Appendix 42

Whale Tail 2018 end-pit lake habitat suitability assessment

TECHNICAL MEMORANDUM

Date: March 8, 2019

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CC: Ryan Vanengen (Agnico Eagle)

Re: Literature review and preliminary study design for assessing fish habitat use in end pit lakes

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1.1 BACKGROUND

In July, 2018, Agnico Eagle Mines Ltd. (Agnico) was issued *Fisheries Act* Authorization 16-HCAA-00370 for the Whale Tail Pit project. Approved fish habitat offsetting related to this Authorization is described in the Fish Habitat Offsetting Plan for Whale Tail Pit (March, 2018). As a component of the offsetting plan, Agnico has included a suite of complementary measures (research projects) aimed at closing knowledge gaps regarding the biology and habitat requirements of northern fish species, developing tools and validating methods to facilitate and advance ongoing monitoring, and/or characterizing responses of fish-bearing aquatic systems to direct anthropogenic manipulations. Six specific research studies were identified, which include:

Study 1: Assessment of changes in aquatic productivity and fish populations due to flooding of Whale Tail South and downstream lakes during operations

Study 2: Assessment of impacts of the Baker Lake wastewater outflow on nutrient status/ fish productivity and fish habitat

Study 3: Literature review and field validation of northern lake fish habitat preferences

Study 4: Arctic grayling occupancy modeling

Study 5: End pit lake habitat suitability assessment

Study 6: eDNA methods development

Conceptual design of each project has been discussed with DFO since March 2017. Details of projects that will occur in the nearer term have been established with DFO and interested academic partners (Studies 1, 2, 3, 4, 6), and field work began in 2018. Due to the extended timeline for reflooding of candidate study pits at Meadowbank (est. 2027 – 2029), research partners and a specific study plan have not yet been determined for Study 5: End Pit Lake Habitat Suitability Assessment. Initial literature reviews and methods development were planned to occur in the years prior to pit reflooding, and analyses in reference systems will begin by 2026. In addition, the possibility for Agnico will collaborate with other industry partners was presented and supported by DFO, if appropriate sites are available in other locations in the nearer term.

This technical memorandum is presented in partial fulfillment of Condition 4.2.1.3 of *Fisheries Act* Authorization 16-HCAA-00370 for the Whale Tail Pit project, which indicates that Agnico will provide to DFO the results of a literature review (Section 1.2) and preliminary study outline (Section 1.3) for Study 5: End Pit Lake Habitat Suitability Assessment.

1.2 LITERATURE REVIEW

1.2.1 Introduction

Developers in remote and relatively pristine Northern environments often experience difficulty in identifying and constructing fish habitat offsetting projects that have readily quantifiable benefits to local fisheries. In the recent past, flooded pit lakes were viewed as a means to restore fish habitat, and were accepted as habitat offsetting by DFO (e.g. Meadowbank Site No Net Loss Plan, 2012). However, over the past few years there has been a departure from this offsetting practice, as there is uncertainty regarding the capability of pit areas to provide productive fish habitat. The relatively limited history of mine development in the North means that many sites are still operational and so, to date, few studies exist that have examined habitat suitability and the general ecological success of Arctic end pit lakes. While the creation of lakes from mining operations is commonplace in temperate regions of Canada, it is relatively new to the North and so lacks the Arctic-specific case studies that could help to ensure success. Nevertheless, the use of rehabilitated end pit lakes as fish habitat should continue to be explored in the North, as these lakes may present a viable option for habitat reclamation and compensation.

Although limited in number, some end pit lake studies have reported the successful re-establishment of fish populations. For example, the ability of former coal mine pits to support fish populations has been observed in the Alberta foothills [1,2]. A comprehensive 2009 Canadian report outlined factors to consider when developing end pit lakes as fish habitat in the north [3]; while the review recognizes a lack of information regarding the aquatic biology of these systems, a number of considerations for fish survival were presented. Until further information is available for Northern pit lakes, much can be interpolated on their suitability as fish habitat from general principles of pit lake limnology.

1.2.2 Habitat Considerations

The relatively low habitat diversity of many pit lakes is one of the greatest factors differentiating them from other nearby natural lakes [4]. Habitat reclamation practices have established that fish require different types of habitat for different life functions [5] and that the availability of diverse substrates and depth zones is important for maximum fish productivity. This dictates that successful end pit reclamation plans must include provisions for habitat diversity [1,4] if use as fish habitat is the desired outcome. Methods to improve habitat that have been suggested in other studies include the addition of logs, rock piles, macrophyte beds or artificial wetland islands [2-4,6]. While the applicability of each of these methods is clear in temperate climates, they are limited in Arctic regions: in areas above the tree line, the addition of log piles would not be in keeping with natural systems; lakes in the region contain few macrophytes and so such additions would be outside of the local ecology, and; floating wetland islands are non-native and would be hindered by the extensive annual ice cover. Of the strategies suggested to improve habitat quality, rock fill presents the greatest utility and most common application in Northern no-net-loss plans for mine pits (e.g. Diavik, Jericho, Doris North, Meadowbank). For offsets outside of pit areas, this typically occurs in the form of artificial reefs or shoals constructed in deep water, soft sediment basins. However, no published studies to date have specifically assessed impact of such constructed habitat features on fish productivity for a Northern Canadian lake. Pit backfill to depths in keeping with nearby natural systems is also a commonly discussed strategy for optimizing fish habitat [2,3]. However, this strategy is based on an assumption that deep water pit areas cannot act as suitable fish habitat for any life function, which again has not specifically been assessed in the North. Given the low productivity of lakes in northern climates, it may well be that, given acceptable water quality, fish use of near-surface pelagic zones over deep pits is similar to that in naturally occurring deep water areas. Use of pit bench areas for benthic feeders is also a possibility, if and when primary and secondary production are sufficiently established.

Along with these landscape additions, methods for re-contouring pit dimensions have been suggested to create more natural habitat systems (Figure 1). These include re-sloping of pit walls, and the creation of shallow littoral zones [2,3]. While the construction of shallow littoral zones and re-sloping of pit walls has been implemented in north-temperate regions, no records of the use of these methods in the North were found to date. However, when re-flooded pit areas are submerged in natural lakes (as planned for the Phaser, BB Phaser, Vault, and Whale Tail Pit at the Meadowbank site), they will be connected to the surrounding natural shallow basins and littoral areas, providing adjacent natural habitat diversity and potentially decreasing the need to artificially create such areas. The ecological development of pit lakes within natural lake basins may also occur more rapidly than in isolated pits, given the presence of organic matter, habitat diversity, and connectivity (see Section 1.2.7.4).

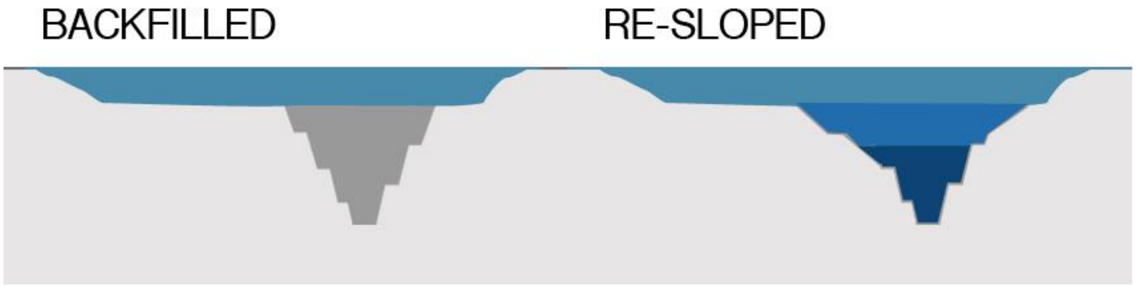

Figure 1: Pit lake re-contouring strategies (backfilling and re-sloping) aimed at increasing fish habitat area and diversity.

Natural riverine flow-through in pit lakes has also been suggested as a means of habitat improvement [1]. Successful trout spawning has been observed in the constructed outlet channel of a reclaimed pit lake in Alberta, Canada [2], although no spawning was observed in the inlet channel and winter ice-cover reduced landscape connectivity of both channels. Viable fish populations at the site were established within three years of opening the inlet and outlet channels connecting the lake to the surrounding watershed [2]. To ensure that the needs of habitat diversity are met, reclamation strategies must consider fish life histories and the habitat requirements of each life stage, with particular consideration given to the habitat requirements of the desired native species. Further studies investigating contemporary methods of habitat optimization in end pit lakes are discussed in Section 1.2.7, below.

Although a lack of diverse habitat can limit the ecological progression of pit lakes, the greatest driver of success is water quality [4]; pit lake water quality must be properly managed and monitored in conjunction with habitat creation if the end goal is the establishment of successful fish populations.

1.2.3 Stratification

Many Northern lakes, including those in the Meadowbank area, are naturally holomictic (non-stratified, or fully mixed). End pit lakes that are formed from the flooding of decommissioned mine voids differ from these natural lakes in that their waters are often brackish [7] and their depth-to-surface ratio is much greater [3,8], potentially promoting the development of stratified meromictic conditions (Figure 2) [8]. It is desired that Northern end pit lakes become part of the natural landscape and be connected to the regional hydrological system and surrounding habitat [9], so the hazards that end pit lake water quality and meromixis may pose to the establishment of successful fish populations must be considered and addressed for reclamation to be successful.

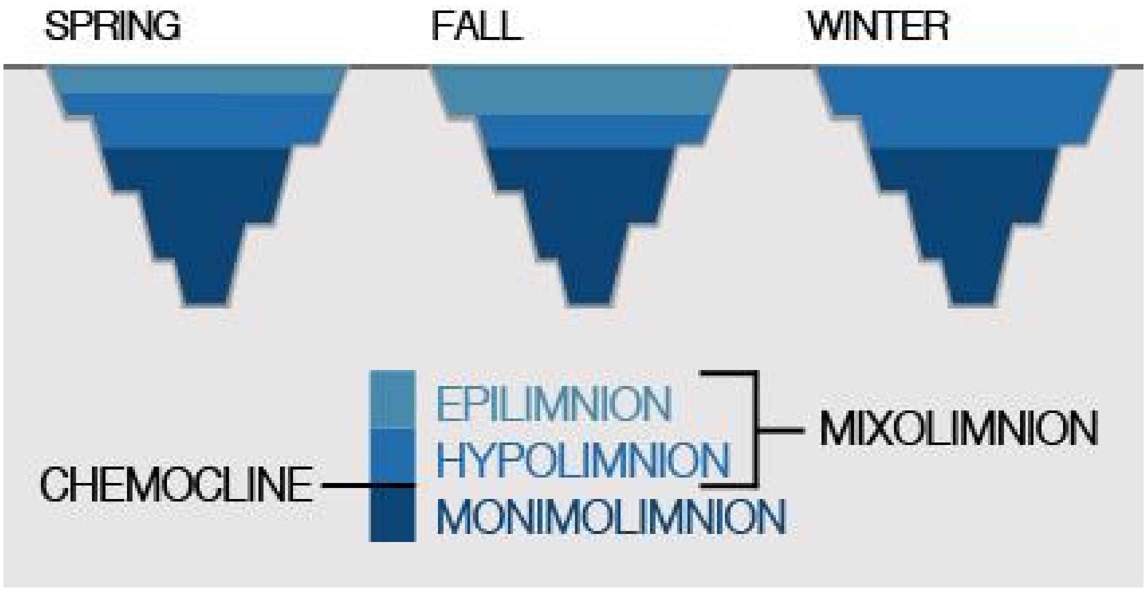

Figure 2: Potential seasonal mixing patterns of northern ice-covered end-pit lakes [8].

Meromictic lakes are defined by a chemocline — a strong temperature/density gradient between upper fresh water layers (the epilimnion and hypolimnion) and the ultra-deep brackish layer (the monimolimnion) [10]. Meromixis occurs when deep waters are denser (usually due to salinity) and so do not mix with upper layers but rather create a permanent stratification that resists spring/summer turnover and under-ice mixing in winter [8]. For monitoring and reclamation of end pit lakes, it is important to assess their potential to become meromictic so as to predict the evolution of their water quality and suitability for habitat or other end uses in the long term [9]. The degree of meromixis can change based on local hydrology and climate and is influenced by a number of factors, including: the commodities extracted (e.g. gold vs. lignite); the neutralizing capabilities of the local geology; the availability of water for flooding, its condition (salinity), and the rate of flooding; pit morphometry; the relative depth of the water table; salt exclusion from ice-up, and; surface wind stress and cooling; [8,10-12]. A study of six ice-covered Northern end pit lakes observed a variety of holomictic and meromictic conditions between the study sites, with the most meromictic lake containing a permanent monimolimnion and seasonal stratification/mixing cycle of the freshwater mixolimnion [8]. The study found that the main cause of meromixis in these lakes was a combination of ice melt, runoff, ice thickness, and proportion of black ice [8]. These Arctic-specific climate drivers of meromixis are discussed further in Section 1.2.5, below.

While full mixing of end pit lakes has the benefit of evenly distributing chemical elements, contaminants or dissolved gases that have accumulated in the monimolimnion may rapidly move to surface layers if mixing occurs suddenly, leading to unfavorable effects [13,14] and potentially, toxicity to fish. Indeed, meromixis may actually be desirable in certain situations, as hazardous contaminants may be 'stored' in the deep monimolimnion of a meromictic end-pit lake as a means of sequestration from the open environment [9,10] This can be achieved by utilizing the natural stratification of a lake, or by engineering meromixis by adding a freshwater cap to saline waters [8]. However, determining meromixis is not adequate in assuming environmental protection or viable fish habitat in overlying strata. The success of such sequestration strategies depends on the concentration of contaminants in the monimolimnion, the level of transport to the mixolimnion, and the acceptable concentration in the mixolimnion; if monimolimnion concentration or inter-strata mixing are small enough, the contaminant can be considered sequestered [8,12]. This strategy may be affected by natural or artificial adjustments to the chemocline that increase or decrease the volume of the monimolimnion; promoting surface mixing will lower the chemocline, while adding fresh water to the surface (e.g. ice melt) or brackish waters at depth (e.g. groundwater inflow) will raise it [8]. This strategy assumes a dynamic steady-state and so requires a monitoring strategy that will detect disturbances that may affect the meromixis, such as:

- Active creep or till wall subsistence;
- Earthquakes and tremors;
- Rockfall or landslides;
- Inflows of water;
- Changes to stream flow;
- Removal of pit water;
- Aeration, and;
- Shoaling of pit walls [8].

The development and dispersal of stratified conditions in end pit lakes can be predicted through modeling, as described in Section 1.2.6.

1.2.4 Water Quality Considerations

The ability of pit lakes to support viable fish populations depends on sustained adequate water quality conditions. Water chemistry is dynamic and is influenced by many processes acting simultaneously, each with implications for the success and sustainability of fish populations in northern pit lakes. Factors commonly considered for pit lake water quality include pH, dissolved oxygen (DO), salinity, turbidity, nutrients, and potentially hazardous substances. In general end pit lakes are regarded as having the potential to be acidic (pH 2-4), with high conductivity, iron, and other metal concentrations [19].

Pit lakes formed from former gold mines may contain heavy metals that have been liberated from the local mineralogy, potentially causing toxicity in fish if concentrations are high enough [3]. The availability of metals in water is predominantly controlled by the tenets of the Biotic Ligand Model: pH and the concentrations of dissolved organic matter and other metallic ions [15]. It has been predicted that pit lakes with low to moderate acidity have a good chance of being rehabilitated so as to provide a beneficial ecological end use [3,16]. This may be achieved naturally or through remediation processes (e.g. the addition of limestone or P [17]) and/or proactive pit lake design (e.g. rapid flooding of pit lakes to reduce oxidation time of the rock face [9,18]). Remedial strategies are further discussed in Section 1.2.7.

Pit lakes often have a higher chemical oxygen demand (COD) than natural lakes, due to factors such as the dissociation of iron ions in the deep, anoxic monimolimnion and oxidation in the hypolimnion [1,3,19]. As a result, fish in these lakes may be more susceptible to winterkill when ice cover prevents oxygen exchange at the surface, causing DO in the layers of the mixolimnion to drop significantly over the course of the winter season [8].

The physical limnology of pit lakes has profound impact on water quality and so its consideration is essential in closure plans [8]. Depth profiles and their modification can affect potential for meromictic conditions (see Section 1.2.3). Drainage through and across the pit surface or processed backfill during flooding has the potential to leach metals and lead to acid mine drainage (AMD) and acidification of the pit lake [1,18], as can iron-rich groundwater seepage [1]—effects that can persist for years following mine closure [19] or cause re-acidification following neutralization efforts [1].

Invertebrates help form the base of the aquatic consumer food web that supports fish populations, and are heavily impacted by the water quality conditions, such as conductivity, pH [4], and contaminants [19]. Species richness and diversity are typically very low in acidic lakes as pH is a limiting factor for the development of many species of phyto- and zooplankton, however biomass may still be high if nutrients are available [19].

Despite the abundant literature focused on acidic and metal-loaded end pit lakes and their impacts on ecology, much less data exists on their successful inclusion in the local hydrologic landscape and integrated watershed management plans, possibly due to the difficulty in establishing appropriate ‘reference’ or ‘baseline’ conditions [11,21]. This is especially true for northern climates. A study of water quality in pit lakes at Ekati Diamond Mine in the Northwest Territories concluded that:

- Using fresh water to fill pit lakes improves pit lake water quality, as does a faster filling rate;

- The larger an upstream watershed is, the higher the water quality;
- The shorter the time between mine closure and infilling, the better the water quality for pit lakes with reactive rock walls or with groundwater inflows;
- If there is no groundwater input, meromixis will not develop. For pits with groundwater input, meromixis formation is influenced by the (head-pressure variable) rate of groundwater flow and the speed at which the pit is filled—once full, lakes are assumed to have zero groundwater flow, and;
- As there are exposed pit walls above the pit lake surface, pit wall runoff is the main source of long-term loadings to full pit lakes [9].

These conclusions mirror the modeling uncertainties expressed in the same report [9] and that are further discussed in Section 1.2.6, below.

While poor water quality as a result of any of the factors discussed above can occur in pit lakes and thereby reduce ecologically optimal end uses, suitable water quality for fish populations is also achievable, even in the absence of specific reclamation efforts. For example, water quality modeling for the Meadowbank pits in the initial 2005 Environmental Impact Statement for this site indicated that end pit water quality was predicted to be similar to un-impacted areas and suitable for use as fish habitat in the long-term (i.e., >25 years post-flooding). The authors predicted that pit lake water quality will meet MMER concentrations and nearly all CCME guidelines—with the exception of cadmium and zinc at a steady state—which are predicted to be elevated but at similar concentrations to background levels.

1.2.5 Climatic Considerations

Unique conditions exist in Northern climates that require specific consideration for managing pit lake water quality [8]. Ice cover persists much longer in Arctic lakes and can influence the development of meromixis [8]. The temperature of the monimolimnion in both temperate and Northern meromictic lakes is theoretically 4°C, the temperature at which water reaches its maximum density [3]. Ice formation can increase salinity in the hypolimnion by excluding salts from the forming ice, reducing the chemocline gradient between strata and causing the fresh layer to mix with the deep monimolimnion through the process of thermohaline convection. This may reduce DO or introduce monimolimnic contaminants into the hypolimnion, endangering fish or fish habitat. In spring, ice melt and freshwater surface runoff enter the hypolimnion, increasing the chemocline gradient and the chances of developing meromictic conditions in the lake [3,9]. However, a recent study of pit lakes suggests that this happens only in select pits that receive groundwater inputs with high levels of dissolved solids [8]. Deep and persistent ice cover can also increase the chances of oxygen depletion [8] by elevating COD in the hypolimnion as a result of anoxic conditions in the monimolimnion [3], leading to fish winterkill.

Persistent and deep ice cover in the north reduces the amount of solar radiation that reaches the water column [3] which, along with extreme seasonal variability, results in photosynthetic processes that are slowed and a reduction in primary production at the base of the aquatic food web [3]. While this may slow the rate at which pit lake habitat is considered ‘reclaimed’, local biota are also adapted to these nutrient- and light-depleted conditions and so should face no greater challenges than those in other local lakes. Likewise, while rates of primary production in the Arctic may be considered slow with respect to studies of temperate-climate pit lakes, Northern lakes are commonly highly oligotrophic in their natural state [3] and so have a comparatively simpler successional goal to attain. While assisted reclamation of Northern end pit lakes may be slower than in temperate climates, this disparity may be counter-balanced by the relatively simple ecological structure that needs to be attained.

1.2.6 End Pit Lake Modeling

Water quality modeling is an essential component of pit lake restoration planning. As each pit's morphology and mineralogy is unique, predictions of water quality parameters need to be modeled on a case-by case basis. Models that exist take a total-systems approach that includes integrating geochemical, hydrologic, and climatological data with specific consideration of: ground water node locations, groundwater flow rate, geologic cell node locations, evaporation rates, precipitation rates, surface run-off rates, ground water chemistry, and chemistry of rock materials [18,22,23].

While common practice within the industry, a variety of uncertainties need to be considered, as with any modeling exercise. There are multiple influences on the water quality of pit lakes and their suitability as fish habitat (e.g. climate, hydrology, geology, limnology) that introduce dynamic uncertainty into predictions of pit lake viability. From their experience, Ekati Diamond Mine identified specific uncertainties in predictions for lake reclamation that may impact the accuracy of model results, namely:

- The rates of inflow and flooding (slower rates of flooding lead to greater lake acidity);
- Groundwater flow rates (groundwater flow promotes meromixis);
- Runoff from waste rock storage (such runoff may introduce contaminants, nutrients, etc.);
- Runoff from pit walls during flooding (runoff from walls promotes acidity of waters), and;
- The effects of climate change (evaporation, precipitation, inflow, etc.) [9].

As pit lakes are increasingly reflooded and opportunities for model validation are available, uncertainties can be expected to decline and the accuracy of models improved.

1.2.7 Reclamation Options

Contemporary studies suggest that options for optimizing fish habitat in end pit lakes can include a combination of: water treatment and fertilization to reduce bioavailable mining by-products (e.g. selenium) via digestion and reduction; deep water aeration to promote de-gassing of the monimolimnion and mixing of monimolimnic contaminants to surface waters for reduction and digestion; engineered flow-through connectivity of the pit (or its host lake) to the local hydrology via inputs and outputs to a feeder stream or river; and manufactured habitat (e.g. bouldered/graveled stream beds and shallow-water pit beds) to promote the establishment and proliferation of local ecology. Studies examining these restoration options are briefly described below.

1.2.7.1 Nutrient Enrichment & pH Adjustment

A study of limestone and phosphorous addition as a means to reduce acidity and heavy metal concentration in pit lakes found that limestone added alone was the most successful technique, neutralizing pit lake pH and heavy metal concentrations (Al by 98%, Mg by 14%) within two months [17]. A concurrent toxicity assay using Ceriodaphnia sp., Chlorella sp., and Tetrahymena sp. also found that toxicity was no longer incurred two months after limestone amendment [17], although uncertainty exists as to the effects of metal bioaccumulation over time or the emergence of chronic and sub-lethal effects. The authors of the study encourage that further multi-species or multi-trophic assays are required to determine if limestone amendment may be a successful remediation method for acidic or metal contaminated pits to develop into natural ecosystems.

1.2.7.2 Promotion of Reducing Organisms

Some hazardous contaminants may be removed by reducing them to less toxic or bioavailable forms, such as selenium (Se)—an essential micronutrient that can be highly toxic to aquatic organisms at marginally elevated concentrations [10]. A study investigating Se reduction in pit lakes applied anaerobic bioreactor principles to a whole pit lake system, successfully reducing concentrations of bioavailable Se (selenite and selenate to their inert elemental form) tenfold within two years, achieving water quality guideline values [10]. This was accomplished through fertilization with nitrogen and phosphorus to promote primary production and anoxic conditions, the preferred habitat of local anaerobic Se and sulphur-reducing bacteria. The authors consider their application of bioreactor techniques to a pit lake as a successful, novel and inexpensive method to remediate large volumes of Se-contaminated waters, with greatest uncertainty surrounding the ability to control lake conditions so as to optimize anaerobic reduction. These techniques could be applied to other contaminants and may benefit from using natural meromictic conditions and local or seeded communities of anaerobic reducing bacteria.

1.2.7.3 Aeration

In a multi year study of a meromictic northern mine pit lake, aerated diffusers were employed in the open-water season at a depth of 57 m in an attempt to mix the different water strata to improve aeration and oxidation of the mining byproduct thiocyanate [24]. The diffusers were not placed on the pit bed so as to reduce re-suspension of sediments. The proponents observed complete mixing to the diffuser depth (57 m) after 34 h and complete mixing of the lake (110 m) after 6.5 days [24], as shown in Figure 3. Oxygen concentrations increased from 0 to 70% below 5 m, oxidizing all residual thiocyanate by the end of the first season of aeration and depleting all ammonia produced by the end of the second season [24]. Aeration by way of compressed air is the most common de-stratification method used [24] but can be a useful and novel remediation technique for both oxidizing contaminants and reducing meromictic conditions as part of viable rehabilitation and decommissioning plans.

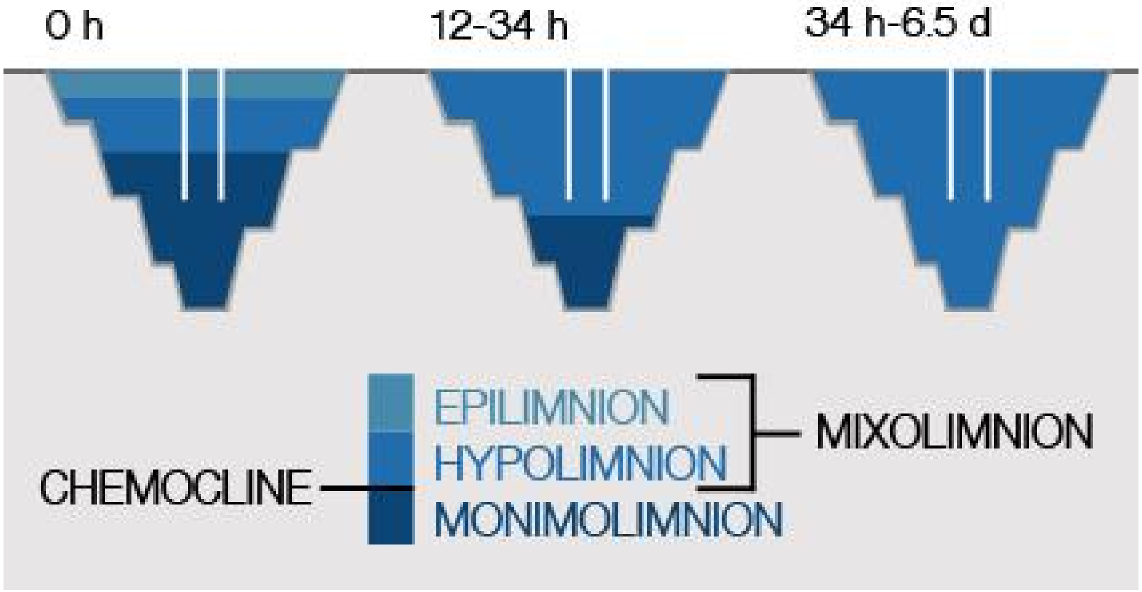

Figure 3: Aeration as a means of mixing meromictic deep-well lakes: 6.5 day progression [24].

1.2.7.4 Engineered Flow and Landscape Connectivity

Connection to the local watershed by way of riverine flow-through as outlined in **Error! Reference source not found.** is increasingly being proposed as a reclamation strategy for pit lakes, as natural chemical and biological processes (e.g. dilution, absorption, flocculation and sedimentation) can reduce pit lake contaminant concentrations [1]. Nutrient inputs from flow-through may promote primary production and phytoremediation of contaminants, while bicarbonate inputs may reduce acidity [1] and act as a long-term buffer against acidic inputs. These potential benefits must be balanced against maintaining the health of the existing river system; any decisions to use this strategy should be risk-based, scientifically justifiable, and include a monitoring strategy and adaptive management framework that is validated by the key stakeholders involved [1]. McCullough et al describe the major benefits of engineered river-flow as a landscape connectivity and remediation technique as:

- Contaminant dilution;
- pH neutralization;
- Metal sorption and precipitation by river nutrients;
- Colonization by aquatic organisms;
- Nutrient enrichment for food webs;
- Sedimentation that caps reactive pit rock;
- Promotion of primary production through nutrient inputs resulting in phytoremediation;
- Inputs of organic substrate for sulfate reduction, and;
- Stabilization of meromixis if desired, sequestering contaminants in the monimolimnion [1].

They describe the major risks of the technique to be:

- Potential solute inputs, increasing meromixis;
- Introduction of riverine nutrients, organic pollutants and metals;
- Establishment of pest species not suited to the proposed ecosystem;
- Eutrophication due to nutrient inputs;
- Nutrient removal from the overall system due to entrapment in the monimolimnion;
- Reduced short-term nutrient availability due to P inputs;
- Is more important as a long-term strategy and requires analysis against short-term risks, and;
- Enrichment of an existing monimolimnion may occur and pose substantial risk in the event of lake mixing or degradation of the steady-state chemocline [1].

In addition to these risks, the authors also caution that the success of flow-through strategies must consider the potential effects of climate change on expected flow and may require significant infrastructure and hydrological management and monitoring to withstand variable flow scenarios.

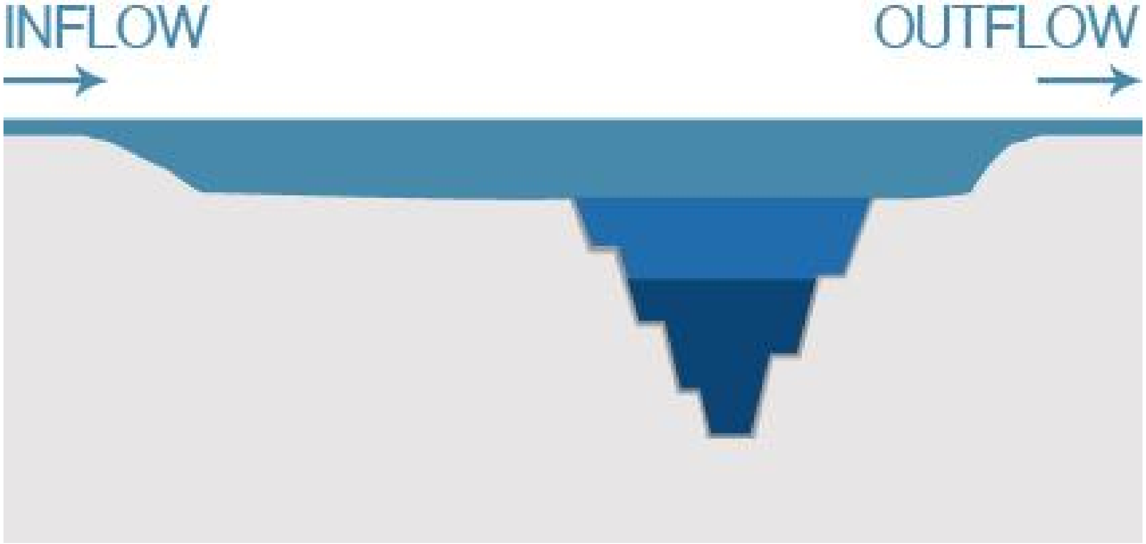

Figure 4: Engineered flow-through of a submerged end pit lake: habitat-enriched inlets and outlets are connected to the local watershed, assisting in reclamation of the lake as habitat and providing continuity with the regional landscape.

1.2.7.5 Engineered Habitat

If productive habitat in end pit lakes is to be established, it is assumed to usually require thoughtful engineering to promote successful species proliferation at all levels of the food web. In a study comparing the invertebrate communities of pit and reference lakes, open water macroinvertebrates (e.g. Coleoptera and Hemiptera) dominated the pit lakes while those associated with more complex habitats were scarce—an effect the authors contribute significantly to the lake slope [4]. Habitat heterogeneity, including a substantial littoral zone and macrophyte cover, which were lacking in the pit lake, were determined to promote species richness and abundance (and that moderates predation) [4]. They suggest that increasing the macrophyte community through littoral seeding and the introduction of floating wetland islands can significantly diversify the invertebrate community, a prerequisite for establishing a healthy fish habitat.

To date, most research on pit lake quality has documented efforts to improve water quality, not the effects of habitat engineering. If a community of fish is to be established in a pit lake, the species chosen must either be adapted to subsistence on a pelagic diet or a concerted effort must be made to improve the littoral ecology [4]. Appropriate habitat and fish-ways for inter-system movement and successful spawning must be created [6]. With this in mind, northern climates and ecology present a unique challenge amidst already-limited research and so any opportunity to study fish use of engineered habitat in these climates would be valuable.

1.2.8 End Pit Lake Reclamation Case Studies

1.2.8.1 Lake TR-33, Germany

A historical (pre-1900) lignite mine, Lake TR-33 has not been subject to anthropogenic remediation but rather began a natural neutralization process 38 years following pit flooding [19]. Although not yet home to a viable fish population, the lake provides an estimate of the projected timeline of un-assisted pit lake neutralization; lake neutralization lasted approximately 23 years (61 years post flooding) and experienced four distinct stages:

1. A shallow, sandy reservoir containing fine lignite particles and very poor diatom and cladoceran communities;
2. A deep acidic water body with increasing phyto- and zooplankton abundance;
3. A transitional lake with benthic and planktonic flora and fauna with wide ecological tolerances; and
4. A circumneutral lake with increased planktonic taxa that prefer fertile waters (eutrophication) [19].

1.2.8.2 Sphinx Lake, Canada

Sphinx Lake comprises a former Albertan coal mine that has been partially backfilled, flooded, and connected to the local watershed via a clean water diversion [1]. The key engineered reclamation strategies were the creation of inlet and outlet channels to the lake and the provision of varying water depths and substrates that support diverse habitats. Following successful establishment of fish, invertebrate, zooplankton and aquatic plant communities, downstream water temperatures were observed to be greater than upstream and than that of non pit lakes; however, downstream rainbow trout populations were greater than previously observed and substantial populations of both native rainbow and bull trout were observed in the lake—Species of Special Concern in that province [1].

1.2.8.3 Lake Kepwari, Australia

A three-year flow-through study of a former coal pit lake found that a suite of remediation strategies could lead to successful reclamation of end pit lakes as habitat. Using nutrient additions to reduce metal/metalloid concentrations, acidity neutralization to increase pH, and flow-through hydrologic connectivity, the water of the lake has significantly improved and reduced the risks posed by the retired mine [20]. As result, the abundance and diversity of aquatic biota has significantly increased and shifted to the functional ecology of a more typical freshwater lake [20].

1.2.9 Summary

This literature review was conducted to understand the current status of knowledge regarding fish use of end pit lake habitat, and variables affecting successful establishment of fish populations. It aimed to identify key areas of uncertainty regarding the habitat suitability of pit areas.

Likely effects of habitat diversity, stratification, water quality, and climate change on the ability of pit lakes to provide functioning aquatic habitat were considered. Available case studies on fish use of pit lakes were reviewed. These consisted of just three pit lakes from Germany, Australia, and Alberta, Canada. While viable fish populations were successfully established in these cases, overall it is clear that information on pit lake use by fish is very limited, and studies tend to focus on water quality rather than habitat-based variables. The planned research studies will therefore provide valuable information to support policy development around use of pit lakes in fish habitat offsetting plans.

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1.3 PRELIMINARY STUDY OUTLINE

1.3.1 Study Site & Research Collaboration

Due to the projected timeline for the re-flooding of potential study pits at the Meadowbank site (2027 – 2029), Agnico is currently in search of a potential industry collaborator for this project. The ideal collaborator would be a Northern metal mining operation with a pit lake or compensation lake planned to be flooded and suitable for fish access within the next few years. However, Agnico is not aware of any such sites. Agnico is currently reaching out to other industry representatives (diamond, coal & oil sites) in hopes of identifying potential partnerships.

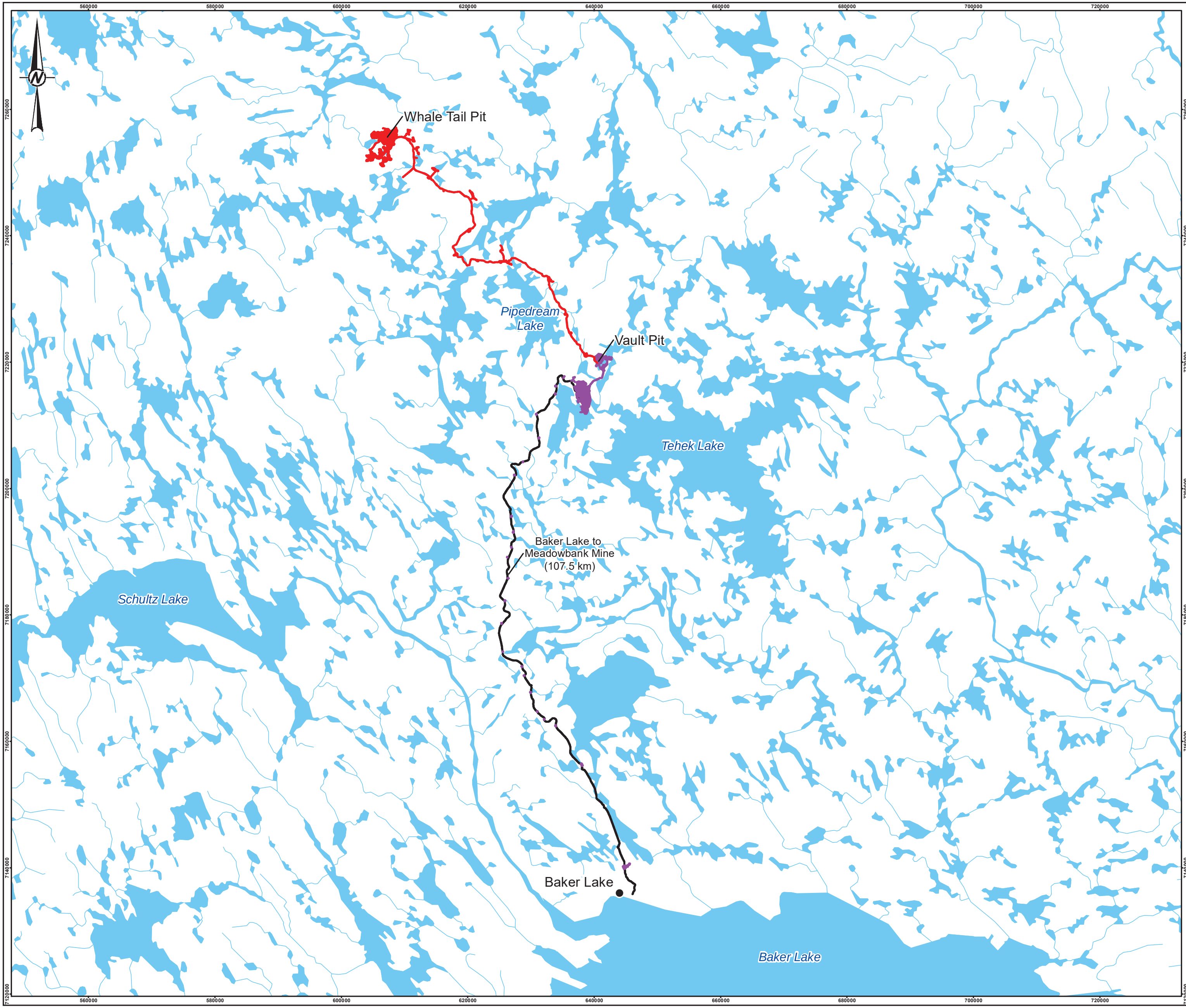
The study outline presented here has been developed with potential Meadowbank study areas in mind (e.g. Phaser Pit, BB Phaser Pit, Vault Pit, Whale Tail Pit – Figure 1), however it is presumed to be readily adaptable to other locations.

Finally, it is noted that academic research partners will not be identified until a study site and project timeline are finalized. As a result the outline presented below is preliminary, and anticipated to be further developed in consultation with the research group.

1.3.2 Research Goal

With a view towards supporting policy development around the use of pit areas and pit lakes in fish habitat offsetting in the North, research studies will focus on fish use of pit lake habitat types (e.g. deep water pit areas, pit photic zones, steep-walled pit edges), and how those uses change over time as lake ecosystems become more established. Adequate water quality within pit lakes will be required to introduce fish and study population development. As a result, water quality modeling and validation research will not be the focus of these studies, but will be a pre-requisite component of establishing a research site. Changes in water quality will, however, be monitored throughout the study and related to fish movements and population growth parameters. Frequency and spatial scale of water quality analyses will be consistent with model outputs. Based on the literature review, analytes of particular interest will be pH, DO, salinity, turbidity and concentrations of nutrients and potentially toxic metals. As a result, water quality model validation could be included in study goals depending on interests of the researchers and guidance of the Meadowbank Fisheries Research Advisory Group (MFRAG). Depending on the site chose, it is likely that water quality monitoring will be conducted to some degree as a site license requirement (as for the Meadowbank site NWB Type A Water License), but supplemental analyses could be considered as required for research purposes.

Similarly, habitat diversity in keeping with natural lake systems is also assumed. While this may be engineered (as in Section 1.2.7.5), preliminary study design is based on the Meadowbank pit



LEGEND

●	COMMUNITY
🟥	HAUL ROAD
—	ALL WEATHER ROAD
🟥	WHALE TAIL PIT
🟪	MEADOWBANK OPERATION AND INFRASTRUCTURE
—	WATERCOURSE
🟦	WATERBODY

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REFERENCE(S)
1. HAUL ROAD OBTAINED FROM AGNICO EAGLE MINES LIMITED.
2. WATERCOURSE AND WATERBODY DATA OBTAINED FROM CANVEC © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
3. INSET MAP DATA OBTAINED FROM ESRI.

DATUM: NAD 83 CSRS PROJECTION: UTM ZONE 14

CLIENT
AGNICO EAGLE

AGNICO EAGLE MINES LIMITED:
MEADOWBANK DIVISION

PROJECT
WHALE TAIL PIT - EXPANSION PROJECT

TITLE
PROJECT LOCATION

CONSULTANT
GOLDER

YYYY-MM-DD	2018-11-22
DESIGNED	JR
PREPARED	CDB
REVIEWED	JR
APPROVED	DF

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lakes, which are characterized by pit areas (some deep and some backfilled) contained within the dewatered basins of natural lakes. The morphology of these lakes is different from isolated pits, as flooded pit areas are surrounded by lake habitat at natural depths with a large proportion of littoral zones intact. Thus, while in-depth habitat assessments will be performed as a component of the study, no habitat engineering to create additional littoral zones is planned at this time.

Based on this review and experience with data gaps in aquatic habitat suitability modeling, primary research questions are identified as:

- How do fish use pit areas of re-flooded lakes (e.g. which species, for which life functions)?
- Do the species using pit areas and/or functions provided by these areas change over time as re-flooded habitats become more established and populations grow?
- How are movements and habitat use affected by water quality/stratification?
- How do the functions provided by pit areas differ from natural deep water basins?
- Do engineered features (e.g. pit backfilling, constructed shoals) provide the same quality of habitat within re-flooded basins as similar natural features?

Amendments to the questions or supplemental research goals will be determined in consultation with academic partners, and the MFRAG, and in particular will be refined once a study site is confirmed.

1.3.3 Study Timeline

The following general study timeline is presented based on use of the Meadowbank pit lakes, but may be compressed if another study site is identified in the nearer term. General methods are provided in Appendix A and except where supplemental analyses are included (i.e. invertebrate populations, fish habitat associations) these are consistent with methods used historically under the Meadowbank Habitat Compensation Monitoring Plan (2017) and Core Receiving Environment Monitoring Plan (2015). Detailed methods will be further determined in consultation with academic partners, once identified.

Study Design (Study Year 1[1]*)*

- Site selection
    - Based on available collaborations, favourable water quality predictions, & sufficient habitat diversity within the potential study lake
    - May require a review/update of water quality models
- Preliminary academic partner identification
    - To be finalized in consultation with MFRAG, may change depending on study site selection and final study timeline

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[1] Based on current re-flooding plans for the Meadowbank site, re-flooding of the Vault and Phaser pits will begin in 2024 and be complete in 2027 – 2029. Therefore the initial study year (Study Year 1) will be 2021.

- Final study design
    - Pending academic partner identification

Pre-flooding (Study Years 2 & 3)

- Reference lake identification
- Habitat mapping
    - Prior to flooding, a complete analysis of habitat types within the pit lake and reference lake will be conducted. This is likely to include use of high-resolution aerial photography, and/or LIDAR imagery, combined with ground truthing.

Flooding (Years 4 – 7)

- General water quality monitoring of study lake and reference lake

Early Post-flooding (Years 8 - 9) - all subsequent phases assume adequate water quality for fish introduction.

- Water quality monitoring
- Periphyton growth assessment
- Invertebrate population assessment
- Fish habitat associations

Late Post-flooding (Years 12 – 13)

- Water quality monitoring
- Periphyton growth assessment
- Invertebrate population assessment
- Fish habitat associations

1.3.4 Project Deliverables

In accordance with the Fish Habitat Offsetting Plan for Whale Tail Pit (March, 2018), project deliverables will include development of peer-reviewed manuscripts for publication in the scientific literature and presentations by researchers at relevant scientific conferences.

Due to the staged nature and extended timeline of this study, multiple interim presentations and publications will be targeted. For example, it is anticipated that reports could be presented on methods development for habitat mapping (Study Year 4), as well as publications on both early and late post-flooding conditions (Study Years 10 & 14). As mentioned above, if a study collaborator is able to be identified in the nearer term, this timeline is expected to be compressed.

APPENDIX A

Preliminary Study Methods

PRELIMINARY STUDY METHODS

The following general methods are consistent with Meadowbank's Habitat Compensation Monitoring Plan (February, 2017). Detailed and supplemental methods for assessment of end pit lake habitat use will be determined in consultation with academic partners, once identified.

1.1 INTERSTITIAL WATER QUALITY

Interstitial water quality monitoring will be used to verify predictions regarding leaching of metals from quarried rock used to construct underwater features (e.g. dike faces, rock fill).

In order to collect a representative sample from the bioactive zone between the rocks, an electric diaphragm pump with food-grade silicon tubing is used. If possible, samples will be taken at depths between 1 and 4 m, and analyzed in an accredited laboratory for total suspended solids, and total and dissolved metals. Results will be compared to background concentrations, CCME guidelines where available, or Core Receiving Environment Monitoring Program (CREMP) threshold values.

1.2 OPEN BASIN AND PIT WATER QUALITY

Water quality within both natural lake basin and pit areas will be monitored during and post-reflooding, at a frequency and spatial scale to be determined based on license requirements and final research questions.

Water samples will be collected from approximately 3 m depth by pumping lake water using weighted flexible (food-grade silicone) tubing, and a diaphragm pump connected to a 12 volt battery. A syringe filter is used when filling bottles for dissolved metals and dissolved organic carbon analyses. At a minimum, parameters to be monitored include:

Total and dissolved metals: aluminum, antimony, arsenic, boron, barium, beryllium, cadmium, copper, chromium, iron, lithium, manganese, mercury, molybdenum, nickel, lead, selenium, tin, strontium, titanium, thallium, uranium, vanadium and zinc

Nutrients: Ammonia-nitrogen, total kjeldahl nitrogen, nitrate nitrogen, nitrite-nitrogen, ortho-phosphate, total phosphorous, total organic carbon, total dissolved organic carbon and reactive silica

Conventional Parameters: bicarbonate alkalinity, chloride, carbonate alkalinity, conductivity, hardness, calcium, potassium, magnesium, sodium, sulphate, pH, total alkalinity, TDS, and TSS, turbidity;

Total cyanide and free cyanide: If CN total is detected above 0.05 mg/L in an analysis result for monitoring station in receiving environment; further analysis of CN WAD will be triggered.

Organic Parameters: chlorophyll-α, dissolved and total organic carbon;

Supplemental Analyses: Vertical depth profiles of temperature, DO and conductivity to a representative depth. Secchi depth and surface pH.

Results of water quality monitoring will be compared to background concentrations, CREMP trigger or threshold levels, CCME guidelines where available, and any site-specific criteria.

1.3 PRIMARY PRODUCTION

The periphyton community consists of a collection of microorganisms, including algae, that grow attached to or in very close proximity to submerged substrate. Colonization of the community occurs over time, with rates depending on nutrient and light availability. Periphyton is an important food source for benthic invertebrates, so colonization will be monitored to ensure that quarried rock substrate and re-flooded natural substrate provides habitat that is as suitable at this level of the food chain as untouched natural substrate.

Periphyton Samplers: Briefly, a specialized scrubber will be used to collect periphyton samples from a prescribed area of rock face, in order to calculate cell density and/or biomass (µg/cm^2). This method will be appropriate to assess growth of periphyton in the flooded littoral zone and on surface-accessible constructed features.

Underwater Video: For deeper areas (constructed shoals, backfilled pit areas, pit benches and side walls) underwater video will be used to make qualitative assessments of periphyton growth.

Results will be compared to reference sites, baseline data, and/or historical monitoring programs.

1.4 INVERTEBRATE POPULATIONS

Development of invertebrate populations is an important link in assessing potential for ecological functionality of aquatic systems. Benthic invertebrate sampling for the end pit lake study will follow Meadowbank CREMP monitoring methods to facilitate comparisons to reference areas. Since that program has found limited utility in zooplankton monitoring due to very high variability and low statistical power, zooplankton methods are not specifically planned or discussed here.

Benthic invertebrates are collected first in the sequence, using a Petite Ponar grab (0.023 m2) and a 500-µm sieve. Two independent grabs per replicate are composited to form a single sample to reduce sampling variation within areas and to increase the surface area sampled. Samples are preserved in the field with a 10% buffered formalin solution and sent for taxonomic identification and analysis.

1.5 FISH HABITAT ASSOCIATIONS

In general, analyses of fish populations in reflooded pit lakes will aim to determine if the system has reached full ecological functionality (i.e. supports fish reproduction, growth, and survival). While some assessments of this type may be required under site licenses (depending on the final study site), more intensive methods are proposed to specifically track habitat associations and answer the research questions identified.

While the following approaches are suggested based on past experience, Agnico will aim to build on results of method development from Whale Tail Pit Project Fish Habitat Offsetting Plan – Complementary Measures, Study 3: Literature review and field validation of Northern lake fish habitat preferences. This is a two-year study being lead by Dr. Sue Doka, and aims to test and develop methods around assessing habitat preferences for Northern fish species.

It is anticipated that use of pit areas by large-bodied fish will primarily be assessed through an acoustic tagging program. This will likely be complemented with annual hydroacoustic sonar surveys to estimate changes in population size. The number of fish to be tagged will depend on the final study site size. Underwater video techniques could also be used to specifically identify fish use of pit side walls and benches. Night-time spawning surveys will be used to identify reproductive behaviours.

Methods for assessing habitat use and population development of small-bodied fish could include electrofishing and potentially minnow traps in littoral zones.

Since the use of gill nets has historically been found to result in elevated incidences of mortality, these will be avoided in newly flooded lake areas which will be assumed to have initially low population density.

Results of all analysis will be compared to reference areas and/or historical results, as the dataset allows.