
YK Bay NF	S03	S3-2	2/8/2013	< 3.0	1.93
YK Bay NF	S10	S10-1	2/8/2013	< 3.0	0.35
YK Bay NF	S10	S10-2	2/8/2013	< 3.0	2.07
YK Bay NF	S02	S2-1	2/8/2013	< 3.0	0.44
YK Bay NF	S17	S17-1	2/9/2013	< 3.0	0.35
YK Bay NF	S01	S1-1	2/10/2013	< 3.0	0.37
YK Bay NF	S04	S4-1	2/10/2013	< 3.0	0.33
YK Bay NF	S04	S4-2	2/10/2013	< 3.0	2.02
YK Bay FF	S23	S23-1	2/11/2013	< 3.0	0.38
YK Bay FF	S23	S23-2	2/11/2013	< 3.0	0.39
YK Bay FF	S08	S8-1	2/11/2013	< 3.0	0.38
YK Bay FF	S08	S8-2	2/11/2013	< 3.0	0.41
YK Bay FF	S07	S7-1	2/11/2013	< 3.0	0.45
YK Bay FF	S06	S6-1	2/11/2013	< 3.0	0.34
YK Bay NF	S01	S1-1	6/14/2013	< 3.0	3.00
YK Bay NF	S01	S1-2	6/14/2013	< 3.0	2.83
YK Bay NF	S19	S19-2	6/15/2013	< 3.0	2.39
YK Bay NF	S04	S4-1	6/15/2013	< 3.0	2.14
YK Bay NF	S04	S4-2	6/15/2013	< 3.0	1.76
YK Bay NF	S19	S19-1	6/15/2013	< 3.0	2.89
YK Bay FF	S06	S6-1	6/15/2013	< 3.0	2.24
YK Bay FF	S06	S6-2	6/15/2013	< 3.0	1.29
YK Bay NF	S11	S11-1	6/15/2013	< 3.0	2.13

Group	Location	Sample Name	Sample Date	TSS (mg/L)	Total Arsenic (µg/L)
YK Bay NF	S11	S11-2	6/15/2013	< 3.0	1.62
YK Bay NF	S10	S10-1	6/16/2013	< 3.0	3.18
YK Bay NF	S10	S10-2	6/16/2013	< 3.0	1.66
YK Bay NF	S03	S3-1	6/16/2013	< 3.0	2.88
YK Bay NF	S03	S3-2	6/16/2013	< 3.0	1.71
YK Bay NF	S12	S12-1	6/16/2013	< 3.0	1.79
YK Bay NF	S12	S12-2	6/16/2013	< 3.0	1.86
YK Bay NF	S14	S14-1	6/16/2013	< 3.0	2.11
YK Bay NF	S14	S14-2	6/16/2013	< 3.0	1.75
YK Bay NF	S15	S15-1	6/16/2013	< 3.0	2.60
YK Bay NF	S15	S15-2	6/16/2013	< 3.0	2.07
YK Bay NF	S13	S13-1	6/17/2013	< 3.0	2.31
YK Bay NF	S13	S13-2	6/17/2013	< 3.0	1.99
YK Bay NF	S02	S2-1	6/17/2013	< 3.0	2.29
YK Bay NF	S02	S2-2	6/17/2013	< 3.0	1.95
YK Bay NF	S16	S16-1	6/17/2013	< 3.0	2.10
YK Bay NF	S16	S16-2	6/17/2013	3.0	2.99
YK Bay NF	S17	S17-1	6/17/2013	< 3.0	1.57
YK Bay NF	S17	S17-2	6/17/2013	< 3.0	2.62
YK Bay FF	S23	S23-1	6/18/2013	< 3.0	0.81
YK Bay FF	S23	S23-2	6/18/2013	< 3.0	0.55
YK Bay FF	S08	S8-1	6/19/2013	< 3.0	1.99
YK Bay FF	S08	S8-2	6/19/2013	< 3.0	0.58
YK Bay FF	S07	S7-1	6/19/2013	< 3.0	1.96
YK Bay FF	S07	S7-2	6/19/2013	< 3.0	1.05
	Data >DL (TSS) or outliers (arsenic)				

Source: Golder (2013)

Table A 4: Station Coordinates for the Phase 4 EEM Program (Golder 2013), the Aquatics Baseline Study (Stantec 2014b), and the Source Selection Study (AECOM 2011).

Station	Exposure	UTM Coordinates	
		Easting	Northing
Surface Water and Surficial Sediment Sample Sites (Golder 2013: Stantec 2014b)			
S01	YK Bay Near Field	636387	6929500
S02	YK Bay Near Field	636642	6931127
S03	YK Bay Near Field	637488	6931174
S04	YK Bay Near Field	637730	6930819
S06	YK Bay Far Field	637863	6929997
S07	YK Bay Far Field	636854	6927146
S08	YK Bay Far Field	637485	6926460
S09	YK Bay Near Field	638120	6935316
S10	YK Bay Near Field	637481	6931158
S11	YK Bay Near Field	637536	6931086
S12	YK Bay Near Field	637404	6931215
S13	YK Bay Near Field	637340	6931205
S14	YK Bay Near Field	636932	6931155
S15	YK Bay Near Field	636289	6931287
S16	YK Bay Near Field	636632	6931296
S17	YK Bay Near Field	636615	6931757
S19	YK Bay Near Field	636698	6930399
S20	YK Bay Near Field	636795	6932243
S21	YK Bay Near Field	636913	6932167
S22	YK Bay Near Field	636733	6932175
S23	YK Bay Far Field	637574	6922995
Surficial Sediment Sample Sites (AECOM 2011)			
YB-01	Pump House #1	636640	6927234
YB-02	Pump House #1	636667	6927245
YB-03	Pump House #1	636665	6927293
YB-04	Pump House #1	636691	6927218
YB-05	Pump House #1	636636	6927223

Source: Golder (2013), Stantec (2014b), AECOM (2011); see Figure 2-1

Table A 5: Meteorological Conditions in Yellowknife the Week Prior to Water Sampling during the Open-Water Season

Julian Day	Date	Dissolved Arsenic (µg/L)	Total Arsenic (µg/L)	Total Precipitation (mm)	Mean Wind Direction (°)	Wind Speed (kph)	
						Mean	Max
277	4-Oct-05	2.7	2.7	11.3	147	13	22
157	6-Jun-06	2.4	2.4	11.2	167	14	21
185	4-Jul-06	1.8	1.8	26.9	200	14	23
215	3-Aug-06	1.4	1.2	2.8	127	9	19
220	8-Aug-06	1.2	1.2	0.0	129	7	11
248	5-Sep-06	1.5	1.4	0.4	127	11	16
277	4-Oct-06	1.6	1.0	7.4	165	9	17
156	5-Jun-07	1.6	1.8	4.0	125	11	18
184	3-Jul-07	1.4	1.3	0.6	120	12	20
219	7-Aug-07	1.9	2.0	11.4	211	9	10
247	4-Sep-07	0.9	0.9	19.9	192	8	13
277	4-Oct-07	0.6	0.9	9.6	145	15	24
162	10-Jun-08	2.2	2.4	0.2	126	13	18
182	30-Jun-08	1.6	1.7	37.8	163	11	15
190	8-Jul-08		1.4	2.4	111	12	16
218	5-Aug-08	2.1	1.9	22.8	173	9	13
260	16-Sep-08	2.7	1.9	15.8	151	8	16
281	7-Oct-08	2.6	2.6	11.0	122	13	19
157	5-Jun-09	2.5	2.8	4.4	121	12	22
187	6-Jul-09	0.9	0.7	23.0	134	8	15
216	4-Aug-09	1.1	1.1	0.8	117	8	14
247	4-Sep-09	1.0	1.3	0.2	202	8	13
278	5-Oct-09	1.7	1.9	13.8	149	9	15
200	19-Jul-10	1.5	1.8	7.8	187	10	17
228	16-Aug-10	1.6	2.0	15.2	146	8	12
179	28-Jun-11	0.4	0.4	0.0	129	9	13
186	05-Jul-11	0.4	0.5	30.8	169	7	13
215	03-Aug-11	0.5	0.5	38.8	154	5	10
250	07-Sep-11	0.4	0.5	2.0	162	12	18
270	27-Sep-11	0.4	0.6	12.0	199	13	21
157	05-Jun-12	1.5	1.9	0.0	115	10	15
185	03-Jul-12	1.5	1.6	22.0	132	11	19
220	07-Aug-12	1.1	1.3	13.8	190	14	23
218	06-Aug-13	0.7	1.3	0.0	164	13	17
247	04-Sep-13	0.6	1.7	6.6	183	15	18
275	02-Oct-13	1.4	1.6	0.4	115	16	23
154	03-Jun-14	0.7	0.8	0.4	157	16	20
255	12-Sep-14	0.4	0.4	0.0	257	15	21

Julian Day	Date	Dissolved Arsenic (µg/L)	Total Arsenic (µg/L)	Total Precipitation (mm)	Mean Wind Direction (°)	Wind Speed (kph)	
						Mean	Max
280	07-Oct-14	0.4	0.6	1.8	208	18	26
154	03-Jun-15	2.2	2.6	5.6	182	19	29
188	07-Jul-15	1.4	1.8	3.8	212	15	21
224	12-Aug-15	1.6	1.8	4.8	190	15	18
245	02-Sep-15	1.9	1.8	4.2	194	16	26
279	06-Oct-15	2.8	2.9	2.6	179	17	22
159	07-Jun-16	0.8	0.9	19.8	166	13	25
187	05-Jul-16	0.5	0.5	0.0	144	15	19
215	02-Aug-16	0.4	0.2	0.0	176	14	21
250	06-Sep-16	0.4	0.5	0.0	152	18	27
278	04-Oct-16	0.3	0.4	5.8	241	15	24

Source: Environment Canada website at: http://weather.gc.ca/index_e.html

Table A 6: Mean Seasonal Arsenic Concentration (μg/L As)

Year	Open-Water Season		Ice-Covered Season	
	Dissolved	**Total**	**Dissolved**	**Total**
2005	2.70	2.70	1.60	1.80
2006	1.65	1.50	1.05	1.34
2007	1.28	1.38	1.31	1.44*
2008	2.24	1.98	0.96	1.14
2009	1.44	1.56	0.80	0.90
2010	1.55	1.90	0.74	0.80
2011	0.42	0.50	0.55	0.60
2012	1.37	1.60	0.83	0.87*
2013	0.90	1.53	0.52	0.70
2014	0.50	0.60	0.47	0.63
2015	1.98	2.18	0.54	0.88
2016	0.48	0.50	0.39	0.40
2017	---	---	0.35	0.35
Mann-Kendall Trends Test Results**				
N	12	12	13	13
S	-30	-17	-66	-58
g	0	1	0	0
tp	0	2	0	0
VAR(S)	213	212	269	269
Z	-1.99	-1.10	-3.97	-3.48
p-value	0.02	0.14	0.00004	0.0002

**Mean values for the Mann-Kendall trends test were calculated without the extreme outliers.*
*** See Meals et al (2011) for explanation of test output*

Table A 7: Maximum Seasonal Arsenic Concentration (µg/L As)

Year	Open-Water Season		Ice-Covered Season	
	Dissolved	Total	Dissolved	Total
2005	2.7	2.7	2.0	2.3
2006	2.4	2.4	1.3	2.7
2007	1.9	2.0	2.8	*6.4 (2.2)
2008	2.7	2.6	1.7	1.8
2009	2.5	2.8	1.2	1.3
2010	1.6	2.0	1.1	1.1
2011	0.5	0.6	0.7	0.7
2012	1.5	1.9	1.0	*7.4 (1.0)
2013	1.4	1.7	0.8	0.9
2014	0.7	0.8	0.5	0.8
2015	2.8	2.9	0.8	1.1
2016	0.8	0.9	0.8	0.8
2017	---	---	0.4	0.4
Mean	**1.79**	**1.94**	**1.16**	**2.13 (1.32)**
STD	**0.83**	**0.81**	**0.67**	**2.22 (0.71)**

**Metrics were calculated with and without the extreme outliers. The value in brackets is the next highest arsenic concentration for that period of record (see Table A.1).*

Appendix B

Vendor Data

- B-1 Northwest Pipe
- B-2 DeNora Adsorptive Media

Appendix B-1 Northwest Pipe

Northwest Pipe Company
12005 N. Burgard, Portland, OR 97203
Phone: (503) 285-1400, (800) 824-9824
Fax: (503) 382-2327

To: Cortney McCracken, P.Eng.
AECOM/Edmonton, AB
Phone: D +1-780-732-9467
Email: cortney.mccracken@aecom.com

Date: August 28, 2017
Project: Yellowknife Waterline
Quotation No. YT-17-20783

Budgetary Quotation

We are pleased to offer prices for steel pipe for the above noted project for materials as listed below. The estimating prices are provided for reference only and Northwest Pipe shall not be bound by pricing or any other provisions herein. Final pricing and delivery can be provided once project requirements are finalized.

SPECIFICATIONS:

Pipe: Manufactured and tested per AWWA C200.
Length: 48 ft joints
Joints: Beveled Ends for butt welding
Lining: cement mortar per AWWA C205
Coating: polyurethane per AWWA C222
Freight: Prices are FOB our plant with full freight allowed to jobsite. Jobsite shall specifically mean truckbed delivery as close to installation site as possible with truck under it's own power. All unloading shall be done by the buyer.
Delivery: Delivery of pipe can commence approximately 10 -12 weeks after receipt of approved shop drawings.
Fabrication: Straight pipe - no fabrication - elbows, blowoffs & airvacs would be extra.
Currency: US Dollars

Item	Qty. (lf)	OD (in)	Wall (in.)	Yield (psi)	Working Pres.(psi)	D/T Ratio	Unit Price $/lf	Extension Total $
	27,889	25.75	0.308	42,000	502	84	$130.00	$3,625,570.00
	Meters	**MM**	**MM**				**Price/meter**	**Extension**
	8,500	654.05	7.823	42,000	502	84	$426.53	$3,625,570.00

For Further Information:

If you have any questions, or need additional information, please contact me at 503-939-8700.

Sincerely,

Jeffrey S. Curl

Sales Representative
Northwest Pipe Company

Appendix B-2 DeNora Adsorptive Media

1.0 SCOPE OF SUPPLY

The following is the equipment supply for for a SORB 33® Engineered Arsenic System (EAS) EAS-6812 for the City of Yellowknife, Northwest Territory, Canada. This proposal is in accordance with the specifications and drawings of De Nora and the information provided by the client for a possible upset condition of 280 L/s design flow (no bypass) and 4,600 µg/L arsenic concentration

Five (5) Adsorber Vessels

75 psig vertical pressure vessels, 12'-0" dia. with 5'-3" straight side wall and design features as follows:

- SA516-70 carbon steel plate.
- Designed and stamped to ASME Section VIII, Division 1 Code
- Interior coated with ANSI / NSF Std. 61 certified epoxy.
- Exterior coated with two coats of self-priming epoxy
- Access ports: (1) 24" diameter on side wall, (1) 14" x 18" on top head
- 304 stainless steel inlet distributor/backwash collection pipe
- 304 stainless steel effluent header with 304 stainless steel screened laterals

Bayoxide® E33 Media with support gravel

Adsorber Piping

- Cement-lined ductile iron process piping, painted same as adsorber exterior.
- Galvanized carbon steel rupture disc and vent piping

Valves & Accessories

Butterfly valves will have lugged cast iron bodies and stainless steel discs. Manual butterfly valves have handwheel operators. Accessories will include expansion joints, rupture discs, quick connect adaptors and air release valves.

Instrumentation

- Influent magnetic flow meter for each adsorber
- Differential pressure switch for each adsorber

Local Control Panel

None. Adsorbers are to be backwashed manually.

Blending Bypass Equipment

- Bypass Flow Magmeter
- Bypass Flow Control Valve (manual butterfly valve)

2.0 FIELD SERVICES

De Nora will furnish the services of a qualified field representative to instruct operation personnel and advise on equipment and media installation and start-up for 10 days in 2 trips.

Additional services can be purchased, if desired, at the rate of $1,500 per day (8 hr/day max.), including travel days, plus travel and living expenses to be billed at cost.

3.0 QUALIFICATIONS

The following items are not included in the De Nora budget price:

- ARRA or AIS compliance
- Freight to the job site
- Taxes, customs fees, duties, GST, brokerage fees, etc.
- Receiving, unloading, storing and installation of De Nora supplied equipment.
- Any pretreatment equipment required for turbidity removal
- Foundations for vessels, building/architectural work and engineering thereof.
- Anchor bolts for vessels or mechanical equipment
- Access ladders & platforms for adsorbers and other tanks
- Interconnecting piping or piping supports including flanges, bolts, nuts and gaskets, and engineering thereof, outside the boundary of the piping on the adsorber vessels. Note, piping for bypass is part of the piping not supplied by De Nora
- Electrical starters, transformers, circuit breakers, VFDs, motor control center, and engineering thereof, and power supply
- Conduit and wire to all devices
- Tubing for DP switches
- Mounting brackets for transmitters
- Heat trace and insulation for freeze protection of pipe and instruments
- Polyurethane top coat for outdoor service
- Water supply/disposal for flushing of adsorber internals
- Performance testing; collection of samples and lab analysis
- Any provisions required to produce a backwash flow of 1,470 gpm (for approximately 12 minutes) which is required for the adsorber backwash. This flow may be provided from backflowing from the distribution system or a separate potable water connection can be provided. Pressure regulation of this water to approximately 25 psig with pressure relief for backwashing, if required, is by others. Final pressure rating will be based on the actual line pressure of the system and piping layout, which must still be confirmed.
- Backwash water storage and/or disposal - Assumes backwash waste will be disposed of to the sanitary sewer
- Spare parts
- Containment area and safety equipment (ie; eyewash and safety showers) for chemical storage and feed system
- Storage of chemicals (assume totes will be used for storage)
- Chemicals

4.0 PRODUCTION SCHEDULE

- Submittal of approval drawings 5 to 6 weeks after acceptance of PO

- Delivery of equipment 14 to 20 weeks after submittal approval.
- All delivery times are subject to confirmation at time of award.

5.0 OPTIONAL EQUIPMENT – NOT INCLUDED, BUT AVAILABLE

- Automatic operation
- AWWA butterfly valves
- Media fill and withdraw piping and valves. Withdraw piping to be polypropylene-lined steel. Valves to be 4" diameter 316 SS full port ball valves with lever handles. Hose connections to be quick disconnect adapters with dust covers with flush connection.
- Access platforms with handrail and ladders to top of adsorbers
- Auxiliary equipment for pH control, full bypass, and backwash handling
- Systems that operate in lag/lead series operation or are capable of both parallel or lag/lead operation.
- Piping materials of various materials and linings.

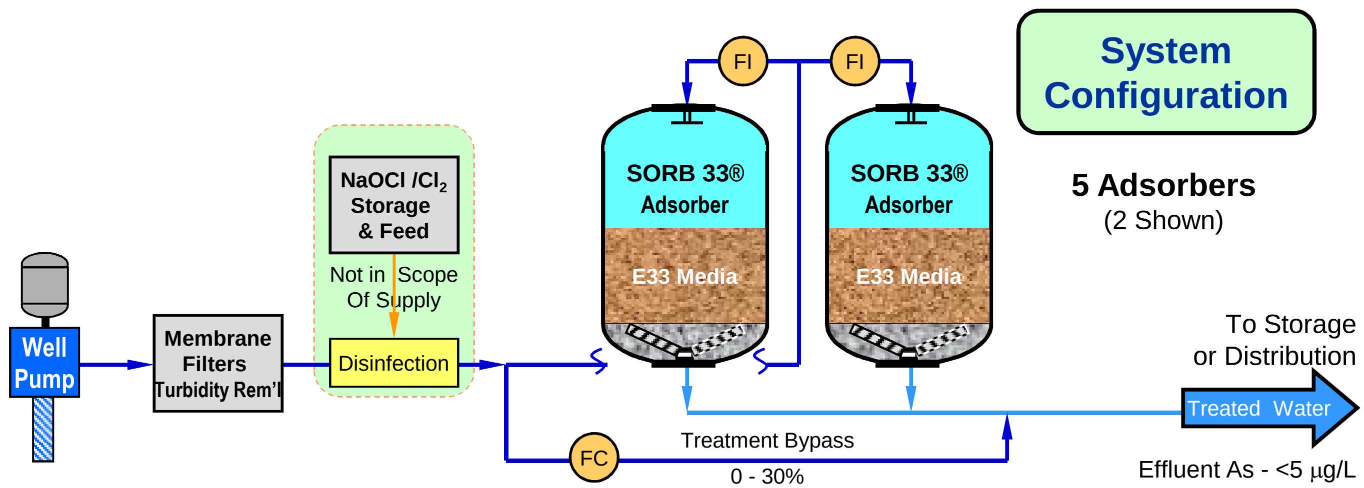
SORB 33® As Removal System Sizing & Estimate

Project Name & General Information

Client:	**City of Yellowknife, NT**	Average Flow:	**6.39**	MGD Avg
Name of Site:	Yellowknife Bay - Worst Case	Well Capacity:	**4,438**	gpm
Primary Contact:	Cortney McCracken	Treatment Flow:	**4,438**	gpm
Engineer:	AECOM	Op Factor: 24.0 Hrs/Day or **100%**	0.0%	Bypass

System Design

SORB 33® Model No:	EAS-6812	Contact Time (EBCT) & Bed Depth:	3.3 Min / 3.5 ft
Adsorber No & Size:	Five 12.0 ft Diameter	Average Treatment Rate:	6,390,720 gals/Day
System Footprint:	70'L x14'W x 14'H	Design Flow Rate per Adsorber:	888 gpm
Flow Configuration:	Parallel w/Bypass		
Adsorptive Media:	Bayoxide E33 Granules	Loading Rate (Specific Velocity):	7.8 gpm/ft^2
Media Quantity:	57,881 lbs (26.25 MT)	Estimated Working Capacity:	141,000 BV's
	1,972 cubic ft	Media Cycle Life:	10.7 Months
Backwash Volume:	19,110 gals/vessel	Volume Treated per Cycle:	2,074.4 million gals
SORB Backwash Rate:	1470 gpm	Arsenic Analysis:	**20.0** µg/L As
pH Adjustment:			
Special Features:	Membrane Fltr Pretreatment for Turbidity Removal	Pres:	20 psig minimum



Budgetary Capital & Operating Costs

Annual O&M Costs: **$463,600** per Yr or **$65 / Acre Ft**

Total Capital Costs: **$1,170,000**

Unit Capital Costs: **$0. 151** per Gal/Day of Capacity

Total Water Volume Treated: **2,074** Million Gallons

Special Notes

No SiO_2 Assays.

Bay (Surface) Water with High [Fe] & [Mn]. Solubility Check; Removal by Membranes. NaOCl or Cl_2 Use

Designed for catastrophic flow & 4,600 µg/L As peak level

Issued: 09-Aug-17 A10 Proposal No. 34769 S07

DE NORA our research - your future

AECOM

Appendix C

Conceptual Cost Estimates

- C-1 Option 1 River
- C-2 Option 2 Bay

Appendix C-1 River Conceptual Cost Estimate

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 1
Date: 28-Nov-17

Option 1: River Supply

Item	Description	Quantity	Unit	Unit Price	Value ($)
1.0	**General Requirements**	1	LS	N/A	$ 3,915,000
2.0	**Civil**	1	LS	N/A	$ 13,902,404
3.0	**Structural and Architectural**	1	LS	N/A	$ 112,000
4.0	**Process Mechanical**	1	LS	N/A	$ 580,700
5.0	**Building Mechanical**	N/A	LS	N/A	$ -
6.0	**Electrical**	1	LS	N/A	$ 452,889
7.0	**Instrumentation**	1	LS	N/A	$ 143,200
8.0	**Demolition of Unused Buildings (old part of PH1)**	1	LS	N/A	$ 56,000
	Sub-Total				$ 19,162,193
	Contingency (30%)				$ 5,748,658
	Engineering (15%)				$ 2,874,329
	TOTAL ESTIMATE CAPITAL COST				**$ 27,790,000**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Option 1: River Supply

Item	Description	Quantity	Unit	Unit Price	Value ($)
1.0	**GENERAL REQUIREMENTS**				
1.1	Performance Bonds & Insurance Bonds (1.6% of project value)	1	LS	240,000	$ 240,000
1.2	Overhead & Indirect Costs (10% of Project Value)	1	LS	1,500,000	$ 1,500,000
1.3	Profit (10% of Project Value)	1	LS	1,500,000	$ 1,500,000
1.4	Site Soft Costs	5	months	35,000	$ 175,000
1.5	Permitting & Environmental	1	LS	500,000	$ 500,000
	TOTAL 1.0 - GENERAL REQUIREMENTS				**$ 3,915,000**

Overhead is based on 10% of the construction cost before including the construction contingency and general requirements. The contractor overhead covers office management and support staff, main office costs, etc.
Profit is based on 10% of the total project cost before including the construction contingency and general requirements.
Site soft costs are for construction power, site office, site foreman, first-aid attendant, telephones, site trailers, crew trucks and other miscellaneous support equipment located on-site.

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 1
Date: 28-Nov-17

Option 1: River Supply

Item	Description	Quantity	Unit	Unit Price	Value ($)
2.0	**CIVIL**				
2.1	Pipe material, 500 psi w.p. (0.3" wall), cement-lined, coated	8500	m	554	$ 4,713,157
2.2	Pipe fittings	$ 4,713,157	%	10%	$ 471,316
2.4	Welding pipe	581	joint	2,760	$ 1,603,560
2.5	Installing pipe (layout, cutting & removing ice, lowering pipe)	8500	m	230	$ 1,955,000
2.6	Excavation at Pumphouses, including fill & material disposal	1,825	m3	$320	$ 583,891
2.7	Excavation in River/Bay, including material disposal but no fill	8,500	m3	$170	$ 1,445,000
2.8	PH tie-ins & river excavation: dewatering, silt walls, pipe fittings, etc	1	lump sum	300,000	$ 300,000
2.9	Bathymetric Survey	1	lump sum	25,000	$ 25,000
2.1	Side-scan Sonar Survey	1	lump sum	25,000	$ 25,000
	SUB-TOTAL				**$ 11,121,923**
	Working on Ice Risk Factor		%	25	$ 2,780,481
	Factor to allow for difference between Edmonton and Yellowknife		%	0%	$ -
	TOTAL 2.0 - CIVIL				**$ 13,902,404**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Option 1: River Supply

Item	Description	Quantity	Unit	Unit Price	Value ($)
6.0	**STRUCTURAL**				
4.1	Modifications / New Room at Pumphouse 1 (allowance)	1	LS	80,000	$ 80,000
	SUB-TOTAL				**$ 80,000**
	Factor to allow for difference between Edmonton and Yellowknife	$ 80,000	%	40%	$ 32,000
	TOTAL 5.0 - STRUCTURAL				**$ 112,000**

Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

Option 1: River Supply

Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Item	Description	Quantity	Unit	Unit Price	Value ($)
4.0	**PROCESS MECHANICAL**				
4.1	Replace Raw Water Intake Screens	2	each	60,000	$ 120,000
4.2	Demolish existing piping, valves, and pumps (PH1 and PH2)	2	lump sum	22,000	$ 44,000
4.3	New piping and valves - PH2	1	lump sum	70,000	$ 70,000
4.4	New piping and valves - PH1	1	lump sum	40,000	$ 40,000
4.5	New raw water pumps, 165 L/s at 82m, 300 hp	2	each	70,000	$ 140,000
4.6	Installation allowance	$260,000	%	25	$ 65,000
	SUB-TOTAL				**$ 479,000**
	Factor to allow for difference between Edmonton and Yellowknife	$339,000	%	30%	$ 101,700
	TOTAL 4.0 - PROCESS MECHANICAL				**$ 580,700**

Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

Option 1: River Supply

Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 15-Sep-17

Item	Description	Quantity	Unit	Unit Price		Value ($)
5.0	**ELECTRICAL**					
4.1	VFDs for new raw water pumps in PH 2 (300 hp)	1	LS	200,000	$	200,000
4.2	1000 amp, 600V incoming section, breaker & three stacks MCC	1	LS	100,000	$	100,000
4.3	120/208V TFMR/Panel	1	LS	10,000	$	10,000
4.4	New size 2 across the line starters in PH1 MCC (recycle pumps)	2	each	3,750	$	7,500
4.5	Lighting/receptacles for new 4x8m room at PH1	48	m2	104	$	4,992
4.6	Customer contribution to upgrade existing transformer at PH2	1	LS	100,000	$	1,000
	SUB-TOTAL				**$**	**323,492**
	Factor to allow for difference between Edmonton and Yellowknife		%	40%	$	129,397
	TOTAL 5.0 - ELECTRICAL				**$**	**452,889**

Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 15-Sep-17

Option 1: River Supply

Item	Description	Quantity	Unit	Unit Price	Value ($)
6.0	**INSTRUMENTATION & CONTROLS**				
4.1	Arsenic Online Analyzer - medium range 0.5 - 200 ppb	1	each	44,000	$ 44,000
4.2	Analyzers Installation	1	LS	8,200	$ 8,200
4.3	WTP PLC and HMI update, including Pall programming update	1	LS	25,000	$ 25,000
4.4	New radio tower and equipment at PH 2	1	LS	40,000	$ 40,000
	SUB-TOTAL				**$ 117,200**
	Factor to allow for difference between Edmonton and Yellowknife	$ 65,000	%	40%	$ 26,000
	TOTAL 5.0 - INSTRUMENTATION & CONTROLS				**$ 143,200**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Annual Incremental O&M Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Option 1: River Supply

Item	Description	Annual Quantity	Unit	Unit Price	Value ($)
1.0	**Raw Water Pumping**				**$ 207,673**
1.1	Electricity - PH2 raw water pumping	639238	kWh	0.25	$ 159,810
1.2	Electricity - PH1 recycle water pumping	41452	kWh	0.25	$ 10,363
1.3	Labour - maintaining extra 2 sets of pumps	60	manhours	125	$ 7,500
1.4	Annual diver inspection of pipeline	1	LS	30,000	$ 30,000
2.0	**Building HVAC**				**$ 41,337**
2.1	Diesel Fuel for Heating Building - PH2 and part of PH1 only	39200	L	1.022	$ 40,062
2.2	Electricity for Air Handling Equipment - PH2 and part of PH1	5100	kWh	0.25	$ 1,275
	Sub-Total				$ 249,010
	Contingency (20%)				$ 49,802
	TOTAL ESTIMATE ANNUAL O&M COST				**$ 300,000**

Notes & Assumptions:

O&M costs above only include items that vary between the options (incremental costs), not the entire O&M costs for water treatment and supply

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Life Cycle Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 15-Sep-17

Option 1: River Supply

Year	Cost
0	$27,790,000
1	$300,000
2	$300,000
3	$300,000
4	$300,000
5	$300,000
6	$300,000
7	$300,000
8	$300,000
9	$300,000
10	$300,000
11	$300,000
12	$300,000
13	$300,000
14	$300,000
15	$300,000
16	$300,000
17	$300,000
18	$300,000
19	$300,000
20	$300,000
21	$300,000
22	$300,000
23	$300,000
24	$300,000
25	$300,000
25-year Net Present Value =	$33,013,944.31
Rounded NPV =	$33,000,000

annual discount rate for present worth (NPV) = 3%

Based on an inflation rate of 2% and an interest rate of 5%.

Appendix C-2 Bay Conceptual Cost Estimate

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

Option 2: Bay with Arsenic Removal Equipment

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 15-Sep-17

Item	Description	Quantity	Unit	Unit Price	Value ($)
1.0	**General Requirements**	1	LS	N/A	$ 1,300,000
2.0	**Civil**	1	LS	N/A	$ 28,000
3.0	**Structural and Architectural**	1	LS	N/A	$ 1,077,888
4.0	**Process Mechanical**	1	LS	N/A	$ 2,793,320
5.0	**Building Mechanical**	1	LS	N/A	$ 648,700
6.0	**Electrical**	1	LS	N/A	$ 317,380
7.0	**Instrumentation**	1	LS	N/A	$ 157,700
8.0	**Demolition of Unused Buildings (PH2 and old part of PH1)**	1	LS	N/A	$ 120,000
	Sub-Total				$ 6,442,988
	Contingency (30%)				$ 1,932,897
	Engineering (15%)				$ 966,448
	TOTAL ESTIMATE CAPITAL COST				**$ 9,340,000**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Option 2: Bay with Arsenic Removal Equipment

Item	Description	Quantity	Unit	Unit Price	Value ($)
1.0	**GENERAL REQUIREMENTS**				
1.1	Performance Bonds & Insurance Bonds (1.6% of project value)	1	LS	80,000	$ 80,000
1.2	Overhead & Indirect Costs (10% of Project Value)	1	LS	500,000	$ 500,000
1.3	Profit (10% of Project Value)	1	LS	500,000	$ 500,000
1.4	Site Soft Costs	5	months	35,000	$ 175,000
1.5	Permitting & Environmental	1	LS	45,000	$ 45,000
	TOTAL 1.0 - GENERAL REQUIREMENTS				**$ 1,300,000**

Overhead is based on 10% of the construction cost before including the construction contingency and general requirements. The contractor overhead covers office management and support staff, main office costs, etc.
Profit is based on 10% of the total project cost before including the construction contingency and general requirements.
Site soft costs are for construction power, site office, site foreman, first-aid attendant, telephones, site trailers, crew trucks and other miscellaneous support equipment located on-site.

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

Option 2: Bay with Arsenic Removal Equipment

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Item	Description	Quantity	Unit	Unit Price	Value ($)
2.0	**CIVIL**				
2.1	Allowance for Parking Lot repair/relocation	1	LS	20,000	$ 20,000
	SUB-TOTAL				**$ 20,000**
	Factor to allow for difference between Edmonton and Yellowknife		%	40%	$ 8,000
	TOTAL 2.0 - CIVIL				**$ 28,000**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Option 2: Bay with Arsenic Removal Equipment

Item	Description	Quantity	Unit	Unit Price	Value ($)
3.0	**STRUCTURAL**				
3.1	*DIV 1 General Requirements*				
3.1.1	Permits, Layout and Survey	1	LS	28,299	$ 28,299
3.2	*DIV 2 Site Work*				
3.2.1	Blasting/Rock Dowels (contingency)	1	LS	20,000	$ 20,000
3.2.2	Excavation	310	m3	18.50	$ 5,735
3.2.3	Backfill & Compaction of Gravel	244	m3	91.70	$ 22,375
3.2.4	Hauling	66	m3	59.40	$ 3,920
3.3	*DIV 3 Concrete*				
3.3.1	**Structural Slab**				
	Forming	20.4	m2	195.00	$ 3,978
	Concrete Supply	79.2	m3	273.00	$ 21,622
	Reinforcement	6217.2	kg	2.63	$ 16,351
	Placement	79.2	m3	37.10	$ 2,938
	Finish	264	m2	12.90	$ 3,406
3.3.2	**Grade Beams on Bedrock**				
	Forming	133.2	m2	195.00	$ 25,974
	Concrete Supply	18.36	m3	273.00	$ 5,012
	Reinforcement	1441.26	kg	2.63	$ 3,791
	Placement	18.36	m3	42.80	$ 786
	Finish	20.4	m2	12.90	$ 263
3.3.3	**Housekeeping Pads (small x6)**				
	Forming	9	m2	195.00	$ 1,755
	Concrete Supply	5.63	m3	273.00	$ 1,537
	Reinforcement	441.56	kg	2.63	$ 1,161
	Placement	5.63	m3	42.80	$ 241
	Finish	37.5	m2	12.90	$ 484
3.3.4	**Housekeeping Pads (large x4)**				
	Forming	8.11	m2	195.00	$ 1,581
	Concrete Supply	8.71	m3	273.00	$ 2,378
	Reinforcement	683.99	kg	2.63	$ 1,799
	Placement	8.71	m3	42.80	$ 373
	Finish	58.09	m2	12.90	$ 749
3.4	*DIV 4 Masonry*				
3.4.1	Concrete Block Wall - Reinforced	102	m2	270.00	$ 27,540
3.5	*DIV 5 Steel and Metals*				
3.5.1	Connections to Existing Building	1	LS	50,000.00	$ 50,000
3.5.2	Beams W530x74	5920	kg	5.39	$ 31,909
3.5.3	Columns HSS254x254x8	6130.2	kg	6.24	$ 38,252
3.5.4	Bracing HSS64x64x4.8	1983.96	kg	6.24	$ 12,380
3.5.5	Girts HSS102x102x4.8	1579.2	kg	6.24	$ 9,854
3.5.6	OWSJ	3900	kg	5.13	$ 20,007
3.5.7	Metal Deck	264	m2	80.00	$ 21,120

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Option 2: Bay with Arsenic Removal Equipment

Item	Description	Quantity	Unit	Unit Price	Value ($)
3.5.8	**Platforms/Mezzanine**				
	Columns HSS102x102x6.4	1081.08	kg	6.24	$ 6,746
	Bracing HSS64x64x4.8	720.8	kg	6.24	$ 4,498
	Beams & Joists W150x22	3608	kg	5.39	$ 19,447
	Extra Steel for MAU	1217.22	kg	6.24	$ 7,595
	Grating	112	m2	219.00	$ 24,528
	Handrail	767.52	kg	5.39	$ 4,137
	Ladder	1	LS	5,000.00	$ 5,000
3.5.9	Misc Metals	2640.45	kg	7.00	$ 18,483
3.6	*DIV 7 Thermal & Moisture Protection*				
3.6.1	Roofing Insulation/Vapour Barrier/Exterior Gypsum	264	m2	196.01	$ 51,747
3.6.2	Waterproofing	264	m3	30.00	$ 7,920
3.6.3	Siding	476	m4	388.50	$ 184,926
3.6.4	Vapour Barrier	476	m5	1.95	$ 928
3.6.5	Flashing	136	m6	107.00	$ 14,552
3.6.6	Fall Protection Handrail	15000	LS	1.00	$ 15,000
3.6.7	Roof Penetrations	15000	LS	1.00	$ 15,000
3.7	*DIV 8 Doors & Windows*				
3.7.1	Exterior Double Door	1	ea	2,193.00	$ 2,193
3.7.2	Interior Double Door	1	ea	1,462.00	$ 1,462
3.7.3	Glazing	1.49	m2	375.00	$ 559
	SUB-TOTAL				**$ 772,291**
	Factor to allow for difference between Edmonton and Yellowknife	$ 763,992	%	40%	$ 305,597
	TOTAL 3.0 - STRUCTURAL				**$ 1,077,888**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
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Revision: 0
Date: 12-Sep-17

Option 2: Bay with Arsenic Removal Equipment

Item	Description	Quantity	Unit	Unit Price	Value ($)
4.0	**PROCESS MECHANICAL**				
4.1	Raw water intake screen	1	LS	100,000	$ 100,000
4.2	Replace raw water pumps including shelf spare. 165 L/s at 69m (additional head needed for arsenic removal process)	3	each	60,000	$ 180,000
4.3	Replace existing sodium hypochlorite dosing pumps	1	LS	20,000	$ 20,000
4.4	Second NaOCl generation skid	1	LS	150,000	$ 150,000
4.5	3,000 usg pressure tank for oxidation contact time	1	LS	46,000	$ 46,000
4.6	Arsenic Treatment System - ferric adsorptive media	1	LS	1,600,000	$ 1,600,000
4.7	Installation of major equipment listed above	2,096,000	%	15	$ 314,400
4.8	Demolition of pumps, piping and valves at PH1	1	LS	22,000	$ 22,000
4.9	New piping and valves in PH1 (relocate pipe for building demo)	1	LS	25,000	$ 25,000
4.10	New piping and valves in WTP	1	LS	175,000	$ 175,000
	SUB-TOTAL				**$ 2,632,400**
	Factor to allow for difference between Edmonton and Yellowknife	$ 536,400	%	30%	$ 160,920
	TOTAL 4.0 - PROCESS MECHANICAL				**$ 2,793,320**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

Option 2: Bay with Arsenic Removal Equipment

AECOM Project #: 60541637
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Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Item	Description	Quantity	Unit	Unit Price	Value ($)
5.0	**BUILDING MECHANICAL**				
5.1	Building HVAC	1	ea	288,000	$ 288,000
5.1.1	Packaged Indoor Air Handling Unit w/ Heat Recovery Option	4	ea	6,000	$ 24,000
5.1.2	35kW Hydronic Unit Heater	1	LS	57,000	$ 57,000
5.1.3	Rectangular Ductwork and Fittings	8	ea	500	$ 4,000
5.1.4	Diffusers/Grilles	2	ea	800	$ 1,600
5.1.5	Louvers				
5.2	Building Hydronics				
5.2.1	3.7 kW 50% PG pump	1	ea	15,000	$ 15,000
5.2.2	25mm SCH 40 Steel Piping	1	LS	4,000	$ 4,000
5.2.3	25mm SCH 40 Steel Pipe Fittings	1	LS	2,000	$ 2,000
5.2.4	50mm SCH 40 Steel Piping	1	LS	8,000	$ 8,000
5.2.5	50mm SCH 40 Steel Pipe Fittings	1	LS	2,000	$ 2,000
5.2.6	Valves and Misc. Equipment	1	LS	6,000	$ 6,000
5.3	Plumbing				
5.3.1	100mm Floor Drain	3	ea	200	$ 600
5.3.2	100mm PVC Drainage Piping and Fittings	1	LS	17,000	$ 17,000
5.3.3	0.37kW Sump Pump	1	ea	3,000	$ 3,000
5.3.4	100mm Cleanouts	3	ea	600	$ 1,800
5.4	Controls				
5.4.1	DDC Controls	20	ea point	1,000	$ 20,000
5.5	Fire Protection				
5.5.1	4.5kg Fire Extinguisher	2	Ea	500	$ 1,000
5.6	Miscellaneous				
5.6.1	Air and Water Balancing	1	Lump Sum	20,000	$ 20,000
5.6.2	Miscellaneous	1	Lump Sum	24,000	$ 24,000
	SUB-TOTAL				**$ 499,000**
	Factor to allow for difference between Edmonton and Yellowknife	$ 499,000	%	30%	$ 149,700
	TOTAL 5.0 - BUILDING MECHANICAL				**$ 648,700**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 15-Sep-17

Option 2: Bay with Arsenic Removal Equipment

Item	Description	Quantity	Unit	Unit Price	Value ($)
6.0	**ELECTRICAL**				
6.1	two size 2 motor starters, and MCC stack for new MAU fans	1	LS	4,000	$ 4,000
6.2	glycol pump electrical	1	LS	1,500	$ 1,500
6.3	Hydronic heaters electrical	1	LS	1,200	$ 1,200
6.4	actuator connections for process electric control valves	7	each	250	$ 1,750
6.5	Minor control and power connections for second NaOCl skid	1	LS	500	$ 500
6.6	VFDs for two new Bay pumps in PH1 (250 hp)	1	LS	180,000	$ 180,000
6.7	new NaOCl pumps electrical	1	LS	250	$ 250
6.8	New trip unit on main breaker in PH1	1	LS	1,000	$ 1,000
6.9	service conductors, upgrading 400 amp to 800 amp, in PH1	1	LS	35,000	$ 35,000
6.10	drive feeder breakers for new Bay pumps in PH1	1	each	1,500	$ 1,500
	SUB-TOTAL				**$ 226,700**
	Factor to allow for difference between Edmonton and Yellowknife	$ 226,700	%	40%	$ 90,680
	TOTAL 6.0 - ELECTRICAL				**$ 317,380**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Capital Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 15-Sep-17

Option 2: Bay with Arsenic Removal Equipment

Item	Description	Quantity	Unit	Unit Price	Value ($)
7.0	**INSTRUMENTATION & CONTROL**				
7.1	Arsenic Online Analyzer - custom range 0.5 - 5,000 ppb	1	each	70,500	$ 70,500
7.2	Arsenic Online Analyzer - medium range 0.5 - 200 ppb	1	each	44,000	$ 44,000
7.3	Analyzers Installation	1	LS	8,200	$ 8,200
7.4	WTP PLC and HMI update, including Pall programming update	1	LS	25,000	$ 25,000
	SUB-TOTAL				**$ 147,700**
	Factor to allow for difference between Edmonton and Yellowknife	$ 25,000	%	40%	$ 10,000
	TOTAL 7.0 - INSTRUMENTATION & CONTROL				**$ 157,700**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Annual Incremental O&M Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 12-Sep-17

Option 2: Bay with Arsenic Removal Equipment

Item	Description	Annual Quantity	Unit	Unit Price	Value ($)
1.0	**Raw Water Pumping**				**$ 228,589**
1.1	Electricity - Raw Water Pumps in PH1	914355	kWh	0.25	$ 228,589
2.0	**Building Mechanical**				**$ 129,480**
2.1	Diesel Fuel for Heating Building - WTP expansion only	90000	L	1.022	$ 91,980
2.2	Electricity for Air Handling Equipment - WTP expansion only	150000	kWh	0.25	$ 37,500
3.0	**Adsorptive Media**				**$ 65,202**
3.1	Labour	74	manhours	125	$ 9,250
3.2	Backwash Pumping Electricity	3808	kWh	0.25	$ 952
3.3	Allowance for Treating Backwash Waste (or Sewer Pumping)	1	LS	1,000	$ 1,000
3.4	Media Disposal and Replacement	0.1	LS	540,000	$ 54,000
	Sub-Total				$ 423,271
	Contingency (20%)				$ 84,654
	TOTAL ESTIMATE ANNUAL O&M COST				**$ 510,000**

Yellowknife Potable Water Source Selection Study
Class "D" / Order of Magnitude Life Cycle Cost Estimate (±50%)

AECOM Project #: 60541637
Client Project #: 17-016
Client: City of Yellowknife
Revision: 0
Date: 15-Sep-17

Option 2: Bay with Arsenic Removal Equipment

Year	Cost
0	$9,340,000
1	$510,000
2	$510,000
3	$510,000
4	$510,000
5	$510,000
6	$510,000
7	$510,000
8	$510,000
9	$510,000
10	$510,000
11	$510,000
12	$510,000
13	$510,000
14	$510,000
15	$510,000
16	$510,000
17	$510,000
18	$510,000
19	$510,000
20	$510,000
21	$510,000
22	$510,000
23	$510,000
24	$510,000
25	$510,000
25-year Net Present Value =	$18,220,705.32
Rounded NPV =	$18,200,000

annual discount rate for present worth (NPV) = 3%

Based on an inflation rate of 2% and an interest rate of 5%.

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AECOM (NYSE: ACM) is built to deliver a better world. We design, build, finance and operate infrastructure assets for governments, businesses and organizations in more than 150 countries.

As a fully integrated firm, we connect knowledge and experience across our global network of experts to help clients solve their most complex challenges.

From high-performance buildings and infrastructure, to resilient communities and environments, to stable and secure nations, our work is transformative, differentiated and vital. A Fortune 500 firm, AECOM companies had revenue of approximately US$19 billion during the 12 months ended June 30, 2015.

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