FINAL

AECOM

Potable Water Source Selection Study

Water Source Review 2024 Update

City of Yellowknife

60673796

February 2025

Delivering a better world

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Chris Greencorn
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February 10, 2025

Project #
60673796

Subject:

Dear Chris:

We are pleased to submit the FINAL report for the Yellowknife Water Source Selection Study. We look forward to review of the document and its findings with the City. If you have any further questions, please do not hesitate to contact us.

Sincerely,
AECOM Canada Ltd.

Ryan King
Market Sector Leader, Conveyance
Western Canada, Water
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Encl.

cc:

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AECOM: 2015-04-13

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Revision History

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Distribution List

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Executive Summary

Prior to 1968, the City of Yellowknife obtained its raw 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 arsenic contamination concerns from the Giant and Con mines, where the City continues to obtain its drinking water.

An intake in Yellowknife River supplies water to Pumphouse 2, which then pumps the water through an eight-kilometre submarine pipeline to Pumphouse 1, which acts as an in-line booster to supply the Water Treatment Plant (WTP). There are concerns with respect to the condition of the submarine pipeline, condition of the two pumphouses, and shortfalls in capacity of the pipeline and pumphouse equipment compared to the forecast water demands to which the WTP was designed. These concerns have led the City to evaluate and re-evaluate the costs and the risks of continuing to source water from the Yellowknife River or relocate its waster source to Yellowknife Bay.

A Potable Water Source Selection Study was initially carried out in 2017, where two options were considered:

- ⇒ **Option 1 River Source**: Continued use of Yellowknife River as primary water source, with a new submarine pipeline of increased capacity, and major upgrades to both Pumphouse 1 and Pumphouse 2 to achieve satisfactory operation over a 25+-year window. The existing emergency back-up supply from Yellowknife Bay would be retained in the event of non-availability of the submarine pipeline or associated pump house equipment
- ⇒ **Option 2 Bay Source**: Yellowknife Bay as the sole water source using an upgraded pumphouse 1, with a new treatment process within the WTP for arsenic removal in case of increased arsenic level contamination from a release from the adjacent mines (Upset Conditions.

In 2017 the Yellowknife River source with a new submarine pipeline was determined to have a higher capital cost but 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. 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 or breach at Giant Mine.

A matrix-style decision model was developed to evaluate the two options. It was determined that the River source was the preferred option based on 2017 cost estimates, Yellowknife Bay water quality data, and understanding of failure modes and risk associated with a major spill from the Giant Mine surface ponds.

Since the 2017 study, there have been several developments which directly impact the evaluation of each source, specifically:

- ⇒ Commencement of detailed design of Pumphouse 1 and Pumphouse 2 upgrades as well as design for the replacement of the Submarine Pipeline has resulted in an updated construction cost estimate, with expected project costs having risen substantially since 2017.
- ⇒ More information is available related to the Giant Mine Remediation Project (GMRP). The GMRP includes construction of a new Water Treatment Plant (GMWTP) intended to treat contaminated water to potable water standards for arsenic before it is discharged to Yellowknife Bay. Risk of breach of the Northwest Pond resulting in catastrophic release affecting the Yellowknife Bay source is expected to be reduced when the new GMWTP enters service in 2026, and be further reduced by 2032 when the ponds are intended to be fully decommissioned and other mine closure activities have been completed.

The purpose of this 2024 update to the potable water source study is to re-evaluate viable water source options using as much of the 2017 assessment matrix as practicable, such that the methodology is consistent. However, in addition to the original two water source options (River and Bay), an additional two options have been added for consideration.

⇒ **Option 3 Status Quo**: Yellowknife River using the existing submarine pipeline with back-up supply from Yellowknife Bay in the event of non-availability of the pipeline or associated pump house equipment. The only difference from present day operation is that Pumphouse 1 is fully upgraded to match Options 1 and 2, and minor upgrades are implemented at Pumphouse 2. No arsenic removal process is included at the WTP. At some point when the existing submarine pipeline is no longer usable, the primary water source would become Yellowknife Bay.

⇒ **Option 4 Hybrid Source with Arsenic Removal**: Yellowknife Bay is the primary water source, and includes the arsenic removal process included in Option 2. In addition, the existing submarine pipeline is retained as secondary source and back-up in the event of an upset condition where the arsenic concentration exceeds the levels that can be removed by the WTP. Pumphouse upgrades are identical to Option 3.

Additional definition of the three raw water conditions in Yellowknife Bay with respect to impact on the City WTP operations has been defined:

⇒ **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 an unintended release of arsenic from a major source related to activities at the Giant Mine.

- Upset Condition #1 – where the GMWTP fails either partially or in whole for a long duration (months), the mine pond level rises and eventually releases contaminated water to surface and ultimately into the YK Bay.
- Upset Condition #2 – where the GMWTP releases effluent with metals concentrations above the effluent targets. This is a hypothetical situation with less impact on arsenic concentrations in the Bay and correspondingly less risk than upset condition #1.

Scoring of each option has been updated to reflect changes in estimated costs, changes in risk profile and timeline of the GMRP.

As with the evaluation carried out in 2017, Option 1: River Source, was scored the highest, while Option 4 scored the second highest, with a small margin of 13% separating the two scores. Option 1 also scored highest in all except one alternative considered as part of the sensitivity analysis undertaken within the scoring section of the study. Option 2 Bay Source was scored the lowest.

The evaluation outcome remained similar to the outcome in 2017 despite a signficant increase in expected Capital Cost for Option 1 since 2017, and the decrease in likelihood of an upset event affecting the Bay Source. However, per the original evaluation matrix, Lifecycle Cost only amounts to 15% of the score. The arsenic susceptibility also plays a relatively minor role in the outcome, weighted at 16%, and Option 1 would still have the highest total score even if all three options were rated identically for that category.

The Reliability of Water Supply has the biggest bearing on the evaluation outcome (50% of weighting), with the redundancy offered by Option 1 identified as a significant benefit to the City in the event of elevated levels of arsenic, or other issue affecting the Bay Source. Diversity of water sources provides a level of reliability that is highly sought after, but out of reach for many cities and municipalities across Canada. While Options 3 and 4 also offer redundancy of sources, the major difference is that the existing submarine pipeline is retained as part of those options, and the basis of the evaluation is that the existing pipeline would not remain serviceable for a 25-year period.

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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. 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 environment 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 to manage the mine pool level. When remediation is complete, the site will need continued maintenance and monitoring 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 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 Yellowknife 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)

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.

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

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.

In 2017, AECOM completed a potable water source selection study to provide an updated recommendation for the City's potable water source based on current arsenic data and cost information. Two water source options were evaluated using a matrix decision model to provide City Council with the information necessary to make a well-founded and defensible decision. The Yellowknife River source, including replacement of the submarine pipeline, was the highest scoring option. This option concluded to have a higher cost but less risk of arsenic contamination.

In 2018 Dillon Consulting Limited (Dillon) completed a third-party engineering review of the source selection study and affirmed the conclusions that AECOM had derived in the source study.

Since the completion of the 2017 study, more information has become available about arsenic concentrations in Yellowknife Bay. AECOM has also done the preliminary design for a new submarine pipeline, intakes, and associated pumphouse upgrades. The lifecycle costing established in the 2017 source study has become outdated and no longer applicable, largely due to increases in labour and materials that have accelerated since 2020. AECOM also has a more detailed understanding of the scope of the pipeline replacement following the preliminary design work completed since 2021 for the upgrade of the submarine pipeline to the Yellowknife River. The Submarine Waterline Replacement Preliminary Design Report (AECOM, 2023) was issued in April 2023, and 66% detailed design submitted in October 2023 (AECOM).

1.3 Source Selection Update

This report is an update of the previous source selection study completed in 2017. The key objective is to provide an updated recommendation for the City's potable water source prior to further capital investment in the submarine pipeline system. This update will reevaluate the decision model scoring based on updated lifecycle costs and new information about Yellowknife Bay water quality, risks related to Giant Mine, and developments in treatment technology.

Four water source options have been evaluated, with the first two options being identical to those studied in 2017:

- ⇒ **Option 1 River Source:** Yellowknife River through a new submarine pipeline, with emergency back-up supply from Yellowknife Bay in the event of non-availability of the pipeline or associated pump house equipment
- ⇒ **Option 2 Bay Source:** Yellowknife Bay with a new treatment process within the WTP for arsenic removal in case arsenic levels increase.
- ⇒ **Option 3 Status Quo:** Yellowknife River using the existing submarine pipeline with back-up supply from Yellowknife Bay in the event of non-availability of the pipeline or associated pump house equipment. The only difference from present day operation is that Pumphouse 1 is fully upgraded to match Options 1 and 2, and minor upgrades implemented at Pumphouse 2. No arsenic removal process is included at the WTP. At some point when the existing submarine pipeline is no longer usable, the primary water source would become Yellowknife Bay.
- ⇒ **Option 4 Hybrid Source with Arsenic Removal:** Yellowknife Bay is the primary water source, and includes the arsenic removal process included in Option 2. In addition, the existing submarine pipeline is retained as secondary source and back-up in the event of an upset condition where the arsenic concentration exceeds the levels that can be removed by the WTP. Pumphouse upgrades are identical to Option 3.

2. Arsenic Risks

Risks related to arsenic involve a release that results in contamination in water at the Pumphouse 1 intake, which would be where arsenic contaminated water would enter the Yellowknife WTP. To establish a risk level, potential arsenic concentrations at Pumphouse 1 had to be developed. To meet this objective, AECOM obtained available surface water dissolved and total arsenic data from a variety of sources. This data was 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.

- ⇒ **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.

An updated analysis of Normal Conditions and human health risks is presented in a separate technical memorandum (Water Quality Characterization Memorandum, AECOM, 2024) attached to this report as Appendix A.

Antimony in the raw water is also a potential concern under Upset Conditions. This section includes estimates of antimony concentrations as well as arsenic concentrations.

2.1 Arsenic Concentrations Evaluated in 2017 Study

Key conclusions from the original 2017 memorandum 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.

2.2 Updated Arsenic Concentration Considerations

2.2.1 Remediation Timing

Remediation activities at Giant Mine should reduce the risk of arsenic release in the near future. The short-term scenario Upset Condition from the 2017 study (i.e., catastrophic loss of containment at the Giant Mine Northwest surface pond) is only applicable until the Northwest Pond at Giant Mine is remediated, after the new WTP is commissioned. According to the Giant Mine Remediation Project (GMRP) Closure and Reclamation Plan (CRP) Table 5.6.3, plans to meet Closure Objective T1 include covering the tailings containment areas to meet closure criteria for runoff water quality (CIRNAC/GNWT, 2021). Once the new GMWTP is commissioned, the existing Northwest Pond would no longer be used as part of the water treatment process although this pond would temporarily hold smaller amounts of contaminated water until the ponds are drained and covered as part of remediation activities.

After the ponds are decommissioned, the risk of contaminated water release from a surface pond is eliminated, but there are still risks related to failure of water management at Giant Mine. There is also a risk that remediation plans could change in the future. For example, a surface pond might be repurposed to provide temporary additional storage of contaminated water instead of being fully decommissioned.

Table 1 below shows selected site remediation activities at Giant Mine along with their anticipated timing. Note that actual remediation schedule could be affected by unforeseen issues with funding or construction.

Table 2-1: Giant Mine Remediation Activities

Activity	Anticipated in Year	Reference
Commissioning of new Giant Mine WTP	2026	GMRP CRP section 5.8.1.2 (CIRNAC/GNWT, 2021)
Dewatering of Northwest Pond	2026 - 2028	Dewatering of NW Pond in "Year 7" per section 6.6 of the GMRP CRP, and WTP commissioning is "Year 5" (CIRNAC/GNWT, 2021). NW Pond pumped to underground in years 2026 – 2032, with lower flows after 2026, per Appendix C Model Results of Water Balance Model 2020 Updates (Golder, 2021)
Finish placing cover on Northwest Pond and other surface ponds	2031-2032	Cover placed in "Year 7" to "Year 10" in section 6.6 of the GMRP CRP, and WTP commissioning is "Year 5" (CIRNAC/GNWT, 2021). Pond runoff no longer directed to underground in 2033 per Figure B-13 in Appendix B Flow Diagrams of Water Balance Model 2020 Updates (Golder, 2021).

2.2.2 Normal Conditions

The key conclusions from the Water Quality Characterization Memorandum 2024 (Appendix A) were as follows:

1. Arsenic levels are higher during periods of open water compared to ice-covered periods. There is a general trend of decreasing arsenic concentrations at Pumphouse 1 but the trend is only statistically significant for the ice-covered condition.

2. The water from the Yellowknife River continues to provide the lowest concentration of total arsenic with a mean concentration in the river of 0.00052 mg/L compared to 0.00107 mg/L at Pumphouse 1.
3. Health Canada's Maximum Acceptable Concentration (MAC) for arsenic in drinking water is 0.01 mg/L (10 µg/L) based on considerations for health, practical measurement, and achievable treatment. The concentration of arsenic in drinking water representing an "essentially negligible" level of health risk is 0.0003 mg/L (0.3 µg/L). The practical quantitation level, based on the ability of laboratories to measure arsenic within reasonable limits of precision and accuracy, is 0.003 mg/L (3 µg/L).
4. Calculated incremental lifetime cancer risk (ILCR) associated with the normal arsenic concentrations is 4.39×10^{-5} for water from the Pumphouse 1 intake (the Bay) or 1.87×10^{-5} for water from the Pumphouse 2 intake (the River). Both of these risk values are slightly outside the range of "essentially negligible" risk as defined by Health Canada (i.e. $1x10^{-5}$ to $1x10^{-6}$). For context, Health Canada estimates that the average Canadian has a 40% risk of developing cancer over their lifetime (ILCR = 0.40 for baseline). The calculated incremental lifetime cancer risks associated with drinking water exposures from the Bay and the River increase that value to 0.400044 and 0.400019 respectively.

There is a relatively small difference in the calculated incremental lifetime cancer risks associated with drinking water sourced from Yellowknife Bay versus the Yellowknife River under normal conditions, and both options present a very low risk to human health. As such, normal water quality conditions are not considered in the decision model for this water source options evaluation. If the decision model criteria and weightings were changed to include differences in lifetime cancer risk in the evaluation, we expect this would only affect options that include Bay water without an arsenic treatment process, i.e. the overall score for Option 3 could become relatively lower.

2.2.3 Storm Conditions

The conclusions from the 2017 study are assumed to still be valid, i.e. precipitation and wind are not expected to measurably affect water column arsenic concentration. This was based on available data, which did not include extreme storm conditions, therefore there is some uncertainty in the conclusions for Storm Conditions. Some of this uncertainty could be reduced by additional monitoring as recommended in the 2017 study (continuous monitoring of turbidity at the water intake during storm conditions, and sampling for total and dissolved arsenic if a spike in turbidity occurs) although this sampling would not necessarily account for the possibility of worsening storms in the future due to climate change. No updates were completed related to storm conditions.

2.2.4 Upset Conditions

For this 2024 update of the source selection study, AECOM has considered the following potential failure scenarios:

1. **Upset Condition #1**: A scenario where the Giant Mine Water Treatment Plant (GMWTP) stops operating or fails to treat and discharge sufficient volumes of water for an extended period of time (months). In this scenario the underground mine pool level rises and eventually releases contaminated mine pool water to surface and ultimately into Yellowknife Bay. This may be more likely to occur in years 2026-2038 when the inflows to the mine pool are anticipated to be approximately twice as high compared to years after 2038 when active remediation will be complete (see "Total Inflows to Underground" figures in the EQC report, CIRNAC/GNWT, 2019). However, flow reduction is based on today's baseline and does not account for potential climate change impacts. Climate change may increase inflows and infiltration, as well as contribute to supply chain disruption that may increase WTP downtime and increase risk of mine pool flooding.

   For this scenario, we have assumed a mine pool high arsenic concentration of 200 mg/L is released at 2,778 m^3/day, which is the daily average of the maximum annual inflow to underground of 1,000,000 m^3/year. The effect on water quality at the City's Bay intake location could be conservatively estimated using a dilution factor of 200, which is slightly higher than the minimum dilution factor of 166 stated in the 2019 Effluent Quality Criteria report (EQC report) (CIRNAC/GNWT, 2019) for Giant Mine for dilution to the edge of the mixing zone 200 m from the Giant Mine WTP outfall. For these assumptions, the arsenic concentration at the City's Bay intake could be 1.8 mg/L, which is lower than the worst-case Upset Condition concentration from 2017 but still very high and challenging to treat.

If the mine pool spill has a lower arsenic concentration, then concentrations at the Pumphouse 1 intake would be lower. For example, underground minewater with the Base Case predicted median arsenic concentration of 15 mg/L from the EQC report (CIRNAC/GNWT, 2019) with a dilution factor of 200 would result in an arsenic increase of 0.075 mg/L at Pumphouse 1.

This is a conservative estimate. It may be possible for members of the Giant Mine remediation team to refine the assumptions, especially the dilution factor, using the model of Yellowknife Bay developed for the Giant Mine remediation project. However, it is expected the conclusion from a more detailed analysis would remain that a long-term interruption of water treatment at Giant Mine could result in arsenic concentrations above the drinking water MAC at the City's Pumphouse 1 intake location.

This failure is not expected to affect the River intake which is located upstream of the Giant Mine. The estimated water quality at the Bay intake following this hypothetical failure will be referred to as "Upset Condition #1" for the remainder of this report.

2. **Upset Condition #2**: A scenario where the GMWTP is releasing treated water with arsenic concentrations above the target Effluent Quality Criteria of 0.01 mg/L (which matches the drinking water MAC). This is a hypothetical situation where the GMWTP is operating, but not working as effectively as intended and is releasing only to prevent a more severe mine pool flooding scenario. Note that the GMWTP is required to stop release of any treated water with an As concentration above 0.01 mg/L.

   Summarized assumptions and outcomes:

   - GMWTP effluent in this scenario is assumed to have an arsenic concentration of 0.3 mg/L (similar to current performance from the Existing Effluent Treatment Plant (ETP), as assumed for the ETP Base Case in the EQC report CIRNAC/GNWT, 2019),
   - Dilution factor from the outfall to Pumphouse 1 is conservatively assumed to be 166 (matching the minimum dilution factor from the EQC report for the outfall mixing zone, which is much closer to the outfall than is Pumphouse 1),
   - Arsenic concentrations at the Pumphouse 1 intake would increase by 0.002 mg/L.
   - In this case the average concentration of total arsenic at Pumphouse 1 would be 0.00307 mg/L including normal median arsenic, or 0.00419 mg/L if added to the normal 95%ile arsenic instead, which is still below the MAC of 0.01 mg/L.

Table 2-2: Estimated Arsenic Concentrations for Upset Conditions

Parameter	Value	Units	Notes
Upset Condition #1			
Assumed Daily Flow (spill)	2,740	m^3/day	Assumed mine pool overflow volume based on average of approximate maximum wet-year annual flow 1,000,000 m^3/year from Figure D2.2-6c in EQC Report (CIRNAC/GNWT, 2019).
Assumed Arsenic Concentration (spill), assumed high concentration	360	mg/L	Assumed mine pool arsenic concentration based on 2017- 2023 results from the C Shaft Void location (station CS-V in the Operational Monitoring Program).
Assumed Arsenic Concentration (spill), median	15	mg/L	Based on "Base Case" underground minewater quality for years 2026-2040, median concentration from Table 4-1 of EQC report (CIRNAC/GNWT, 2019).
Assumed Dilution Factor to Pumphouse 1	200		Depends on flowrates including other inputs to Yellowknife Bay. Based on a minimum dilution factor of 166 stated in the 2019 Effluent Quality Criteria report for Giant Mine for dilution from the Giant Mine WTP outfall to the edge of the mixing zone (200 m from outfall) at WTP design discharge flowrate.
Estimated increase in arsenic at Pumphouse 1, assumed high concentration	1.800	mg/L	Estimated concentration = discharged concentration / dilution factor
Estimated total arsenic at Pumphouse 1, assumed high concentration	1.802	mg/L	Estimated high concentration increase + normal 95%ile
Estimated increase in arsenic at Pumphouse 1, median	0.075	mg/L	Estimated concentration = discharged concentration / dilution factor
Estimated total arsenic at Pumphouse 1, median	0.076	mg/L	Estimated median increase + normal median

Parameter	Value	Units	Notes
Upset Condition #2			
Assumed Daily Flow (effluent)	2,592	m^3/day	Giant Mine WTP design maximum effluent flowrate (30 L/s per section 4.2 of the Water Treatment Plant Design Plan, CIRNAC/GNWT, 2023). Flows after 2038 are expected to be lower, estimated closer to 1,000 m3/day per EQC report Figure D2.2-6a (CIRNAC/GNWT, 2019).
Assumed Arsenic Concentration (effluent)	0.3	mg/L	Based on "Predicted Base Case" for Existing Effluent Treatment Plant, 95%ile concentration from Table 4-2 of EQC report (CIRNAC/GNWT, 2019).
Assumed Dilution Factor to Pumphouse 1	166		See notes under Upset Condition #1
Estimated increase in arsenic at Pumphouse 1	0.002	mg/L	Estimated concentration = discharged concentration / dilution factor
Estimated total arsenic at Pumphouse 1	0.003	mg/L	Estimated increase + normal median

The untreated mine contact water contains various metals and other contaminants besides arsenic. For the “Base Case” predicted underground minewater quality for years 2026-2040 in Table 4-1 of the Giant Mine EQC report (CIRNAC/GNWT, 2019), the parameters anticipated to be above MAC limits from the Guidelines for Canadian Drinking Water Quality (GCDWQ) in the underground minewater are arsenic, antimony, manganese, and lead. Sulphate and total dissolved solids (TDS) are above GCDWQ aesthetic objectives. Using the “Upset Condition #1” assumptions for flow and dilution factor, all of these parameters are expected to be below GCDWQ guidelines at the Pumphouse 1 intake except for antimony.

The antimony concentrations under upset conditions are estimated in Table 3 below using similar assumptions and calculation as for arsenic. Giant Mine contact water concentrations of antimony from the EQC report (CIRNAC/GNWT 2019) are 1.1 mg/L (95%ile) and 0.55 mg/L (average). The GCDWQ MAC for antimony is 0.006 mg/L. Normal antimony concentrations at Pumphouse 1 are below the MAC.

Table 2-33: Estimated Antimony Concentrations for Upset Conditions

Parameter	Value	Units	Notes
Upset Condition #1			
Assumed Daily Flow (spill)	2,740	m^3/day	Assumed mine pool overflow volume.
Assumed Antimony Concentration (spill)	2.2	mg/L	Assumed mine pool antimony concentration based on 2017-2023 results from the C Shaft Void location (station CS-V in the Operational Monitoring Program).
Assumed Dilution Factor to Pumphouse 1	200		See notes in Table 2.
Estimated increase in antimony at Pumphouse 1	0.011	mg/L	Estimated concentration = discharged concentration / dilution factor
Estimated total antimony at Pumphouse 1	0.012	mg/L	Estimated increase + normal 95%ile

Parameter	Value	Units	Notes
Upset Condition #2			
Assumed Daily Flow (effluent)	2,592	m^3/day	Giant Mine WTP design maximum effluent flowrate.
Assumed Antimony Concentration (effluent)	0.52	mg/L	Based on "Predicted Base Case with ETP Treatment Efficiency Applied" years 2026 to 2040, 95%ile concentration from EQC report (CIRNAC/GNWT, 2019).
Assumed Dilution Factor to Pumphouse 1	166		See notes in Table 2.
Estimated increase in antimony at Pumphouse 1	0.003	mg/L	Estimated concentration = discharged concentration / dilution factor
Estimated total antimony at Pumphouse 1	0.004	mg/L	Estimated increase + normal median

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 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. In Yellowknife, arsenic is naturally present in gold ore (arsenopyrite) and was released during ore processing. 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 “Upset Condition #1” (i.e., long-term failure of the GMWTP leading to mine pool overflow to surface), arsenic concentrations at the Pumphouse 1 intake could be approximately 75 µg/L to 1,800 µg/L total arsenic as estimated in Section 2.

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 1,800 μg/L during Upset Condition #1 would include 468 μg/L of As^{+3} and 360 μg/L of organo-arsenic compounds.

3.1.3 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). Total antimony in River water is typically <1 ug/L (based on 3 samples 0.6 – 0.8 ug/L from 2022-2007 and 3 samples all <0.1 ug/L from 2021-2023 from City of Yellowknife water sampling). 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). As the normal conditions for arsenic based on recent data are similar to arsenic concentrations from the 2017 study, antimony concentrations under normal conditions have not been updated.

During Upset Condition #1, the antimony concentrations at the Pumphouse 1 intake may exceed the GCDWQ limit. Upset antimony concentrations are estimated in Section 2.

3.2 Treatment Options Comparison

3.2.1 High Level Treatment Options Comparison

Table 4 presents a high-level comparison of arsenic removal treatment options. Only ferric (iron oxide/hydroxide) adsorptive media was selected to carry forward for the detailed water source options evaluation.

In the third-party review (Dillon, 2018) of the 2017 source selection study, Dillon recommended that a PASS/FAIL approach be used to screen treatment options. Using this approach, ferric adsorptive media would be rated as a "FAIL" due to uncertainty about whether it could treat water to a potable standard during upset conditions, unless pilot testing or additional processes could be used to make this a viable treatment option. For this 2024 study update, AECOM has not implemented a PASS/FAIL approach because this would not account for risks associated with startup of the treatment process during upset conditions. None of the treatment processes considered here are feasible for both operation during normal conditions, and treatment of worst-case high arsenic concentrations during upset conditions. The adsorptive media process selected for detailed evaluation is capable of treating water to potable standards at estimated median arsenic concentrations for upset conditions.

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 Metsorb HMRG 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]. Ferric adsorptive media is expected to be able to treat arsenic concentrations around 75 µg/L as estimated at Pumphouse 1 for an Upset Condition #1 with median mine pool arsenic concentration of 15 mg/L.

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 for Upset Condition #1. From Section 2, the estimated concentrations of total arsenic at the Pumphouse 1 intake for Upset Condition #1 could be approximately 1,800 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. A more conservatively-sized system (with more vessels and/or spare media) would be more likely to handle sudden high concentrations of arsenic but also more expensive, and there is still a risk of early break-through under high loading conditions.

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[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*

3.2.3 Coagulation

Coagulation using iron-based (ferric) coagulant, aka chemical co-precipitation, is a common treatment process for arsenic removal. The GMRP uses a ferric coagulation process at the existing ETP and will use a similar process at the new GMWTP. Coagulation can remove large amounts of arsenic from the water. For the new Giant Mine WTP, an adsorptive media process will be used downstream of coagulation to "polish" the water by removing remaining small concentrations of arsenic to meet the effluent target, i.e. the drinking water limit for arsenic.

Adding a coagulation process at the Yellowknife WTP upstream of the existing membranes along with new adsorptive media could theoretically improve the arsenic removal such that the system could treat very high arsenic concentrations. This would require more building footprint with additional heating costs. We expect a precipitation pre-treatment process would require a lengthy start-up period at the beginning of an upset event due to the chemistry involved, so we do not recommend adding this process to the Yellowknife WTP.

3.2.4 Ion Exchange

An ion exchange process removes certain dissolved parameters from water by substituting one ion in the water for another on the ion exchange resin. A suitable resin or combination of resins would need to be selected to remove arsenic and antimony. When the resin is regenerated, the waste brine would contain arsenic so would likely need to be concentrated and sent to a hazardous waste facility. Ion exchange is expected to be more complicated than a similar system using adsorptive media.

3.2.5 Reverse Osmosis

A reverse osmosis treatment system uses a semi-permeable membrane to separate 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. RO is a complex process which requires chemical pre-treatment and post-treatment to control scaling on the membranes and avoid corrosion in the distribution system.

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. The sanitary lagoon would likely not remove arsenic, so for Upset Conditions the arsenic in the RO brine would ultimately be released back to the environment. 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). Alternatively membranes can be used to minimize the volume of brine, which may be more feasible for Yellowknife. However, the concentrated brine still requires disposal and the brine would contain arsenic in the case of Upset Conditions.

⇒ **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, an RO system operating during normal conditions is not considered feasible for Yellowknife WTP.

A standby RO process could be considered for operation during upset conditions only. This would require start-up time in the event of an upset condition. During normal conditions, there would be O&M costs associated with heating the building space, maintenance of equipment, replacement of standby chemicals, and periodic refresher training for operators. RO elements need to be preserved in a chemical solution when not in use, so operators would need to drain and flush the elements if operating the system during training, then re-preserve the elements in chemical solution after training is complete. Even if strict protocols are followed for preserving membranes, there is a risk of problems occurring after long periods where the system is not used. During upset conditions, potable water production would be limited to 50-90% of the current capacity unless the existing treatment system is upgraded to accommodate the additional RO waste stream. Regulators such as the Water Board and DFO would need to confirm whether RO brine could be disposed of in Yellowknife Bay during upset conditions and also during periodic refresher training if training includes running the RO system.

A standby RO system only used during upset condition events might be feasible for Yellowknife WTP if regulators approve the residuals disposal. Compared to an adsorptive media system, RO is capable of treating higher concentrations of arsenic and antimony. An RO system may have higher life cycle costs than an adsorptive media system even if it is not used during normal conditions. A standby RO system would have different risks for water quality (risk of arsenic in treated water if an arsenic increase is not detected while the standby system is offline, and risk of distribution system corrosion when running the standby system) and water supply (risk of water interruption while starting up the standby system). The overall score is expected to be similar for the Bay option with either RO or adsorptive media, therefore reverse osmosis is not considered further for this study.

3.2.6 Emerging and Other Technologies

Three additional technologies were identified for this 2024 study update based on a review of grey literature (i.e., technical reports) and white literature (i.e., journal articles):

1. Photocatalysis-based advanced oxidation
2. Electrocoagulation
3. Greensand filtration

Photocatalysis-based advanced oxidation would remove As(III) by using a semiconductor such as TiO_2 and a light source to oxidize As(III) to As(V). Another treatment process would also be needed to remove the As(V). Most applications of this technology are at a bench scale; a full-scale system would be expensive and require bench-testing to determine if it were viable here. This is expected to be more complex and expensive compared to oxidation using sodium hypochlorite (which is already used at Yellowknife WTP), so photocatalysis-based advanced oxidation is not recommended.

Electrocoagulation would generate the coagulant on-site by running an electric charge through iron electrodes. It has an advantage over typical coagulation in that chemicals could be shipped as solid anodes rather than in solution, which could reduce shipping costs, but the process would increase electricity costs. We are not aware of any existing applications using electrocoagulation specifically for arsenic removal. Electrocoagulation is not considered viable for Yellowknife WTP for similar reasons as noted for coagulation (difficulty with operation and startup time) plus additional complexity and capital cost for generating the coagulant on site.

Finally, greensand filtration can remove trace arsenic if there is excess iron (>300 µg/L) in the feed water. A greensand process alone would not sufficiently remove the elevated arsenic during upset conditions. Greensand combined with ferric coagulation (to add iron to the water) could remove more arsenic but would have similar operating and start-up challenges as a coagulation process or coagulation + adsorption.

Table 3-1: 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**	Moderate	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	Moderate	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)	2 or 3 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)	3	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 significantly 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, unless regulators approve another disposal method for intermittent use only for a standby RO system.
Distribution System Effects			Could increase corrosion in distribution due to increased chlorides in the water.	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 (and low doses of certain coagulants) 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. System would use lead/lag vessels to avoid impact on treated water quality. ➢ 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 - 25% (depending on RO system design) due to water wasted as RO reject, potentially resulting in water restrictions during Upset Conditions.
Considered viable for Yellowknife?		No	No	Yes	No	Yes*
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 once the process is started up. However, very expensive and complex (including chemical pre and post treatment). *Feasibility depends on regulatory approval of residuals disposal (brine potentially containing metals).

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

Table 3-2: Arsenic Treatment Options Comparison

Name of Process		Adsorptive Media Filtration - Greensand Filtration
Ranked Low to High	Process Complexity	Moderate
	Mechanical Complexity	Moderate
	Relative Capital Cost	Moderate
	Relative O&M Cost	Moderate
1 to 5 Ranked Efficacy for Reduction/Treatment of… (1 = minimal effect, 5 = very effective)	Particulate Arsenic	2 (Note 1)
	Dissolved Arsenic (III)	2
	Dissolved Arsenic (V)	2
	Organo-arsenic	Unknown
Ability to Handle Rapid Changes in Arsenic Concentration (storm or upset)		Poor. Dependent on iron in influent water
Residuals		Greensand adsorptive system backwash waste would be combined with membrane backwash waste for treatment. Spent greensand media would be sent to landfill.
Distribution System Effects		Potential to release fines from the media, i.e. adding particulates and potentially arsenic to the distribution system.
Other Comments		➢ Greensand filtration is not considered a Best Available Technology (BAT) per USEPA; however, it can meet drinking water objectives for source waters with high iron (>300 ug/L) and low total arsenic.
Considered viable for Yellowknife?		No
Rationale		Expect greensand media would require adding an adequate dose of iron to the raw water. Potential difficulty with operation/startup so may not provide adequate arsenic removal at upset concentrations.

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.

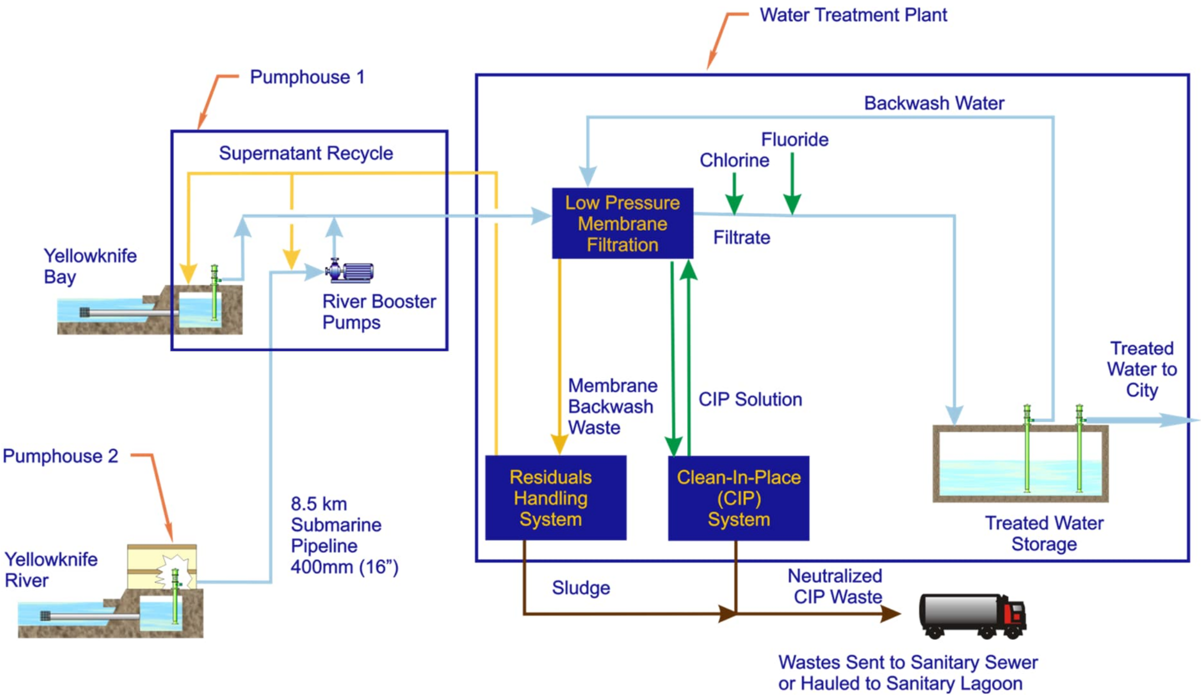


Figure 4-1: Existing Water System Schematic

4.2 Option 1 – River Source

Option 1 is to continue to use the Yellowknife River water source, replace infrastructure such as the pipeline that is reaching the end of its service life, and implement significant upgrades at both Pumphouse 1 and 2. The main difference between the upgraded system and the existing system is a higher capacity of the submarine pipeline, and the material of the new pipeline, which should offer decades of reliable service. The following sections describe the upgrades and work required for Option 1.

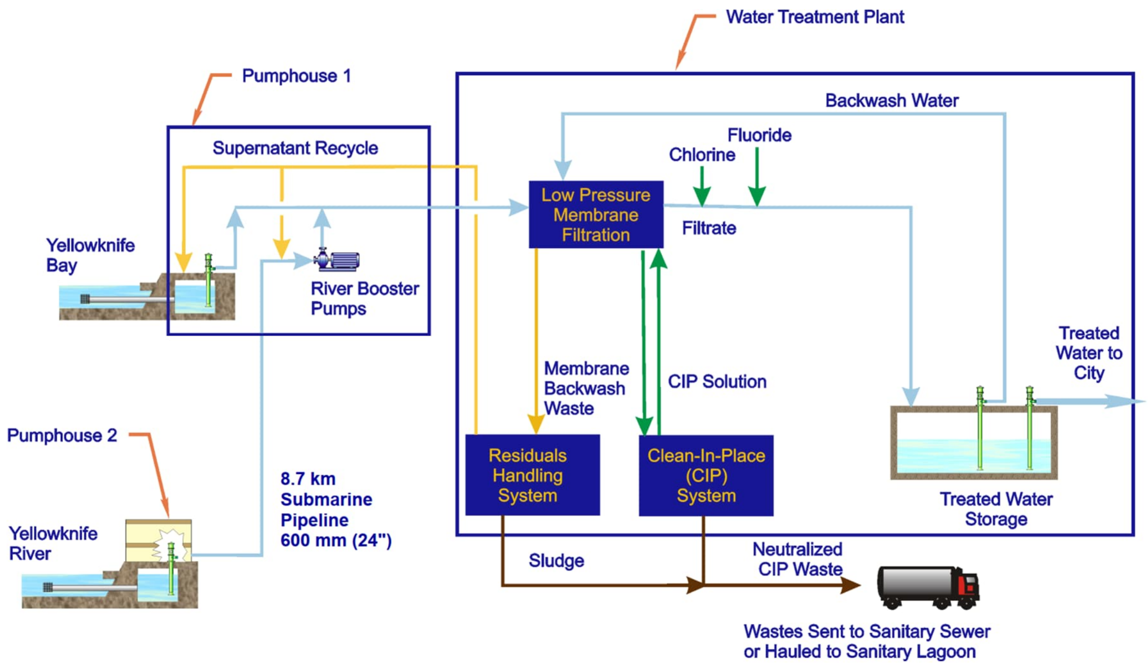


Figure 4-2: Option 1 River Source System Schematic

4.2.1 Surveys

Bathymetric survey and side-scan sonar survey along the pipeline route were completed in 2022 for the Submarine Waterline Replacement project to facilitate design and installation.

4.2.2 Intake and Pumphouse 2

For the 2017 study, some assumptions were made regarding extent of upgrades required to meet capacity and reliability requirements for the intended design horizon. Since that time, detailed design has commenced, which has provided a more complete understanding of intended upgrades. Proposed upgrades include:

⇒ Expansion of above-grade structure footprint to accommodate new electrical room, generator room, boiler room and building mechanical room.

⇒ Expansion of above-grade structure around pump room to accommodate new pump discharge header, compressed air systems and potentially improved means of removal of pumps and motors.

⇒ Replacement of existing pumps and piping. Two new raw water pumps would each have a capacity of 278 L/s at 51m (300hp) and operate in a duty/standby configuration to meet the raw water requirement of 278 L/s to suit the WTP 20-year design maximum flowrate. New discharge piping to interconnect to new submarine pipeline, with new discharge flow meter and valves, is included.

⇒ Provision of river intake fish screening. The existing intake piping and wetwell is retained.

⇒ Electrical upgrades to include new utility power service, new standby generator capable of operating one raw water pump in addition to essential building services. Provision of VFDs for operation of new raw water pumps. All existing building services and wiring will be replaced with new.

⇒ Building mechanical systems will include diesel fuelled boilers to provide hydronic heat for the facility with the objective of exceeding energy code requirements by 25% per City of Yellowknife standards. Upgrades also include provision of new air handling equipment, fuel storage tanks, and building management system.

The changes to the Pumphouse 2 exterior envelope, as well as the site layout and grading are significant. All of the structure shown in the image below is new, with the exception of the below grade wetwell, which will be retained.

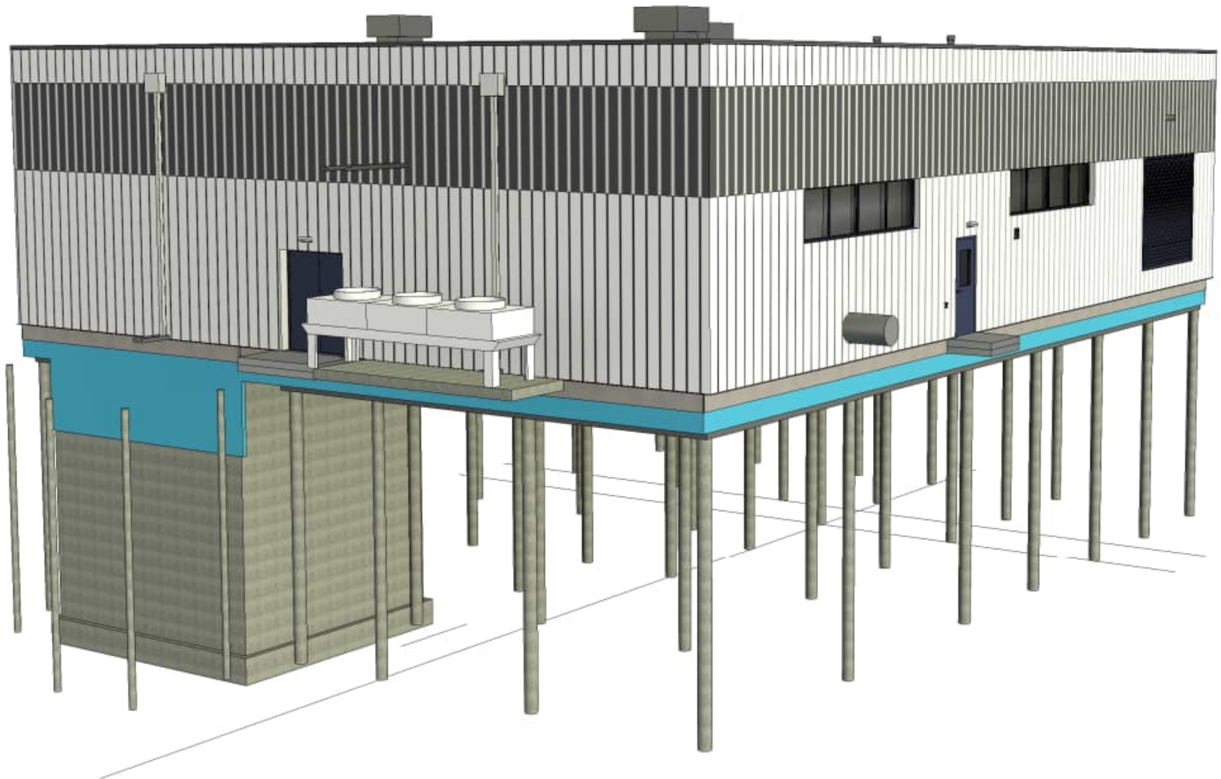


Figure 4-3: Upgraded Pumphouse 2 Architectural View

4.2.3 Pipeline

The existing 8.5 km of Ø 400 mm steel submarine pipeline would be replaced with a new HDPE pipeline. During preliminary design of the Submarine Pipeline Replacement project, it was found that the most feasible alignment would be to route the north portion of the pipeline overland on the east side of the bay. This overland option, shown as the pink line (Route B) in the figure below, is 8.7 km in length and avoids the narrow corridor of the river, multiple crossings of the existing Ø 400mm line, as well as the environmental challenges of disturbing potentially contaminated sediments in the shallow north end of the bay. The maximum flow capacity of the new pipeline would be 504 L/s and generally consist of Ø 650 mm HDPE DR17 pipe installed along the submarine pipeline alignment through Yellowknife Bay with the buried pipe along overland section being Ø 750 mm HDPE DR9. The overland portion of Route B is not without its challenges, however, as it will require pipeline installation through permafrost rich areas and entry into Yellowknife Bay will require an extensive horizontal directional drill installation of over 1 km in length through bedrock before continuing along the surface of the lake bottom.

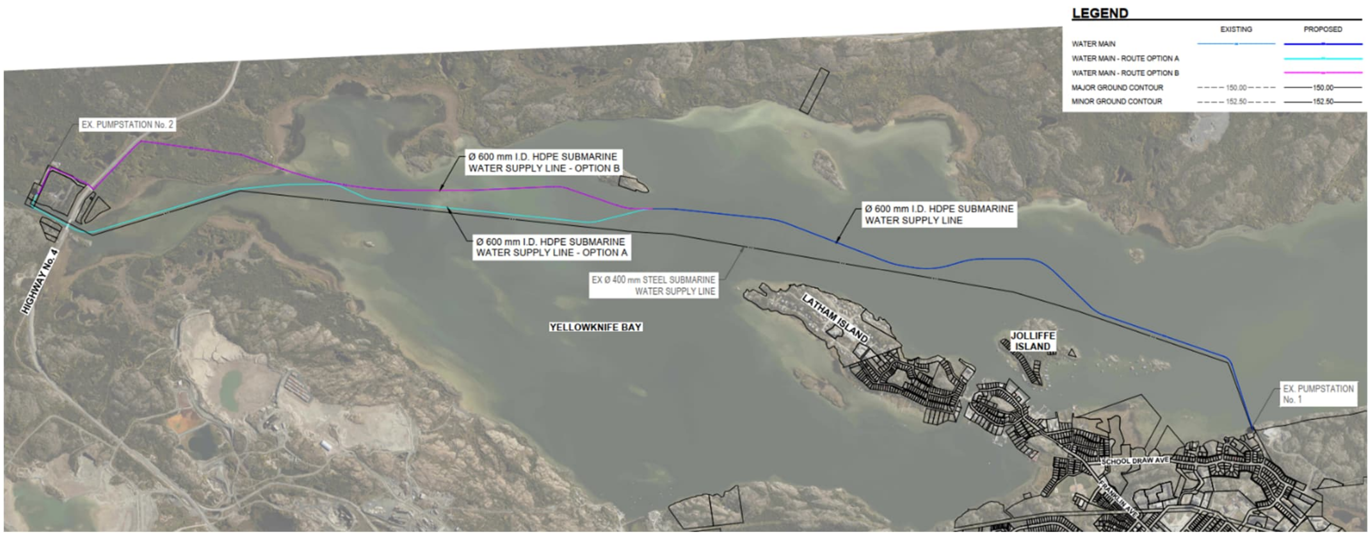


Figure 4-4: Pipeline from Pumphouse 2 to Pumphouse 1

4.2.4 Pumphouse 1 and WTP

Detailed design for upgrades at Pumphouse 1 commenced in 2023, which has provided a more complete understanding of intended upgrades. Proposed upgrades include:

- ⇒ Demolition and replacement of above grade structures (except for the existing Bay Pump Room) to provide a structure suitable for long-term service, as well as addition of a second floor to include office space for City engineering staff.
- ⇒ Replacement of booster pumping and piping systems. Back-up pumps used for bay source pumping to remain.
- ⇒ Replacement of existing intake screen with a new screen that meets the Department of Fisheries and Oceans (DFO) guidelines to avoid entraining or impinging fish. The existing intake piping and wetwell is retained.
- ⇒ Electrical upgrades to include new utility power service, new standby generators capable of operating either booster pumping or bay pumping systems in addition to essential building services. Provision of VFDs for operation of booster and bay water pumps. All existing building services and wiring will be replaced with new.
- ⇒ Building mechanical systems will include diesel fuelled boilers to provide hydronic heat for the facility with the objective of exceeding energy code requirements by 25% per City of Yellowknife standards. Upgrades also include provision of new air handling equipment, fuel storage tanks, and building management system.

The changes to the Pumphouse 1 exterior envelope, as well as the site layout and grading are significant. All of the structure is new, with the exception of small existing structure associated with the existing Bay source wetwell, which is the small area with the lowest roof shown in the image below.

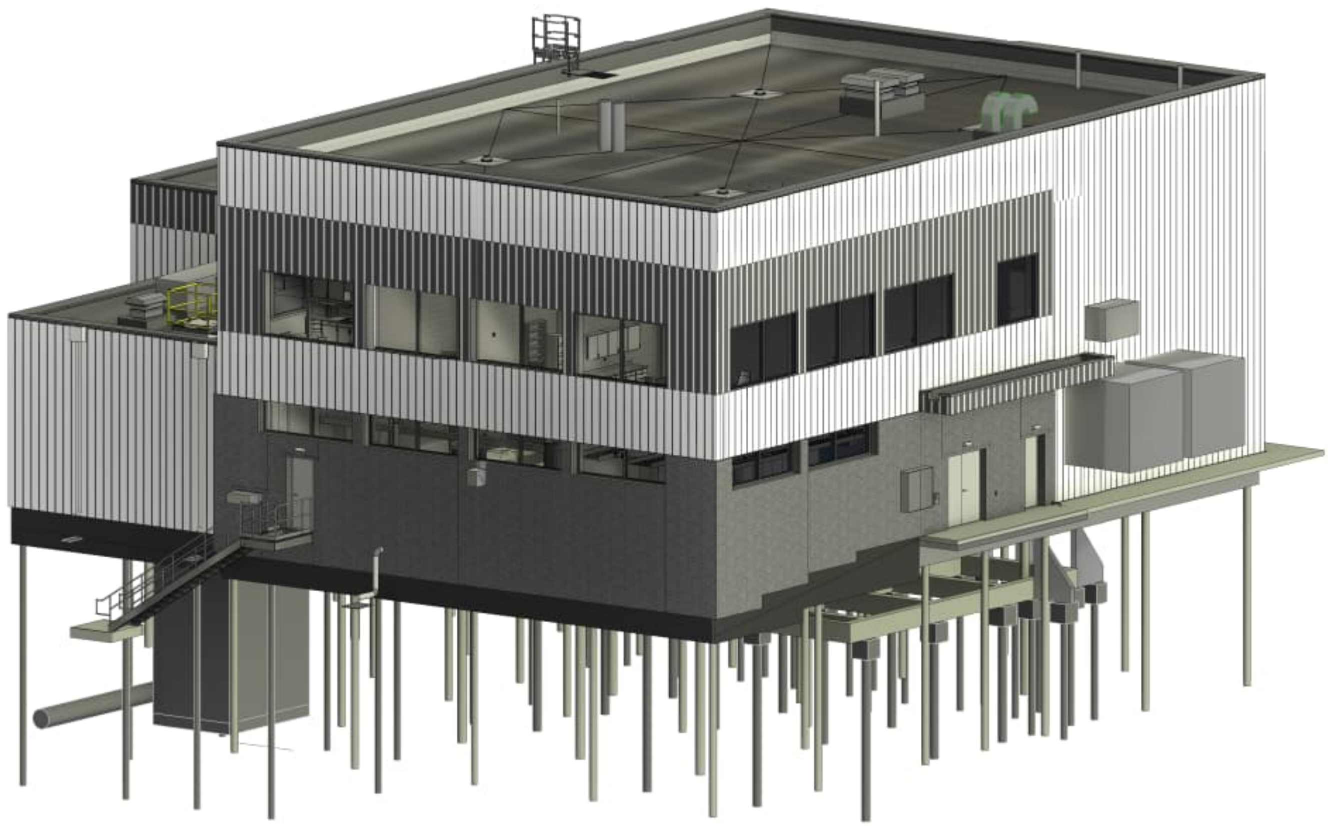


Figure 4-5: Upgraded Pumphouse 1 Architectural View

4.2.5 Permitting Requirements

4.2.5.1 Water Licence

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 (MV2021L3-0003) was granted May 31, 2022 and expires May 30, 2037. This licence limits water withdrawals to 4 million m^3/year and / or 575,000 m^3/month from the Yellowknife River. Changes to water withdrawal limits are not anticipated to be required as part of Option 1, and would not necessitate a licence amendment application. However, development of Option 1 may trigger an amendment through the following:

1. Infrastructure changes . The proposed changes to water supply infrastructure (substantial deviation from existing pipeline right-of-way, expanded pumphouse footprints, replacement intake screens) are interpreted to “reflect changes to project activities” as described by MVLWB water licence amendment guidance (Section 6.1 of the Guide to the Water Licencing Process).

2. Water withdrawal profile changes: Option 1 construction will require various temporary uses of water. These uses, while not cumulatively exceeding the currently licenced rate of 4,000,000 m^3/year or 575,000 m^3/month, represent changes to the withdrawal profile (rates and locations) specified in the licence.

The potential thresholds for triggering a water licence amendment noted above have been previously discussed with the MVLWB during water licence development in 2022 and 2023. The MVLWB should be engaged further to confirm their interpretation and recommended approach for Option 1. In general, given the sensitivity of the community regarding water supply and Yellowknife Bay water quality, it is AECOM's opinion that MVLWB would initiate the water licence amendment process to ensure public stakeholders and Indigenous communities are consulted on the project.

A water licence amendment application for Option 1 was started and shared with the MVLWB in 2023, but the project was paused before it was officially accepted for review. As per MVLWB requirements, the application included a description of project activities, an environmental screening, and various plans for managing environmental effects (specifically waste management, erosion and sediment control, and spill contingency). If the amendment application was resubmitted and accepted by the MVLWB, it would initiate the review process. The milestones and timeline related to this process is summarized in Table 5 below.

Table 4-1: Estimated Permitting Timeline for Option 1

TASK	Duration
Application Received and Deemed Complete	milestone
Review of Application Package	6-11 weeks
Technical Session	5-6 weeks
Public Hearing	8-14 weeks
Draft Water Licence Developed and Circulated for Review	4-7 weeks
Closing Arguments –and MVLWB Decision	4-7 weeks
Final Water Licence Sent to the Minister for Approval	5-9 weeks

4.2.5.2 Other Requirements

In addition to the water licence amendment, other regulatory permitting processes are applicable to Option 1. These processes include obtaining a land use permit from the MVLWB and securing land tenure (leases, easements, etc.) from GNWT Lands for project components that occur within Commissioner's or Territorial land. Feedback from the MVLWB and GNWT Lands indicate that these applications are preferred to be submitted concurrently with the water licence amendment application so that regulator-led public and Indigenous engagement for all applications can occur simultaneously. As experienced with the previous water licence amendment, this approach can create challenges with meeting all permit application information requirements (e.g., exact locations for all project components like worker camp) at the preferred time of water licence amendment submission.

The Fisheries Act also applies, given the extensive work required in Yellowknife Bay. At minimum, the Fisheries and Oceans Canada Request for Review from 2023 would need to be restarted, and potentially a full submission for Fisheries Act authorization may be required.

4.2.6 Environmental Protection

As described in Section 4.2.5, an environmental screening assessment was completed as part of the water licence amendment application. The assessment included a series of mitigation measure commitments related to protecting water quality and fish habitat in Yellowknife Bay, minimizing terrestrial disturbance from the on-land pipeline right-of-way, and reducing disruption to public and Indigenous use of the lake. High level environmental management plans for waste management, erosion and sedimentation control, and spill contingency were also developed as part of the application. Additional work expected related to environmental protection will include:

- ⇒ Updating the environmental screening and management plans based on further feedback from regulators and public and Indigenous stakeholders
- ⇒ Development of more detailed management plans in consultation with contractors
    - Key components of updated plans would include contingency planning for drilling fluid release during horizontal directional drilling of a portion of the submarine pipeline, and sediment/turbidity monitoring during placement of new pipeline sections.
- ⇒ Completion of additional site-specific assessments to satisfy other potential regulatory and permitting requirements, e.g., Fisheries Act authorization.

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 could be added at Pumphouse 1 to monitor arsenic concentrations in the Bay source. Online arsenic analyzers require reagents (chemical solutions) and gases to function, including a small supply of hydrogen gas and nitrogen gas that could be provided using on-site generators or gas cylinders. Due to the complexity, cost, and additional chemical handling associated with online arsenic analyzers, we have assumed that Option 1 would not include an online analyzer and would rely instead on grab samples when the Bay source is used, similar to current operation.

The new raw water pumps in Pumphouse 2 would each provide 100% of the design maximum day flow for year 2041. A diesel generator would provide standby power. The Bay pumps at Pumphouse 1 would also be maintained as an emergency back-up water source.

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 an 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.

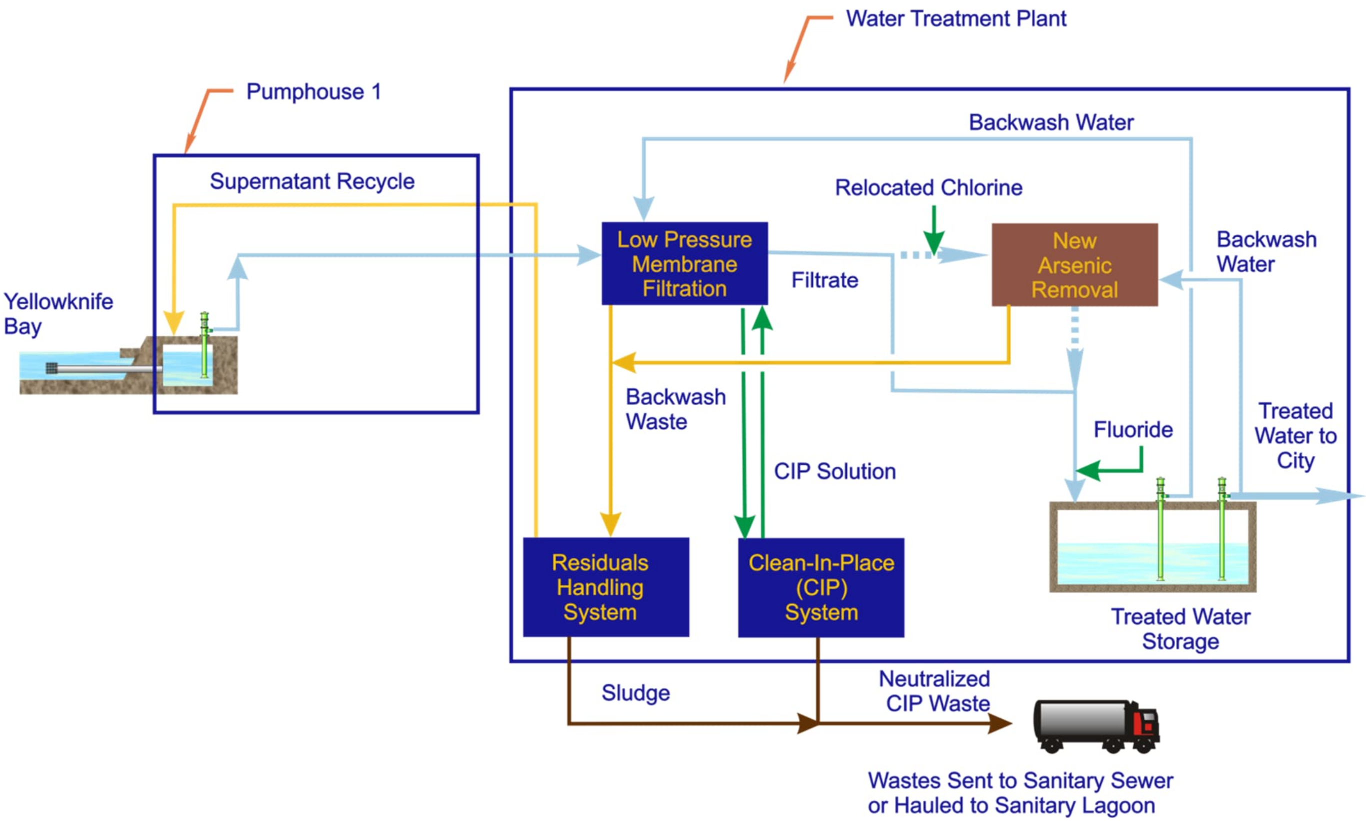


Figure 4-6: Option 2 Bay Source System Schematic

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 or impinging fish.

It might be possible to replace the existing emergency raw water pumps in Pumphouse 1 with larger pumps in order to supply enough pressure for the new arsenic treatment system. If this is not possible due to pressure limitations for the existing membrane system, then booster pumps would be needed at the WTP to increase the pressure between the existing membrane treatment system and the new arsenic removal system. For this study we have assumed that the arsenic removal media would be installed in pressure vessels and that new booster pumps in the WTP expansion would be required to provide an additional 24 m of pressure compared to the existing system. If Option 2 (Bay with arsenic treatment) is selected for further design, then other options could be considered to potentially lower the capital and operating costs, such as a gravity system instead of pressure vessels, or increased pressure through the membrane system to avoid booster pumping in the WTP.

The river water booster pumps in Pumphouse 1 would no longer be needed in this Option. The other upgrades to Pumphouse 1 described for Option 1, such as electrical, mechanical upgrades as well as addition of second floor office space, would still be implemented.

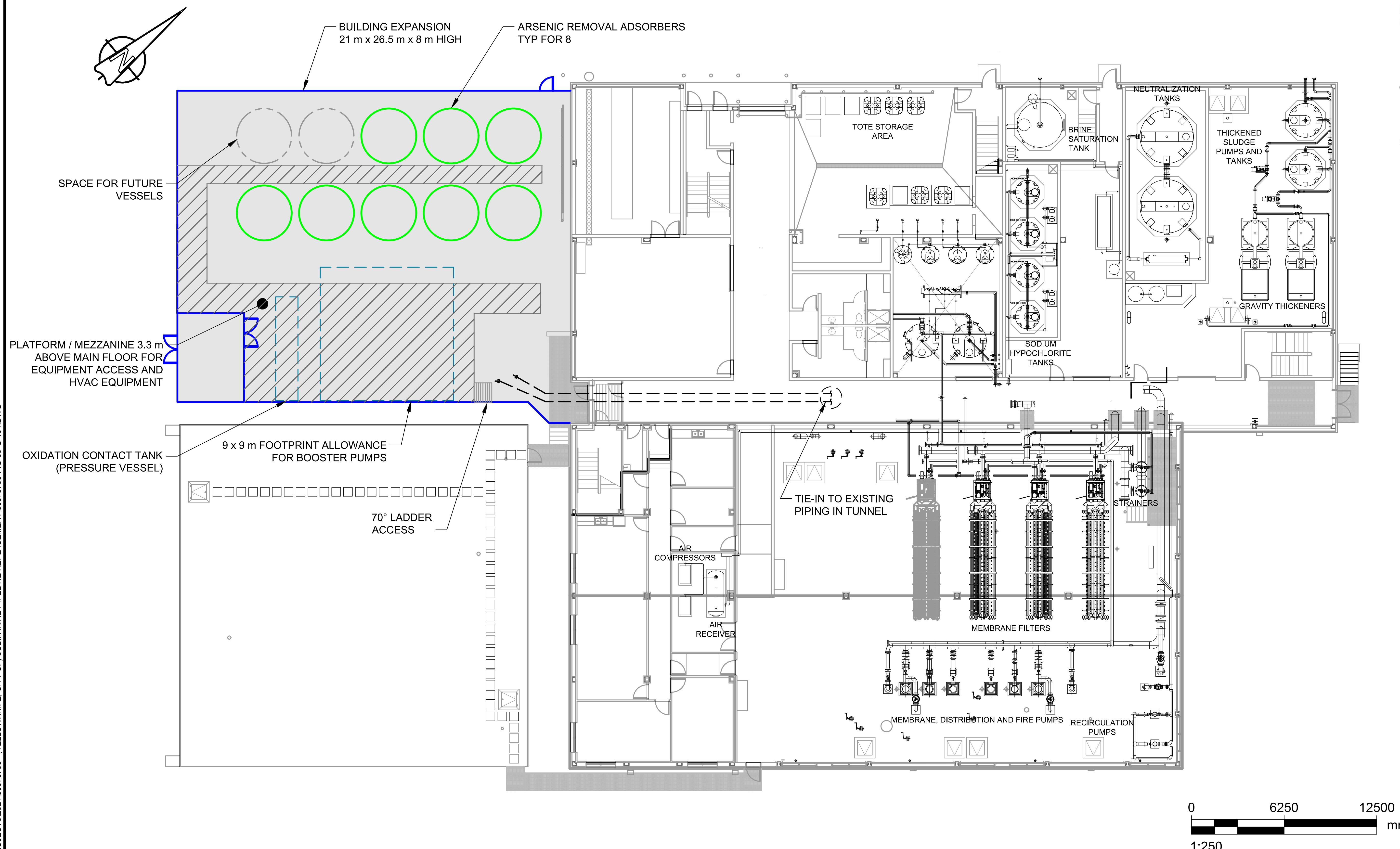
Long-term operation of the system using a single wetwell may not be desirable, so a second wetwell and redundant raw water pump(s) would be included. While not providing redundancy between water sources, there would be some operational flexibility to allow for maintenance of mechanical equipment and wetwells.

4.3.2 Pumphouse 2 and Submarine Pipeline

The existing Pumphouse 2 would be demolished, and the existing submarine pipeline would be abandoned.

4.3.3 Water Treatment Plant Expansion

The WTP building would need to be expanded to provide space for the arsenic treatment equipment. Figure 4-7 Building Floor Plan shows the conceptual layout of this building expansion.



Issue Status: DRAFT

AECOM

00-G-101

BUILDING FLOOR PLAN

CITY OF YELLOWKNIFE
WATER TREATMENT PLAN

Project No.: 60673796 Date: 2024-10-11

ANSI B 279.4mm x 431.8mm

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

Last saved by: POLSKIJ(2024-10-11) Last Plotted: 2024-10-11
Filename: F:\00-PROJECTS\2024\60673796 - (YELLOWKNIFE, CITY OF) SUBMARINE PIPELINE REPLACEMENT\60673796-FIG-00-G-101.DWG

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 21 m wide x 26.5 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 a steel structure and concrete foundations. The new roof and wall construction is assumed to be similar to the existing work carried out in 2015.

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. 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.

4.3.4 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.

4.3.5 Electrical

Electrical upgrades would be required at the WTP to serve new building services within the expanded area, as well as instrumentation and controls of the new treatment process. The addition of new pumps at the WTP to boost the pressure between membrane treatment and the new adsorptive treatment will add some complexity to the upgrades, specifically:

- ⇒ Additional electrical room space will be required to accommodate three 100 HP VFDs
- ⇒ Capacity of existing diesel standby generators and transfer switches would need to be evaluated to determine if the new pumping system can be operated using existing generators, or if increased generator capacity is required.
- ⇒ Changes to existing PLC controls systems to add new instrumentation, update programming sequences and failure mode responses. Programming and commissioning work would need to be undertaken without affecting existing processes, with the exception of short duration shutdowns.

4.3.6 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 Mequipco/Napier Reid for a system using Metsorb HMRG media. This system would have eight units, each 12' in diameter, normally operating as four parallel trains of two units in series, to reduce the risk of arsenic breakthrough into the treated water. Backwash water would be provided through a takeoff from the treated water pipeline in the basement before it leaves the WTP to distribution.

The arsenic treatment process design is based on treating the year 2041 demands with at least 5 minutes of total per-train Empty Bed Contact Time (EBCT). Eight vessels provide more EBCT than the five vessels assumed for the 2017 study, for a more conservative design. If the vessels are operated as four parallel trains, each with two vessels in series, this arrangement provides over 5 minutes of EBCT per vessel at year 2041 projected average flows, or over 5 minutes of total EBCT per train at year 2041 maximum day demand.

For flowrates higher than the 2041 maximum projected demand, the loading rates may be too high and EBCT may be too low for four trains of lead/lag adsorptive vessels. Additional vessels may be needed for higher flows; alternatively, the eight vessels could be operated as eight parallel trains although this would have a higher risk of arsenic breakthrough into the treated water. Eight vessels operating in parallel would provide almost 5 minutes of EBCT at the current maximum design flowrate for the WTP (315 L/s). For this study update the building footprint includes space for two more vessels (for a total of 10) that are not included in the process equipment cost estimate but could be added in the future for standby or additional capacity. If a fourth membrane filtration train was added to the WTP in future then another two adsorption vessels with additional building expansion (for a total of 12 vessels) would be needed to provide a lead/lag adsorption system with per-train 5 minutes of EBCT at future maximum flow 445 L/s.

Table 4-2: Adsorptive Media System Sizing

WTP Design Condition	Future 4 MF Trains Maximum	Current 3 MF Trains Maximum	Max. Day Demand (2041)	Average Day Demand (2041)	Units
Instantaneous feed flowrate	445	315	240	132	L/s
Number of adsorptive treatment trains	10	8	4	4	
Vessels per train	1	1	2	2	
Flow per train	2.67	2.36	3.60	1.98	m3/min/train
Surface loading rate	15.2	13.5	20.6	11.3	m/hr
Empty Bed Contact Time (EBCT) per vessel	4.2	4.7	3.1	5.7	minutes

Note 1: For 3.66 m diameter vessels with 1.067 m adsorptive media bed depth

Note 2: "4 Trains" and "3 Trains" flowrate design conditions in the table above refer to the number of MF membrane trains, not adsorptive trains.

The ferric media may provide some removal of arsenite (As $^{+3}$), but some vendors recommend 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 arsenic adsorption media is not expected to remove chlorine residual from the water.

Assuming there is up to 468 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 0.5 mg/L would be required to oxidize the As $^{+3}$ to As $^{+5}$.

For this evaluation we have assumed that the existing on-site sodium hypochlorite generation skid would be used to oxidize arsenic, if needed. If high arsenite concentrations occur together with high water demands during Upset

Conditions, the City could use totes of 12% sodium hypochlorite (diluted using the existing dilution panel) to supplement the existing generation capacity. A water tank should be installed upstream of the new arsenic treatment process to provide at least 1 minute of holding time to ensure that As^{+3} is oxidized prior to the adsorptive media process. For this study we have assumed that the pressure boosting pumps at the WTP would operate inline and would not need additional tank volume for equalization of pumped flows.

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. Online arsenic analyzers require reagents (chemical solutions) and gases to function, including a small supply of hydrogen gas and nitrogen gas that could be provided using on-site generators or gas cylinders.

4.3.7 Permitting Requirements

4.3.7.1 Water Licence

For Option 2, withdrawal from the Bay would represent a material change to the water use profile in the current water licence, and an amendment application would be required. The amendment application process would be as described in Section 4.2.5, with key differences as follows:

- ⇒ A new amendment application would need to be prepared that reflects a substantial shift in project approach and design. The application would likely need to focus heavily on information updates regarding Bay water quality to alleviate concerns by regulators, Indigenous communities, and the public. Overall, less information regarding project design and environmental effects, mitigation, and management would be required due to the reduction in project scale.
- ⇒ While Option 1 could likely leverage the previous consultation efforts related to the 2023 water licence amendment application, Option 2 would require a new engagement plan to be initiated.
- ⇒ The freshwater intake at Pumphouse #1 has served the function of emergency intake, and was not intended for use as the primary source. The amendment application would therefore require further evaluation of long-term water withdrawal at the Pumphouse #1 location.

4.3.7.2 Other Permitting

Other permits required for Option 2 largely mirror that of Option 1, requiring a MVLWB land use permit and GNWT land tenure authorizations. However, these permit applications would be less complex than Option 2, due to the reduction in proposed infrastructure and required land area. Also, as with Option 1, the in-water work and potential effects due to long-term water withdrawal at Pumphouse #1 will require a Fisheries and Oceans Canada Request for Review and potentially a Fisheries Act authorization.

4.3.8 Environmental Protection

The expected environmental protection requirements described for Option 1 would apply to Option 2 as well, but at a reduced scale. Environmental management plans for waste management, erosion and sedimentation control, and spill contingency would still be required; however, these would be limited to the in-water construction work for intake/screen modifications and Pumphouse #1 upgrades. Potential environmental risks, mitigation measures, and monitoring programs would be substantially reduced with removal of pipeline construction, horizontal directional drilling, intake/screen replacement at Pumphouse #2, and on-land pipeline trenching from the project plan.

As with Option 1, 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)

4.3.9 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 basis of this option is to provide a second wetwell, intake line, and intake screen, to allow operational flexibility in the event that maintenance is required within one wetwell, or one raw water pump is out of service. The new raw water pumps in Pumphouse 1 would each provide 50% of the 20-year design maximum day flow, and a third 50% capacity pump would be installed for redundancy.

The new adsorptive media system would have eight (8) adsorber vessels. While one vessel is out of service for media replacement, equipment repair, etc., the others would continue to operate, and the WTP capacity would be temporarily reduced assuming all vessels are running in parallel for higher total flow capacity. If vessels are running in four trains of two vessels each (lead/lag) for lower total capacity and lower risk of arsenic breakthrough, the capacity would not change during media replacement as the lag vessel would continue to treat water.

4.4 Option 3 – Status Quo

The objective of this option is to maintain some redundancy of water sources until year 2038 without having to replace the existing submarine pipeline. 2038 is expected to be the completion of the Giant Mine remediation, where risk of catastrophic upset event affecting the Bay water source is expected to be further reduced.

A major benefit of considering a design horizon of 2038 for the River source, instead of the longer horizon considered in Option 1, is that the only concern becomes the existing submarine pipeline condition, as opposed to capacity:

- ⇒ The Bay pump system would utilize two wetwells, with firm capacity to meet maximum day demand to suit the Future 4-train maximum capacity of the WTP of 500 L/s.
- ⇒ The back-up submarine pipeline capacity need only be equal to the 2041 Maximum capacity of 278 L/s, instead of the 450 L/s capacity assumed for Option 1. The theoretical existing pipeline capacity is approximately 250 L/s, which is adequate for that time period. In practice, the pipeline capacity may be limited to some lower flowrate related to the effective pressure rating of the existing pipe. As the pipeline corrodes, the risk increases that higher pressures (required for higher flowrates) may cause more leaks.

It is very difficult to accurately predict the remaining lifespan of the existing submarine pipeline with the information available currently, and whether reliable operation to 2038 is realistic. For the purpose of this study, it has been assumed that the existing pipeline can remain operable at 250 L/s until 2038 with a regular O&M program as detailed below. Once the Giant Mine remediation project has progressed until inflows into the mine pool have decreased, the primary water source would revert to the Bay without the option of using the River source. The 2038 timeline falls short of a 25-year design horizon considered for other options.

4.4.1 Pumphouse 2

Modest upgrades to Pumphouse 2 would be carried out with the intent of improving reliability for an operating timeline to 2038. Existing equipment is unlikely to meet this performance basis. The upgrades would work within the existing building footprint, are mostly related to electrical equipment, and would not include addition of intake screening.

4.4.2 Submarine Pipeline

Complete replacement of the submarine pipeline to suit the 450 L/s capacity proposed in Option 1 has not been considered for Option 3. However, given the existing condition, it is unreasonable to assume that the existing pipeline can continue to operate until 2038 without any O&M costs. The existing pipeline has been in service for 56 years and the internal and external coatings required to maintain the integrity of the steel material have been compromised throughout the length of the pipe. Although the ultimate mode of failure is unknown at this time, it can be assumed that areas where localized corrosion first began occurring have widened and deepened as time has gone on. As the corrosion continues to progress throughout the existing submarine pipeline, the wall of the steel pipe loses thickness making it more susceptible to leaks or ruptures. Proactive measures such as scheduled inspections and non-destructive testing will allow the City to monitor the remaining service life and maximum allowable operating pressure rating of the pipeline. Spot repairs of critical sections are expected to be required in order to continue operating the submarine pipeline.

For the purposes of evaluation, it has been assumed that the City will implement an annual program of inspection and repair / rehabilitation of existing pipeline to maintain reliable operating conditions, with assumed funding of $1 million / year until 2038. Operation of the existing pipeline beyond 2038 has not been considered.

4.4.3 Intake and Pumphouse 1

All upgrades to Pumphouse 1, including mechanical, electrical and office spaces would remain as presented for Option 1. The main difference would be the addition of a second wetwell for installation of new vertical turbine pumps, instead of a dedicated River booster pumping room. The new wetwell could be used with either the Bay or the River source. The second wet well is considered for long-term operation using the Bay source beyond 2038.

4.4.4 Water Treatment Plant

No upgrades to the WTP are proposed. Arsenic removal systems proposed for Option 2 are not considered, meaning that the submarine pipeline would need to be kept in reliable operating condition, and use of the Bay source would mean exposure to elevated arsenic during upset conditions.

4.5 Option 4 – Hybrid Source with Arsenic Removal

Option 4 is a hybrid of Option 2 and Option 3. The primary water source is expected to be the Bay, which allows for demand scenarios to be met throughout the 25-year design window. The existing submarine pipeline is retained, and is assumed to be operable until 2038, as defined for Option 3. The River source would also need to be used regularly to prevent stagnation and freezing in the pipeline.

The intent would be to operate from the River source in the event of an upset condition affecting the Bay source before 2038. The arsenic removal process included for Option 2 is provided at the WTP, to provide some mitigation for upset conditions where the pipeline is no longer serviceable. It has been assumed that there is the possibility of blending the River and Bay sources to achieve overall water demand, and to reduce the arsenic levels from the Bay Source to within a range that is treatable by the WTP processes.

4.5.1 Pumphouse 2

Modest upgrades to Pumphouse 2 would be carried out with the intent of improving reliability for an operating timeline to 2038. Existing equipment is unlikely to meet this performance basis. The upgrades would work within the existing building footprint, are mostly related to electrical equipment, and would not include addition of intake screening.

4.5.2 Submarine Pipeline

The existing submarine pipeline would be retained, as described for Option 3. For the purposes of evaluation, it has been assumed that the City will implement an annual program of inspection, repair / rehabilitation of existing pipeline to maintain reliable operating conditions, with assumed funding of $1 million / year until 2038. Operation of the existing pipeline beyond 2038 has not been considered.

4.5.3 Intake and Pumphouse 1

All upgrades to Pumphouse 1, including mechanical, electrical and office spaces would remain as presented for Option 3. The main difference would be the addition of a second wetwell for installation of new vertical turbine pumps, instead of a dedicated River booster pumping room. The new wetwell could be used with either the Bay or the River source. The second wet well is considered for long-term operation using the Bay source beyond 2038.

4.5.4 Water Treatment Plant Expansion

Upgrades to add the arsenic removal process to the WTP would be identical to Option 2.

4.6 Cost Estimates

4.6.1 Capital Costs

Capital cost estimates for each option are shown in Table 4-3. All costs are rounded to the nearest $100,000.

4.6.1.1 Option 1: River Source

Capital costs for the submarine pipeline upgrade (Option 1) were developed in March 2023, by AECOMs in-house estimating group, who are cost estimating specialists, and operate independently of the design team. Escalation of 8% has been applied to the 2023 estimate, assuming construction start in Q1 of 2025. Detailed cost breakdown is shown in Appendix C.

Option 1 has a total Capital cost of **$107,700,000.**

4.6.1.2 Option 2: Bay Source

The Pumphouse 1 cost has been increased approximately $5,000,000 from Option 1 to include provision for construction of a second wetwell to provide redundancy in the operation of the Bay Source. Total Pumphouse 1 cost is $35,000,000.

Demolition of Pumphouse 2 has been assumed at $500,000. Disconnection and capping of the submarine pipeline has been assumed at $100,000.

Expansion of the WTP and installation of the arsenic treatment system and associated mechanical and electrical equipment has been estimated to be $27,000,000. A breakdown of the WTP expansion component only is included in Appendix C.

Option 2 has a total Capital cost of **$62,600,000.**

4.6.1.3 Option 3: Status Quo

Pumphouse 1 costs are assumed to be identical to Option 2, at $35,000,000.

An allowance of $2,000,000 has been included for upgrades to existing electrical equipment at Pumphouse #2 to improve reliability of operation in the medium-term but are far less extensive than Option 1.

Option 3 has a total Capital cost of **$37,000,000.**

4.6.1.4 Option 4: Hybrid Source with Arsenic Removal

Pumphouse 1 costs are assumed to be identical to Option 2, at $35,000,000.

An allowance of $2,000,000 has been included for upgrades to existing electrical equipment at Pumphouse #2 to improve reliability of operation in the medium-term but are far less extensive than Option 1.

Expansion of the WTP and installation of the arsenic treatment system and associated mechanical and electrical equipment has been estimated to be $27,000,000.

Option 4 has a total Capital cost of **$64,000,000.**

4.6.2 O&M Costs

Operation and maintenance (O&M) costs are incremental costs which only include items that vary between the 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. O&M cost breakdowns for Option 1 and Option 2 are included in Appendix C.

The O&M costs were calculated based on projected year 2041 average flows for 8.8 ML/day treated water. This is equivalent to 9.9 ML/day of raw and filtered water, i.e. raw water instantaneous flow rate of 130 L/s over 20.9 hours/day of operation accounting for process downtime or 115 L/s average flow over 24 hours.

4.6.2.1 Option 1: River Source

The River source option has annual O&M costs of approximately $283,000 related to operation of Pumphouse 2, which are not required for option 2:

- ⇒ Pumphouse 2 HVAC, including diesel fuel: $168,000
- ⇒ Pumphouse 2 Pumping Energy Cost Difference: $29,000
- ⇒ Process Equipment Maintenance (Operating Standby Pumps): $9,000
- ⇒ Annual pipeline inspection and maintenance: $42,000
- ⇒ Pumphouse 2 Equipment Maintenance: $15,000
- ⇒ Pumphouse 2 General Site Allowance – snow clearing, road maintenance, exterior maintenance: $20,000.

Option 1 includes annual O&M costs of **$283,000 ($ 2024).**

4.6.2.2 Option 2: Bay Source

The O&M cost impact of one Upset Condition #1 event is assumed to range from $0.2 to $3.4 million per month of upset conditions, depending on the arsenic concentrations at the intake and the performance of the treatment process media. For the purposes of evaluation, an O&M cost of $5M is applied to year 10 of operation, to account for an upset condition. It is expected that this is conservative, as a major event is not expected to be a 1-in-10 year event.

O&M costs for normal operation of the additional treatment systems include higher pumping energy required, as well as additional costs related to instrument reagents, increased operation of backwash systems, disposal of spent filter media, and HVAC costs associated with the WTP expansion. An annual cost of $530,000 has been assumed. This includes an allowance of $144,000 per year towards a full adsorptive media replacement every 15 years for normal raw water quality conditions.

Option 2 includes annual O&M costs of **$530,000 ($ 2024),** with a one-time cost of **$5,000,000 (2024)** applied to year 10 of operation (2038) for Upset Condition O&M.

4.6.2.3 Option 3: Status Quo

For the purposes of evaluation, it has been assumed that the City will implement an annual program of inspection, repair / rehabilitation of existing pipeline to maintain reliable operating conditions, with assumed funding of $1M/year until 2038. Operation of the existing pipeline beyond 2038 has not been considered.

Pumphouse 2 will remain in operation for this option, with similar O&M costs as for option 1. However, Option 3 requires an additional $76,000 per year for increased pumping energy required due to higher headlosses in the smaller existing pipeline, and has $110,000 per year lower estimated building HVAC costs for the smaller existing Pumphouse 2 footprint compared to the upgraded Pumphouse 2 in Option 1.

- ⇒ Pumphouse 2 HVAC, including diesel fuel: $58,000
- ⇒ Pumphouse 2 Pumping Energy Cost Difference: $105,000
- ⇒ Process Equipment Maintenance (Operating Standby Pumps): $9,000
- ⇒ Pumphouse 2 Equipment Maintenance: $10,000
- ⇒ Pumphouse 2 General Site Allowance – snow clearing, road maintenance, exterior maintenance: $15,000.

The incremental O&M allowance for Pumphouse 2 in Option 3 is $197,000 ($ 2024) per year. Option 3 includes a total O&M cost of **$1,197,000 (2024)** per year including pipeline maintenance. These costs apply until year 2038.

4.6.2.4 Option 4: Hybrid Source with Arsenic Removal

Option 4 includes annual O&M costs of $530,000 (2024) related to the WTP expansion and arsenic removal process, as described for Option 2.

Incremental O&M costs for Pumphouse 2 have been included at $145,000 / year, including the same costs as for Option 3 except with Pumphouse 2 pumping energy cost of $53,000 assuming 50% use of the River source and 50% use of the Bay source. Pipeline inspection and repair costs of $1M / year to 2038 have been included, consistent with Option 3.

Option 4 includes a total O&M cost of **$1,675,000 (2024)** per year, with an additional one-time cost of **$2,200,000 (2024)** applied to year 10 of operation (2036) for Upset Condition O&M. This upset allowance is less than the allowance for Option 2, because upset cost in Option 4 is assumed to be mitigated by supplemental pumping from the River source.

4.6.3 Lifecycle Costs

The life cycle costs were calculated using a 25-year period, a discount rate of 5% with escalation of annual costs and utilities of 4%. This 2024 estimate assumes higher inflation compared to the 2017 cost estimates, which had life cycle costs based on a net discount rate of 3% (i.e. assumed interest rate of 5% with inflation rate of 2%). Capital costs are spread over years 1 to 3, as a 30%, 50%, 20% distribution, assuming construction commencement in Q1 2025, and completion in Q2 2027. O&M costs commence in year 4.

Capital costs and Net Present Value (NPV) are rounded to the nearest $100,000.

Table 4-3: Conceptual Cost Estimates

	Option 1 – River Source	Option 2 – Bay Source	Option 3 – Status Quo	Option 4 – Hybrid with Arsenic Removal
Total Estimated Capital Cost (Q1 2025)	**$107,700,000**	**62,600,000**	**$37,000,000**	**$64,000,000**
Pumphouse 1 Capital Cost	30,900,000	$35,000,000	$35,000,000	$35,000,000
Pumphouse 2 Capital Cost	$17,000,000	$500,000	$2,000,000	$2,000,000
Submarine Pipeline Capital Cost	$59,800,000	$100,000	$0	$0
WTP Capital Cost	$0	$27,000,000	$0	$27,000,000
Total Annual Estimated O&M Cost (Difference)	**$283,000**	**$530,000**	**$1,197,000** Note 2	**$1,675,000** Note 3
Pumphouse 1 Annual O&M Cost	+$0	+$0	+$0	+$0
Pumphouse 2 Annual O&M Cost	$241,000	$0	$197,000	$145,000
Submarine Pipeline Annual O&M Cost	$42,000	$0	$1,000,000	$1,000,000
WTP Annual O&M Cost	$0	$530,000 Note 1	$0	$530,000 Note 4
25-year Life Cycle Cost (NPV)	**$108,800,000**	**$75,000,000**	**$49,600,000**	**$87,000,000**

Note 1: Plus a single $5,000,000 upset allowance for 2038.

Note 2: To year 2038; zero incremental cost thereafter.

Note 3: To year 2038; $530,000 incremental cost per year thereafter.

Note 4: Plus a single $2,200,000 upset allowance for 2038.

5. Options Evaluation

5.1 Decision Model Basis

The raw water source options are 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 5-1. The weights in the second column were reviewed and approved by Yellowknife City Council as part of the 2017 study. The criteria and weights have remained unchanged for the 2024 study, with the exception of:

- ⇒ Life-cycle cost: Scoring was changed to accommodate the significant increases beyond the $35,000,000 upper limit for capital cost that was considered in 2017. New scoring method is described in more detail below.
- ⇒ Constructability: The previous "Schedule" sub-criteria has changed to "Permits and Approvals", which has the most significant bearing on the project schedule. All options are dependent on major upgrades at Pumphouse 1 which is the governing factor in construction schedule, meaning all three options would score identically. Construction schedule is therefore ignored.
- ⇒ Sub-criteria "Organics" has changed to "Organics and TSS" to address a comment from the 2018 third-party review of the 2017 study.

The design horizon for the purpose of scoring options is defined as 25-years from the time of commencing construction of the preferred option (2050).

Scoring of Options 1 and 2 have been kept consistent with the 2017 scoring to the extent possible. However, since the options are scored relative to the other options, the introduction of two additional options has caused scoring to change. Additional commentary has been provided where Option 1 and Option 2 scoring from 2017 to 2024 deviates by 20% or above.

Table 5-1: Decision Model Evaluation

Criteria	Weight	Sub-Criteria	Sub-Weight	Overall Weight
Susceptibility to Raw Water Quality Changes	20%	Arsenic	80%	16%
		Organics and TSS	20%	4%
Constructability	10%	Permits and Approvals	25%	2.5%
		Ease of Construction	50%	5%
		Impact on Existing Operation	25%	2.5%
Reliability of Water Supply	50%	Infrastructure Failure	50%	25%
		Process / Operation / Monitoring Failure	50%	25%
Ease of Operation	5%	Ease of Operation	100%	5%
25-year Life Cycle Cost	15%	25-year Life Cycle Cost	100%	15%

5.2 Qualitative Evaluation (Ratings)

5.2.1 Susceptibility to Raw Water Quality Changes

Susceptibility to Raw Water Changes is rated based on how a change in raw water quality (within expected range for each source) would affect WTP operation during normal facility operation – e.g. all processes, pumping systems and pipelines are available at designed firm capacity.

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, or could require water use restrictions.

5.2.1.1 Arsenic

5.2.1.1.1 Option 1: River Source

The River source is not expected to experience any notable changes in arsenic concentrations, regardless of upset condition caused by failure of the new GM WTP, overflow of the underground mine pool, or breach of the Giant Mine tailings pond perimeter dam. The Bay Source is considered as unavailable during an Upset Condition.

5.2.1.1.2 Option 2: Bay Source

For the purposes of evaluation under the “Susceptibility to Raw Water Quality Changes” criterion, it is assumed that the selected arsenic treatment process is in permanent operation, does not require significant effort to implement treatment operations at the start of an Upset Condition, and can maintain treated water quality within permitted ranges for the duration of the defined Upset Conditions.

During Upset Conditions, the arsenic treatment would likely be operated as four trains of lead/lag vessels to reduce the risk of arsenic breakthrough into the treated water. In this case the capacity of the treatment system could be reduced to as low as half of the maximum plant capacity depending on acceptable loading rates and required EBCT.

The conceptual design for the Bay option assumes that the arsenic treatment media is replaced every fifteen years, although the raw water arsenic levels are currently low enough that theoretically the media could last even longer than ten years. However, if Upset Conditions as described in Section 2 were to occur, where Giant Mine releases more arsenic than expected 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 during 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 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 2, we expect that the adsorptive media may need to remove antimony as well as arsenic in Upset Conditions. The performance of the media could be confirmed by bench tests or pilot testing to remove some uncertainty, although the amount of arsenic that may be released from the mine site will remain uncertain.

The rating considers the likelihood of arsenic Upset Conditions occurring. The new GMWTP is expected to be operational by 2026, which is before any option selected as part of this study could be reasonably implemented. For the purposes of this study, the GM WTP is assumed to be designed to current best practices for operational flexibility and redundancy, as well as including sophisticated control and monitoring systems to detect failures very quickly. Shutdowns of long enough duration to affect water quality in the Bay are considered unlikely. For a large release of arsenic to occur after 2026, the GM WTP would need to have a significant and long duration failure, as described in Section 2.

While the susceptibility to increased arsenic is clearly higher than Option 1, given the planned operation of the GM WTP and the closure in years 2026-2032 of surface ponds for storage of contaminated water, the likelihood of increased arsenic is lower than when this was evaluated in 2017.

There are clearly impacts to WTP operation using the additional treatment process. However, appropriate process selection, good design practice for redundancy and maintainability as well as regular operator training, should mean that impact is within what can be reasonably handled by operations staff.

5.2.1.1.3 Option 3: Status Quo

Option 3 is comparable with Option 1, with the condition of the existing submarine pipeline and Pumphouse 2 being the most significant concerns, which is dealt with by the Reliability of Water Supply criteria below. Since the River is the normal source, there is no switchover between sources required in the event of an upset condition. However, the existing pipeline would likely not be available after 2038, which significantly increases susceptibility to elevated arsenic levels in the Bay source.

5.2.1.1.4 Option 4: Hybrid – With Arsenic Removal

This option is scored higher than Option 2, Bay Source, as there is the possibility of blending and back-up from the River source until 2038, which increases the likelihood of the Bay source arsenic concentration being within the treatable range of the WTP process. The option is scored lower than Option 1 as the existing pipeline would likely not offer reliable operation for the 25-year design window, so Option 4 would be susceptible to an upset condition of the Bay source beyond 2038.

Arsenic Ratings:

⇒	Option 1 – River Source:	100/100
⇒	Option 2 – Bay Source:	60/100
⇒	Option 3 – Status Quo:	70/100
⇒	Option 4 – Hybrid – With Arsenic Removal:	80/100

Scoring for Option 2 has increased significantly (+40%) since 2017, to reflect that design of the new GMRP WTP is complete, and should be in-service before any of the upgrade options presented in this study could reasonably be expected to be implemented. Upset conditions for this 2024 study have lower estimated raw water arsenic concentrations, with correspondingly lower estimated impact on WTP operation.

5.2.1.2 Organics and TSS

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).

Total suspended solids (TSS) and turbidity in the raw water can impact membrane cleaning schedules. Similar to TOC, average TSS concentrations are expected to be generally similar for the Yellowknife River and Yellowknife Bay.

5.2.1.2.1 Option 1: River Source

The River water quality is expected to have more variation throughout the year, potentially requiring more adjustments to chlorine dosages or membrane cleaning schedules. If significant volatility in organics or TSS causes operational concerns, a controlled switchover to the Bay source could be implemented, assuming there is no Upset Condition causing elevated arsenic levels.

5.2.1.2.2 Option 2: Bay Source

The Bay source is expected to have slightly lower average organics and TSS, and less seasonal variation. However, there is no means of alternative water source in the event of higher organics or solids at the bay intake location.

5.2.1.2.3 Option 3: Status Quo

Identical to Option 1.

5.2.1.2.4 Option 4: Hybrid – With Arsenic Removal

This option would use the Bay as the primary source, which has the benefits described for Option 2. In addition, there is the option to revert to the River source in the event of elevated organics or suspended solids at the Bay.

Organics and TSS Ratings:

- ⇒ Option 1 – River Source: 70/100
- ⇒ Option 2 – Bay Source: 80/100
- ⇒ Option 3 – Status Quo : 70/100
- ⇒ Option 4 – Hybrid – With Arsenic Removal: 90/100

5.2.2 Constructability

For this item, a project with lower risk and quicker schedule is generally rated higher. Schedule is affected by factors including environmental permitting, construction season, and material/equipment lead times.

5.2.2.1 Licensing, Permits and Approvals

The 2017 study considered design and construction timeline, as well as licensing and permitting requirements. However, all options require significant work at Pumphouse 1, which requires multiple stages of construction spanning multiple years, and there would be no significant difference in construction timelines between the three options. This sub-criteria has therefore been changed to consider timeline, complexity and risk of achieving required licenses, permits and approvals. As a result, there are significant reductions in scoring for Options 1 and 2 when compared to the 2017 scoring.

5.2.2.1.1 Option 1: River Source

Operation under Option 1 would see no significant change in intended operation when compared to current day, and is not expected to require changes to the existing Water License, expiring 2037.

Areas of the Yellowknife River and Yellowknife Bay are considered ecologically and culturally sensitive. Permits and approvals related to Environmental Protection for this option are significant due to the construction of a new submarine pipeline. The environmental regulatory roadmap was defined in the project Preliminary Design Report, 2023-04-12, and included lengthy Fisheries and Oceans Canada (DFO) and Canadian Navigable Waters Act reviews and approvals, spanning potentially 12 months. Field Surveys and Archaeological Overview and Impact Assessments and Consultation with Yellowknives Dene (Degray 2020) will also be required under this option, adding additional risk, complexity and time required for project implementation.

5.2.2.1.2 Option 2: Bay Source

Exclusive use of the Bay source is a significant change of intended operation, which would require consultation with the Regulator - Mackenzie Valley Land and Water Board (MVLWB) to satisfy them that the proposed source and process changes are acceptable. There is also a requirement for public consultation, which can be expected to result in resistance to any proposal to change to a Bay only source. Significant efforts by the City would be required in educating the public on proposed changes, resulting changes in risk profiles, and potential public health impacts.

5.2.2.1.3 Option 3: Status Quo

This option would have a similar process for environmental permitting as Option 2, as no new pipeline is to be constructed.

Normal operation would be using the River Source, so there is no significant change in intent from a Water License perspective. However, the age and condition of the existing submarine pipeline can reasonably be expected to lead to increased use of the Bay source during periods of maintenance, and would likely exceed the maximum quantity allowed by the existing water license.

It could be argued that catastrophic failure of the submarine pipeline leading to exclusive use of the bay source is foreseeable for the 2038 timeline, given the age and known condition of the pipeline. The approach of reverting to the Bay Source as the only available option could be seen by the public and MVLWB as an intent to change the intended operation through willful neglect of the infrastructure required under the License, as opposed to gaining approval for use of the bay as the primary source as proposed for Option 2.

For this option we have assumed that the water licence would need to be amended and public consultation may be required to allow larger quantities of water to be drawn from the Bay, although the primary source would remain the River in the short term. This option would also include concerted efforts at maintenance and rehabilitation of the pipeline, although that is challenging due to the pipeline route, depth, and material.

5.2.2.1.4 Option 4 – Hybrid – With Arsenic Removal

A more robust mitigation for an upset condition affecting the Bay source is provided. It is expected that the inclusion of the arsenic removal process in addition to retention of the existing pipeline would make the option more favourable in the eyes of the Regulator and Public than options 2 and 3. However, this option requires a change to the Bay Source and may be seen as less favourable than a new submarine pipeline.

Environmental approvals are expected to be simpler than Option 1 as no new pipeline is constructed, though there would be consideration of disposal of residual and backwash waste from the arsenic removal process.

Permits and Approvals Ratings:

- ⇒ Option 1 – River Source: 40/100
- ⇒ Option 2 – Bay Source: 10/100
- ⇒ Option 3 – Status Quo: 20/100
- ⇒ Option 4 – Hybrid – With Arsenic Removal: 30/100

5.2.2.2 Ease of Construction (Construction Risk)

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

5.2.2.2.1 Option 1: River Source

Construction of the new pipeline is assumed to include working on ice above cold water, which carries significant safety risks to personnel and potential for equipment loss or damage. Pipeline construction would be carried out in a limited timeframe (from January to mid-April, when the ice is thick enough to support vehicles, though there is some uncertainty of this timeline depending on the weather conditions. This risk has been partially addressed in the cost estimates as well by including a contingency cost, though there remains the risk of unexpected events.

Upgrades to Pumphouse 1 are complex and require significant planning and phasing. There is risk associated with blasting on the site within close proximity to areas and wetwells that are required to remain operational. This is generally consistent for all four options except that more blasting would be required for the new wetwell in Option 2.

Upgrades to Pumphouse 2 are the most complex of any of the four options considered.

5.2.2.2.2 Option 2: Bay Source

Some in-water work is required for the replacement of the existing intake screen, though these in-water risks are considered very minor compared to Option 1. The expansion of the WTP structure is considered to be routine, but this expansion adds one more construction location with risk of incidents affecting City employee safety or existing infrastructure.

More blasting would be required for this option compared to Option 1, for construction of a redundant Bay wet well.

5.2.2.2.3 Option 3: Status Quo

Some in-water work is required for the replacement of the existing intake screen, though these in-water risks are considered very minor compared to Option 1. There are no modifications required to the WTP. There are the fewest locations having upgrades undertaken (only Pumphouse 1 and Pumphouse 2) and the upgrades are the lowest complexity of any option.

5.2.2.2.4 Option 4 – Hybrid – With Arsenic Removal

This option is similar to Option 2, with the exception that additional complexity is added to the project by additional works at Pumphouse 2.

Ease of Construction Ratings:

- ⇒ Option 1 – River Source: 10/100
- ⇒ Option 2 – Bay Source: 50/100
- ⇒ Option 3 – Status Quo: 80/100
- ⇒ Option 4 – Hybrid – With Arsenic Removal: 40/100

Option 1 rating is 30% lower than in 2017, as having completed 50% of detailed design, far more is now understood about the constructability challenges, and two other new options have lower constructability risks. Option 2 rating is 30% lower than in 2017, to make room in the ratings for Option 3, which is considered less challenging to construct.

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, risk of falling outside of License requirements, and risk of depletion of reservoir storage volumes.

5.2.2.3.1 Option 1: River Source

Construction of upgrades to Pumphouse 1 require extensive planning and phasing while keeping the existing systems operational, which carry significant risk. However, these risks are consistent between all three options.

Upgrades to Pumphouse 2 are more onerous in this option than any other option, though the bay source could be used as mitigation during tie-ins and unexpected issues. It is expected that there will be multiple transitions between sources, and transitions between which pipeline is in use during the construction and commissioning phase, which increases the risk of water interruptions.

Since major upgrades are required at Pumphouse 1, Pumphouse 2, and the pipeline, there will almost certainly be overlap such that work is taking place at multiple locations simultaneously using multiple contractors. This increases risk of mis-coordination resulting in loss of raw water supplies, severely restricts operations activities, and increases risk of incident affecting operator safety.

5.2.2.3.2 Option 2: Bay Source

The existing Pumphouse 2 and submarine pipeline would no longer be available once the existing booster pumping system is demolished at Pumphouse 1. Prolonged use of the Bay source during construction would be acceptable on the basis that the Water License had already been updated to allow for permanent, continuous operation using only that source.

Construction of a new treatment process at the WTP could cause depletion of treated water reservoir storage in the event of unexpected issues during tie-ins or commissioning.

5.2.2.3.3 Option 3: Status Quo

This option would be closely aligned with Option 2, with the exception of some limited upgrades at Pumphouse 2, which could be more easily coordinated than for Option 1. There is no impact to operations at the WTP.

5.2.2.3.4 Option 4 – Hybrid – With Arsenic Removal

Considered similar to Option 2, due to the upgrades required at the WTP. Rated more favorably than Option 1 as there are fewer locations where work and tie-ins are required.

Impact on Existing Operation Ratings:

- ⇒ Option 1 – River Source: 50/100
- ⇒ Option 2 – Bay Source: 60/100
- ⇒ Option 3 – Status Quo: 80/100
- ⇒ Option 4 – Hybrid – With Arsenic Removal: 60/100

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. This criteria includes risk of water interruptions related to raw water quality which the water treatment system cannot adequately treat.

5.2.3.1.1 Option 1: River Source

The River option is rated highly because a new pipeline could be expected to provide reliable operation for decades without failure.

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 or Pumphouse 2 could fail at the same time as a 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, water quality sampling at Pumphouse 1 would detect elevated arsenic levels and the City would have no acceptable water supply until the pipeline or Pumphouse 2 repair is completed.

5.2.3.1.2 Option 2: Bay Source

The primary risk with the Bay option is that in an 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. This process treatment failure is somewhat less likely for the 2024 estimated raw water Upset Condition arsenic concentrations compared to the higher concentrations for the Upset Condition in the 2017 study. 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. This is within the City's control to a much lesser extent than pipeline repairs required under Option 1.

WTP capacity would be temporarily reduced to 7/8 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.

Other events affecting a localized area within Yellowknife Bay could also cause a significantly bigger issue than where a River source was available. The risk of localized events such as a hydrocarbon spill affecting the Bay intake location is mitigated in other options by the availability of the River source.

5.2.3.1.3 Option 3: Status Quo

The Status Quo option offers the benefits of Option 1 under normal circumstances, but with diminished life-expectancy for the existing pipeline, and without the arsenic treatment processes provided under Option 2. Repairs of the existing pipeline can be expected to be required more frequently, and be more challenging than Option 1.

This option could experience a water interruption if an Upset Condition and a river pipeline break occur at the same time. This is more likely for Option 3 than for Option 1 due to the condition of the existing pipeline.

The existing pipeline has a lower capacity and less tolerance for increased flow demands compared to the new pipeline in Option 1. This option therefore has the potential for water restrictions in the future related to pipeline capacity.

5.2.3.1.4 Option 4 – Hybrid – With Arsenic Removal

This option is scored higher than Option 2 since the existing River source and pipeline is expected to be available to mitigate arsenic concentrations higher than the treatable limit, or to reduce O&M costs associated with operating the WTP process during an upset event. The option is scored higher than Option 3, since the arsenic removal process is used in the event the pipeline is unavailable. The option is scored lower than Option 1 as the existing pipeline has a diminished life-expectancy and capacity compared to the pipeline provided in that option. Beyond 2038, Option 4 is considered to be identical to Option 2.

Infrastructure Failure Ratings:

- ⇒ Option 1 – River Source: 90/100
- ⇒ Option 2 – Bay Source: 60/100
- ⇒ Option 3 – Status Quo: 40/100
- ⇒ Option 4 – Hybrid – With Arsenic Removal: 75/100

The gap in scoring between Option 1 and Option 2 has widened by 10% since 2017 to make room for scoring of new Option 4, which is considered more resilient than Option 2 but less resilient than Option 1.

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.

5.2.3.2.1 Option 1: River Source

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 as 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 failure leading to “Upset Condition”, a submarine pipeline failure, and failure of arsenic monitoring at Pumphouse 1.

5.2.3.2.2 Option 2: Bay Source

The primary risk with the Bay option is that in 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.

Failure to replace the media when it is nearing contaminant breakthrough could also lead to arsenic and/or antimony passing through exhausted adsorptive media.

5.2.3.2.3 Option 3: Status Quo

Treatment process risk is similar to Option 1 except that the pipeline infrastructure failure is more likely in Option 3.

5.2.3.2.4 Option 4 – Hybrid – With Arsenic Removal

This option has similar failure modes as Option 2 pertaining to media replacement and reliability of arsenic instrumentation. However, the option is scored higher than Option 2, as there is the ability to use the River Source in the event that the arsenic removal process or instrumentation needs to be bypassed for media replacement or instrument troubleshooting. The option scores higher than Option 3, as the availability of the arsenic removal process may mitigate failure of instrumentation to detect upset conditions. The option scores lower than Option 1 as the need for reliable arsenic detection is higher, since the Bay is the primary source, compared to a river source that has a reliable pipeline with capacity for the entire flow envelope.

Process/Operation/Monitoring Failure Ratings:

- ⇒ Option 1 – River Source: 100/100
- ⇒ Option 2 – Bay Source: 60/100
- ⇒ Option 3 – Status Quo: 70/100
- ⇒ Option 4 – Hybrid – With Arsenic Removal: 80/100

The gap in ratings between Option 1 and Option 2 has widened by 20% since 2017 to make room for rating of new Options 3 & 4, which are considered to have lower risks or impacts for process operation or monitoring failure than Option 2.

5.2.4 Ease of Operation

Ease of operation is partially addressed in O&M costs but this item gives more weight to operation complexity, and includes items not reflected in costs like troubleshooting a new treatment process, desirability of driving to a remote site, operation during interruptions in communication between facilities, and intuitiveness of operator responses to upset conditions.

5.2.4.1 Option 1: River Source

The upgraded River supply pumping would be almost identical to the existing system, with the exception that there would be improved status monitoring over SCADA, and more automated responses to failure modes. No new treatment processes would be needed at the WTP.

5.2.4.2 Option 2: Bay Source

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.

5.2.4.3 Option 3: Status Quo

Option 3 would be very similar to Option 1, with very similar infrastructure and processes. The main difference is that the bay source could be needed more frequently, which results in more frequent monitoring of arsenic in the raw water source, as well as potential for treatment process upsets each time the source water is switched. Monitoring for failure of the existing submarine pipeline may also be an operational concern.

5.2.4.4 Option 4 – Hybrid – With Arsenic Removal

This option was considered to be the most complex for operation, as it requires continued operation of Pumphouse 2, the existing submarine pipeline, as well as the new WTP treatment process. Similar to Option 3, there are concerns about operating ageing infrastructure beyond its intended lifespan. With the Bay being the primary source, there are concerns about turnover of the submarine pipeline, including risks of freezing in the pipeline and possibly taste and odour concerns if the River source is put back into service after a long period of Bay source use.

Ease of Operation Ratings:

- ⇒ Option 1 – River Source: 80/100
- ⇒ Option 2 – Bay Source: 80/100
- ⇒ Option 3 – Status Quo: 60/100

⇒ Option 4 – Hybrid – With Arsenic Removal: 50/100

5.2.5 Life Cycle Cost

The estimated 25-year net present value for each option is presented in Section 4.6. For the decision model evaluation, net present value costs are scored from 0 – 100, using the formula: (1 - (Option Cost / Highest Cost)) x 100.

The formula used in 2024 has been modified to allow for cost escalation since 2017, though the method of scoring uses the same principle as 2017.

Life Cycle Cost Ratings:

⇒	Option 1 – River Source:	$108,800,000	0/100
⇒	Option 2 – Bay Source:	$75,000,000	31.1/100
⇒	Option 3 – Status Quo :	$49,600,000	54.4/100
⇒	Option 4 – Hybrid – With Arsenic Removal:	$87,000,000	20/100

The gap in ratings between Option 1 and Option 2 has reduced by 27.9% since 2017, which reflects the Option 2 - Bay Source cost now being estimated as approximately 70% of the cost of the Option 1 River source, as opposed to 55% of the Option 1 cost estimated in 2017.

The massive escalation in costs of all options since 2017 also caused the rate at which points are scored to change, while retaining ratings on a range of 0 - 100. In 2017, four points were awarded for each $1,000,000 below the upper limit of $35,000,000 e.g. Option 1 was awarded 8 points as it was $2,000,000 below $35,000,000. In 2024, an option is only awarded 0.9 points for each $1,000,000 below the upper limit of $108,800,000.

5.3 Evaluation Results

Table 5-2 shows the matrix decision model, including criteria weightings and option scores. Figure 5-1 illustrates the same results graphically, to show the contribution of each major criteria to the overall score.

Table 5-2: Decision Model Evaluation

					Ratings				Weighted Scores			
Criteria	**Weight**	**Sub-Criteria**	**Sub-Weight**	**Overall Weight**	**Option 1: River**	**Option 2: Bay**	**Option 3: Status Quo**	**Option 4: Hybrid**	**Option 1: River**	**Option 2: Bay**	**Option 3: Status Quo**	**Option 4: Hybrid**
Susceptibility to Raw Water Quality Changes	20%	Arsenic	80%	16%	100	60	70	80	16.0	9.6	11.2	12.8
		Organics and TSS	20%	4%	70	80	70	90	2.8	3.2	2.8	3.6
Constructability	10%	Permits and Approvals	25%	2.5%	40	10	20	30	1.0	0.3	0.5	0.5
		Ease of Construction	50%	5%	10	50	80	40	0.5	2.5	4.0	2.0
		Impact on Existing Operation	25%	2.5%	50	60	80	60	1.3	1.5	2.0	1.5
Reliability of Water Supply	50%	Infrastructure Failure	50%	25%	90	60	40	75	22.5	15.0	10.0	18.8
		Process / Operation / Monitoring Failure	50%	25%	100	60	70	80	25.0	15.0	17.5	20.0
Ease of Operation	5%	Ease of Operation	100%	5%	80	80	60	50	4.0	4.0	3.0	2.5
25-year Life Cycle Cost	15%	25-year Life Cycle Cost	100%	15%	0.0	31.1	54.4	20.0	0.0	4.7	8.2	3.0
								Total Score	73.1	55.7	59.2	64.9

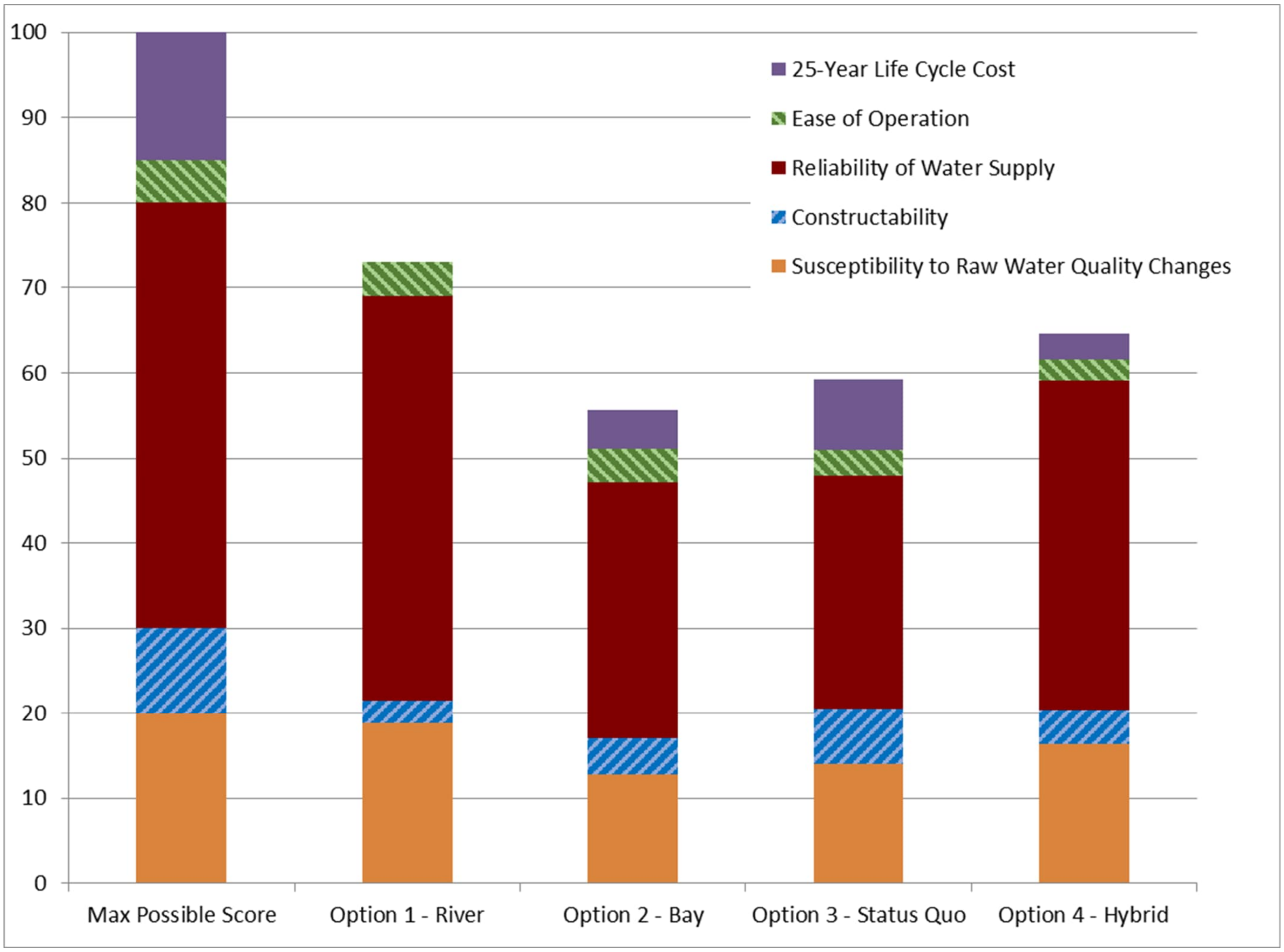


Figure 5-1: Decision Model Evaluation

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 5-2).
2. Alternative weights: Susceptibility to Raw Water Changes 15%, Constructability 5%, Reliability of Water Supply 40%, Ease of Operation 5% and Life Cycle Costs 35%. This demonstrates the effect of making cost more important to the decision. The 2017 study increased cost to 60%, which may not be realistic. It is noted that increasing the Life Cycle Cost to 35% is the lowest weighting that causes a change in overall outcome; this is more than double the 15% weighting of the base model.
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 and less emphasis on the reliability of the water supply.

4. Life Cycle Cost 50% higher than the Base Model estimate for Option 1.
5. Life Cycle Cost 50% higher than the Base Model estimate for Option 2.
6. Life Cycle Cost 50% higher than the Base Model estimate for Option 3.
7. Life Cycle Cost 50% higher than the Base Model estimate for Option 4.
8. Alternative ratings: Reliability of Water Supply ratings of 70, 50, 30, and 60 for Infrastructure Failure and 80, 60, 65, and 70 for Operation/Monitoring Failure respectively for Options 1 through 4. These ratings match the 2017 evaluation ratings for Options 1 and 2, instead of changing those ratings to provide a wider range for differences in new option ratings as done for the 2024 Base Model.
9. Alternative ratings: Susceptibility to Raw Water Quality – Arsenic rating changed to 20 for Option 3 Status Quo. This alternative rating puts more emphasis on the long-term susceptibility after the existing pipeline is no longer usable, compared to the Base Model where the relative scores reflect the availability of the existing pipeline in the short term.
10. Alternative Cost Scoring Methodology: The scoring methodology applied in both 2017 and 2024 assigns a weighting for cost integrated as part of the decision model. Triple Bottom Line (TBL) models can also use a benefit-to-cost ratio, where the weighted scores (excluding cost) are divided by the NPV cost. For this sensitivity scenario, the 15% score for cost was distributed between the remaining four criteria, pro-rated based on their previous weighting: Susceptibility to Raw Water Changes 24%, Constructability 12%, Reliability of Water Supply 59%, Ease of Operation 6%. The new weighted scores of 85.9, 60.1, 60.0, 72.8 for Options 1 through 4 are then divided by the costs of $108.8, $75, $49.6 and $87. The benefit-to-cost ratios are shown in the table below, with Option 3 offering the best ratio, and Option 1 the worst.
11. 2017 Scoring

The alternative total scores are shown in Table 5-3. 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 or Hybrid option, with Option 4 being scored second.

Of the alternative conditions considered here, one case that applied a higher weight to project cost resulted in a higher score for Option 3. Another case resulted with Option 3 being the preferred option, with Option 4 being scored second, where a benefit-to-cost model was utilized instead of weighting cost as a % of the total score.

Table 5-3: Alternative Decision Model Scores for Sensitivity Analysis

Model	Description	Weighted Scores				Margin for Top Score to Second Score
		Option 1: River	Option 2: Bay	Option 3: Status Quo	Option 4: Hybrid	
1	Base	73.1	55.7	59.2	64.9	13%
2	Alternative Weights – Cost to 35%	57.5	50.6	57.8	54.9	1%
3	Alternative Weights – Susceptibility to 50%	72.8	56.9	63.7	66.3	10%
4	Life Cycle – Option 1 Cost Increase by 50%	73.1	59.2	61.4	68.9	6%

5	Life Cycle – Option 2 Cost Increase by 50%	73.5	51.1	59.4	65.3	13%
6	Life Cycle – Option 3 Cost Increase by 50%	73.1	55.7	55.7	64.9	13%
7	Life Cycle – Option 4 Cost Increase by 50%	73.5	57.4	60.3	61.9	22%
8	Alternative Rating: Reliability Match 2017 ratings	63.1	53.2	55.4	58.7	8%
9	Alternative Rating: Susceptibility to arsenic rated 20 for Option 3	73.1	55.7	51.2	64.9	13%
10	Alternative Cost Scoring: Benefit-to-Cost-Ratio	0.79	0.80	1.21	0.84	--
11	2017 Scoring	65.2	54.5	--	--	20%

6. Summary and Recommendation

In this evaluation, Option 1 - River has a Total Score of 73.1 which is 13% ahead of the next nearest score (Option 4 – Hybrid) and 31% ahead of the least favorable option (Option 2 – Bay) suggesting that the Yellowknife River is the preferred option. This is consistent with the findings from 2017.

Option 1 scored highest in nine (9) of the eleven (11) sensitivity cases, with the exceptions being where cost was increased in weighting to 35% (case 2), and where the cost weighting was replaced by a benefit-to-cost ratio (case 10). Option 4 scored second-highest for all cases, with the same exception for cost weighting (case 2).

Option 1 - River has the highest estimated life cycle cost of $108,800,000 compared to the lowest cost option of $49,600,000 for Option 3 – Status Quo. 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 water treatment failure at Giant Mine. Options 3 and 4 received lower scores due to reliability concerns around continued use of the existing submarine pipeline and Pumphouse 2.

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.

The evaluation of options was carried out using the framework developed and approved by Council in 2017. While this provides some consistency in decision-making between the 2017 and 2024 project teams, there are some concerns regarding affordability of the project. A weighting of 15% for the 25-year life cycle cost implies that cost is a relatively minor concern, and that any of the options is generally affordable. However, the reality of Option 1 is that it is very dependent on early capital investment (>$100,000,000 spread over three years of construction), compared to Option 3, where $37,000,000 is spread over three years of construction.

External funding through the Government of Canada Disaster Mitigation and Adaption Fund (DMAF) was secured in 2020 to a maximum of $25,862,218, and the remaining capital of approximately $80,000,000 would need to be funded by the City, through borrowing, re-structuring of the capital budget, or other funding programs. Given the significance of this financial commitment, it would be prudent for the City and Council to review the 2017 decision model criteria and weightings to confirm that it still accurately reflects the values and priorities of the City in 2024.

Other items that have been used as a design basis for the evaluation should also be carefully reviewed by the City. Changes to multiple different inputs in the evaluation could affect the outcome. In particular the City should review and confirm:

- Assumptions relating to the condition and pressure rating of the existing submarine pipeline, its capacity, and suitability for continued operation.
- Confirmation that a 25-year design horizon (to 2050) is an appropriate basis for all four options, as opposed to 2038 to align with the GMRP project timeline.

7. References

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Appendix A. Technical Memorandum - Characterization of Water Quality at Pumphouse 1: Water Source Review 2024 Update

FINAL

AECOM

Characterization of Water Quality at Pumphouse 1

Water Source Review 2024 Update
Technical Memo

City of Yellowknife

60673796

July 2024

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AECOM: 2015-04-13

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Revision History

Rev #	Revision Date	Revised By:	Revision Description
A	July 2024	Ryan King	Draft Technical Memo

Distribution List

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	✓	City of Yellowknife
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1. INTRODUCTION

The City of Yellowknife currently obtains its drinking water from the Yellowknife River via an 8.8 kilometer submarine pipeline. The pipeline carries water from Pump House #2 (PH2), which is located upstream of the City on the shores of the Yellowknife River, through Yellowknife Bay to Pump House #1 (PH1), which is located in the City of Yellowknife itself. This water line was constructed in 1969 because of concerns that the City's previous raw water source, Yellowknife Bay, was contaminated with arsenic by neighbouring Giant and Con Mines. The existing submarine water line is now nearing the end of its design life and does not have enough capacity to meet the City's future water needs.

In 2017, AECOM carried out a Potable Water Source Selection Study, which took a triple bottom line (TBL) approach to review two options: Yellowknife River with a new submarine pipeline, or Yellowknife Bay with a new adsorptive media treatment system. The Yellowknife River source, including submarine pipeline was the highest scoring option, and was concluded to have "a higher capital cost, but has less risk of arsenic contamination."

Since 2017, there has been significant development in available water quality data as well as lifecycle costs associated with upgrade of the Yellowknife River conveyance system since the previous source water study completed in 2017. The purpose of this technical memo is to provide an update to the characterization of water quality (arsenic and other selected contaminants of concern) in Yellowknife Bay and at PH1 using recent data from the City of Yellowknife and the Giant Mine Remediation Team and to provide an interpretation of the risk to human health.

2. SUMMARY OF THE 2017 WATER SOURCE SELECTION STUDY

AECOM completed a Water Source Selection Study in 2017 which included characterizing and defining arsenic concentrations in surface water from Yellowknife Bay collected through various monitoring programs conducted by other parties, as well as for PH1 data collected between 2005 to 2017 (AECOM 2017). Monthly water sampling results from PH1 during this period indicated that average dissolved arsenic concentration was 1.1 µg/L and average total arsenic concentration was 1.2 µg/L in Yellowknife Bay. Health Canada's maximum drinking water quality guideline for arsenic is 10 µg/L however, the guidance also indicates that every effort should be made to maintain arsenic levels in drinking water as low as reasonably achievable.

Seasonal separation of the PH1 arsenic data was evaluated as part of the Water Source Selection Study and indicated a 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 (AECOM 2017). The mean dissolved arsenic during ice-cover was 0.78 µg/L and open-water was 1.32 µg/L. The mean total arsenic during ice-cover was 0.92 µg/L and open-water was 1.41 µg/L. 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 because of increased microbial metabolic activity during the warmer months (Chételat et al. 2017, Andrade 2006).

The Water Source Selection Study concluded that because the risk of a potential failure at Giant Mine cannot be eliminated, the Yellowknife River is the preferred option for long-term raw water supply (AECOM 2017). The water treatment plant, built in 2015, currently uses membrane filtration which includes sodium hypochlorite generation for disinfection to account for turbidity events of increased sediment in the Yellowknife River.

3. Other Studies of Note

3.1 Giant Mine Human Health and Ecological Risk Assessment – 2018

The objective of the risk assessment conducted by CanNorth in 2018 on behalf of the Giant Mine Remediation Team was to determine what effects the remedial activities at the Giant Mine will have on residents in the surrounding communities.

Current base case - In the base case, everyone was assumed to get their drinking water from the municipal source. Other scenarios were also considered that were added to the base case. The scenarios for Ndilo and Dettah involve the assumption that people in these two communities would drink water from Yellowknife Bay instead from the municipal source.

Future scenarios were also evaluated for after the Giant Mine remediation activities are completed. The effect of the relocation of the treated water discharge near the mouth of Baker Creek was evaluated using modelling to determine what the water and sediment concentrations would be in Back Bay and North Yellowknife Bay. The results determined that the concentrations in water and sediment in North Yellowknife Bay would essentially remain unchanged.

For the Giant Mine HHRA, it was important to examine the bioaccessibility of arsenic in particular, since it was the primary COPC associated with the activities at the Giant Mine and since it is present in many different chemical forms (arsenopyrite, arsenic trioxide, etc.). In the absence of other information, the bioaccessibility of arsenic in water was assumed to be 100%.

Exposure point concentrations (EPCs) were developed for the current scenario and the future scenario for residents of Ndilo, Dettah, Latham Island, and City of Yellowknife. For the risk assessment it was assumed that everyone used the municipal water supply. For some of the scenarios, it was assumed that people may get water from different parts of Yellowknife Bay (Back Bay, North Yellowknife Bay and South Yellowknife Bay). Background EPCs were also developed.

All receptor locations were assumed to obtain water from the municipal supply. These concentrations are summarized in the table below taken from Appendix F of the Giant Mine HHRA. Additional assessments were completed for the ingestion of drinking water from South Yellowknife Bay (for Dettah receptors), North Yellowknife Bay (for Ndilo receptors), and Back Bay (for Latham Island receptors). All the concentrations in the table are below the Health Canada drinking water guidelines.

Media	Location	Concentration (mg/L)			Statistic
		Arsenic	Antimony	Manganese	
Drinking Water	Municipal	0.002	0.0002	0.002	95% UCLM except Antimony (Yellowknife River BG, 95%ile)
	South Yellowknife Bay	0.001	0.0001	0.001	95% UCLM
	North Yellowknife Bay	0.002	0.0004	0.003	95% UCLM
	Back Bay	0.002	0.0003	0.003	95% UCLM

The effect of the treated water discharge near the mouth of Baker Creek was evaluated using modelling to determine what the water and sediment concentrations would be in Back Bay and North Yellowknife Bay. It should be noted that the future predicted concentrations are no different that the range of current measured concentrations.

3.2 Giant Mine Effluent Quality Criteria Report – 2019

Water quality objectives were developed to protect current and future water uses in Yellowknife Bay. Effluent Quality Criteria (EQC) were set so that water quality objectives in Yellowknife Bay will be met 200 metres from the Giant Mine Water Treatment Plant (GMWTP) outfall. EQC were proposed for the new GMWTP for pH, total suspended solids, un-ionized ammonia, total petroleum hydrocarbons, radium-226, cyanide, arsenic, antimony, copper, lead, nickel, and zinc. Treated effluent from the GMWTP must meet or be lower than the federal Metal and Diamond Mining Effluent Regulations limits. In addition, it is a requirement of one of the Environmental Assessment Measures that arsenic be treated to the Canadian drinking water guideline of 0.01 mg/L.

3.2.1 Model Approach

As part of the water licence process, detailed modelling of water quality and quantity was completed to support setting of the EQC for the Giant Mine site and to understand the effects of closure activities on water quality in Baker Creek and Yellowknife Bay in the future. The models were first set up to mimic current conditions on site and in Yellowknife Bay to check that the model framework reflected these accurately. Then information on future plans over the course of remediation was incorporated to obtain a best estimate of conditions over the Water Licence period. Modelling results were used to identify parameters that have the potential to adversely affect water quality in Yellowknife Bay.

Water quantity and quality models were developed to meet these requirements, support EQC derivation, and understand the effects of closure activities on water quality in Baker Creek and Yellowknife Bay in the future. A complex model framework was developed using several modules and software packages to represent different aspects of the Site and receiving environment.

There were two main models developed:

1) The site model, which was developed in GoldSim and contains a two-dimensional underground module and a surface module (Appendices D1, D2, D3 of the 2019 report). The key purposes of the site model was to predict the daily volume of minewater pumped from the underground mine to the surface, predict the daily volume of runoff from TCAs and pits and flows in Baker Creek, predict parameter concentrations in minewater and Baker Creek for the present-day and future simulation periods, and assess achievability of the proposed EQC for the existing ETP.

2) The Yellowknife Bay models, which included a near-field mixing model developed in the Cornell Mixing Zone Expert System (CORMIX) platform and a three-dimensional model of the bay that was developed in the Generalized Environmental Modelling System for Surfacewaters (GEMSS) platform. The key purposes of the Yellowknife Bay models was to predict mixing of effluent from the new GMWTP and Baker Creek with waters in Yellowknife Bay, predict the assimilative capacity of Yellowknife Bay accounting for discharges from the new GMWTP, Baker Creek, and the Yellowknife River to predict parameter concentrations in Yellowknife Bay under present-day conditions and future simulation periods.

3.2.2 Model Timeframe

The models were run from 1 January 2011 to 31 December 2040, with the year 2040 representing the end of the anticipated Water Licence term. For this report, model results were interpreted based on the following periods:

- 2011 to 2018—present-day simulation period, or calibration period.
- 2019 to 2026—future simulation period when the existing ETP discharges to Baker Creek.
- 2026 to 2040—future simulation period when the new GMWTP discharges to Yellowknife Bay.

3.2.3 Model Coverage

A 3-D grid of Yellowknife Bay was developed that extends from the Yellowknife River in the north to approximately two kilometres south of Joliffe Island, which includes the location of the proposed City of Yellowknife drinking water intake. The grid spacing was 200 m horizontally and 1 m vertically. The comparison of hypsographic curves (i.e., depth and volume and depth and area) calculated by the model and from the bathymetric map of Yellowknife Bay showed a good match**.**

3.2.4 Model Results for the Receiving Environment

The effluent from the new GMWTP is predicted to disperse rapidly in Yellowknife Bay. The minimum predicted dilution factor at the edge of the mixing zone was 166 (i.e., less than 1% of initial effluent concentration) in all scenarios and cases considered. Parameter concentrations in Yellowknife Bay are not predicted to vary over a wider range than present-day concentrations near the breakwater, in North Yellowknife Bay, or in South Yellowknife Bay near the proposed drinking water intake for the city of Yellowknife. Total arsenic concentrations were predicted to remain below the Health Canada DWG near the proposed drinking water intake.

3.3 Government of the Northwest Territories – Health Advisories for Arsenic in Lake Water Around Yellowknife

In July 2019, the NWT Chief Public Health Officer began providing advice to residents and visitors about precautions to avoid exposure to elevated arsenic levels found in some of the lakes located around Yellowknife. This public health advice is updated and based on the most current environmental and human health data available. It may be adjusted as more information becomes available from ongoing or future monitoring or research activities.

It includes a map of lakes in the Yellowknife area where the arsenic levels are below Health Canada's drinking water guidelines of 0.01 mg/L and are safe for swimming and fishing, lakes with arsenic levels above Health Canada's drinking water guidelines of 0.01 mg/L but below 0.052 mg/L, are still considered safe for swimming and fishing. At lakes with elevated arsenic levels exceeding 0.052 mg/L , users are warned to avoid drinking water, fishing, swimming, and harvesting berries, mushrooms, and plants from and immediately around the lake.

4. METHODS

4.1 Data Acquisition

Data for arsenic water column concentrations, sediment concentrations, and ancillary chemistry data for Yellowknife Bay and Pumphouse #1 have been acquired from the following sources:

1. **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 2023.
2. **City of Yellowknife (Excel format):** Annual full suite water quality of Pump House #1 raw (supply) and return (treated) water from 2005 to 2023.
3. **Environment Canada (website):** Rainfall, and wind speed and wind direction data were acquired for dates relevant to previous water column sampling to resolve whether prevailing meteorological conditions were normal or storm conditions for any given sampling event.
4. **Giant Mine Remediation Team, Indigenous and Northern Affairs Canada (INAC), and Government of Northwest Territories (GNWT) (Excel format):** AECOM received an export of compiled data from 2016-2023 of Yellowknife Bay and Yellowknife River for all water quality and Yellowknife Bay sediment analytics collected. AECOM has data used for the previous 2017 Source Selection Study dating back until 2013.
5. **Northwest Territories Geological Survey (Chétalat et al. 2017) (Excel format):** Water column total arsenic, dissolved arsenic and arsenic speciation data. The samples were collected in September 2014, at sites off the shoreline of Ndilǫ and Dettah Communities around Yellowknife Bay

4.2 Data Management

Upon receiving water and sediment data from various sources. AECOM created a surface water and sediment database to compile all data acquired previously for the 2017 study and data received recently up to 2023. In the database, all data was cleared of any previous formatting, and ensured that all units were uniform for ease of analysis. The database was QAQC at 50% of records to ensure they matched the source data files.

Compiled data was grouped based on location of samples and generally followed the groupings identified in the Giant Mine Remediation Project's Aquatic Effects Monitoring Program Design Plan (CIRNAC & GNWT, 2022) with some additional groups identified in Table 4-1. For the purposes of this study of characterizing water quality, data analyses was focused on samples collected from Pumphouse #1 (Wet Well Samples, and Yellowknife Bay Supply), South Yellowknife Bay, Dettah Shoreline (which was grouped into South Yellowknife Bay for analysis), and Yellowknife River. Sampling locations are presented in Figure 1.

Table 4-1. Surface Water Sample Location Information

Surface Water Data Grouping	# of Sample Locations	# of Years of Record	# of Observations	Source Data
Baker Creek behind Breakwater	9	2017-2021	12	Golder, EEM and SNP Programs, DCNJV EEM
Yellowknife Bay near Breakwater	7	2003-2021	363	Golder, EEM and SNP Programs, DCNJV EEM

Surface Water Data Grouping	# of Sample Locations	# of Years of Record	# of Observations	Source Data
Yellowknife Bay Back Bay	10	2012-2023	318	Golder EEM, Stantec (2014), Chételat (2015)
Foreshore Tailings	7	2012, 2013; 2020-2023	29	Nash (2014), Stantec (2014), Golder EEM
North Yellowknife Bay	7	2012, 2013; 2016-2023	101	Stantec (2014), Golder EEM
South Yellowknife Bay	4	2012, 2013; 2018-2023	108	Stantec (2014), Golder EEM
Yellowknife Bay Ndilǫ Shoreline	4	2014	16	Chételat
Yellowknife Bay Dettah Shoreline	4	2014	18	Chételat
Yellowknife River	19	2004, 2005, 2010-2013, 2016-2022	76	Golder, EEM and SNP Programs, DCNJV EEM, Golder, Baker Creek Study (2013), Stantec 2014, City of Yellowknife (2019-2021)
Horseshoe Island Bay	2	2012, 2013	8	Stantec
Pumphouse #1 (Wet Well Samples, and Yellowknife Bay Supply)	2	2005-2023	210	City of Yellowknife

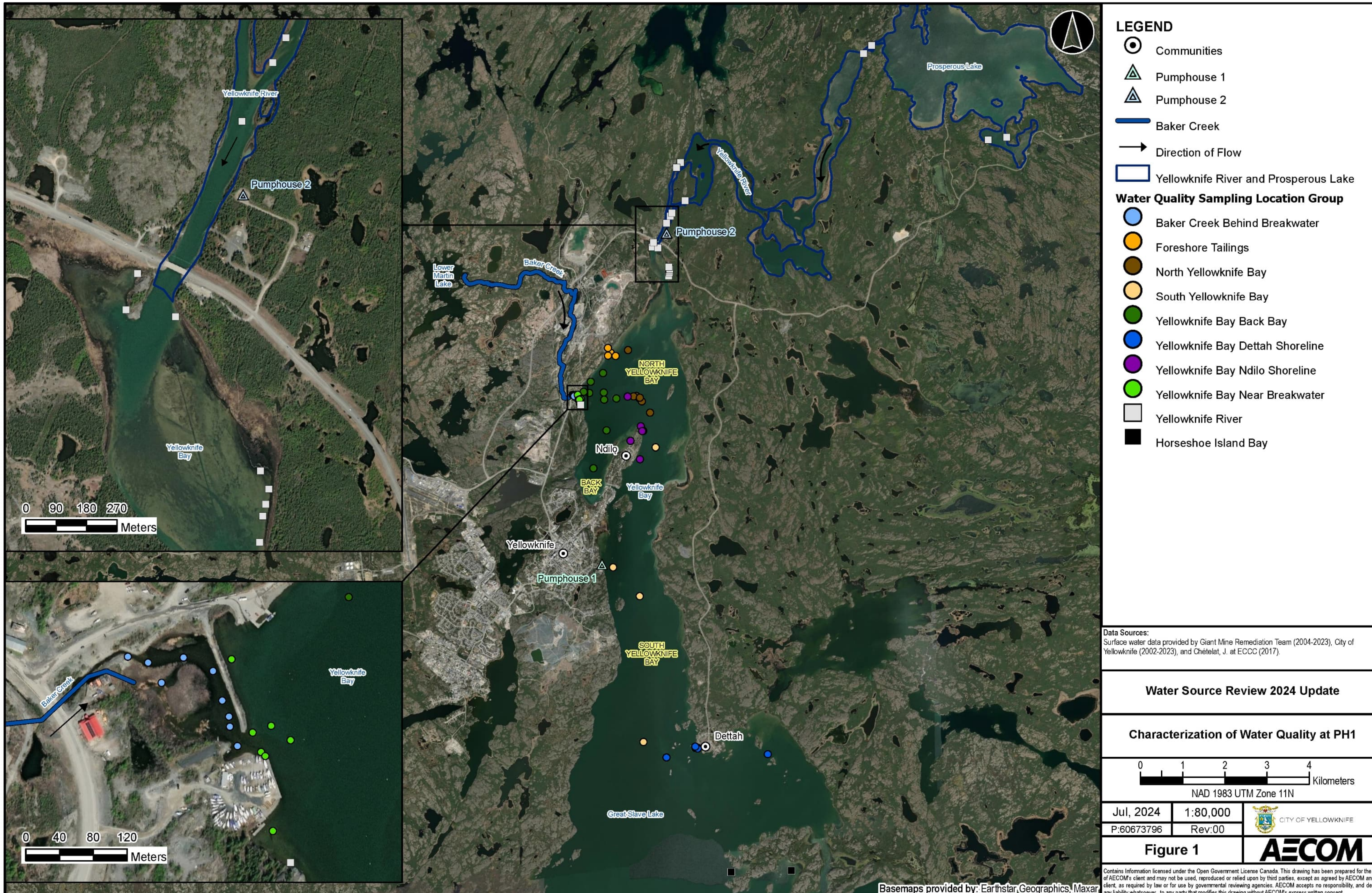


Figure 4-1. Map Of Yellowknife Bay And All Sampling Locations

4.3 Selection of Parameters of Interest

Historically, arsenic has been selected as the primary parameter of interest due to historical mining activities and associated contamination. Arsenic is classified as a human carcinogen and in some instances drinking water is the major source of arsenic exposure. Arsenic characterization will be a main focus of this technical memo; however, additional parameters of interest were identified within the dataset. These include:

a. Substances of interest identified in Yellowknife Bay in recently published literature, namely chloride and sulphate; and,

b. Substances for which Health Canada (2024) Canadian Drinking Water Quality Standards provides a health based Maximum Acceptable Concentration (MAC).

The substances of interest considered in the present study are outlined in Table 4-2.

Table 4-2. Health Canada Guidelines for Parameters Selected for Characterization of Water Quality in Yellowknife Bay

Parameter	Type	MAC	Common Sources	Health Considerations
E. coli		0 (MPN/100mL)	Fecal contamination	Gastrointestinal illness
Aluminum	T	2.9	Naturally occurring, aluminum salts used as coagulants	Neuromuscular effects, urinary tract effects
Antimony	I	0.006	Naturally occurring, industrial effluents	Changes in liver histology
Arsenic	I	0.01	Naturally occurring, mining releases	Cancer (lung, bladder, liver, skin)
Barium	I	2	Naturally occurring, industrial releases	Kidney effects
Boron	I	5	Naturally occurring, industrial runoff	Reproductive effects in males
Cadmium	I	0.007	Leaching from galvanized pipes, industrial waste	Kidney damage
Chloride	I	≤ 250 (AO)	Naturally occurring, industrial effluents	Based on taste
Chromium (total)	I	0.05	Naturally occurring, industrial sources	Carcinogenicity
Copper	I	2	Corrosion of pipes, plumbing materials	Gastrointestinal effects
Cyanide	I	0.2	Industrial processes, natural sources	Acute toxicity
Ethylbenzene	P	0.14	Industrial releases	Neurological effects
Lead	I	0.005	Plumbing materials, industrial processes	Neurological effects
Manganese	I	0.12	Naturally occurring, industrial discharge	Neurological development effects
Mercury	I	0.001	Industrial effluents, waste disposal	Irreversible neurological symptoms
Nitrate	I	45	Agricultural runoff, septic systems	Methemoglobinemia
Nitrite	I	3	Microbial activity, fertilizer runoff	Methemoglobinemia
Selenium	I	0.05	Naturally occurring, industrial releases	Essential nutrient, toxicity at higher levels
Strontium	I	7	Naturally occurring; effluents from mining or other industries	Bone effects

Parameter	Type	MAC	Common Sources	Health Considerations
Sulphate	I	≤ 500 (AO)	Naturally occurring, industrial discharges	Laxative effect, based on taste
Toluene	O	0.06	Industrial spills	Neurological effects
Uranium	I	0.02	Naturally occurring, industrial emissions	Kidney effects
Radium-226		0.5 (Bq/L)	Naturally occurring	Carcinogenicity

Notes:
All concentrations expressed as mg/L unless otherwise noted
Parameter types: A – Acceptability; D – Disinfectant; DBP – Disinfection by-product; P – Pesticide; I – Inorganic chemical; O – Organic chemical; T – Treatment related parameter
MAC = Health Canada Maximum Acceptable Concentration   AO = Aesthetic Objective (i.e. affecting taste, odour, etc.)

4.4 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:

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

Microsoft Excel was used to manipulate data and create a digital database. ProUCL was used for calculating summary statistics and identifying censored (non-detect) data. R Software was used to conduct statistical analyses (non-parametric two-mean tests) and generating graphical outputs of data.

4.4.1 Non-detect Data

The presence and proportion of censored data (i.e. values below the reportable limits of detection) are of critical importance, because censored data cannot be used in the calculation of the required upper bound estimates. ProUCL Software uses the Kaplan-Meier (KM) or regression on order statistics (ROS) methods to handle datasets with censored or non-detect values. These methods allow for calculation of summary statistics without the use of substitution methods.

4.4.2 Outliers

Outliers were identified based on methods described by Reimann *et al.* (2005). The boxplot method for identifying outliers is a robust method for identifying outliers, when the suspected proportion of outliers is below 10%. One advantage of this method is the ability to use ROS methods to calculate intervals (25*th* and 75*th* percentiles), which are resistant to both transformation bias and skewness, allowing for transformation of lognormal datasets.

Outliers in the data were identified using boxplots and calculating an Upper Inner Fence (UIF) and an Upper Outer Fence (UOF) using the following calculations:

Upper Inner Fence = Q3 + (1.5 x IQR)

Upper Outer Fence = Q3 +(3 x IQR)

Data points that were outside the Upper Outer Fence were considered extreme outliers and were removed from the dataset.

4.4.3 Data Distribution

ProUCL Software was used to understand the underlying distribution of the dataset. 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.

4.4.4 Seasonal Effects

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 (on the 15^{th} of October) and ended in mid-May (on the 15^{th} of May).

Based on this assumption, the arsenic data from Pumphouse 1, South Yellowknife Bay, and Yellowknife River were separated into ice-covered and open-water subsets. Differences in the concentration of arsenic between open-water and ice-covered conditions was assessed using two-sample hypothesis tests, appropriate for the characteristics of the data (i.e. parametric or non-parametric tests).

4.4.5 Temporal Trends

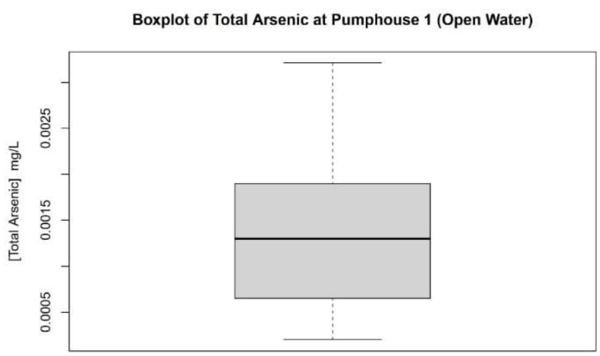
After the data was separated by season, an assessment of temporal trends was undertaken for each season. Since the Giant mine has been closed since 2004 and remediation of the site has been on going it is expected there would be a reduction in the amount of mine related contaminants entering the receiving environment resulting in the improvement of water quality in Yellowknife Bay. AECOM (2017) reported decreasing arsenic concentrations in the Bay from 2005 to 2017 and the expectation is that further improvements would be observed in the next 6 years of data.

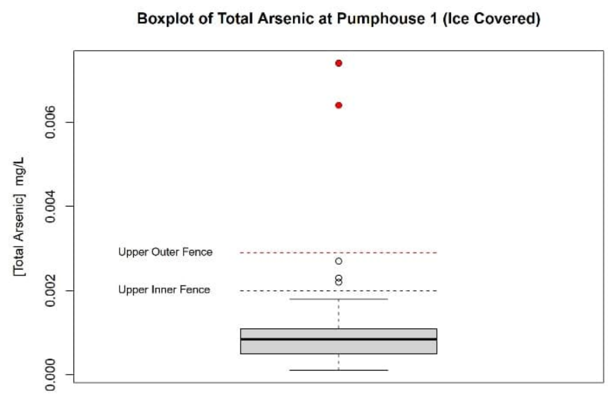
The temporal trends were examined visually and tested using a Mann-Kendall trends test. The Mann-Kendall trends test is a non-parametric test that makes no assumptions regarding data distribution, although it does require that the trend (if any) be monotonic (Meals et al. 2011). The data record was also 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.

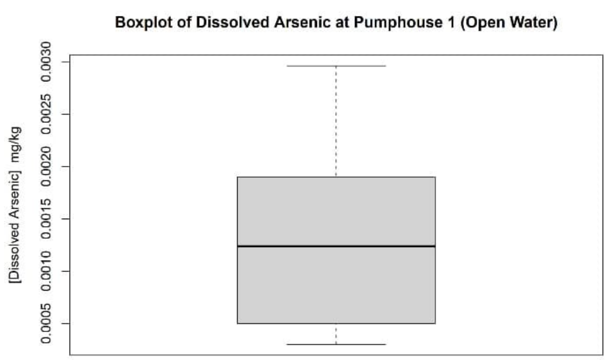
5. RESULTS

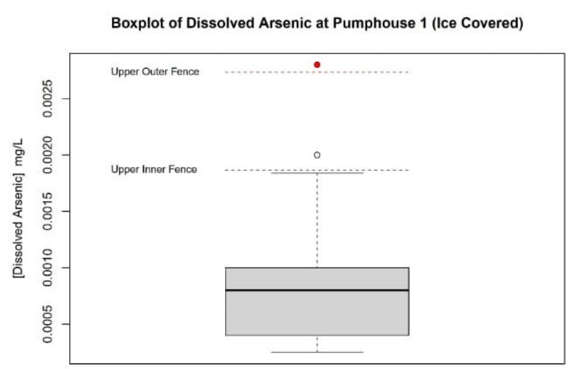
5.1 Outliers

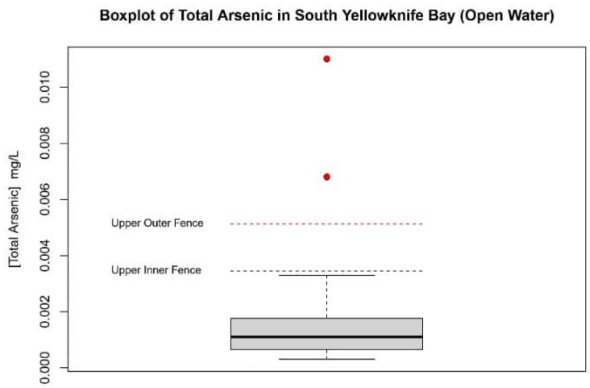
Data was subset into groups based on location for the purposes of this study. Three locations were identified including Pumphouse 1, South Yellowknife Bay, and Yellowknife River. Within each location, total and dissolved arsenic was analysed under both open-water and ice-covered seasons. Boxplots were graphed using R Software and Upper Outer Fence and Upper Inner Fence were graphed to determine the outliers. The boxplots are shown in the figures below:

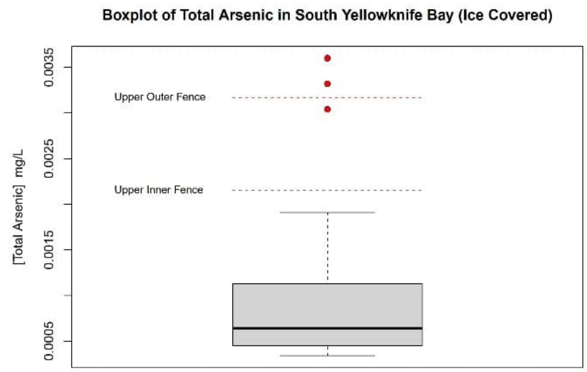


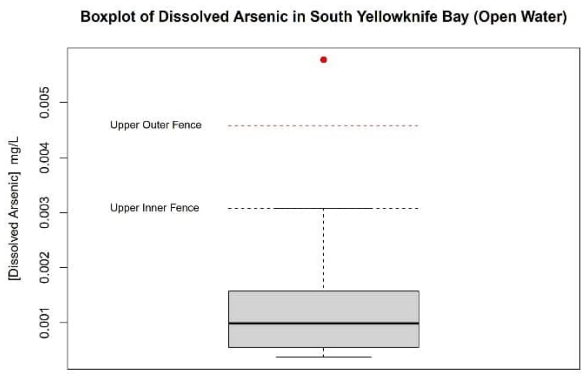


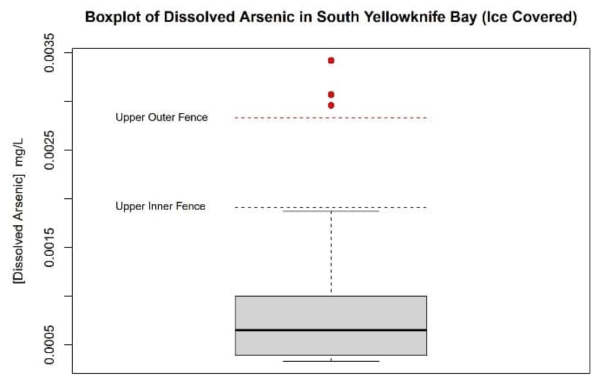


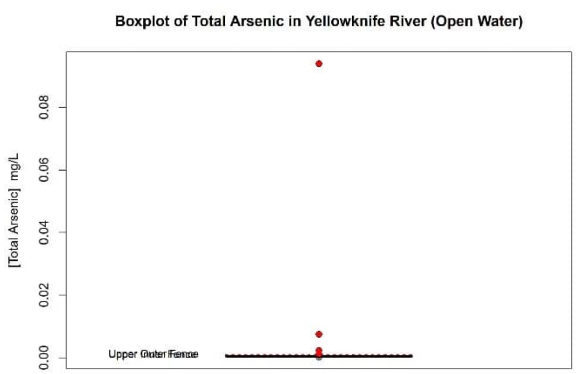


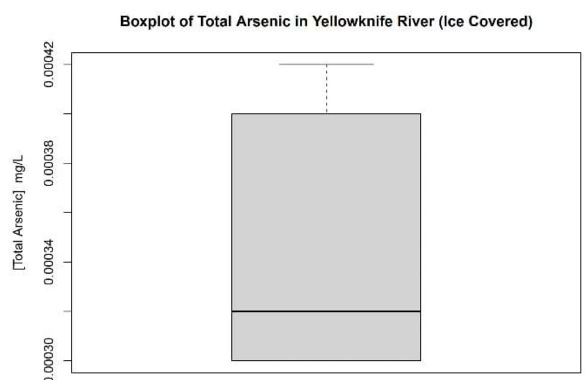

Boxplot of Total Arsenic in South Yellowknife Bay (Open Water)
[Total Arsenic] mg/L
Upper Outer Fence
Upper Inner Fence
0.000
0.002
0.004
0.006
0.008
0.010


Boxplot of Total Arsenic in South Yellowknife Bay (Ice Covered)
[Total Arsenic] mg/L
Upper Outer Fence
Upper Inner Fence
0.0005
0.0015
0.0025
0.0035


Boxplot of Dissolved Arsenic in South Yellowknife Bay (Open Water)
[Dissolved Arsenic] mg/L
Upper Outer Fence
Upper Inner Fence
0.001
0.002
0.003
0.004
0.005


Boxplot of Dissolved Arsenic in South Yellowknife Bay (Ice Covered)
[Dissolved Arsenic] mg/L
Upper Outer Fence
Upper Inner Fence
0.0005
0.0015
0.0025
0.0035


Boxplot of Total Arsenic in Yellowknife River (Open Water)
[Total Arsenic] mg/L
0.00
0.02
0.04
0.06
0.08


Boxplot of Total Arsenic in Yellowknife River (Ice Covered)
[Total Arsenic] mg/L
0.00030
0.00034
0.00038
0.00042

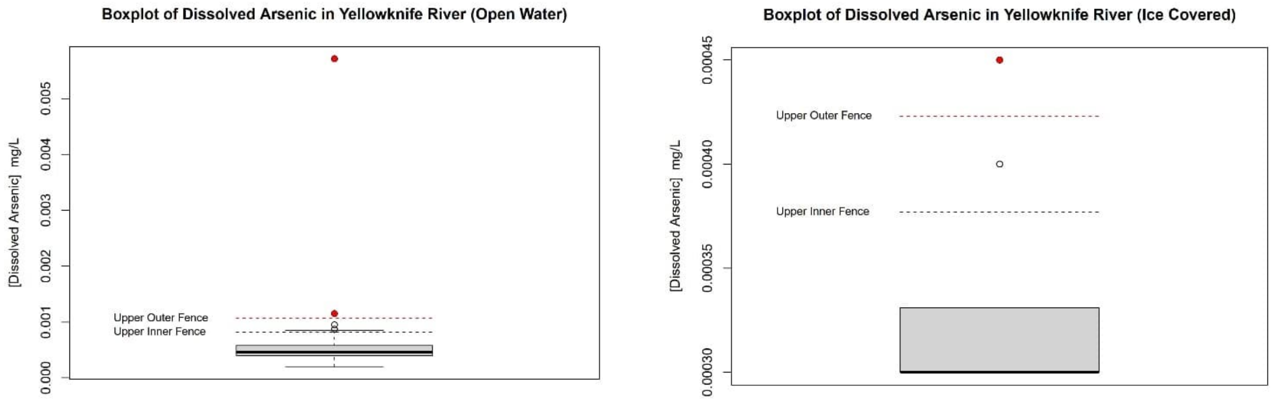


Figure 5-1: Boxplots with Upper Outer Fence and Upper Inner Fence for both Total and Dissolved Arsenic at Pumphouse 1, South Yellowknife Bay, and Yellowknife River

Data points which were outside of the UOF were identified as extreme outliers and removed from the dataset. In the South Yellowknife Bay (Ice Covered) Total Arsenic dataset, one data point was identified to be in between the UOF and UIF (Figure 5-1). It was decided to remove this data point due to its proximity to the UOF and other outliers in the dataset. The details of the outliers removed are outlined in Table 5-1.

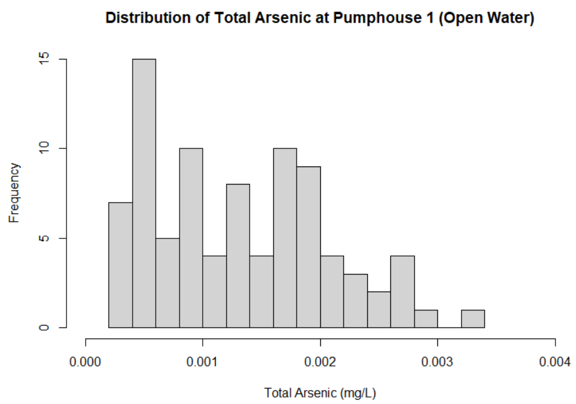
Table 5-1: Outliers in Dataset for Pumphouse 1, South Yellowknife Bay, and Yellowknife River by Season

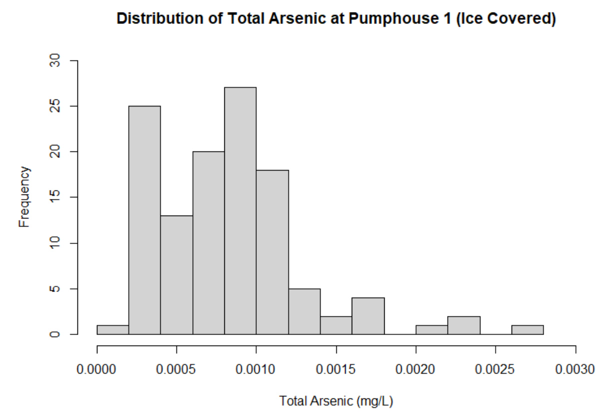
Location and Season	Sample Date	Total Arsenic (mg/L)	Dissolved Arsenic (mg/L)
Pumphouse_Ice	2012-10-31	0.0074	-
Pumphouse_Ice	2007-05-01	0.0064	0.0028
South Yellowknife Bay_Ice	2020-02-10	0.0036	0.00342
South Yellowknife Bay_Ice	2012-03-27	0.00332	0.00307
South Yellowknife Bay_Ice	2019-02-12	0.00304	0.00296
South Yellowknife Bay_Water	2023-07-31	0.0068	0.00578
South Yellowknife Bay_Water	2022-06-21	0.011	-
Yellowknife River_Ice	2012-10-16	-	0.00045
Yellowknife River_Water	2017-05-23	0.0939	-
Yellowknife River_Water	2006-08-17	0.0075	0.00571
Yellowknife River_Water	2006-08-17	0.00233	-
Yellowknife River_Water	2011-10-11	0.00121	0.00115

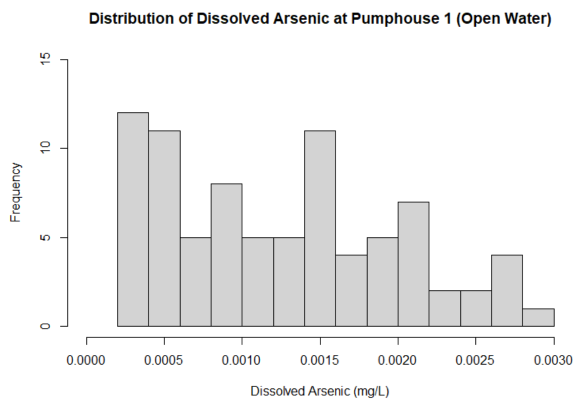
Although the values identified in Table 5-1 were considered outliers in comparison to the dataset, it is important to recognize that most of the values were below the Health Canada drinking water guideline of 0.01 mg/L. Two outliers that were removed exceeded the Health Canada drinking water guideline of 0.01 mg/L total arsenic, one sample at South Yellowknife Bay (open water season) taken on June 21, 2022 and one sample at Yellowknife River (open water season) taken on May 23, 2017.

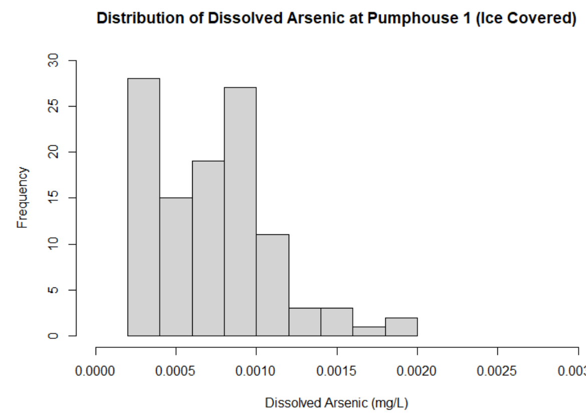
5.2 Data Distribution

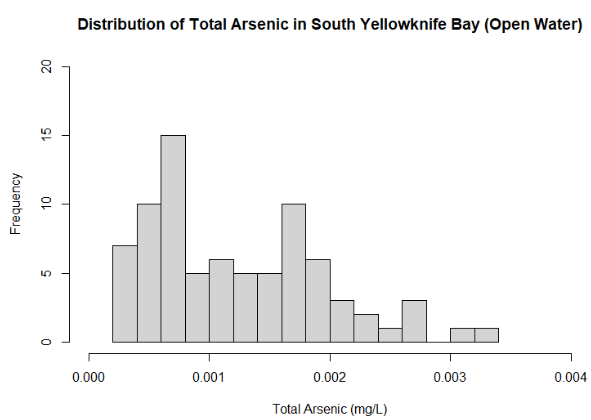
Based on the subset groups identified (Pumphouse 1, South Yellowknife Bay, and Yellowknife River) the data distribution was graphically analyzed using R Software (Figure 5-2). ProUCL Software was also used to understand the underlying distribution of each group within each season (open water and ice covered). Based on the results, South Yellowknife Bay total arsenic during ice covered season appeared lognormally distributed at 10% significance level. For all other groups, data did not follow a discernable distribution.

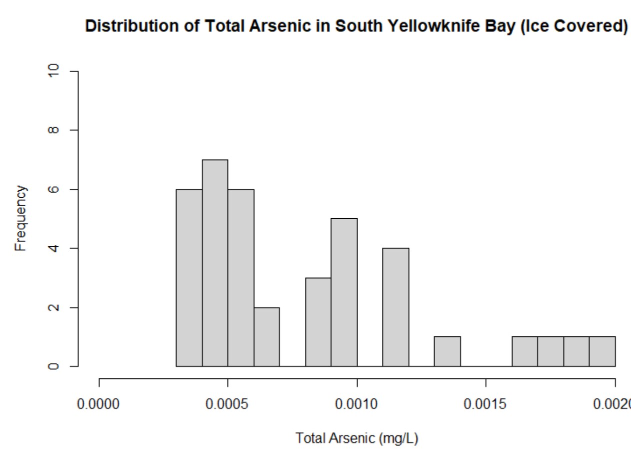












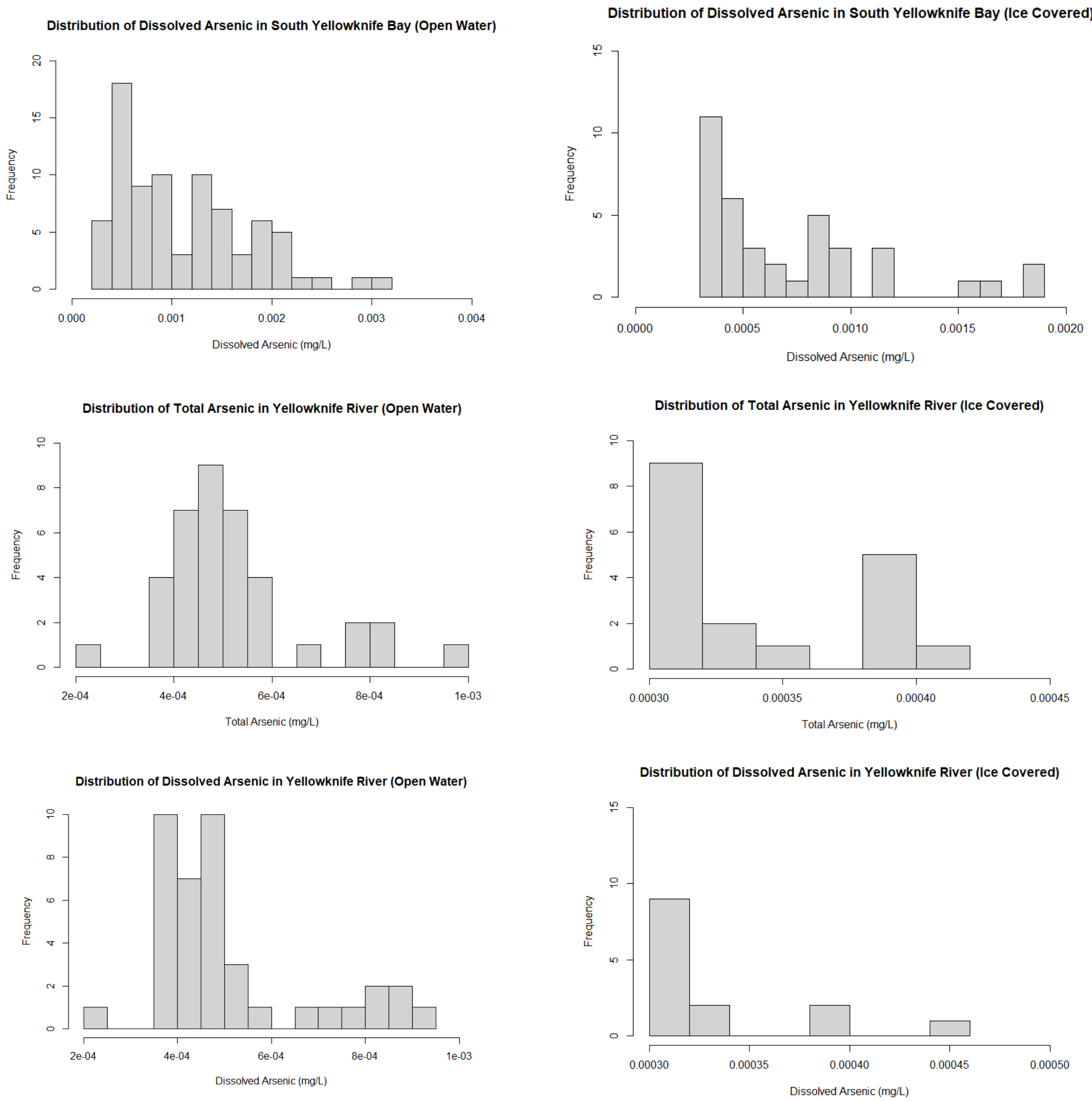


Figure 5-2. Frequency Distribution of Total and Dissolved Arsenic at Pumphouse 1, South Yellowknife Bay, and Yellowknife River during Open Water and Ice-Covered Seasons

5.3 Seasonal Effects

A non-parametric Wilcox rank sum test (also known as the Mann-Whitney test) was used to determine whether a statistically significant difference exists in the open-water and ice-covered seasons in the Pumphouse-1, South Yellowknife Bay, and Yellowknife River subsets. Side-by-side boxplots of the concentration of dissolved arsenic (Figure 5-3) and total arsenic (Figure 5-4) demonstrate the relative difference between seasons across groups.

Results of hypothesis tests between groups are as follows:

- A statistically significant difference in dissolved arsenic was detected between open-water (Mean = 0.00128, SD = 0.000738) and ice-covered conditions (Mean = 0.000775, SD = 0.000369) at **Pumphouse 1** (W = 2681.5, p =$3.5x10^{-6}$). A statistically significant difference was observed in the concentration of total arsenic between open-water (Mean =0.00135, SD=0.00075) and ice-covered (Mean =0.00087, SD=0.00046) conditions at Pumphouse 1 (W = 3217.5, p =$2.2x10^{-6}$).
  - The hypothesis tests provide evidence to support the conclusion that concentrations of total and dissolved arsenic in raw water samples from Pumphouse #1 are higher during open-water periods than during ice-covered conditions
- A statistically significant difference in dissolved arsenic was detected between open-water (Mean = 0.00113, SD = 0.00065) and ice-covered conditions (Mean = 0.00073, SD = 0.00043) in **South Yellowknife Bay** (W = 895, p = 0.00024). A statistically significant difference was observed in the concentration of total arsenic between open-water (Mean =0.00125, SD=0.00071) and ice-covered (Mean =0.00081, SD=0.00045) conditions in South Yellowknife Bay (W = 932, p =0.00071).
  - The hypothesis tests provide evidence to support the conclusion that concentrations of total and dissolved arsenic in raw water samples from South Yellowknife Bay are higher during open-water periods than during ice-covered conditions.
- A statistically significant difference in dissolved arsenic was detected between open-water (Mean = 0.000533, SD = 0.000166) and ice-covered conditions (Mean = 0.000329, SD = 0.00004) in samples collected from the **Yellowknife River** (W = 42, p = $2.4x10^{-6}$). A statistically significant difference was observed in the concentration of total arsenic between open-water (Mean =0.00052, SD=0.00014) and ice-covered (Mean =0.00034, SD=0.00004) conditions in Yellowknife River (W = 33, p =$5.5x10^{-8}$).
  - The hypothesis tests provide evidence to support the conclusion that concentrations of total and dissolved arsenic in raw water samples from the Yellowknife River are higher during open-water periods than during ice-covered conditions.

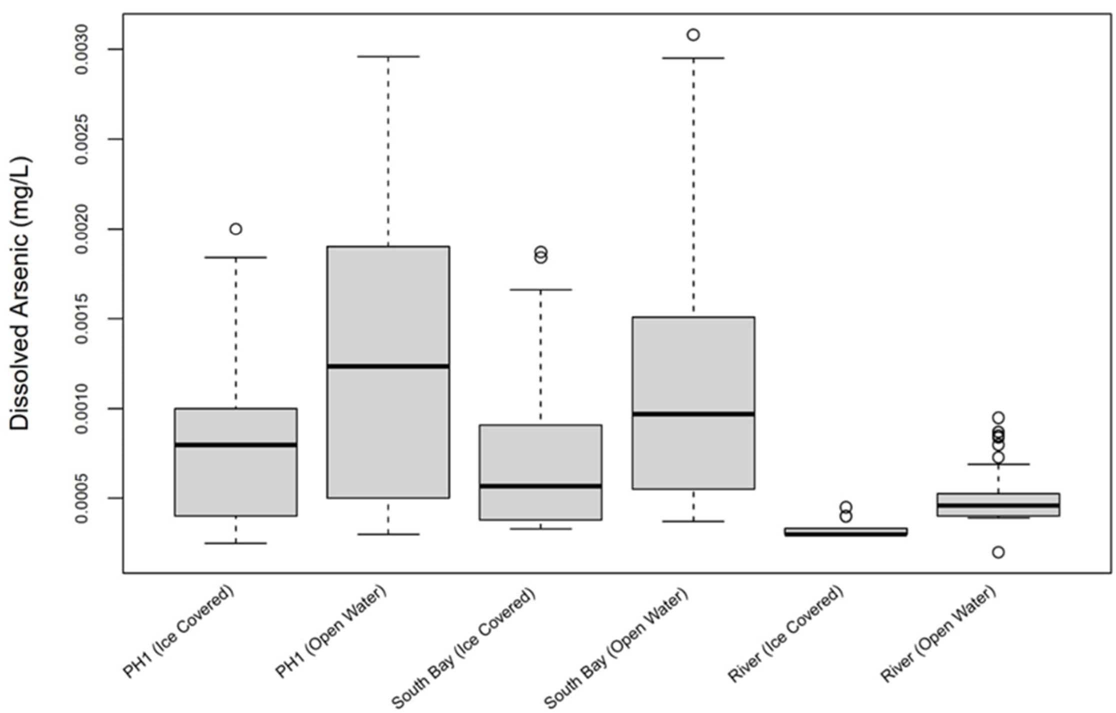


Figure 5-3. Dissolved Arsenic Concentrations during the Ice Covered and Open Water Seasons

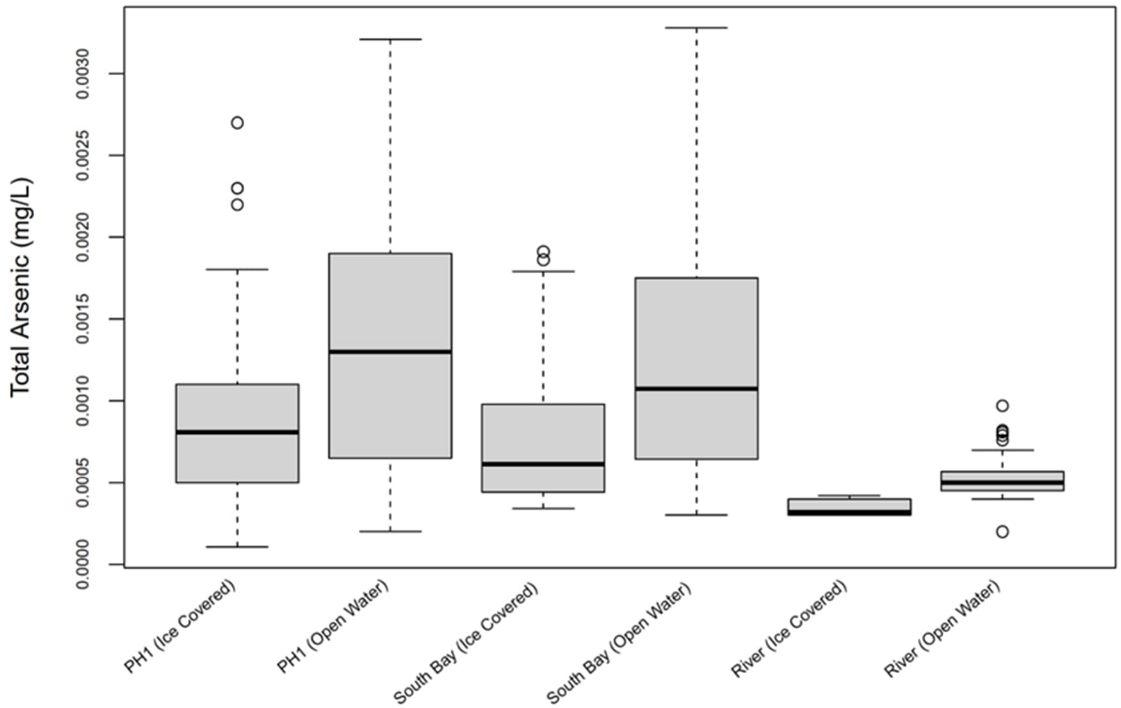


Figure 5-4. Total Arsenic Concentrations During The Ice Covered And Open Water Seasons

5.4 Temporal Trend

Temporal trends in total arsenic concentration in raw water from Pumphouse #1 were investigated for open-water and ice-covered conditions using linear regression and Mann-Kendall trend tests for the complete dataset. Results and graphical representation of the trend analysis are presented in Figure 6. Trend analysis identified a statistically significant decreasing trend in total arsenic concentration over time when examining the ice-covered dataset. No statistically significant trend was observed for the open-water season.

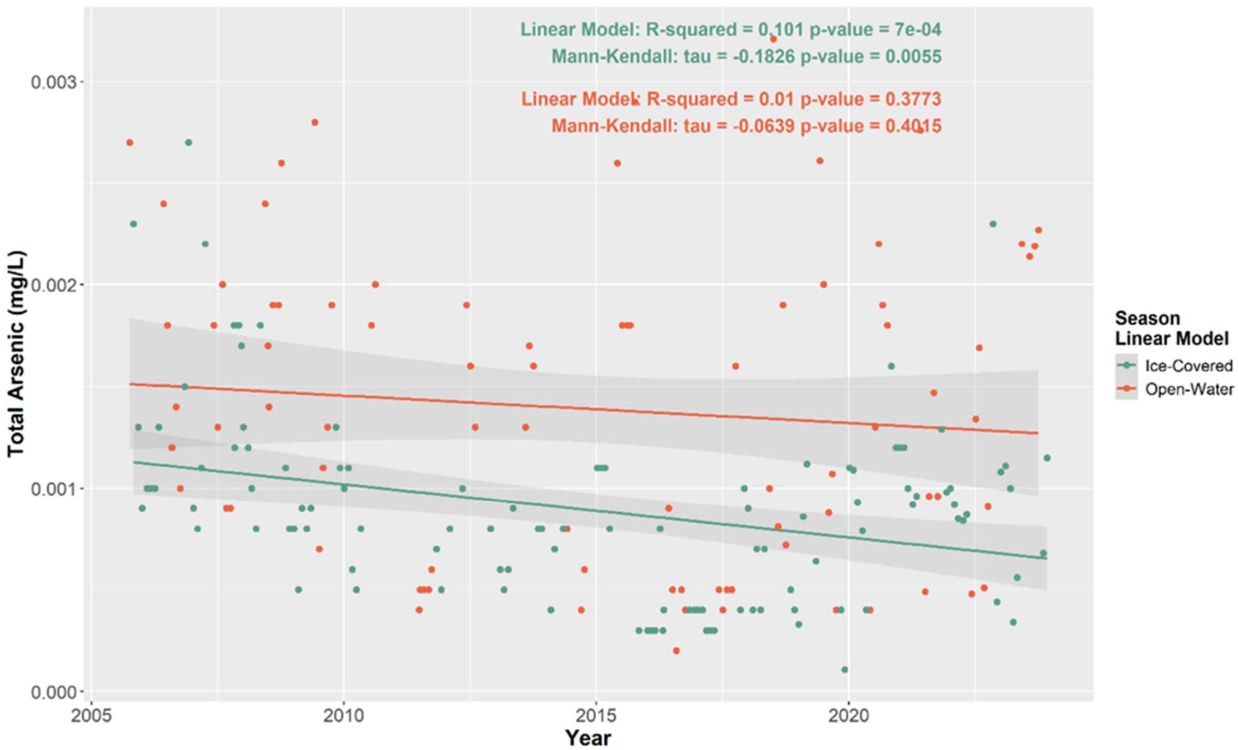


Figure 5-5: Trend Analysis Of Total Arsenic Concentration Measured In Raw Water From Pumphouse #1 During Open-Water And Ice-Covered Seasons.

5.5 Characterization of Water Quality at PH1

5.5.1 Total Arsenic

Summary statistics for total arsenic concentration at the intake to Pumphouse 1 for the period of record (2002-2023) are presented in Table 5-2.

Table 5-2. Summary Statistics For Total Arsenic Concentrations At Pumphouse 1 Intake (Health Canada Maximum Allowable Concentration = 0.01 Mg/L

	Open-Water Season	Ice-Covered Season	All Data
N	87	119	206
Min	0.0002	0.00107	0.000107
Max*	0.0032 (0.0032)	0.0074 (0.0027)	0.0074 (0.0032)
Mean	0.00135	0.00087	0.00107
95th %ile	0.00267	0.0018	0.00238
95% UCLM	0.00149	0.00093	0.00115
95% UTL	0.00282	0.00221	0.00261

Notes:
All concentrations expressed as mg/L
**Maximum values presented for the complete dataset and with outliers removed presented in parentheses.*
Concentration data compared to Health Canada's maximum acceptable concentration for total arsenic (MAC = 0.01 mg/L)

5.5.2 Additional Parameters of Interest

Summary statistics for additional parameters of interest that were available from the annual water testing at the intake to Pumphouse 1 between 2005 to 2023 were calculated and presented in Table 5-3.

Table 5-3. Summary Statistics For Additional Parameters Of Interest At Pumphouse 1 Intake (Mg/L)

Parameter	Health Canada[1]	N	Min	Max	Mean	95th%ile	95% UCLM	95%UTL
Sulphate	≤ 500 (AO)	12	3	8.09	4.051	6.858	4.74	8.09
Nitrate	45[2]	9	0.0353	0.21	0.0836	0.166	0.117	0.247
Aluminum (Total)	2.9	12	0.0026	0.0911	0.045	0.0872	0.0599	0.0911
Barium (Total)	2.0	12	0.00375	0.0129	0.00579	0.0109	0.00699	0.0129
Cadmium (Total)	0.07	12	-	-	-	-	-	-
Chromium (Total)	0.05	12	0.00010	0.00250	0.00037	0.00140	0.00073	0.00250
Chloride	≤ 250 (AO)	12	2.33	8.03	4.476	7.519	5.327	8.969
Copper (Total)	1.0 (AO)	12	0.00183	0.0707	0.0324	0.065	0.046	0.104
Lead (Total)	0.005[3]	12	0.00008	0.00100	0.00019	0.00066	0.00034	0.00100
Manganese (Total)	0.12[4]	12	0.00020	0.00270	0.00166	0.00260	0.00206	0.01040
Mercury (Total)	0.001	12	0.00001	0.00004	0.00001	0.00003	0.00002	0.00004
Selenium (Total)	0.05	12	-	-	-	-	-	-
Uranium (Total)	0.02	12	0.00017	0.00025	0.00021	0.00024	0.00022	0.00025

[1] Value = MAC unless noted [2]MAC = 10 as nitrate-nitrogen [3]as low as reasonably possible [4]AO = 0.02

Maximum concentration of those parameters of interest with data available from the PH1 intake area were generally below their corresponding Health Canada Drinking Water Quality Guidelines. The data available for cadmium and selenium were all below the detection limits and omitted from the table above. There were only three data points available for total cyanide and they were all 0.002 mg/L and omitted from the table above. This comparison confirms that the parameter of primary concern is arsenic.

5.6 Comparison of Potential Drinking Water Sources

A non-parametric two sample test (Wilcox Rank Sum Test) was used to compare the concentration of total and dissolved arsenic between Pumphouse 1 and South Yellowknife Bay and between Pumphouse 1 and Yellowknife River.

There was not a significant difference in dissolved arsenic between **Pumphouse 1** (Mean = 0.000994, SD = 0.000611) and **South Yellowknife Bay** (Mean = 0.001, SD = 0.000613); W = 11242, p =0.8741. There was also not a significant difference in total arsenic between **Pumphouse 1** (Mean = 0.00107, SD = 0.000645) and **South Yellowknife Bay** (Mean = 0.0011, SD = 0.000669); W = 11953, p =0.8047.

There was a significant difference in dissolved arsenic between **Pumphouse 1** (Mean = 0.000994, SD = 0.000611) and the **Yellowknife River** (Mean = 0.000466, SD = 0.00017); W = 8156.5, $p = 6.38\text{x}10^{-11}$. There was also a significant difference in total arsenic between **Pumphouse 1** (Mean = 0.00107, SD = 0.000645) and the **Yellowknife River** (Mean = 0.000466, SD = 0.00015); W = 9522, p= 7.804×10^{-14})

A side-by-side boxplot illustrating the measured concentration of total arsenic at Pumphouse 1 and the Yellowknife River during ice-covered and open-water conditions is presented in Figure 5-6. Concentrations of total arsenic in surface water collected from the Yellowknife River is lower than the concentrations measured in raw water at Pumphouse-1; however, it is important to note that all raw water samples collected from Pumphouse 1 are below Health Canada's Drinking Water Quality Guidelines, Maximum Acceptable Concentration (0.01 mg/L).

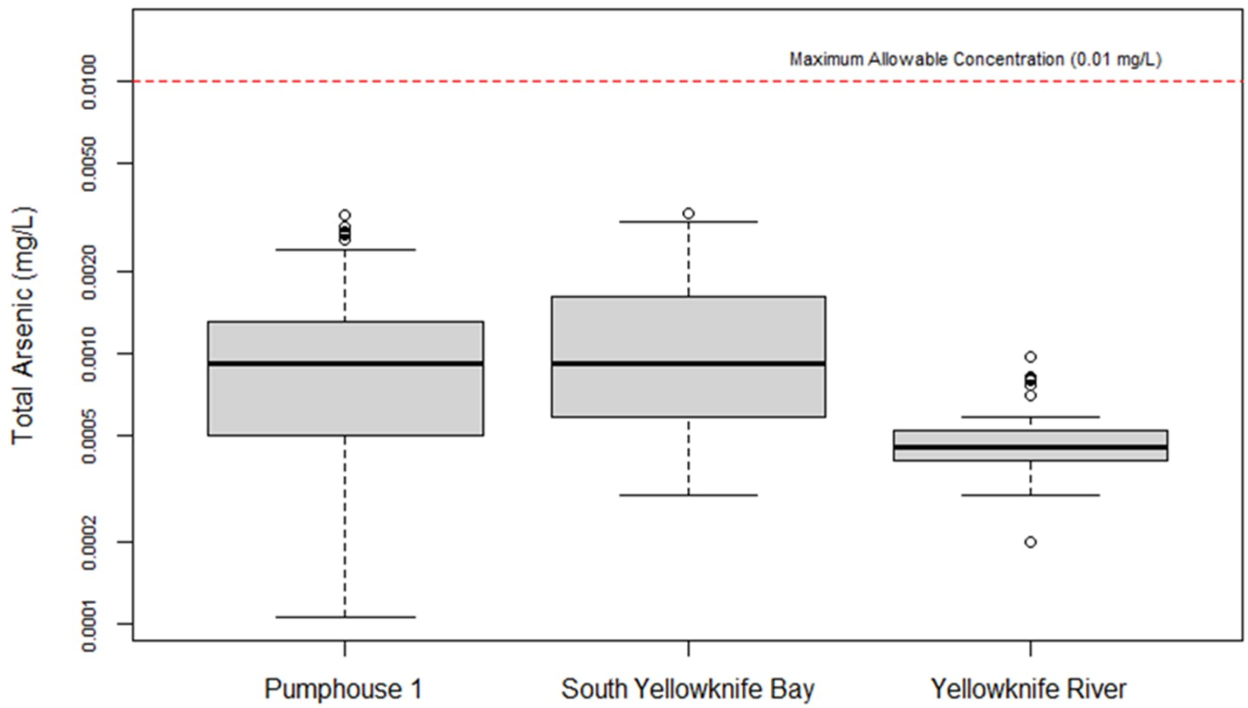


Figure 5-6. Total Arsenic Concentrations At Pumphouse 1, South Yellowknife Bay, And Yellowknife River (Y-Axis Is Log Scale)

6. CONCLUSIONS

The analysis of the additional 6 years of data since the last review of water quality in Yellowknife Bay has confirmed the results from 2017.

- The data that has been collected is robust and reliable. A statistical analysis of the arsenic data suggested that several data points were identified as extreme outliers and were removed from the analysis.
- Arsenic levels are higher during periods of open water than the when the bay and river are covered in ice.
- There is a general trend of decreasing arsenic concentrations at Pumphouse 1 in both open water and ice covered conditions, however, the trend is only statistically significant for the ice-covered condition.
- The water from the Yellowknife River continues to provide the lowest concentration of total arsenic with the mean concentration in the river of 0.00052 mg/L compared to 0.00107 mg/L at Pumphouse 1.

6.1 Human Health Risk

Health Canada has defined the term “essentially negligible” as a range from one new cancer above background per 100 000 people to one new cancer above background per 1 million people (i.e., $1x10^{-5}$ to $1x10^{-6}$) over a lifetime (Health Canda, 2006).

Based on epidemiological data, Health Canada has determined a unit risk (i.e. estimate of the increased cancer risk associated with lifetime exposure) associated with arsenic exposures as a result of drinking water ingestion. Based on this unit risk, an acceptable concentration of arsenic in drinking water can be established that would present an “essentially negligible” level of risk. This target concentration, which is based solely on health considerations, is calculated as 0.0003 mg/L. The upper 95% confidence interval for the lifetime cancer risk associated with this concentration in drinking water is 1.9×10^{-6} to 1.39×10^{-5} (Health Canada, 2006), which falls withing the range of “essentially negligible” risk.

Calculated incremental lifetime cancer risk (ILCR) associated with a total arsenic concentration at Pumphouse 1 (UCLM95 = 0.00115 mg/L) is calculated to be $4.39 \text{ x } 10^{-5}$ based on a lifetime exposure, an adult bodyweight of 70.7 kg and a drinking water ingestion rate of 1.5 L per day, as per Health Canada (2019). This value is marginally outside the range of “essentially negligible” risk established by Health Canda. Similarly, the calculated incremental lifetime cancer risk based on the 95% UCLM of the measured concentration of total arsenic in surface water collected from the Yellowknife River (0.00049 mg/L) is outside the range of “essentially negligible” risk (ILCR = 1.87 x 10^{-5}).

To put these values into context, according to Health Canada estimates that the average Canadian has a 40% risk of developing cancer over their lifetime (ILCR = 0.40 for baseline). The calculated incremental lifetime cancer risks associated with drinking water exposures from Pumphouse 1 and the Yellowknife River increase that value to 0.400044 and 0.400019 respectively.

Upper limits of total arsenic concentration measured at Pumphouse 1 are below the Health Canada MAC. It is important to acknowledge however that the MAC is set to consider available treatment technologies and is not strictly based on health protection.

Health Canada established a MAC of 0.01 mg/L (10 µg/L) for arsenic on the basis of the following considerations:

- • The concentration of arsenic in drinking water representing an “essentially negligible” risk is 0.3 µg/L. Levels of arsenic in drinking water should be as close as possible to this level.

- • The MAC must be measurable. The PQL (practical quantitation level), based on the ability of laboratories to measure arsenic within reasonable limits of precision and accuracy, is 0.003 mg/L.
- • The MAC must be achievable at reasonable cost. Both municipal-scale and residential scale treatment options can remove arsenic from drinking water to below the guideline value.

7. Recommendations for Future Modelling

To be discussed with the City at the Memorandum review meeting.

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}Appendix

Digital Surface Water Database

A Digital Surface Water Database was compiled with all data acquired in Section 3.1 and is available upon request.

aecom.com

Appendix B. Vendor Data

NAPIER-REID

AECOM

Attn.: Cortney McCracken, P.Eng

Date: September, 20 2024

File: cd30200.01

BUDGETARY PROPOSAL

Re: Yellowknife WTP

Napier Reid is pleased to quote the following water treatment system for arsenic removal, with a capacity to produce 1,134 m^3/hr of potable water. The system will consist of 4 trains, 2 vessels per train in lead/lag configuration.

The system design details are as follows.

Item	**Value**
Maximum Design Capacity	315 L/s (1,134 m^3/hr)
Adsorption Vessels	
Train Qty.	4
Vessels Per Train	2 in lead/lag configuration
Quantity	8
Design Flow Rate, each vessel	141.7 m^3/hr
Vessel Dimensions	3.66 m Dia. x 1.8 m Straight Side Height
EBCT per vessel	4.45 min
Bed Volume per vessel	10.52 m^3
Design Filtration Rate	13.47 m/hr
Backwash Rate	13.43 m/hr
Backwash Flow Rate	141.3 m^3/hr
Media Height	Metsorb HMRG: 1 m Gravel: Support layer
Estimated head loss	6-15 psi
Backwash water	Supplied by others, 20psig
Backwash Frequency	Initial Installation Quarterly or less thereafter (estimated)

95 Mary St.
Aurora, Ontario
Canada L4G 1G3
+1 905 475 1545
Napier-reid.com

Scope of Supply

Adsorption Vessels

Arsenic Adsorption System

A pressure filtration system comprised of eight Napier-Reid free standing pressure filters configured in a lead/lag arrangement in four trains. Vessels include associated valves, instruments and Sch. 10 304SS face piping. All components (except vessels) will be pre-assembled on a 304SS skid unless otherwise indicated in this proposal.

EIGHT Adsorption Vessel will be supplied.

Each vessel will be built as follows:

1 - 3.66 m Dia. x 1.8 m Straight Side Height, free standing pressure vessel fabricated of SA-516 Gr 70 carbon steel. The vessel will have top and bottom heads, four structure steel support legs, and rated for 100 psig design pressure at 100°F with zero corrosion allowance. The minimum system operating pressure at inlet should be 50 psi.

Internal preparation:

Vessels are lined with NSF61 epoxy liner.

1 - 8” flanged inlet on side for service inlet/backwash outlet

1 - 8” flanged outlet, on bottom for backwash inlet/service outlet

1 - 6” flanged outlet, on side

1 - Top distributor made from 304 Stainless Steel

1 - Underdrain system, c/w 304 SS head and perforated SS304 SS laterals with 304 SS screen with 0.01” opening

1 - Elliptical manway, 14” x 18”, c/w cover and gasket on straight shell for media loading

1 - Elliptical manway, 14” x 18”, c/w cover and gasket on the top head

1- 1” NPT nozzle on top, for air/vacuum combination valve

1 - 1” NPT nozzle for drain on bottom

3 - Lifting lugs provided in the top head.

4 - Legs welded on side shell of vessel

2 - Port for influent and effluent sampling

Automated Valves (Lead vessels)

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Filtered water inlet to vessel).

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Treated water to Lag vessel).

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Treated water to common header).

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Filtered water bypass to lag vessel).

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Treated water from lag vessel).

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Backwash inlet).

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Backwash outlet).

4 - 100mm manual ball valve, one per vessel (Drain).

4 - Air/vacuum release valve, 25mm, ARI D-040 ore equivalent. The piping from valve outlet to drain by others.

1 - Lot of manual isolation valves.

4 - 1" SS 304 ball valve, for air release/vacuum breaker

Note: All above valves will be Bray 31, with Bray 70 electric actuator, EPDM seat and stainless-steel discs, NSF61.

Automated Valves (Lag vessels)

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Treated water to common header).

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Backwash inlet).

4 - 200mm electrically actuated on/off butterfly valve one per each vessel (Backwash outlet).

4 - 100mm manual ball valve, one per vessel (Drain).

4 - Air/vacuum release valve, 25mm, ARI D-040 ore equivalent. The piping from valve outlet to drain by others.

1 - Lot of manual isolation valves.

4 - 1" SS 304 ball valve, for air release/vacuum breaker

Note: All above valves will be Bray 31, with Bray 70 electric actuator, EPDM seat and stainless-steel discs, NSF61.

Instrumentation

8 - Mag flow meters, 200mm, Endress+Hauser Promag W400 with integrated head, for each vessel outlet.

16 - Pressure gauges, WIKA (or equivalent), Liquid filled, 2.5", for each vessel service inlet and outlet.

8 - Pressure transmitters, Endress+Hauser PMC51, for common inlet and outlet (the differential pressures will be calculated by PLC)

Note:
1. All effluent analyzers, unless mentioned above, are to be supplied by others.

Adsorption Media

1 - Lot media, will be shipped loose in bags for installation onsite by others

Metsorb MHRG (Heavy Metal Removal Granules)
Gravel Support Layer

Face Pipe

4 - Lot of face piping for made from 304 SS with flanges fittings rated for 100 psi pressure. Face piping, valves, instruments and control panel to be pre-assembled on to epoxy coated steel frame.

4 - 304SS skids, one per each train. The pressure vessels will be free standing, and the face piping, valves and instrumentation will be assembled on the skids. The vessels will be shipped loose to be connected to the skids onsite (by others)

Access Stairs and Platforms

Filter access stairs and platforms to be supplied and installed by others.

Skid Wiring

4 - Wiring to the skid mounted control panel.

Backwash Water Supply

Backwash water supply and flow rate control will be by others.

Feed Water Supply

Feed water will be supplied by others at 50 psig.

Control Panel

ONE NEMA-4X panel on skid c/w Allen-Bradley CompactLogix 5370 PLC controller, B&R I/O terminals and Allen-Bradley PanelView Plus 7 performance version 12.1" HMI, switches, terminal strips and solenoid banks, with all data ready via Ethernet.

THREE NEMA-4X panel, with remote I/O blocks.

Submittal Drawings

1 - Set of drawings and submittal in PDF format. Including P&ID's, GA with Cross Section View and product cut sheets.

Operation & Maintenance Manuals

1 - Sets of O & M manuals in PDF. Paper copy is available at $550 per copy.

Site Visits

15 - Days of site service in 3 visits, for installation inspection, starting up, commissioning and operator training,

All additional site visits for technical meetings, installation supervision, start-up, commissioning, performance test and operator training will be extra and will be invoiced separately according to our unit rate as follows.

Standard rate for site service is $1,400 per man-day plus all travel and local expenses at cost. Rate is based on working 8 hours a day, 5 days a week. Overtime will be charged at $240 per hour. Travel time will be charged at $160 per hour but no more than $1,400 per day.

<u>Warranty</u>

Napier-Reid Ltd. warrants all equipment manufactured or supplied by it to be free from defects in design, workmanship and material, and conforming to the specification for a period of one year from the date of substantial completion or 18 months from the date of shipment, whichever occurs first.

TOTAL LOT PRICE – ……………......................................…………... CAD $6,958,000.00

<u>Terms:</u>

- FOB on trucks Yellowknife site if accessible, or nearest curb.
- All sales taxes extra
- Payment should be processed and received net 30 days after submission of valid invoice according to the following progress payment schedule
- 10% upon order placement
- 15% upon the receipt of shop drawings by the buyer's representative
- 35% upon starting of fabrication.
- 35% upon delivery
- 5% upon successful start-up and commissioning
- Drawings: 4-6 weeks from approved purchase order
- Delivery: 22-26 weeks from approved drawings
- Price valid for 30 days.
- Napier-Reid Ltd. reserves the right to withhold equipment and/or services when payment is not received as per our terms, without penalty, not withstanding the purchasing contractor's purchase order, pre-selection or specification documents.
- All purchases are subject to the terms and conditions available at https://napier-reid.com/terms/ which are incorporated by reference and made part of this proposal.

NAPIER-REID LTD.

Dima Mamaev, EIT
Applications Engineer in Training
dima.mamaev@napier-reid.com

NOTES:

1. Start-up and commissioning of Napier-Reid's water treatment plants refers to the mechanical, electrical and hydraulic operation of our supplied equipment. Correct chemical application and dosages are the responsibility of the Operator.

2. Equipment unloading and storage on site will be by others.

3. All pads, anchor bolts will be by others.

4. All lifting pumps for raw water by others.

5. All treated water distribution systems by others.

6. Backwash water supply and flow rate control by others.

7. All water, electricity and chemicals supplied by others.

8. All external pipe and fittings will be by others.

9. All field wiring will be by others.

10. Items not specifically mentioned in the quote are not included in the above price.

11. Napier-Reid is not responsible for any consequential damages and losses, direct or indirect.

Experience Information Arsenic Adsorption System			
Name of Equipment Supplier		Napier-Reid Ltd.	
	1	2	3
Location	Madoc WTP	Dereham Center	Giant Mine (Yellowknife)
Date Installed	2019	2020	TBA
Capacity m^3/day	1,469	50	945
Contact Time	3.7 min	4.3 min	5 min
Main Contaminants	Arsenic	Arsenic	Arsenic
Effluent Concentration (ug/L)	5	< 10	TBA
Meeting Design Requirements (Yes or No)	Yes	Yes	TBA

Appendix C. Cost Estimates

Program, Cost, Consultancy

Submarine Waterline Replacement

Class C Estimate

Project Number	60673796
Issued Date	13 February 2023
Client	City of Yellowknife, NT

Delivering a better world

Submarine Waterline Replacement
City of Yellowknife, NT
Class C Estimate
Project Information
Date: 13 February 2023

Project Title	Submarine Waterline Replacement
Client	City of Yellowknife, NT
Project Number	60673796
Project Manager	Jay Allen
Cost Manager	Ardeane Maharaj
Document Type	Elemental Estimate
Document Title and Status	Class C Estimate
Issued Date	13 February 2023
Quality Management Check by	Jay Allen

This estimate report is confidential and is prepared for Client use subject to the Statement of Qualifications and Limitations.

For AECOM Canada Ltd.

	Initial & Surname	Signature	Date
Compiled by:			
Reviewed by:			
Approved by:			

Approval by Client (if required)

	Initial & Surname	Signature	Date
Approved by:			

Statement of Qualifications and Limitations

The attached Report (the "Report") has been prepared by AECOM Canada Ltd. ("AECOM") for the benefit of the client ("Client") in accordance with the agreement between AECOM and Client, including the scope of work detailed therein (the "Agreement").

The information, data, recommendations and conclusions contained in the Report (collectively, the "Information"):

- is subject to the scope, schedule, and other constraints and limitations in the Agreement and the qualifications contained in the Report (the "Limitations");
- represents AECOM's professional judgement in light of the Limitations and industry standards for the preparation of similar reports;
- may be based on information provided to AECOM which has not been independently verified;
- has not been updated since the date of issuance of the Report and its accuracy is limited to the time period and circumstances in which it was collected, processed, made or issued;
- must be read as a whole and sections thereof should not be read out of such context;
- was prepared for the specific purposes described in the Report and the Agreement; and
- in the case of subsurface, environmental or geotechnical conditions, may be based on limited testing and on the assumption that such conditions are uniform and not variable either geographically or over time.

AECOM shall be entitled to rely upon the accuracy and completeness of information that was provided to it and has no obligation to update such information. AECOM accepts no responsibility for any events or circumstances that may have occurred since the date on which the Report was prepared and, in the case of subsurface, environmental or geotechnical conditions, is not responsible for any variability in such conditions, geographically or over time.

AECOM agrees that the Report represents its professional judgement as described above and that the Information has been prepared for the specific purpose and use described in the Report and the Agreement, but AECOM makes no other representations, or any guarantees or warranties whatsoever, whether express or implied, with respect to the Report, the Information or any part thereof.

Without in any way limiting the generality of the foregoing, any estimates or opinions regarding probable construction costs or construction schedule provided by AECOM represent AECOM's professional judgement in light of its experience and the knowledge and information available to it at the time of preparation. Since AECOM has no control over market or economic conditions, prices for construction labour, equipment or materials or bidding procedures, AECOM, its directors, officers and employees are not able to, nor do they, make any representations, warranties or guarantees whatsoever, whether express or implied, with respect to such estimates or opinions, or their variance from actual construction costs or schedules, and accept no responsibility for any loss or damage arising therefrom or in any way related thereto. Persons relying on such estimates or opinions do so at their own risk.

Except (1) as agreed to in writing by AECOM and Client; (2) as required by law; or (3) to the extent used by governmental reviewing agencies for the purpose of obtaining permits or approvals, the Report and the Information may be used and relied upon only by Client.

AECOM accepts no responsibility, and denies any liability whatsoever, to parties other than Client who may obtain access to the Report or the Information for any injury, loss or damage suffered by such parties arising from their use of, reliance upon, or decisions or actions based on the Report or any of the Information ("improper use of the Report"), except to the extent those parties have obtained the prior written consent of AECOM to use and rely upon the Report and the Information. Any injury, loss or damages arising from improper use of the Report shall be borne by the party making such use.

This Statement of Qualifications and Limitations is attached to and forms part of the Report and any use of the Report is subject to the terms hereof.

Submarine Waterline Replacement
City of Yellowknife, NT
Class C Estimate
Supplementary Notes
Date: 13 February 2023

AECOM

Information

This estimate is based on the following information available: -

		Dwg No.	Revision	Date Received
1.	ARCHITECT			
		(all AECOM sources) Refer to Other Information below		
2.	STRUCTURAL ENGINEER			
			"	
3.	CIVIL ENGINEER			
			"	
4.	ELECTRICAL ENGINEER			
			"	
5.	MECHANICAL ENGINEER			
			"	
6.	FIRE ENGINEER			
			"	
7.	OTHER SERVICES CONSULTANT			
			"	
8.	LANDSCAPE ARCHITECT			
			"	
9.	OTHER INFORMATION	Preliminary Design Report		
	AECOM	PDR Pipeline Alignment (dwgs, 16pp)		
		Preliminary Cost Estimate		
		Key Site Plan		
		Record dwgs (reference only - Pumphouses)		12 Dec 2022

Construction Milestones

The following assumptions have been made to estimate an allowance for likely inflationary price increases: -

	PUMPHOUSE NO. 1	PUMPHOUSE NO. 2	SUBMARINE PIPELINE
Estimate Base Date		01 Jan 2023	
Construction Start Date	01 Mar 2024	01 Mar 2024	01 Mar 2024
Construction Completion Date	01 Feb 2027	01 Jun 2026	01 Dec 2025
Time from Base Date to Construction Start Date	14 months	14 months	14 months
Construction Period	36 months	27 months	21 months
Escalation rate per year		8.0%	

Objective

This estimate represents the design consultant's opinion of value of the fair and reasonable average price that an experienced and capable local general contractor is likely to expect in the current market to:

a. Fully execute the scope of work described in the available design information

b. Carry out the work according to the requirements, standards, and specifications that can reasonably be anticipated

Assumptions

This estimate has been prepared based on the following assumptions: -

1 This estimate is subject to continuous review as new or revised information is provided to the cost management team
2 The presence of contamination is not anticipated, and the estimate excludes any cost premium for dealing with contaminated soils and subsurface water. Hard material (rock, etc.) can reasonably be anticipated and the estimate allows for breaking up hard material where required
3 The excavated soil is assumed to be generally suitable for backfilling. New bedding fills are assumed to be supplied from an approved local quarry
4 Rates utilised in the body of the estimate are current market related rates applicable to projects of a similar nature and size
5 Average qualities and rates consistent with the scope and scale of the project are assumed are included in the body of the estimate
6 The assumed program, for the purposes of calculating escalation, is noted in the Supplementary Notes
7 An allowance for dewatering deep excavations is included in the estimate
8 Site and building areas are scaled off the drawings and reference material where not dimensioned

Exclusions

This is an estimate of capital construction costs, and the following is excluded: -

1 Land costs, and related costs associated with right-of-ways, easements, etc.
2 Deviation of existing unknown services (the diversion of known services, where designed, is included in the estimate)
3 Direct Contracts (excluded from the construction contract), including loose furniture, fittings and equipment, or the relocation, storage, etc. of same
4 Cost of operations, and all related expenses, including relocation, temporary facilities, accommodations, etc.
5 Potential costs of dealing with unknown extraordinary ground conditions
6 Work outside the generally accepted construction season in the region
7 Demolition of existing structures (except where defined in the design materials), cost of removal of hazardous materials, deaing with contamination, etc.
8 Internal and external signage other than statutory
9 Goods and Services Tax

The following project or 'soft' costs are also excluded: -

1 Plan approval fees, development permit, cost charges, and other similar payments to local authorities
2 Professional consultant fees and disbursements
3 Owner's administration costs: project/development manager and other staff that may be assigned to the project
4 Offsite costs for work beyond the construction zone that may become necessary
5 Financing costs and legal fees associated with the project

6 Owner's insurance costs
7 Phasing of the works
8 Allowances for work outside normal working hours and construction season
9 Construction contingency
10 Project contingency

Summary of Changes since Last Estimate

Design is an evolving process, and the following significant changes are reflected since the last revision: -

Not Applicable - this is the first Class C Estimate

AECOM

Contract Form

1 It is assumed that the scope of work described herein will be competitively tendered in one contract.

2 In all cases the estimates are based upon our assessment of fair value for the work to be carried out. We define fair value as the amount a prudent contractor, taking into account all aspects of the project, would quote for the work. We expect our estimate to be in the middle of the bid range to ensure that funding for the work remains adequate for the duration of the project.

3 Where relevant, subtrade management, overhead costs, and markups have been included.

4 This estimate includes allowances for the construction procurement process selected by the Client:
Design-Bid-Build

Bidding Process and Market Conditions

1 This document is based on the measurement and pricing of quantities wherever information is provided and/or reasonable assumptions for other work not covered in the drawings or specifications, as stated within this document.

2 Unit rates have been obtained from historical records and/or discussion with contractors and suppliers.

3 All unit rates relevant to subcontractor work include the subcontractor's overhead and profit unless otherwise stated.

4 Pricing reflects probable construction costs obtainable in the project locality on the date of this statement of probable costs. This estimate is a determination of fair market value for the construction of this project. It is not a prediction of low bid.

5 Pricing assumes competitive bidding for every portion of the construction work with a minimum of 4-6 bidders for all items. Experience indicates that a fewer number of bidders may result in higher bids; conversely an increased number of bidders may result in more competitive bids.

6 Since AECOM has no control over the cost of labour, material, equipment, or over the contractor's method of determining prices, or over the competitive bidding or market conditions at the time of bid, the statement of probable construction cost is based on industry practice, professional experience and qualifications, and represents AECOM's best judgment as professional construction consultants familiar with the construction industry. However, AECOM cannot and does not guarantee that the proposals, bids, or the construction cost will not vary from opinions of probable cost prepared by them.

Contingencies

1 A *Design Contingency* represents the amount and detail of the design information available for this cost estimate. As the design progresses, the amount of the contingency allowance is reduced and is absorbed into the measured elements. On completion of contract documents, at tender stage, the allowance is normally reduced to zero.
Design Contingency is included at 20% of the construction costs, to allow for items that have not been quantified at early design stages.

2 A *Construction Contingency* is intended to fund Change Orders that will arise as a result of unknown conditions. Such changes are often necessary in order to complete the construction in accordance with the original design intent.
Construction Contingency is excluded from this cost estimate.

3 A *Project Contingency* is usually included with the Client's 'soft costs' and allows for intentional changes in scope and other unforeseen design changes that may occur during construction.
Project Contingency is excluded from this cost estimate.

1. Project Description

The proposed scope of work covered in this estimate includes a new replacement submarine pipeline and upgrades to the pumphouses at either end of the pipeline. The estimate therefore includes the following sections: Pumphouse No. 1 (adjacent to the WTP in Yellowknife Bay); Pumphouse No. 2 (mouth of Yellowknife River), and the new Submarine Pipeline between (defined as 'Option B' in the design material, Overland/ Trenchless, approx. 8,800m, including HDD Shoreline crossing (+-1,750m), HDD wetland crossing (+-250m), and Highway No. 4 crossing (+-40m).

2. System of Measurement

Metric

3. Gross Floor Area

This covers the entire building area and is the total sum of the areas measured at each covered floor level to the outside finished surface of permanent external walls, including parking within, ground floor lobbies, corridors, basements, mezzanine floors, stairwells, lift shafts, duct spaces, machine room floors and lift motor rooms, etc.

	PUMPHOUSE NO. 1	PUMPHOUSE NO. 2	SUBMARINE PIPELINE	
Basement - NIL				
Main Floor	808	530		
Second Floor	513	0		
TOTAL GROSS FLOOR AREA	1,321	530	(not applicable)	m²

4. Other Project Measurements

Submarine Pipeline Length	8,800 m		(Option B)
Alterations and Demolitions (if applicable)	EXISTING PUMPHOUSE NO. 1	EXISTING PUMPHOUSE NO. 2	
TOTAL GROSS FLOOR AREA	526	84	m²

5. Estimate Classification

Canadian Institute of Quantity Surveyors   Class   C

AECOM

6. Estimate Cost Summary

	PUMPHOUSE NO. 1	PUMPHOUSE NO. 2	SUBMARINE PIPELINE	TOTAL
SITE PREPARATION, DEMOLITION, ETC.	$589,100	$364,400	$0	$953,500
BUILDING	$11,440,845	$6,580,030	$0	$18,020,875
SITEWORK	$841,894	$351,060	$0	$1,192,954
SUBMARINE PIPELINE	$0	$0	$30,119,500	$30,119,500
SUBTOTAL	$12,871,839	$7,295,490	$30,119,500	$50,286,829
Site General Conditions	$3,862,000	$2,189,000	$6,024,000	$12,075,000
Office Overhead & Profit	$2,574,000	$1,459,000	$3,012,000	$7,045,000
Design Contingency	$3,862,000	$2,189,000	$7,831,000	$13,882,000
CURRENT CONSTRUCTION COST	$23,170,000	$13,132,000	$46,987,000	$83,289,000
Escalation to Construction Start	$2,163,000	$1,226,000	$4,385,000	$7,774,000
Contract Escalation	$3,344,000	$1,421,000	$3,956,000	$8,721,000
ESCALATED CONSTRUCTION COST	$28,677,000	$15,779,000	$55,328,000	$99,784,000

7. General Contractor Mark-up

		PUMPHOUSES	SUBMARINE PIPELINE
The cost estimate includes:	- Site General Conditions	30.0%	20.0%
	- Office Overheads and Profit	20.0%	10.0%

8. Escalation

Escalation has been included in the above estimate in accordance with the tender and construction period noted under Supplementary Notes.

9. GST

Excluded.

Provincial Sales Tax is included in the unit rates where applicable - 0% in NT.

10. Amounts Provided by Others

Not applicable.

11. Indicative Accuracy Limitation

Canadian Institute of Quantity Surveyors	Class	C	from	-15%	$84,816,000
			to	20%	$119,741,000

12. Special Conditions

The proposed schedule assumes winter construction of the submarine pipeline.

Short construction season and limited market could be a source of pricing variance at tender.

Specific construction sequencing is required.

The economic consequences arising from recent global instability and the COVID-19 pandemic are ongoing, affecting broad sectors of the economy, and could be a source of pricing risk and uncertainty.

A wide variance between low and high bid prices can be expected as a consequence of very dynamic market conditions.

Submarine Waterline Replacement				AECOM
City of Yellowknife, NT				
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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
SITE PREPARATION, DEMOLITION, ETC.				
Special Conditions				
Allow for access, temporary works, etc.	1	sum	10,000.00	10,000
Allow for temporary power, heating, hoarding, etc. (assume construction works occur during construction season)	1	sum	50,000.00	50,000
Unidentified utilities diversion - unknown - excluded (known utilities are included in the estimate)				
Allow for Owner's operations during construction, create and move safe zones, safety training, etc.	1	sum	50,000.00	50,000
Stormwater management and erosion control during construction	1	sum	15,000.00	15,000
Structural monitoring (vibration, settlement, etc.) during construction - assume not required				
Environmental monitoring	1	sum	15,000.00	15,000
Make good surrounding sitework on completion	1	sum	25,000.00	25,000
Site signage allowance (stat signage - other signage excluded)	1	sum	5,000.00	5,000
Minor civil structures, pads, chambers, etc.	1	sum	20,000.00	20,000
Coordination and support works to specialist subcontractors and suppliers - as directed on site	1	sum	50,000.00	50,000
Deconstruction				
Careful and sequenced deconstruction of existing structures, remove on completion (excluding the identification and removal of hazardous materials)	526	m²	350.00	184,100
Site Clearance, Site Preparation, etc.				
Clear site, rough grade for new construction zone	1	sum	15,000.00	15,000
Ground improvements - assume not required				

AECOM

PUMPHOUSE NO. 1

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Bulk Earthworks, etc.				
	Bulk excavation to remove unsuitable soils, grading to new grades, etc.	1	sum	50,000.00	50,000
	Allow for breaking up and removing hard material	1	sum	25,000.00	25,000
	Allow for replacement fills, compaction, etc.	1	sum	25,000.00	25,000
	Allow for dewatering subsurface water at deep locations - pumps, hoses, well points, assume discharge on site	1	sum	30,000.00	30,000
	Allow for soils and slope stabilization	1	sum	20,000.00	20,000
	BUILDING				
	Special Foundations				
	Piled foundation system	808	m²	1,750.00	1,414,000
	Lowest Floor Construction				
	Reinforced concrete in grade slabs, curbs, etc. including concrete, reinforcement, and formwork	808	m²	250.00	202,000
	Upper Floor Construction				
	Assume reinforced concrete topping on metal deck, including framing, columns, beams, and bracing	513	m²	500.00	256,500
	Stair Construction				
	Structural steel staircase, including columns, beams, stringers, bracing, treads, balustrading, concrete fill, and finishes (linear rise)	4	m	5,500.00	22,000
	Roof Construction				

PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Assume reinforced concrete topping on metal deck, including framing, columns, beams, and bracing	808	m²	500.00	404,000
Walls Above Main Floor				
Reinforced concrete wall, including concrete, reinforcement, and formwork (250mm thk)	744	m²	400.00	297,600
Prefinished insulated panel wall system and cladding (assume wood product), including girts, clips, flashing, sealing, trims, etc. complete	744	m²	550.00	409,200
Premium cost for faced CMU veneer	330	m²	350.00	115,500
Miscellaneous				
Allow for sealing, penetrations, special trims, removable panels, and other misc work	1	sum	20,000.00	20,000
Windows				
Triple Glazed Aluminum Window, including Frame, Finish, Opening, and Sill				
Window area (premium cost over exterior wall system)	92	m²	1,000.00	92,000
Aluminum Mechanical Louvre Unit, including Frame, Finish, and Opening				
Mech louvre units - allowance	18	m²	750.00	13,500
Doors				
Prefinished insulated aluminum overhead coiling door, size 3.60 x 3.60m high, including beam, opening, hardware, and finishes - auto open	1	No.	20,000.00	20,000
HM insulated door and frame, including opening, hardware, and finishes: Double	2	pr	3,500.00	7,000
Ditto, Single	6	lvs	2,500.00	15,000

AECOM

PUMPHOUSE NO. 1

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Roof Covering				
	Lower Roof (not accessible)				
	Flat roof assembly, including covering, flashing, trims, sealing, insulation, etc.	295	m²	450.00	132,750
	Upper Roof				
	Flat roof assembly, including covering, flashing, trims, sealing, insulation, etc.	513	m²	450.00	230,850
	Projections				
	Loading				
	Ramp at overhead coiling loading door	1	No.	2,500.00	2,500
	Bollard and base, including finish	2	No.	1,500.00	3,000
	External Staircases				
	Structural steel staircase	1	sum	4,500.00	4,500
	Canopies				
	Overhead canopy at entrances	12	m²	1,500.00	18,000
	Miscellaneous				
	Misc. attached building projections	1	sum	10,000.00	10,000
	Fixed Partitions				
	Main Floor				

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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Reinforced concrete wall, including concrete, reinforcement, and formwork (200mm thk)	387	m²	325.00	125,775
Second Floor				
Interior partitions - office, etc.	366	m²	200.00	73,200
Internal Doors				
Main Floor				
HM door and frame, including opening, hardware, and finishes: Double	2	pr	2,800.00	5,600
Ditto, Single	10	lvs	1,600.00	16,000
Second Floor				
HM door and frame, including opening, hardware, and finishes: Double	1	pr	2,800.00	2,800
Ditto, Single	16	lvs	1,600.00	25,600
Floor Finishes				
Main Floor				
Assume sealed smooth concrete	808	m²	20.00	16,160
Second Floor				
Assume sheet vinyl, carpet, etc.	513	m²	100.00	51,300
Miscellaneous				
Floor marking, trims, special floor finishes, tile, etc.	1	sum	15,000.00	15,000

AECOM

PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Ceiling Finishes				
Main Floor				
Paint on soffit	808	m²	15.00	12,120
Second Floor				
Assume acoustic ceiling tile, in suspended metal grid	513	m²	100.00	51,300
Miscellaneous				
Boxing, bulkheads, etc.	1	sum	15,000.00	15,000
Wall Finishes				
Main Floor				
Paint on internal walls	1,242	m²	20.00	24,840
Second Floor				
Paint on internal walls	1,008	m²	20.00	20,160
Miscellaneous				
Special wall finishes, tile, etc.	1	sum	15,000.00	15,000
Fittings and Fixtures				
Allowance for building FF&E included in the construction contract: millwork, rails, bumpers, corner guards, statutory signage	1,321	m²	75.00	99,075
Conveying Systems				

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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Hydraulic passenger elevator (2 stop)	1	sum	200,000.00	200,000
Process handling equipment: small cranes and hoists	1	sum	100,000.00	100,000
MECHANICAL				
Plumbing and Drainage				
Equipment				
Heat Pump Water Heater, Rheem ProTerra Hybrid	1	No.	6,000.00	6,000
Allowance for Water Softener	1	sum	3,900.00	3,900
Sanitary Sump Pumps, Flygt Submersible Grinder Pumps (Duty/ Standby)	2	No.	10,700.00	21,400
Allowance for Potable Water Re-circulation Pump, 1hp	1	No.	4,400.00	4,400
Piping				
Incoming Domestic Water 50mm, completed with meters and BFP	1	No.	5,000.00	5,000
Domestic Cold Water Points	10	No.	1,100.00	11,000
Domestic Hot Water Points	4	No.	1,300.00	5,200
Sanitary Drainage Points	21	No.	1,100.00	23,100
Rainwater Installations	1	sum	18,000.00	18,000
Testing & Chlorination	1	sum	2,000.00	2,000
Plumbing Fixtures				
Sanitary Fixtures -				
WC	2	No.	3,300.00	6,600
Shower	1	No.	2,400.00	2,400
Lavatory	2	No.	1,800.00	3,600
Kitchen Sink	1	No.	1,870.00	1,870

PUMPHOUSE NO. 1

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Plumbing Fixture Rough-in	6	No.	700.00	4,200
	Dishwasher Rough-in	2	No.	880.00	1,760
	Floor Drains (assumed quantity)	15	No.	500.00	7,500
	Special Piping and Fixtures				
	Fuel Storage -				
	Boiler Day Tank, double wall 1,140L	1	No.	5,400.00	5,400
	Generator Day Tank, 2080L	2	No.	8,700.00	17,400
	Outdoor Fuel Oil Tank, 15,000L	1	No.	28,800.00	28,800
	Fuel Transfer Pumps (Duty / Standby)	2	No.	4,000.00	8,000
	Allowance for Fuel Piping, Fittings, Valves, Accessories and Leak Detection	1	sum	30,000.00	30,000
	Fire Protection				
	Fire Extinguishers (Allowance)	1	sum	4,000.00	4,000
	HVAC				
	Equipment				
	Oil Fired Boilers, Weil McLain Two-Stage, budgetary estimate, Weil-McLain, 05 Jan 2023 -				
	246kW	1	No.	57,000.00	57,000
	330kW	2	No.	67,000.00	134,000
	Flue (350mm dia)	20	m	1,100.00	22,000
	Hydronic Pumps -				
	P-1001	1	No.	6,900.00	6,900
	P-1002	1	No.	6,900.00	6,900

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	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	P-1003	1	No.	6,900.00	6,900
	P-1004	1	No.	6,900.00	6,900
	P-1005	1	No.	6,900.00	6,900
	Air Separator	1	No.	2,500.00	2,500
	Expansion Tank	1	No.	2,200.00	2,200
	Allowance for Glycol Equipment	1	sum	3,500.00	3,500
	VRF System -				
	Outdoor Units (42kW / 12 Ton)	2	No.	33,000.00	66,000
	Indoor Units (including refrigerant piping) -				
	Control Room / Fire Dispatch, Cooling Capacity (7kW / 2 Ton)	2	No.	5,800.00	11,600
	Booster Pump Room, Cooling Capacity (21kW / 6 Ton)	1	No.	9,600.00	9,600
	Bay Pump Room, Cooling Capacity (21kW / 6 Ton)	1	No.	9,600.00	9,600
	Electrical Room, Cooling Capacity (2kW / 0.5 Ton)	1	No.	5,400.00	5,400
	Office, Cooling Capacity (2kW / 0.5 Ton)	6	No.	5,400.00	32,400
	Lunchroom, Cooling Capacity (2kW / 0.5 Ton)	1	No.	5,400.00	5,400
	Boardroom, Cooling Capacity (7kW / 2 Ton)	2	No.	5,800.00	11,600
	Electrical Room, Cooling Capacity (5 Ton)	1	No.	8,800.00	8,800
	AHU / HRVs -				
	Heat Recovery Ventilator (HRV), Outside Air Flowrate 1807 L/s / 3830 cfm	1	No.	98,000.00	98,000
	AHU-1, Supply Air Flow Rate 991 L/s / 2100 cfm. With hydronic heating coil and MERV-8 air filter	1	No.	49,000.00	49,000
	AHU-2, Supply Air Flow Rate 1982 L/s / 4200 cfm. With hydronic heating coil and MERV-8 air filter	1	No.	89,000.00	89,000
	AHU-3, Supply Air Flow Rate 1082 L/s / 2295 cfm. With hydronic heating coil and MERV-8 air filter	1	No.	52,000.00	52,000

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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Ductwork				
Ductwork, Accessories, Grills and Insulation (Allowance)	1,321	m²	180.00	237,780
Generator Exhaust Allowance	1	sum	24,000.00	24,000
Piping				
Allowance for heating piping including all ancillary equipment, valves and insulation (Allowance)	1,321	m²	100.00	132,100
Heating Pipework Connection to Equipment -				
Boiler	3	No.	4,900.00	14,700
AHU	4	No.	3,100.00	12,400
HRV	1	No.	6,200.00	6,200
Heater (assumed quantity)	10	No.	1,600.00	16,000
Allowance for Condensate Piping	1	sum	9,000.00	9,000
Piping Terminal Devices				
Heaters -				
Allowance for Heaters (Mixture of Hydronic Unit Heaters, Cabinet Unit Heaters, Baseboard Heaters and Electric Unit Heaters)	1	sum	35,000.00	35,000
Systems Testing and Commissioning				
Testing and Balancing	1	sum	12,000.00	12,000
Commissioning Mechanical Installations	1	sum	15,000.00	15,000
Controls				
BMS	1	sum	69,000.00	69,000

PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Water Heater	1	No.	1,200.00	1,200
Sump Pumps	2	No.	1,000.00	2,000
Fuel Pumps	2	No.	1,000.00	2,000
Air Handling Unit	5	No.	13,800.00	69,000
Heat Recovery Ventilator	1	No.	13,800.00	13,800
VRF Indoor Units	15	No.	1,100.00	16,500
VRF Outdoor Units	2	No.	3,500.00	7,000
Pumps	5	No.	1,000.00	5,000
Boilers	3	No.	4,800.00	14,400
Heaters	1	sum	12,400.00	12,400
Miscellaneous Controls Allowance	1	sum	7,200.00	7,200
PROCESS				
P&I Equipment				
Raw Water Booster Pump				
Horizontal End Suction Booster Pump, 165L/s @ 37.4m TDH, 125HP, with 1800rpm TEFC Motor and VFD, 575v, 3ph, 60Hz, budgetary estimate, DXP Natpro, 13 Jan 2023	3	No.	111,865.00	335,595
Bay Intake Screen				
Allowance for Bay Intake Screen Model T36, budgetary estimate, MEQUIPCO, 16 Jan 2023.	1	No.	160,000.00	160,000
Hydroburst for Intake Screen, budgetary estimate, MEQUIPCO, 16 Jan 2023.	1	No.	264,000.00	264,000
P&I Piping and Ductwork				
Raw Water Pipe (Stainless Steel)				

PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
200mm Pipe	22	m	1,900.00	41,800
300mm Pipe	31	m	3,140.00	97,340
500mm Pipe	6	m	3,530.00	21,180
600mm Pipe	7	m	3,740.00	26,180
Allowance for Fittings	1	sum	83,180.00	83,180
Allowance for Raw Water Discharge Pipe and Fittings (Stainless Steel)	1	sum	270,000.00	270,000
Miscellaneous Pipe				
Allowance for RLF Pipe (200mm Stainless Steel)	30	m	1,900.00	57,000
Allowance for REC Pipe (200mm Stainless Steel)	60	m	1,900.00	114,000
Allowance for DRA Pipe (80mm PVC)	30	m	120.00	3,600
Allowance for DRA Pipe (40mm PVC)	30	m	60.00	1,800
Allowance for Fittings	1	sum	78,465.00	78,465
River Intake Screen Piping				
Allowance for Piping connection to River Intake Screen - all piping between screen and pumphouse existing	1	sum	32,000.00	32,000
Allowance for Air Compressor Pipe (assumed quantity and assumed 150mm contained within existing 400mm Steel Pipe)	96	m	335.00	32,160
Systems Testing and Commissioning				
Allowance for Testing and Balancing	1	sum	51,000.00	51,000
Allowance for Commissioning Process Installations	1	sum	103,000.00	103,000
P&I Piping Accessories				
Valves				

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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
200mm Check Valve	1	No.	8,710.00	8,710
300mm Check Valve	2	No.	12,030.00	24,060
500mm Check Valve	1	No.	20,180.00	20,180
15mm Ball Valve	3	No.	240.00	720
25mm Ball Valve	1	No.	290.00	290
40mm Ball Valve	2	No.	580.00	1,160
50mm Ball Valve	1	No.	620.00	620
80mm Ball Valve	1	No.	1,170.00	1,170
200mm Ball Valve	1	No.	3,400.00	3,400
250mm Ball Valve	2	No.	4,160.00	8,320
300mm Ball Valve	6	No.	5,480.00	32,880
400mm Ball Valve	3	No.	6,230.00	18,690
500mm Ball Valve	2	No.	8,030.00	16,060
600mm Ball Valve	3	No.	11,350.00	34,050
40mm Globe Valve	2	No.	960.00	1,920
200mm Globe Valve	1	No.	3,250.00	3,250
250mm Globe Valve	2	No.	4,000.00	8,000
300mm Globe Valve	9	No.	5,040.00	45,360
400mm Globe Valve	2	No.	6,080.00	12,160
500mm Globe Valve	2	No.	7,880.00	15,760
600mm Globe Valve	1	No.	11,050.00	11,050
600mm Solenoid Valve	1	No.	12,870.00	12,870
250mm Pressure Reducing Regulator Valve	1	No.	7,190.00	7,190
200mm Butterfly Valve	4	No.	4,160.00	16,640
250mm Butterfly Valve	1	No.	4,920.00	4,920

PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
300mm Butterfly Valve	10	No.	5,950.00	59,500
400mm Butterfly Valve	4	No.	9,270.00	37,080
500mm Butterfly Valve	2	No.	12,590.00	25,180
600mm Butterfly Valve	1	No.	14,390.00	14,390
Air Valve	6	No.	660.00	3,960
350mm Magnetic Flow Meter	1	No.	24,170.00	24,170
400mm Magnetic Flow Meter	1	No.	29,000.00	29,000
ELECTRICAL				
Service and Distribution				
Equipment				
The following equipment is existing and excluded from the scope of work -				
Existing Utility distribution				
Existing Pad mounted Transformer -XF-Utility				
Primary & Secondary feeders for Pad mounted Transformer -XF-Utility				
SPL - Utility service splitter	1	No.	18,000.00	18,000
800A, 600V Utility Switchgear - 701, including:	1	No.	215,000.00	215,000
800A, 3Ph - Main Breaker	3	No.		
Testing and arc-flash study Allowance	1	sum		
Allowances for framing, cables, and accessories	1	sum		
Utility Meter	1	No.	19,000.00	19,000
Auxiliary Power Equipment				
Emergency Generator -				
250KW, 600V, 3ph, Diesel Generator c/w 400A circuit breaker	2	No.	116,000.00	232,000

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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Load Bank, allow	2	No.	11,000.00	22,000
Emergency Switchgear -				
800A, 600V Utility Switchgear - 710, including:	1	No.	311,000.00	311,000
800A, 3Ph - Tie Breaker	1	No.		
800A, 3Ph - Main Breaker	4	No.		
Testing and arc-flash study Allowance	1	sum		
Allowances for framing, cables, and accessories	1	sum		
UPS Distribution -				
UPS - allowance	1	sum	30,000.00	30,000
Feeders, Conduit, Busway and Control -				
Feeder from GEN-710A to SWGR-710	1	sum	17,000.00	17,000
Feeder from GEN-710B to SWGR-710	1	sum	17,000.00	17,000
Feeder fromSWGR-710 to MCC-720A	1	sum	9,000.00	9,000
Feeder fromSWGR-710 to MCC-720B	1	sum	9,000.00	9,000
Distribution Conditions				
Distribution Panels -				
120/208V, 3Ph, 4w - Panelboard A1 & A2	2	No.	14,000.00	28,000
120/208V, 3Ph, 4w - Panelboard B1 & B2	2	No.	14,000.00	28,000
Other Distribution -				
Active Harmonic Filter - AHF-(725A, 725B)	2	No.	35,000.00	70,000
Distribution Transformers -				
75KVA, 600-120/208V 3Ph, 4w, Transformers, XF-726A&XF-726B	2	No.	38,000.00	76,000
Feeders, Conduit, Busway and Controls -				
Feeder from service splitter to SWGR-701	1	sum	13,000.00	13,000

PUMPHOUSE NO. 1

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Feeder from SWGR-701 to MCC-720A	1	sum	12,970.00	12,970
	Feeder from SWGR-701 to MCC-720B	1	sum	12,970.00	12,970
	Feeder from MCC-720A to XF-726A transformer	1	sum	3,600.00	3,600
	Feeder from XF-726A transformer to PNL-725A	1	sum	2,000.00	2,000
	Feeder from XF-726A transformer to PNL-727A	1	sum	2,000.00	2,000
	Feeder from MCC-720A to AHF-725A	1	sum	3,000.00	3,000
	Feeder from MCC-720B to XF-726B transformer	1	sum	2,700.00	2,700
	Feeder from XF-726B transformer to PNL-725B	1	sum	2,000.00	2,000
	Feeder from XF-726B transformer to PNL-727B	1	sum	2,000.00	2,000
	Feeder from MCC-720B to AHF-725B	1	sum	4,000.00	4,000
	Motor Controls				
	800A, 600V, 3P, 4w - MCC-720A, including:	1	sum	278,000.00	278,000
	600A.3P - ATS-720A	1	No.		
	250A - CB	3	No.		
	150A - CB	1	No.		
	90A - CB	1	No.		
	30A - CB	2	No.		
	15A - CB	11	No.		
	VFD - 150HP	3	No.		
	FVNR, 15A	9	No.		
	FVNR, 30A	1	No.		
	MET - Power meter (PM-721A)	1	No.		
	SPD-724A, Surge protection device	1	No.		
	Testing and arc-flash study Allowance	1	sum		

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	PUMPHOUSE NO. 1				
	DESCRIPTION	**QUANTITY**	**UNIT**	**RATE**	**COST**
	Allowances for framing, cables, and accessories	1	sum		
	800A, 600V, 3P, 4w - MCC-720B, including:	1	sum	327,000.00	327,000
	800A.3P - ATS-720B	1	No.		
	400A - CB	3	No.		
	250A - CB	1	No.		
	100A - CB	3	No.		
	30A - CB	1	No.		
	15A - CB	9	No.		
	VFD - 150HP	3	No.		
	FVNR, 15A	9	No.		
	FVNR, 30A	1	No.		
	MET - Power meter (PM-721B)	1	No.		
	SPD-724A, Surge protection device	1	No.		
	Testing and arc-flash study Allowance	1	sum		
	Allowances for framing, cables, and accessories	1	sum		
	Mechanical Distribution Conditions - Feeders and Connections -				
	Booster pumps	3	No.	7,200.00	21,600
	Bay pump	2	No.	7,200.00	14,400
	AHU	2	No.	6,900.00	13,800
	Condenser	2	No.	5,600.00	11,200
	Boiler - 075HP	2	No.	5,600.00	11,200
	Boiler - 125HP	1	No.	7,700.00	7,700
	HX Pump - 0.75HP	2	No.	5,600.00	11,200
	HX Pump - 125HP	1	No.	7,700.00	7,700
	Secondary Heat Pumps - 1.5HP	2	No.	5,600.00	11,200

PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Secondary Heat Pumps - 125HP	1	No.	7,700.00	7,700
Recirc Pump	1	No.	5,600.00	5,600
Sanitary Pump	2	No.	5,600.00	11,200
Water Heater	1	No.	5,600.00	5,600
Fuel oil transfer pump - 1HP	1	No.	5,600.00	5,600
HRV Supply fan	2	No.	7,700.00	15,400
Misc. Mechanical power connection - Allowance	1	sum	4,000.00	4,000
Lighting, Devices, and Heat				
Lighting				
Lighting fixture, allow	132	No.	700.00	92,470
Emergency Light Pack (2 heads) c/w battery, allow	10	No.	1,200.00	12,194
Exit Lights	10	No.	800.00	8,000
Conduit & wire	152	No.	250.00	38,065
Fixture installation	152	No.	200.00	30,452
Lighting Controls - allowance	1,321	m²	40.00	52,840
Devices				
Allowance	70	No.	420.00	29,400
Heat				
with Mechanical				
Electrical Systems				
Fire Alarm				

PUMPHOUSE NO. 1

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Allowance	1,321	m²	30.00	39,630
	Communications				
	Allowance	1,321	m²	30.00	39,630
	Security				
	Allowance	1,321	m²	35.00	46,235
	Public Address/ Audio-Visual				
	Allowance	1,321	m²	21.00	27,741
	Lightning Protection				
	Allowance	1,321	m²	17.00	22,457
	Cable Tray				
	Allowance	10	m	420.00	4,200
	Grounding				
	Allowance	1,321	m²	21.00	27,741
	Instrumentation and Controls				
	Control Panels -				
	Local control panel - included with Vendor supplied equipment	2	No.		
	Terminal Box, allow	4	No.	1,000.00	4,000
	Marshalling panel, allow	1	No.	45,000.00	45,000

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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
I/O Modules -				
Discrete Input	37	No.	1,000.00	37,000
Discrete Output	10	No.	1,000.00	10,000
Analog Input	34	No.	1,300.00	44,200
Analog Output	7	No.	1,300.00	9,100
Instruments -				
FE - Flow Rate Sensor	2	No.	5,100.00	10,200
FIT - Flow Rate Indicator Transmit	2	No.	5,100.00	10,200
FCV - control Valve	2	No.	5,100.00	10,200
FSL - Flow Rate Switch Low	5	No.	1,700.00	8,500
LIT - Level Indicator Transmit	1	No.	3,000.00	3,000
LSHH - Level Switch High High	1	No.	800.00	800
LSLL - Level Switch Low Low	1	No.	900.00	900
PIT - Pressure Indicator Transmit	8	No.	5,400.00	43,200
PRV - Pressure Relief Valve	2	No.	2,200.00	4,400
TIT - Temperature Indicating Transmitter	1	No.	600.00	600
Cabling -				
Allowance for Cables	1	sum	30,000.00	30,000
Other Electrical Cost Allowances				
Commissioning	1	sum	134,000.00	134,000
Coordination	1	sum	58,000.00	58,000
SCADA Integration, Programming and Start-up	1	sum	20,000.00	20,000
FAT & SAT	1	sum	14,000.00	14,000

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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Allowances for temporary relocation PLC, MCC, etc. during construction for PH1 sequencing	1	sum	40,000.00	40,000
Electrical Demolition				
Allowance - disconnections, removal, and disposal of electrical equipment	1	sum	8,000.00	8,000
SITEWORK				
General Sitework				
Allow for paving modifications and new paving around	1	sum	125,000.00	125,000
Tie in to existing access road	1	sum	5,000.00	5,000
Make good surrounding sitework and landscaping on completion	1	sum	20,000.00	20,000
Site signage alowance	1	sum	5,000.00	5,000
Minor civil structures, pads, chambers, etc.	1	sum	25,000.00	25,000
Miscellaneous items	1	sum	20,000.00	20,000
Mechanical Site Services				
Water Supply (minimum depth 1.5m below grade and insulated)				
50mm HDPE DR9 Water Main Pipe, within Carrier Pipe (insulated)	204	m	80.00	16,320
200mm Water Main Pipe	68	m	300.00	20,400
75mm Water Main Pipe	70	m	120.00	8,400
Allowance for Fittings	1	sum	7,700.00	7,700
Insulation	342	m	50.00	17,100
Testing and Chlorination	342	m	20.00	6,840
200mm 5.625deg Elbow	1	No.	540.00	540
200mm 22.5deg Elbow	2	No.	540.00	1,080

PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
200mm 45deg Elbow	5	No.	540.00	2,700
400x200mm Reducer	1	No.	1,270.00	1,270
200x75mm Tee	1	No.	630.00	630
Connect to existing 400mm Water Main	1	sum	980.00	980
Connect to existing 200mm Water Main	1	sum	420.00	420
50mm Connection to Building	1	sum	280.00	280
Hydrant Chamber	1	No.	6,430.00	6,430
Allowances for excavation and backfill	111	m³	90.00	10,004
Water Main Recycle (minimum depth 1.5m below grade and insulated)				
200mm Water Main Pipe	29	m	300.00	8,700
Allowance for Fittings	1	sum	1,480.00	1,480
Insulation	29	m	50.00	1,450
Allowances for excavation and backfill	26	m³	90.00	2,340
400x400x200 Tee	1	No.	1,270.00	1,270
Connect to existing 400mm Water Main	1	sum	980.00	980
Connection to Building	1	sum	420.00	420
Water Main WTP Supply (minimum depth 1.5m below grade and insulated)				
500mm Water Main Pipe	12	m	760.00	9,120
Allowance for Fittings	1	sum	1,550.00	1,550
Insulation	12	m	100.00	1,200
Allowances for excavation and backfill	16	m³	90.00	1,440
500mm Tee	1	No.	1,500.00	1,500
Connect to existing 500mm Water Main	1	sum	1,120.00	1,120

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DESCRIPTION	QUANTITY	UNIT	RATE	COST
Connection to Building	1	sum	840.00	840
Sanitary Sewer (minimum depth 1.5m below grade and insulated)				
100mm HDPE DR9 Sanitary Forced Main Pipe, within Carrier Pipe (insulated with heat trace)	206	m	160.00	32,960
Allowance for Fittings	1	sum	7,520.00	7,520
Insulation	206	m	70.00	14,420
Heat Trace	206	m	130.00	26,780
Other Site Mechanical Utilities (minimum depth 1.5m below grade and insulated)				
500mm Carrier Pipe, DR17(minimum depth 1.5m below grade and insulated)	206	m	780.00	160,680
Allowance for Fittings	1	sum	36,300.00	36,300
Insulation	206	m	230.00	47,380
Allowances for excavation and backfill	279	m³	90.00	25,110
Electrical Site Services				
Electrical Site Distribution				
NIL				
Site Lighting and Devices				
Lighting -				
Pole mounted LED luminaire	6	No.	6,800.00	40,800
lighting wiring and conduit, direct buried	6	No.	1,140.00	6,840
Allowance for excavation and backfill	155	m³	80.00	12,400
Exterior Lighting fixture wall mounted LED, allow	8	No.	1,300.00	10,400

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DESCRIPTION	QUANTITY	UNIT	RATE	COST
Electrical power connection	1	sum	4,500.00	4,500
Site Electrical Systems				
Site Communications -				
Allowance	1	sum	4,000.00	4,000
Site Security -				
CCTV Cameras - allow	6	No.	3,800.00	22,800
Conduit & wire	6	No.	1,000.00	6,000
Other Site Electrical Utilities -				
Allowances for resolving unforeseen obstruction and protection	1	sum	30,000.00	30,000
Coordination - allowance	1	sum	13,000.00	13,000
Site Electrical Demolition				
Allowance	1	sum	5,500.00	5,500
SUBTOTAL				12,871,839
Site General Conditions	30%			3,862,000
Office Overheads and Profit	20%			2,574,000
Design Contingency	20%			3,862,000
GST - excluded				

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PUMPHOUSE NO. 1

DESCRIPTION	QUANTITY	UNIT	RATE	COST
TOTAL CURRENT CONSTRUCTION COST excluding GST (1Q 2023)				23,170,000
ESCALATION (construction start 1Q 2024; construction completion 1Q 2027)				
Escalation to construction start date (8% pa.)	14	months		2,163,000
Contract escalation (8% pa.)	36	months		3,344,000
TOTAL ESCALATED CONSTRUCTION COST excluding GST				28,677,000

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PUMPHOUSE NO. 2

DESCRIPTION	QUANTITY	UNIT	RATE	COST
SITE PREPARATION, DEMOLITION, ETC.				
Special Conditions				
Allow for access, temporary works, etc.	1	sum	10,000.00	10,000
Allow for temporary power, heating, hoarding, etc. (assume construction works occur during construction season)	1	sum	50,000.00	50,000
Unidentified utilities diversion - unknown - excluded (known utilities are included in the estimate)				
Allow for Owner's operations during construction, create and move safe zones, safety training, etc.	1	sum	50,000.00	50,000
Stormwater management and erosion control during construction	1	sum	15,000.00	15,000
Structural monitoring (vibration, settlement, etc.) during construction - assume not required				
Environmental monitoring	1	sum	15,000.00	15,000
Make good surrounding sitework on completion	1	sum	25,000.00	25,000
Site signage allowance (stat signage - other signage excluded)	1	sum	5,000.00	5,000
Minor civil structures, pads, chambers, etc.	1	sum	20,000.00	20,000
Coordination and support works to specialist subcontractors and suppliers - as directed on site	1	sum	50,000.00	50,000
Deconstruction				
Careful and sequenced deconstruction of existing structures, remove on completion (excluding the identification and removal of hazardous materials)	84	m²	350.00	29,400
Site Clearance, Site Preparation, etc.				
Clear site, rough grade for new construction zone	1	sum	15,000.00	15,000
Ground improvements - assume not required				

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	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	PUMPHOUSE NO. 2				
	Bulk Earthworks, etc.				
	Bulk excavation to remove unsuitable soils, grading to new grades, etc.	1	sum	25,000.00	25,000
	Allow for breaking up and removing hard material	1	sum	10,000.00	10,000
	Allow for replacement fills, compaction, etc.	1	sum	15,000.00	15,000
	Allow for dewatering subsurface water at deep locations - pumps, hoses, well points, assume discharge on site	1	sum	20,000.00	20,000
	Allow for soils and slope stabilization	1	sum	10,000.00	10,000
	BUILDING				
	Special Foundations				
	Piled foundation system	530	m²	1,750.00	927,500
	Lowest Floor Construction				
	Reinforced concrete in grade slabs, curbs, etc. including concrete, reinforcement, and formwork	530	m²	250.00	132,500
	Upper Floor Construction				
	NIL				
	Stair Construction				
	NIL				
	Roof Construction				
	Assume reinforced concrete topping on metal deck, including framing, columns, beams, and bracing	530	m²	500.00	265,000

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DESCRIPTION	QUANTITY	UNIT	RATE	COST
Walls Above Main Floor				
CMU wall, including bracing	606	m²	300.00	181,800
Prefinished insulated panel wall system and cladding (assume wood product), including girts, clips, flashing, sealing, trims, etc. complete	606	m²	550.00	333,300
Miscellaneous				
Allow for sealing, penetrations, special trims, removable panels, and other misc work	1	sum	10,000.00	10,000
Windows				
Triple Glazed Aluminum Window, including Frame, Finish, Opening, and Sill				
Window area (premium cost over exterior wall system)	29	m²	1,000.00	29,000
Aluminum Mechanical Louvre Unit, including Frame, Finish, and Opening				
Mech louvre units - allowance	4	m²	750.00	3,000
Doors				
Prefinished insulated aluminum overhead coiling door, size 3.60 x 3.60m high, including beam, opening, hardware, and finishes - auto open	1	No.	20,000.00	20,000
HM insulated door and frame, including opening, hardware, and finishes: Double	2	pr	3,500.00	7,000
Ditto, Single	1	lvs	2,500.00	2,500
Roof Covering				
Flat roof assembly, including covering, flashing, trims, sealing, insulation, etc.	530	m²	450.00	238,500

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DESCRIPTION	QUANTITY	UNIT	RATE	COST
Projections				
Loading				
Ramp at overhead coiling loading door	1	No.	2,500.00	2,500
Bollard and base, including finish	2	No.	1,500.00	3,000
Miscellaneous				
Misc. attached building projections	1	sum	5,000.00	5,000
Fixed Partitions				
CMU wall, including bracing	330	m²	300.00	99,000
Internal Doors				
HM door and frame, including opening, hardware, and finishes: Double	2	pr	2,800.00	5,600
Ditto, Single	2	lvs	1,600.00	3,200
Floor Finishes				
Assume sealed smooth concrete	530	m²	20.00	10,600
Miscellaneous				
Floor marking, trims, special floor finishes, tile, etc.	1	sum	5,000.00	5,000
Ceiling Finishes				
Paint on soffit	530	m²	15.00	7,950

PUMPHOUSE NO. 2

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Miscellaneous				
Boxing, bulkheads, etc.	1	sum	5,000.00	5,000
Wall Finishes				
Paint on internal walls	1,266	m²	20.00	25,320
Miscellaneous				
Special wall finishes, tile, etc.	1	sum	5,000.00	5,000
Fittings and Fixtures				
Allowance for building FF&E included in the construction contract: millwork, rails, bumpers, corner guards, statutory signage	530	m²	75.00	39,750
Conveying Systems				
Process handling equipment: small cranes and hoists	1	sum	25,000.00	25,000
MECHANICAL				
Plumbing and Drainage				
Equipment				
NIL				
Piping				
Rainwater drainage	1	sum	8,300.00	8,300
Plumbing Fixtures				

PUMPHOUSE NO. 2

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	NIL				
	Special Piping and Fixtures				
	Fuel Storage -				
	Boiler Day Tank, double wall 1,140L	1	No.	5,400.00	5,400
	Generator Day Tank, 2080L	1	No.	8,700.00	8,700
	Outdoor Fuel Oil Tank, 8,500L	1	No.	16,700.00	16,700
	Fuel Transfer Pumps (Duty / Standby)	2	No.	4,000.00	8,000
	Allowance for Fuel Piping, Fittings, Valves, Accessories and Leak Detection	1	sum	25,000.00	25,000
	Fire Protection				
	Fire Extinguishers (Allowance)	1	sum	2,000.00	2,000
	HVAC				
	Equipment				
	Oil Fired Boilers, De-Dietrich, 200kW - budgetary estimate, Lowe Agencies, 04 Jan 2023	2	No.	84,000.00	168,000
	Flue (300mm dia)	17	m	900.00	15,300
	Hydronic Pumps -				
	P-1007	1	No.	6,200.00	6,200
	P-1008	1	No.	6,200.00	6,200
	P-1009	1	No.	6,200.00	6,200
	P-1010	1	No.	6,200.00	6,200
	P-1011	1	No.	6,200.00	6,200
	Air Separator	1	No.	2,000.00	2,000

PUMPHOUSE NO. 2

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Expansion Tank	1	No.	2,200.00	2,200
Allowance for Glycol Equipment	1	sum	3,200.00	3,200
Water-To-Air Heat Pumps (heating & cooling), Climate Master, budgetary estimate, Excel Systems, 05 Jan 2023 -				
Pump Room (3 Ton / 11kW)	2	No.	20,400.00	40,800
Boiler Room (1 Ton / 4kW)	1	No.	15,400.00	15,400
Electrical Room (3 Ton / 11kW)	1	No.	20,400.00	20,400
Mechanical Room (1 Ton / 4kW)	1	No.	15,400.00	15,400
Water-To-Water Heat Pump, Boiler Room, 15 Ton	1	No.	80,000.00	80,000
Heat Recovery Ventilator (HRV), Outside Air Flowrate 835 L/s / 1775 cfm	1	No.	53,000.00	53,000
Air Handling Unit, Supply Air Flow Rate 1912 L/s / 4200 cfm. With hydronic cooling coil, re-heat coil and MERV-8 air filter	1	No.	87,000.00	87,000
Fluid Cooler (12 Ton / 42kW), installed on roof	1	No.	33,000.00	33,000
Ductwork				
Ductwork, Accessories, Grills and Insulation (Allowance)	530	m²	200.00	106,000
Generator Exhaust Allowance	1	sum	19,000.00	19,000
Piping				
Allowance for hydronic piping including all ancillary equipment, valves and insulation (Allowance)	530	m²	150.00	79,500
Hydronic Pipework Connection to Equipment -				
Boiler	2	No.	4,900.00	9,800
AHU	1	No.	6,200.00	6,200
HRV	1	No.	6,200.00	6,200
Water to Air Heat Pumps	5	No.	1,600.00	8,000

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	PUMPHOUSE NO. 2				
	DESCRIPTION	**QUANTITY**	**UNIT**	**RATE**	**COST**
	Water to Water Heat Pump	1	No.	2,100.00	2,100
	Heater (assumed quantity)	5	No.	1,600.00	8,000
	Allowance for Condensate Piping	1	sum	4,000.00	4,000
	Piping Terminal Devices				
	Heaters -				
	Allowance for Heaters (Mixture of Hydronic Unit Heaters, Cabinet Unit Heaters, Baseboard Heaters and Electric Unit Heaters)	1	sum	15,000.00	15,000
	Systems Testing and Commissioning				
	Testing and Balancing	1	sum	8,000.00	8,000
	Commissioning Mechanical Installations	1	sum	9,000.00	9,000
	Controls				
	BMS	1	sum	29,000.00	29,000
	Fuel Pumps	2	No.	1,000.00	2,000
	Air Handling Unit	1	No.	13,800.00	13,800
	Heat Recovery Ventilator	1	No.	13,800.00	13,800
	Water to Air Heat Pumps	5	No.	1,100.00	5,500
	Water to Water Heat Pump	1	No.	1,700.00	1,700
	Fluid Cooler	1	No.	3,500.00	3,500
	Pumps	5	No.	1,000.00	5,000
	Boilers	2	No.	4,800.00	9,600
	Heaters	1	sum	5,500.00	5,500
	Miscellaneous Controls Allowance	1	sum	3,000.00	3,000

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PUMPHOUSE NO. 2

DESCRIPTION	QUANTITY	UNIT	RATE	COST
PROCESS				
P&I Equipment				
River Raw Water Pumps				
Two Stage Vertical Turbine Pumps, 278L/s @ 46m TDH, 250HP TEFC Motor and VFD, 575v, 3ph, 60Hz, budgetary estimate, Asper SCG Process, 11 Jan 2023	2	No.	172,075.00	344,150
River Intake Screen				
Allowance for River Intake Half Screen Model T54 (4,926mm length), budgetary estimate, 16 Jan 2023	2	No.	212,000.00	424,000
Hydroburst for Intake Screen, budgetary estimate, MEQUIPCO, 16 Jan 2023	1	No.	312,000.00	312,000
P&I Piping and Ductwork				
Raw Water Pipe (Stainless Steel)				
50mm Pipe (assumed quantity)	3	m	310.00	930
80mm Pipe (assumed quantity)	4	m	490.00	1,960
100mm Pipe (assumed quantity)	40	m	840.00	33,600
400mm Pipe	13	m	2,540.00	33,020
500mm Pipe	43	m	3,530.00	151,790
600mm Pipe	11	m	3,740.00	41,140
Allowance for Fittings	1	sum	116,885.00	116,885
River Intake Screen Piping				
600mm River Intake Screen Piping	24	m	2,100.00	50,400

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PUMPHOUSE NO. 2

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Cut existing 600mm excess pipe and bell mouth and weld carbon steel flange	1	sum	9,400.00	9,400
Connect 600mm Piping to River Intake Screens'	1	sum	7,200.00	7,200
Air Compressor Pipe (150mm contained within existing 400mm Steel Pipe)	144	m	335.00	48,240
Systems Testing and Commissioning				
Allowance for Testing and Balancing	1	sum	37,000.00	37,000
Allowance for Commissioning Process Installations	1	sum	74,000.00	74,000
P&I Piping Accessories				
Valves				
Drain	6	No.	2,640.00	15,840
400mm Check Valve	3	No.	16,860.00	50,580
80mm Ball Valve	1	No.	1,170.00	1,170
400mm Ball Valve	6	No.	6,230.00	37,380
500mm Ball Valve	2	No.	8,030.00	16,060
600mm Ball Valve	1	No.	11,350.00	11,350
400mm Globe Valve	3	No.	6,360.00	19,080
500mm Globe Valve	1	No.	7,880.00	7,880
600mm Globe Valve	1	No.	11,050.00	11,050
500mm Pressure Reducing Regulator Valve	1	No.	17,140.00	17,140
100mm Butterfly Valve	1	No.	2,360.00	2,360
400mm Butterfly Valve	3	No.	9,270.00	27,810
500mm Butterfly Valve	4	No.	12,590.00	50,360

PUMPHOUSE NO. 2

DESCRIPTION	QUANTITY	UNIT	RATE	COST
ELECTRICAL				
Service and Distribution				
Equipment				
SPL - Utility service splitter	1	No.	15,000.00	15,000
Utility Meter	1	No.	16,000.00	16,000
Auxiliary Power Equipment				
Emergency Generator -				
300KW, 600V, 3ph, Diesel Generator c/w 400A circuit breaker	1	No.	124,000.00	124,000
Load Bank, allow	1	No.	12,000.00	12,000
UPS Distribution -				
UPS - allowance	1	No.	17,000.00	17,000
Feeders, Conduit, Busway and Control -				
Feeder from GEN-710 to MCC-600	1	sum	17,000.00	17,000
Distribution Conditions				
Distribution Panels -				
120/208V, 3Ph, 4w - Panelboard	2	No.	14,000.00	28,000
Other Distribution -				
Active Harmonic Filter - AHF	2	No.	30,000.00	60,000
Distribution Transformers -				
45KVA, 600-120/208V 3Ph, 4wTransformer T-L2	2	No.	33,000.00	66,000
Feeders, Conduit, Busway and Controls -				
Feeder from service splitter to MCC-600	1	sum	17,290.00	17,290
Feeder from MCC-600 to XF-726 transformer	1	sum	3,350.00	3,350

PUMPHOUSE NO. 2

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Feeder from XF-726 transformer to PNL-726	1	sum	1,950.00	1,950
	Motor Controls				
	800A, 600V, 3P, 4w - MCC-600, including:	1	sum	309,000.00	309,000
	800A.3P - ATS-705	1	No.		
	800A - CB	1	No.		
	250A - CB	2	No.		
	100A - CB	8	No.		
	15A - CB	11	No.		
	VFD - 150HP	2	No.		
	FVNR, 15A	11	No.		
	MET - Power meter (PM-706)	1	No.		
	SPD-724A, Surge protection device	2	No.		
	Testing and arc-flash study Allowance	1	sum		
	Allowances for framing, cables, and accessories	1	sum		
	Mechanical Distribution Conditions - Feeders and Connections -				
	AHU-801	1	No.	5,600.00	5,600
	HRV-1	1	No.	5,600.00	5,600
	River pumps - 1,2 - 250HP	2	No.	7,200.00	14,400
	Boiler - 0.75HP	2	No.	5,600.00	11,200
	Secondary Heat Pumps	4	No.	5,600.00	22,400
	Fuel oil transfer pump - 0.75HP	2	No.	5,600.00	11,200
	AHU-001	1	No.	5,600.00	5,600
	HRV fan	2	No.	5,600.00	11,200
	Misc. Mechanical power connection - Allowance	1	sum	2,000.00	2,000

Submarine Waterline Replacement
City of Yellowknife, NT

Class C Estimate
Date: 13 February 2023 | **Project No.** 60673796

AECOM

PUMPHOUSE NO. 2

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Lighting, Devices, and Heat				
Lighting				
Lighting fixture, allow	59	No.	700.00	41,222
Emergency Light Pack (2 heads) c/w battery, allow	5	No.	1,200.00	6,360
Exit Lights	5	No.	800.00	4,000
Extend Conduit & wire	69	No.	240.00	16,605
Fixture installation	69	No.	200.00	13,838
Lighting Controls - allowance	530	m²	40.00	21,200
Devices				
Allowance	40	No.	420.00	16,800
Heat				
with Mechanical				
Electrical Systems				
Fire Alarm				
Allowance	530	m²	30.00	15,900
Communications				
Allowance	530	m²	30.00	15,900
Security				
Allowance	530	m²	35.00	18,550

PUMPHOUSE NO. 2

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Public Address/ Audio-Visual				
	Allowance	530	m²	21.00	11,130
	Lightning Protection				
	Allowance	530	m²	17.00	9,010
	Cable Tray				
	Allowance	10	m	420.00	4,200
	Grounding				
	Allowance	530	m²	21.00	11,130
	Instrumentation and Controls				
	Control Panels -				
	Local control panel - included with Vendor supplied equipment	2	No.		
	Terminal Box, allow	4	No.	1,000.00	4,000
	Marshalling panel, allow	1	No.	38,000.00	38,000
	I/O Modules -				
	Discrete Input	24	No.	1,000.00	24,000
	Discrete Output	4	No.	1,000.00	4,000
	Analog Input	6	No.	1,300.00	7,800
	Analog Output	3	No.	1,300.00	3,900
	Instruments -				
	FE - Flow Rate Sensor	2	No.	5,100.00	10,200

PUMPHOUSE NO. 2

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	FIT - Flow Rate Indicator Transmit	2	No.	5,100.00	10,200
	FSL - Flow Rate Switch Low	3	No.	1,700.00	5,100
	LIT - Level Indicator Transmit	2	No.	3,000.00	6,000
	LSHH - Level Switch High High	2	No.	800.00	1,600
	LSLL - Level Switch Low Low	2	No.	900.00	1,800
	PIT - Pressure Indicator Transmit	1	No.	5,400.00	5,400
	TIT - Temperature Indicating Transmitter	1	No.	600.00	600
	Cabling -				
	Allowance for Cables	1	sum	10,000.00	10,000
	Other Electrical Cost Allowances				
	Commissioning	1	sum	56,000.00	56,000
	Coordination	1	sum	26,000.00	26,000
	SCADA Integration, Programming and Start-up	1	sum	10,000.00	10,000
	FAT & SAT	1	sum	8,000.00	8,000
	Electrical Demolition				
	Allowance - disconnections, removal, and disposal of electrical equipment	1	sum	6,000.00	6,000
	SITEWORK				
	General Sitework				
	Allow for paving modifications and new paving around	1	sum	150,000.00	150,000
	Tie in to existing access road	1	sum	5,000.00	5,000
	Make good surrounding sitework and landscaping on completion	1	sum	20,000.00	20,000
	Site signage alowance	1	sum	5,000.00	5,000

PUMPHOUSE NO. 2

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Minor civil structures, pads, chambers, etc.	1	sum	25,000.00	25,000
	Miscellaneous items	1	sum	20,000.00	20,000
	Mechanical Site Services				
	NIL				
	Electrical Site Services				
	Electrical Site Distribution				
	NIL				
	Site Lighting and Devices				
	Lighting -				
	Pole mounted LED luminaire	4	No.	5,600.00	22,400
	lighting wiring and conduit, direct buried	4	No.	1,140.00	4,560
	Allowance for excavation and backfill	100	m³	80.00	8,000
	Exterior Lighting fixture wall mounted LED, allow	8	No.	1,300.00	10,400
	Allowance for electrical power connection	1	sum	9,000.00	9,000
	Site Electrical Systems				
	Site Communications -				
	Allowance	1	sum	4,000.00	4,000
	Site Security -				
	CCTV Cameras - allow	4	No.	3,800.00	15,200
	Conduit & wire	4	No.	1,000.00	4,000
	Other Site Electrical Utilities -				

Submarine Waterline Replacement
City of Yellowknife, NT

Class C Estimate
Date: 13 February 2023 — **Project No.** 60673796

AECOM

PUMPHOUSE NO. 2

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Allowances for resolving unforeseen obstruction and protection	1	sum	30,000.00	30,000
	Coordination - allowance	1	sum	13,000.00	13,000
	Site Electrical Demolition				
	Allowance	1	sum	5,500.00	5,500
	SUBTOTAL				7,295,490
	Site General Conditions	30%			2,189,000
	Office Overheads and Profit	20%			1,459,000
	Design Contingency	20%			2,189,000
	GST - excluded				
	TOTAL CURRENT CONSTRUCTION COST excluding GST (1Q 2023)				13,132,000
	ESCALATION (construction start 1Q 2024; construction completion 2Q 2026)				
	Escalation to construction start date (8% pa.)	14	months		1,226,000
	Contract escalation (8% pa.)	27	months		1,421,000
	TOTAL ESCALATED CONSTRUCTION COST excluding GST				15,779,000

SUBMARINE PIPELINE

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Site Clearance, Demolition, Site Preparation, etc.				
	Demolition and removal of redundant existing work - allowance	1	sum	30,000.00	30,000
	Clear site of vegetation, etc., rough grade to Yellowknife Bay shore	1	sum	50,000.00	50,000
	Ground improvements - assume not required				
	General Sitework				
	Allow for access, temporary works, etc.	1	sum	25,000.00	25,000
	Allow for temporary power, heating, hoarding, etc. (on-shore - current construction schedule during winter season)	1	sum	50,000.00	50,000
	Stormwater management and erosion control during construction	1	sum	50,000.00	50,000
	Allow for temp shoring and dewatering at shoreline around construction zone	1	sum	50,000.00	50,000
	Make good surrounding sitework on completion	1	sum	50,000.00	50,000
	Site signage allowance	1	sum	2,500.00	2,500
	Minor civil structures, pads, chambers, etc.	1	sum	50,000.00	50,000
	Protect work to remain in place	1	sum	10,000.00	10,000
	Make good on completion at PH1 & 2 connections	1	sum	20,000.00	20,000
	Coordination and support works to specialist subcontractors and suppliers - as directed on site	1	sum	100,000.00	100,000
	Bulk Earthworks				
	The following quantities provided by Eng:				
	Topsoil Stripping, Stockpiling, & Replacement	45,000	m³	10.00	450,000
	300mm Granular Base Course	1,800	m²	55.00	99,000
	75 mm Traffic Gravel	1,800	m²	15.00	27,000

Submarine Waterline Replacement
City of Yellowknife, NT

Class C Estimate
Date: 13 February 2023 **Project No.** 60673796

SUBMARINE PIPELINE

	DESCRIPTION	QUANTITY	UNIT	RATE	COST
	Shoreline				
	Clear shoreline - PH1 & 2 connection points	1	sum	20,000.00	20,000
	Shoreline dredging and shoreline bulk excavations to design profile, including disposal of surplus material	1	sum	30,000.00	30,000
	Temporary work, silt fabric, detention, water management monitoring, etc.	1	sum	20,000.00	20,000
	Retaining structures - not required				
	Geotextiles and ties - allowance	1	sum	30,000.00	30,000
	The following quantities provided by Eng:				
	Imported Granular Bedding / Fill	540	m³	150.00	81,000
	Rip Rap Armor	600	m³	200.00	120,000
	Marine Works				
	Marine works mob/demob	1	sum	250,000.00	250,000
	Temporary marine work, environmental monitoring, permitting, consultations, etc.	1	sum	150,000.00	150,000
	Marine safety ops during construction	1	sum	50,000.00	50,000
	Temporary shoreline stabilization during marine operations - allowance	1	sum	50,000.00	50,000
	Dealing with hard material - assume not applicable				
	Dealing with marine contaminants - assume not applicable				
	Mechanical Sitework				
	NIL				
	Process Sitework				
	* Submarine Pipeline - Option B				

Submarine Waterline Replacement
City of Yellowknife, NT

AECOM

Class C Estimate
Date: 13 February 2023 | **Project No.** 60673796

SUBMARINE PIPELINE

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Submarine Pipeline Construction				
650mm HDPE DR17 (Submarine Installation), including Fittings and concrete ballast / blocks	5,150	m	2,100.00	10,815,000
Allowance for Imported Granular Bedding / Fill - with Shoreline				
Allowance for Rip Rap Armor - with Shoreline				
On-Land Construction				
650mm HDPE DR17 (Insulated), including Fittings and Insulation	1,550	m	1,800.00	2,790,000
Highway No. 4 Crossing (Steel Casing)	40	m	4,000.00	160,000
750mm HDPE DR9 (Wetland Crossing Horizontal Directional Drilling [HDD]), including Fittings	250	m	3,400.00	850,000
Trenchless Construction				
750mm HDPE DR9 (Yellowknife Bay North Shoreline Crossing Maxi HDD), including Fittings and Mobilization	1,750	m	7,600.00	13,300,000
750mm HDPE DR9 (Pumphouse No. 1 Shoreline Crossing HDD), including Fittings	100	m	3,400.00	340,000
Electrical Sitework				
NIL				
SUBTOTAL				30,119,500
Site General Conditions	20%			6,024,000
Office Overheads and Profit	10%			3,012,000

Submarine Waterline Replacement
City of Yellowknife, NT

Class C Estimate
Date: 13 February 2023

Project No. 60673796

SUBMARINE PIPELINE

DESCRIPTION	QUANTITY	UNIT	RATE	COST
Design Contingency	20%			7,831,000
GST - excluded				
TOTAL CURRENT CONSTRUCTION COST excluding GST (1Q 2023)				46,987,000
ESCALATION (construction start 1Q 2024; construction completion 4Q 2025)				
Escalation to construction start date (8% pa.)	14	months		4,385,000
Contract escalation (8% pa.)	21	months		3,956,000
TOTAL ESCALATED CONSTRUCTION COST excluding GST				55,328,000

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

AECOM Project #: 60673796
Client Project #:
Client: City of Yellowknife
Revision: 0
Date: 21-Oct-24

Option 1: River Supply

Item	Description	Annual Quantity	Unit	Unit Price	Value ($)
1.0	**Raw Water Pumping**				**$ 79,971**
1.1	Electricity - PH2 raw water pumping through new pipeline, excluding pumping pressures required for all options	115886	kWh	0.25	$ 28,971
1.2	Labour - maintaining extra 1 set of pumps	60	manhours	150	$ 9,000
1.3	Annual diver inspection or other maintenance of pipeline	1	LS	42,000	$ 42,000
2.0	**Building HVAC**				**$ 168,302**
2.1	Diesel Fuel for Heating Building - new expanded PH2	115000	L	$1.44	$ 165,377
2.2	Electricity for Air Handling Equipment - new expanded PH2	11700	kWh	0.25	$ 2,925
3.0	**General PH2 Maintenance**				**$ 35,000**
3.1	Other equipment maintenance at PH2 including electrical	1	LS	15,000	$ 15,000
3.2	Site Allowance: snow clearing, road maintenance, exterior maintenance	1	LS	20,000	$ 20,000
	Sub-Total				$ 283,273
	Contingency (0%)				$ -
	TOTAL ESTIMATE ANNUAL O&M COST				**$ 283,000**

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 Capital Cost Estimate (±50%)

Option 2: Bay with Arsenic Removal Equipment - WTP Costs Only

AECOM Project #: 60673796
Client Project #:
Client: City of Yellowknife
Revision: 1
Date: 11-Oct-24

Item	Description	Quantity	Unit	Unit Price	Value ($)
1.0	**General Requirements**	1	LS	N/A	$ 4,259,000
2.0	**Civil**	1	LS	N/A	$ 42,000
3.0	**Structural and Architectural**	1	LS	N/A	$ 3,329,060
4.0	**Process Mechanical**	1	LS	N/A	$ 8,850,130
5.0	**Building Mechanical**	1	LS	N/A	$ 853,645
6.0	**Electrical**	1	LS	N/A	$ 942,130
7.0	**Instrumentation**	1	LS	N/A	$ 357,600
	Sub-Total				$ 18,633,565
	Contingency (30%)				$ 5,590,069
	Engineering (15%)				$ 2,795,035
	TOTAL ESTIMATE CAPITAL COST				**$ 27,020,000**

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

AECOM Project #: 60673796
Client Project #:
Client: City of Yellowknife
Revision: 0
Date: 21-Oct-24

Option 2: Bay with Arsenic Removal Equipment

Item	Description	Annual Quantity	Unit	Unit Price	Value ($)
1.0	**Water Pumping**				**$ 80,330**
1.1	Electricity - Pressure Boost Pumping at WTP for Adsorption	321320	kWh	0.25	$ 80,330
2.0	**Building Mechanical**				**$ 293,474**
2.1	Diesel Fuel for Heating Building - WTP expansion only	178000	L	$1.44	$ 255,974
2.2	Electricity for Air Handling Equipment - WTP expansion only	150000	kWh	0.25	$ 37,500
3.0	**Adsorptive Media**				**$ 156,519**
3.1	Labour	74	manhours	150	$ 11,100
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	0.066667	LS	2,152,000	$ 143,467
	Sub-Total				$ 530,323
	Contingency (0%)				$ -
	TOTAL ESTIMATE ANNUAL O&M COST				**$ 530,000**

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

AECOM Project #: 60673796
Client Project #:
Client: City of Yellowknife
Revision: 0
Date: 21-Oct-24

Option 3: Status Quo (Existing Pipeline plus Bay)

Item	Description	Annual Quantity	Unit	Unit Price	Value ($)
1.0	**Water Pumping**				**$ 1,114,351**
1.1	Electricity - PH2 raw water pumping through new pipeline, excluding pumping pressures required for all options	421403	kWh	0.25	$ 105,351
1.2	Labour - maintaining extra 1 set of pumps	60	manhours	150	$ 9,000
1.3	Annual diver inspection or other maintenance of pipeline	1	LS	1,000,000	$ 1,000,000
2.0	**Building Mechanical**				**$ 57,647**
2.1	Diesel Fuel for Heating Building - WTP expansion only	39200	L	$1.44	$ 56,372
2.2	Electricity for Air Handling Equipment - WTP expansion only	5100	kWh	0.25	$ 1,275
3.0	**General PH2 Maintenance**				**$ 25,000**
3.1	Other equipment maintenance at PH2 including electrical	1	LS	10,000	$ 10,000
3.2	Site Allowance: snow clearing, road maintenance, exterior maintenance	1	LS	15,000	$ 15,000
	Sub-Total				$ 1,196,997
	Contingency (0%)				$ -
	TOTAL ESTIMATE ANNUAL O&M COST				**$ 1,197,000**

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