Kugaaruk Sewage Lagoon Study

Final Report

Prepared for:
Government of Nunavut
Community and Government Services

Prepared by:
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Project No. 1101 26041

June 1, 2016

Sign-off Sheet

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Executive Summary

The sewage lagoon serving the Hamlet of Kugaaruk is a rectangular earth berm structure, with an internal geomembrane to provide sewage retention. The facility was commissioned in 2009, and it has been operating almost continuously since then. In 2014, seepage from the toe of the south berm was first observed, and no other deterioration in the berm structures was reported.

A site inspection and review of the existing structure by Stantec in July 2015 identified a notable flow from the base of the lagoon on the south side. The flow originates from two general areas on the south berm, and within these areas are 4 distinct sources with varying degrees of flow that contribute ultimately to one main channel of flow to the ocean, and one minor channel of flow to a beach area. A single point of minor flow was also observed in the south west corner, and this flow infiltrates into the ground within 20 metres of the toe of the berm.

The absence of sagging, sloughing or other deformation of the perimeter berms suggests that the berms remain geotechnically stable. It is indeterminate how any instability may progress or over what timeframe. If seepage accelerates, the opportunity for material loss increases, which will negatively impact the geotechnical stability of the berms.

The seepage from the berm was confirmed to be sewage with several samples taken and tested. The test results indicate that the seepage is above the effluent quality parameters for the facility, which is a non-compliance issue in the context of the water licence. The seepage may also be an environmental and public health concern with its discharge into the ocean, particularly with the discharge path in proximity to a beach area that may be used for camping and recreation.

Options for remedial work on the lagoon were developed, and include remedial work to eliminate the seepage, and remedial work to manage the seepage. The remedial work to eliminate the seepage has capital costs in the range of $1 million to $4 million, although a very low probably of success, and zero cost option was identified to eliminate seepage by the accumulation of sewage sludge. The remedial work to manage the seepage has capital costs in the range of $640,000, to $1 million.

It was recommended that a plan be prepared to address the management of the seepage to satisfy the current concerns of the regulators; a dialogue with the Nunavut Water Board should also be initiated for consideration of minor continuous discharge. It was also recommended that additional topographic data be collected on the south and west portions of the lagoon to develop a more accurate estimate of work necessary to construct a seepage diversion channel.

1.0 INTRODUCTION

1.1 PROJECT LOCATION

Kugaaruk is located on the northeastern mainland, 524 km east of Cambridge Bay, on the shore of Pelly Bay, just off the Gulf of Boothia, on the Simpson Peninsula. Access to the community is by air to and by annual supply sealift.

As of the 2011 census, the population was 771, an increase of 12.1% from the 2006 census.

The terrain is rocky and there are large outcrops of bedrock interspersed with plains of glacial till. There are also many shallow lakes in and around the community. The terrain around the sewage lagoon itself is generally steep with bedrock in close proximity to the surface, and numerous bedrock outcrops.

The community lies north of treeline in the Southern Arctic Tundra biome, a region commonly referred to as the "Barren Grounds." Rock surfaces are often bare, while much of the landscape is sparsely covered by grasses, and other arctic vegetation.

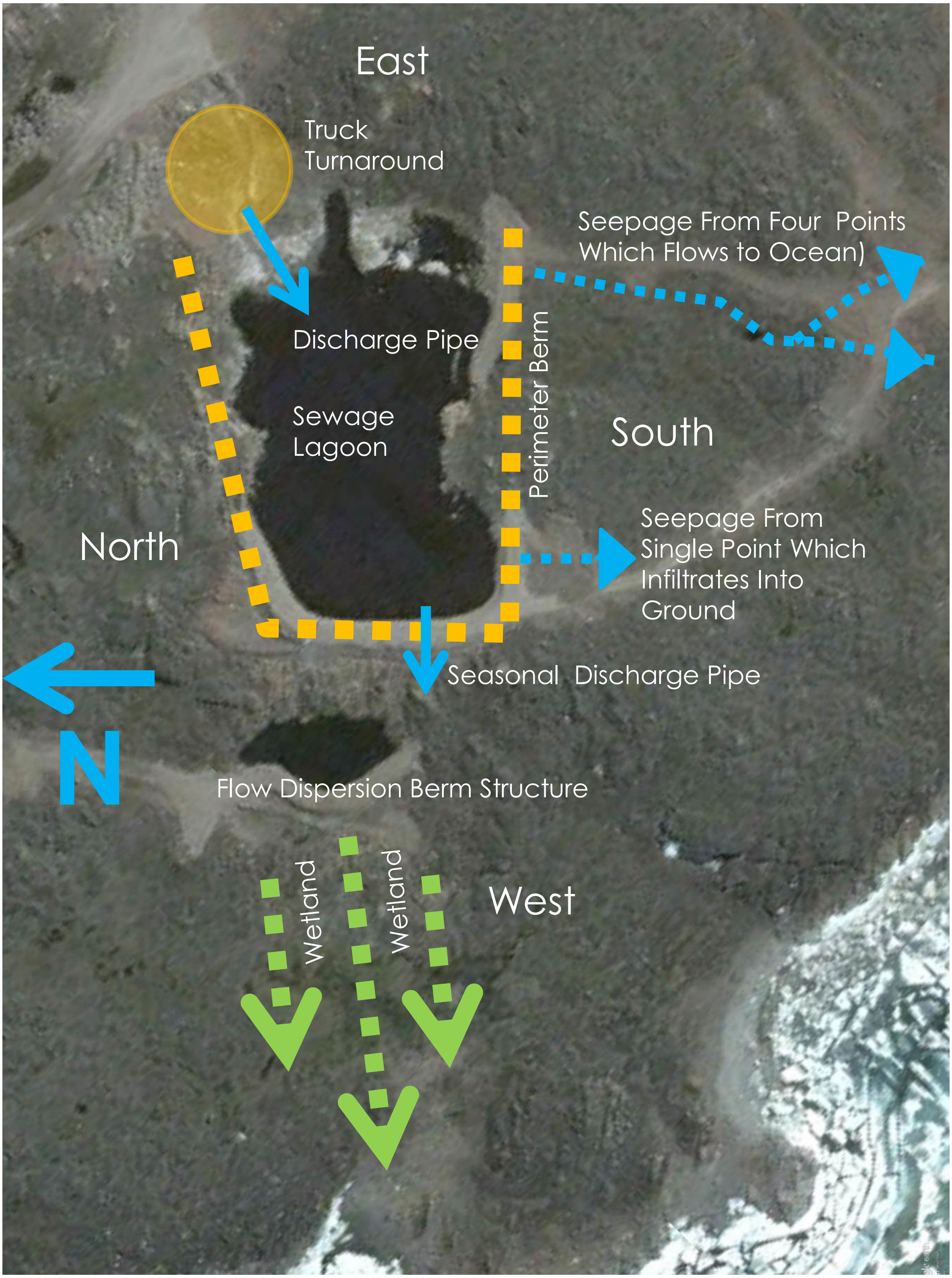
The region has an arctic climate, with very cold winters, light snowfall, and cool summers. July has a mean daily temperature of 7 °C, and January has a mean daily temperature of – 33 °C.

1.2 PROJECT BACKGROUND AND OBJECTIVES

The sewage lagoon serving the Hamlet of Kugaaruk is a granular earth berm structure (See **Figures 1 and 2**), which was a reconstruction of an existing un – engineered pond that was previously used for wastewater detention. The lagoon has a rectangular configuration approximately 150 metres long and 90 metres wide, and an impermeable bentonite membrane integral within the berm structure.

The original pond system was a "leaky" lagoon which discharged into a lower pond that ultimately discharged into a wetland area to the west of the site. Engineered improvements were completed in 2009 to increase the lagoon size to provide sewage retention and to provide a controlled discharge into the previously used secondary pond system and wetland.

The facility was commissioned in 2009, and it has been operating almost continuously since then. Until 2014 no significant operating related issues had been experienced, other than the use of a pumped discharge from the lagoon instead of a piped discharge due to freezing of the discharge pipeline. In 2014, seepage from the toe of the south berm was first observed. No additional observations regarding the development or change in the seepage were available over the course of the first half of 2014. No other deterioration in the berm structures has been reported.



Hamlet of Kugaaruk, Nunavut

Sewage Lagoon Assessment

FIGURE 1. Satellite Image

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Northwest corner looking southeast

Discharge control manhole on west side flowing onto flow dispersion berm structure

Seepage from toe of south berm

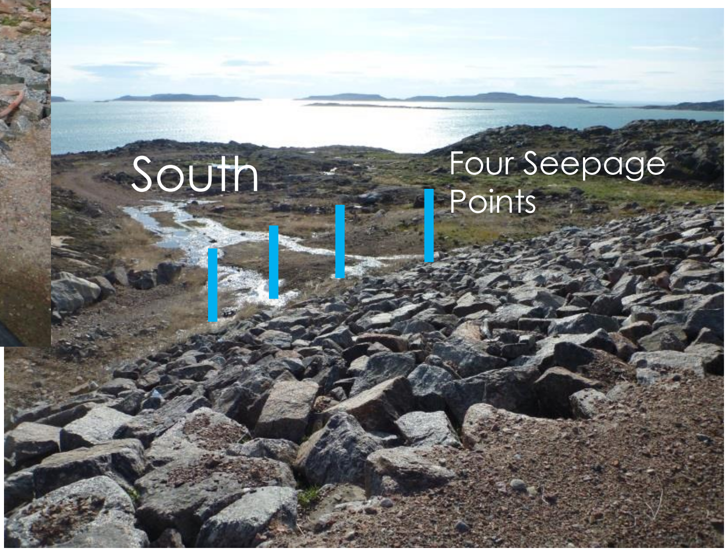

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FIGURE 2. Site Photographs

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Stantec was been retained to provide an assessment and planning report on remedial work to the Kugaaruk sewage lagoon in response to the specific seepage issue in the berm structure that has occurred over the course of past year. With the potential need for short term remedial work in the 2015 construction season, Stantec prepared an interim report concerning short term remedial action to address the seepage in the south berm of the facility (See **Appendix A**).

2.0 PREVIOUS REPORTS AND STUDIES

The following subsections provide a summary of the previous studies, reports and documents that were reviewed as background information for the current assignment.

1. Sewage and Solid Waste Site, Detailed Design Phase 2 (Dillon Consulting Ltd., July 2007). This report contains the detailed design for the rehabilitation and expansion of the Lagoon intended to meet the needs of Sewage disposal of the Hamlet for the next 20 years (2008 to 2028). The proposed design includes demolishing and reconstructing the existing berms, installation of synthetic liner, expansion of the storage capacity of the Lagoon to 46,300 m^3, new truck pad, and new decanting and drainage systems. The construction of this phase was completed at the end of 2008.
2. Municipal Water Use Inspection Report (Indian and Northern Affairs Canada, August 2008). In this report the quality of the discharge and the decanting structure were rated as unacceptable since during the time of inspection upgrading work was underway and temporarily the sewage was being dumped in the decanting area which flows to small wetland and ultimately discharge into the ocean.
3. Water Use Inspection Report (Indian and Northern Affairs Canada, August 2009). In this report all the lagoon structures were rated acceptable and the completion of the upgrading works acknowledged. The only concern was the icy conditions in the discharge chute due to the sewage splash during truck delivery. The Hamlet is advised to modify delivery practices in order to prevent spills.
4. Water Use Inspection Report (Indian and Northern Affairs Canada, July 2010). In this report the discharge quality, the decanting structure, and seepage were rated as unacceptable. The annual scheduled decanting did not take place due to freezing of the discharge pipe. A secondary cell was constructed below the level of the primary cell to contain seepage from the primary cell without a discharge pipe so it was assumed that the flow would discharge as effluent reaches the top of the berm of the secondary cell down into the ocean. The inspector requested that the Hamlet submit a plan for compliance with the licence requirements.
5. Dam Safety Review for the Kugaaruk Sewage Lagoon (Dillon Consulting Ltd. - Amec, November 2010). On behalf of Dillon Consulting Ltd., AMEC Earth and Environmental carried out a Dam Safety Review. The purpose of the study was to conduct a geotechnical review of the site (Sept 13 to 16, 2010), as well as, review of the following documents: Licence 3BM-PEL0712 (September, 2007), Sewage Lagoon Cut-off Trench Construction Monitoring Report (October, 2007), and Sewage & Solid Waste Sites – Record Drawings (December, 2009). From documentation review, Amec reported that some activities were not compliant with specifications such as location of the manholes, broken equipment during compaction that lead to use alternative measures; however, densometer tests confirmed that compacted material met specifications. The cut-off trench was partially completed by fall 2007 and needed to be fully completed in the

spring of 2008. From the site visit, Amec reported that seepage was not observed in the slopes of the dam and the external slopes looked stable. The flume culvert, lagoon drainage outfall, and emergency overflow were inspected and found in good condition according to the report. Amec recommended developing an operation manual and keeping operation records of the dam.

6. Municipal Water Use Inspection Report (Indian and Northern Affairs Canada, July 2011). In this report the lagoon structure was rated as acceptable. Records of the operation and sampling of the lagoon were not available for inspector review.
7. Multi Year Municipal Compliance Summary Licence 3BM-PEL0712 (Overview 2007-2012). This summary contains the list of activities not compliant with the terms of the Licence such as record keeping, monitoring programs, operation manuals, filing annual report and compliance plans.
8. Annual Report Hamlet of Kugaaruk (2011). In this report the quantity of water drawn from all sources and quantity of sewage discharged was reported as same and equivalent to 27,587,527 liters. Modifications or unauthorized discharges were not reported for the sewage lagoon. The results of sewage lagoon sampling conducted in July 2012 were reported and showed that the lagoon was in compliance with the treatment goals established in the Water Licence.
9. Kugaaruk Water Licence Annual Report 2013 (February, 2014). In this report the quantity of water drawn from all sources and quantity of sewage discharged was reported as same and equivalent to 27,696,366 liters. Modifications or unauthorized discharges were not reported for the sewage lagoon. The report states that yearly monitoring program has been implemented. The results of sewage lagoon sampling conducted in July 2013 were reported and showed that the lagoon is in compliance with the treatment goals established in the Water Licence.
10. Kugaaruk Water Licence Annual Report 2010 (May, 2014). This report is submitted 3 years past the due date, however, it is done in an effort to fulfill outstanding obligations from previous years. The quantity of sewage discharged was reported to be 27,200 $m^{3.}$ The upgrades of the Sewage Lagoon are described and the new capacity is reported as 46,000 m^3. The geotechnical safety review conducted by Amec in 2010 is also acknowledged. It is reported that sludge sampling and management is under planning to be conducted in the near future.
11. Kugaaruk Water Licence Renewal (May, 2014). The Water licence of the Hamlet of Kugaaruk was renewed for a period of 5 years up to May 2019 (Licence 3BM-PEL1419). The NWB set a maximum water usage for all purposes of 45,000 m^3 per year or up to 170 m^3 per day. The requirements for the operation of the sewage lagoon include: submitting annual reports, Implementation of the sewage treatment facility operation and maintenance plan, complying with monitoring plan, conducting wetland assessment and geotechnical inspection, and implementing QA/QC plan for sampling, monitoring and reporting. The effluent discharged from the wetland treatment areas shall not exceed the following limits:

- 45 mg/L BDO5
- 45 mg/L TSS
- No visible sheen of oil and grease
- pH between 6 and 9
- 10exp4 CFU/dL of Fecal Coliforms

12. Water Licence Inspection Report (Aboriginal Affairs and Northern Development Canada, August 2014). In this report the wastewater disposal facility was rated as acceptable. The inspector noticed that sewage lagoon was not operating according to the O&M plan due to a frozen valve located in the pipe that conveys sediment from the lagoon to the sediment pond. The operators are pumping sewage to the sediment pond and allowing the effluent to exfiltrate or overtop the sediment pond. According to the manual the operation of the lagoon should be passively allowing sediment to flow into the sediment pond, and actively decanting from the pond to the wetland. The inspector recommended if the valve is not going to be repaired the system must be assessed in order to rule out issues related to the integrity of the berm.
13. Dam safety review report for the lagoon prepared by (Exp, 2014). A geotechnical site reconnaissance was conducted by Exp in late July 2014. No seepage from the lagoon was identified at the time of reconnaissance and interviews with Hamlet staff did not suggest any lagoon integrity issues.

3.0 SITE INSPECTION

A site inspection of the Kugaaruk sewage lagoon was completed in July 20, 21, 22, and 23, 2015 by Ken Johnson, M.A.Sc., P.Eng.; several strategic photographs concerning the lagoon and elements of the inspection are presented in **Figure 2.** A synopsis of the inspection and the notable features of the facility are presented in **Figure 3.** The inspection was completed with walking excursions along the top of the berm (walking in both directions), and along the exterior base of the south berm (walking in both directions). The excursions were documented with high definition (1080p) video and digital photographs.

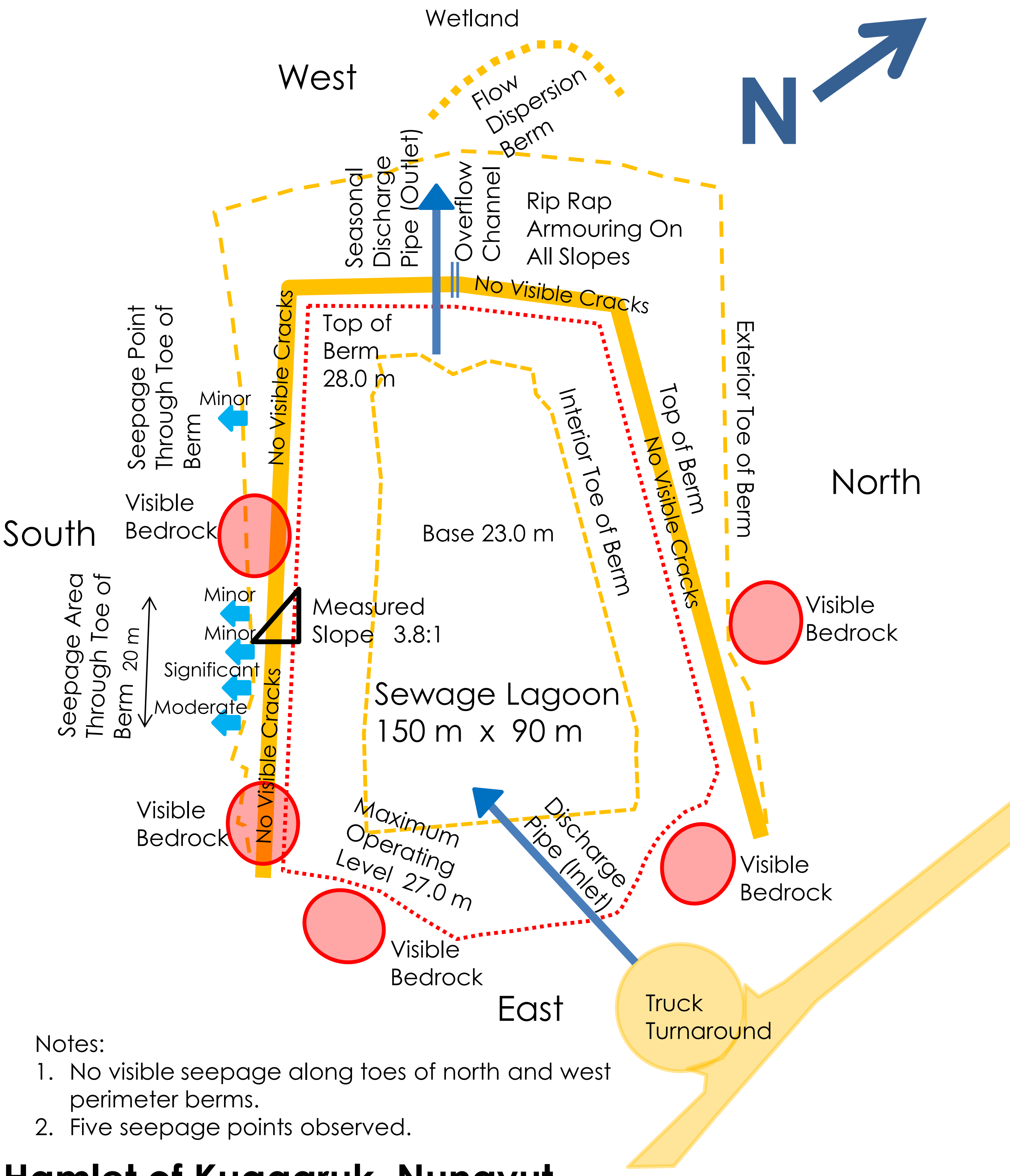
Some infrared photos were taken, as well, above the seepage points in the berms as a potential means to collect supplementary information on the origin of the seepage in the berm structure. However, the rip rap armouring shielded the granular surface of the berm from any meaningful infrared imagery, and the results were inconclusive.

Concerning the top of the berm, there was no visible deterioration in the berm structures along the north, west and south berms (See **Figures 4 and 5).** The east berm, where the truck discharge is located, shows visible bedrock and riprap armouring where the truck discharge is located. The proximity to bedrock is evident with visible bedrock outcrops in several locations around the lagoon perimeter, specifically in the east segment of the lagoon. The top of the berm structures have a 4 meter wide gravel surface. This gravel surface shows very little, if any, deterioration from surface erosion or other factors. The interior and exterior slopes are armoured with riprap with sizes generally greater than 30 cm in diameter.

The discharge structure for the lagoon is a pipe on the west side of the lagoon which discharges into a flow dispersion structure and ultimately into a wetland (See **Figure 6).** An overflow structure is also located on the west berm beside the discharge structure.

A notable flow from the base of the lagoon on the south side was clearly visible. The flow originates from two general areas on the south berm, and from specific flow points in each area. The flow area in the south east corner has 4 distinct points of flow (See **Figures 7 and 8**), with varying degrees of flow that contribute to two channels of flow immediately downstream, that form one channel of flow. A single point of minor flow was observed in the south west corner, and this flow infiltrates into the ground within 20 metres of the toe of the berm.

Further downstream, the flows from the south east corner separates into 2 channels once again (See **Figure 9)** with the majority of the flow travelling southwest (See **Figure 10)** and a minor flow travelling southeast. The flow travelling southwest ultimately discharges into the ocean, and the flow travelling southeast also discharges into the ocean. The ocean discharge of the southeast flow appears to be an area used for camping.



Notes:

1. No visible seepage along toes of north and west perimeter berms.
2. Five seepage points observed.

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FIGURE 3. Field Inspection Synopsis

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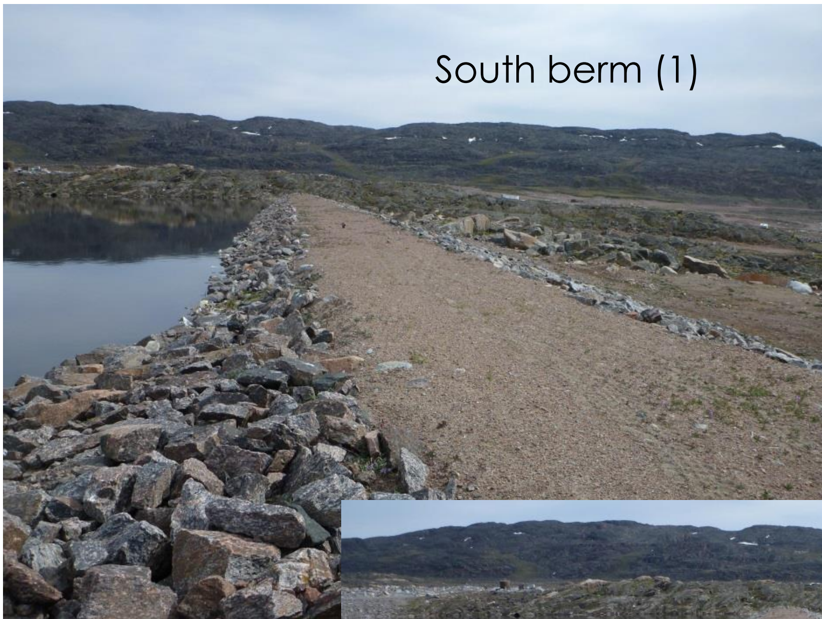

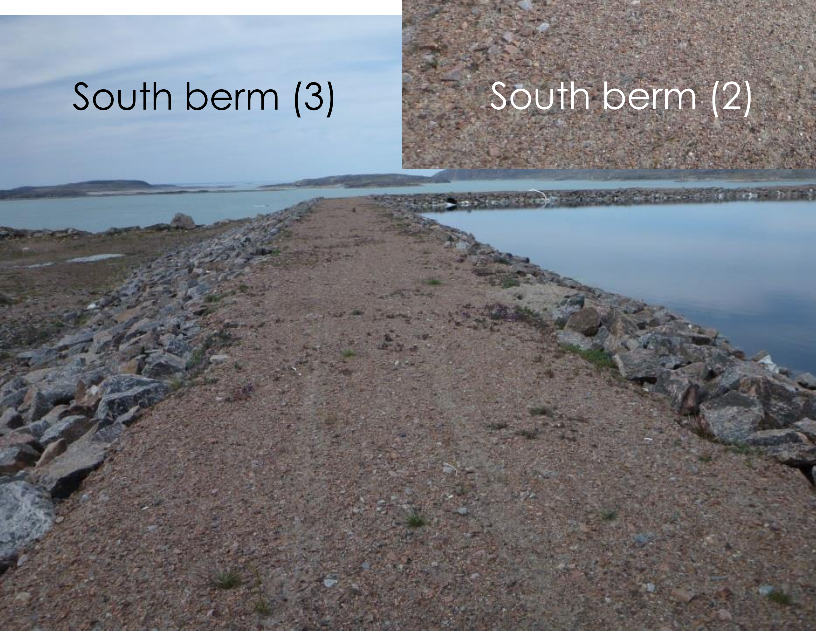

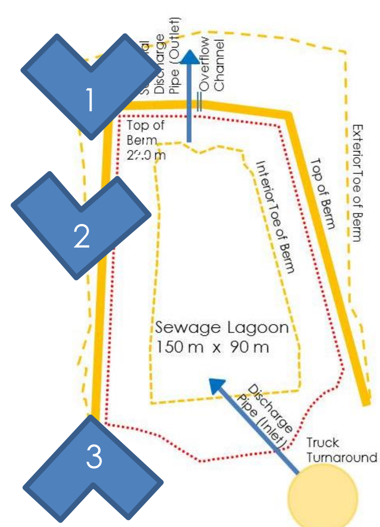

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FIGURE 4. Berm Condition - South

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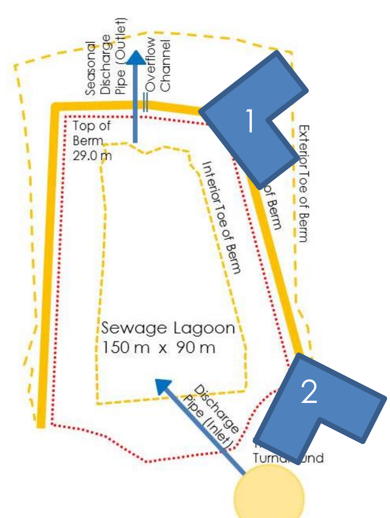

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FIGURE 5. Berm Condition – North/West

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FIGURE 6. Overflow and Discharge

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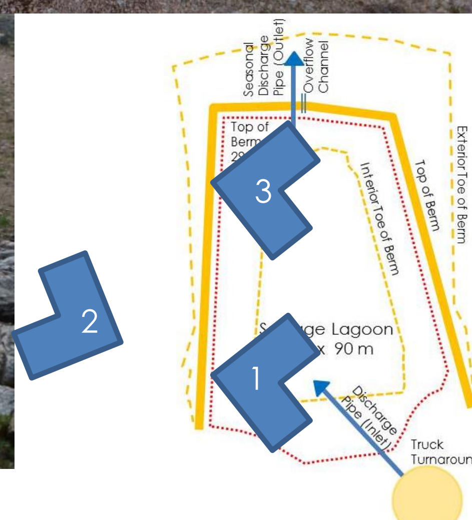

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FIGURE 7. Seepage Detail

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3.8 to 1 Slope

3.8 to 1 Slope

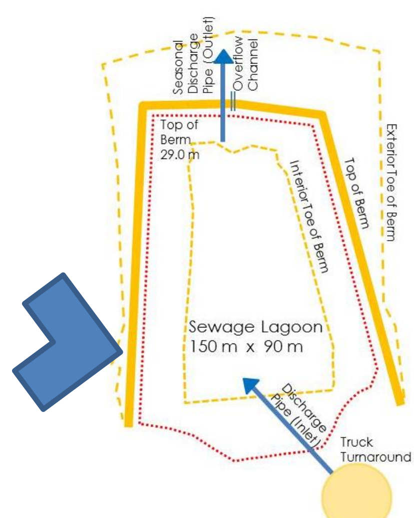

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FIGURE 8. Seepage Details

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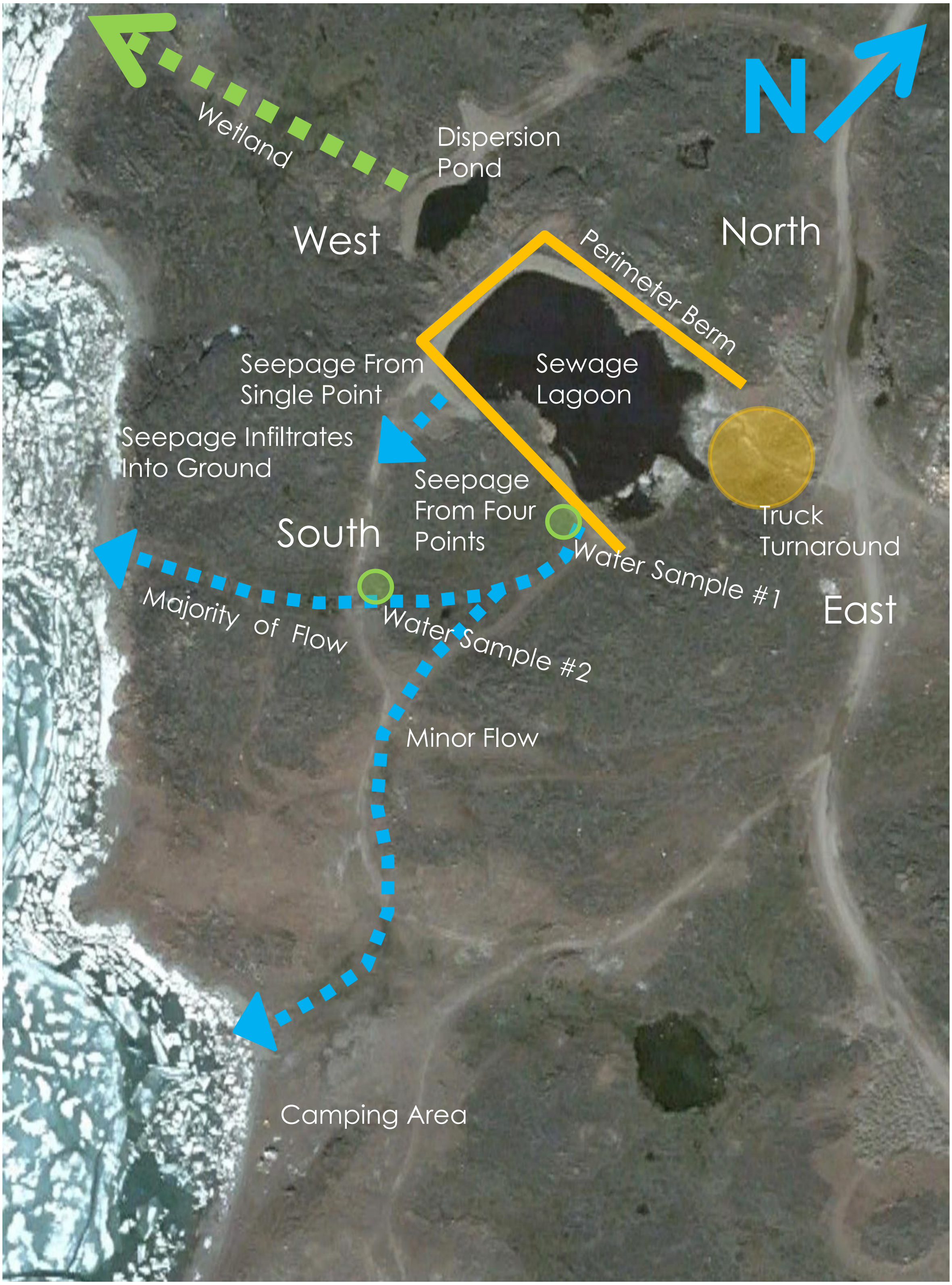

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FIGURE 9. Route of Seepage to Ocean

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FIGURE 10. Seepage Path

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The seepage from the perimeter berm was confirmed to be sewage with several samples taken and tested. The test results indicate that the seepage is above the effluent quality parameters for the facility, which is a non-compliance issue in the context of the water licence. The seepage may also be an environmental and public health concern with its discharge into the ocean, particularly with the discharge path in proximity to an area that may be used for camping and recreation.

4.0 TECHNICAL MEMO AND SHORT TERM REMEDIAL ACTION

An interim technical memo (See **Appendix A**) was prepared in August following the site inspection in recognition of the need and opportunity to provide a technical review and recommendations for preliminary intervention associated with the observed deterioration in the lagoon system, particularly along the southeast berm. The memo presented several options for preliminary intervention both active and passive. The seepage from the perimeter berm was confirmed to be sewage with several samples taken and tested. The test results indicate that the seepage is above the effluent quality parameters for the facility, which is a non-compliance issue in the context of the water licence. The seepage may also be an environmental and public health concern with its discharge into the ocean, particularly with the discharge path in proximity to an area that may be used for camping and recreation.

4.1 GEOTECHNICAL INTEGRITY

The presence of seepage from the perimeter berms reflects a loss of containment by the synthetic liner and/or its cut-off trench and not a containment failure of the perimeter berm itself (See **Figure 11**). The presence of seepage through the berms raises geotechnical integrity concerns for the berms as the seepage may lead to ground loss (piping) that could weaken or undermine the perimeter berms or reduce the geotechnical stability of the perimeter berms.

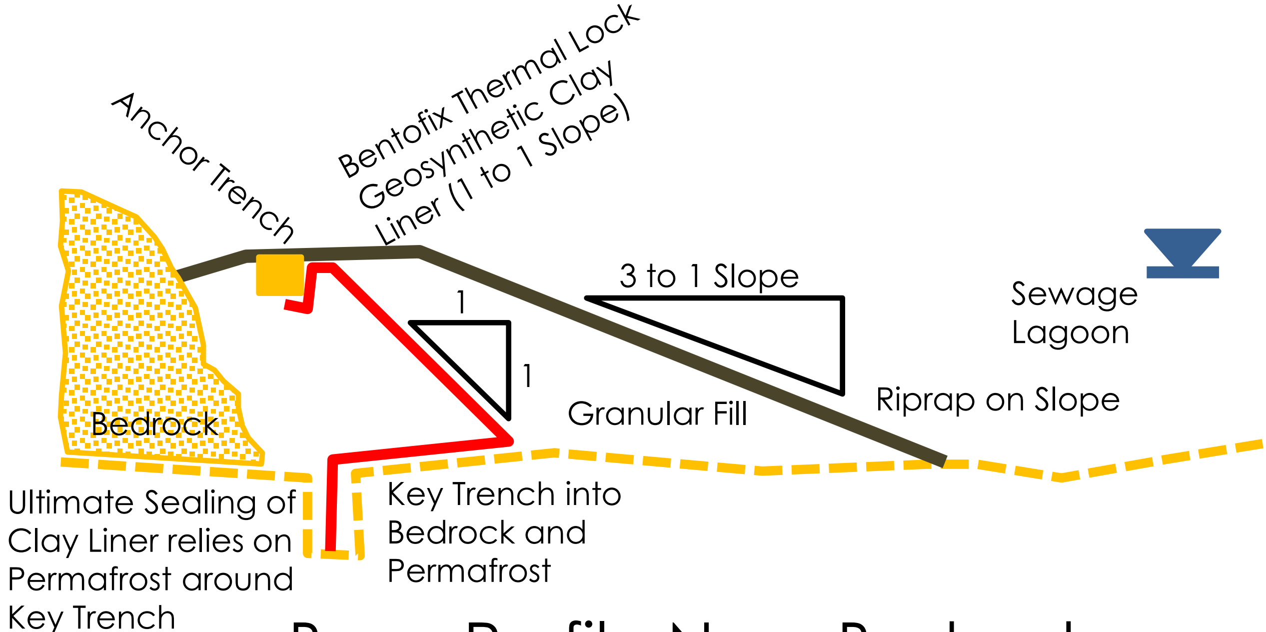
The absence of sagging, sloughing or other deformation of the perimeter berms suggests that the berms remain geotechnically stable. It is indeterminate how any instability may progress or over what timeframe. If seepage accelerates, the opportunity for material loss increases, which will negatively impact the geotechnical stability of the berms.

The design of the geosynthetic clay liner is shown in **Figure 11**; the design elements associated with the containment system are the liner itself, the liner keyed into bedrock and permafrost at the base, and an anchor trench at the top of the liner. The potential sources of leakage with this configuration may be a fault in the liner itself due to damage, or improper installation between panels of the liner, or a fault in the in the impermeability of the liner / bedrock / permafrost system at the base of the berm.

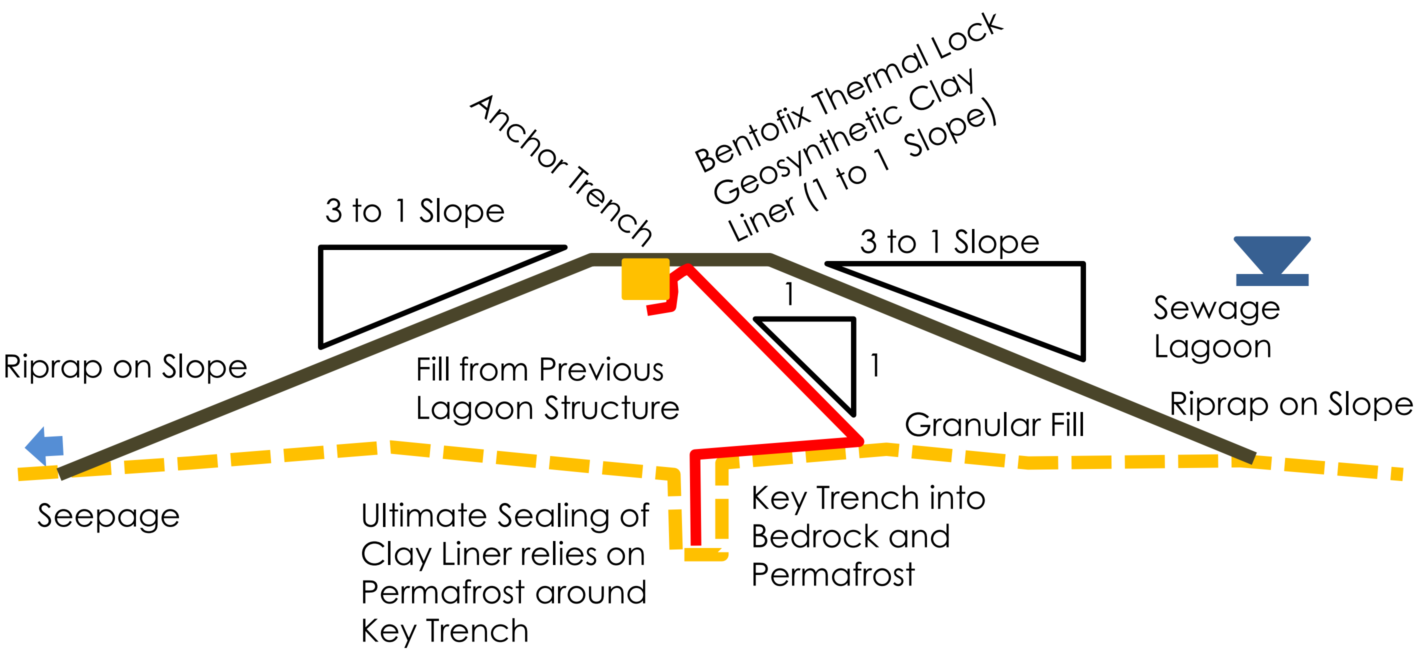
4.2 OBSERVATIONAL APPROACH TO SHORT TERM REMEDIAL ACTION

The observed seepage is of concern from a geotechnical perspective in terms of potential impacts on perimeter berm stability. Application of the so-called “observational approach” to the perimeter berm stability is one potential approach. The observational method is based on two important principles:

- Regular and thorough inspections of critical components of the system.



Berm Profile Near Bedrock



General Berm Profile

Note: 3.8 to 1 exterior slope measured in field on southeast segment of berm.

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FIGURE 11. Potential Influencing Conditions

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- Advance preparation of a reaction plan (emergency response plan) and implementation of the plan should circumstances change and stability conditions deteriorate.

The value of the observational approach is that it may defer any costly intrusive investigations and remediation for many years. It is critical to recognize that the observational approach is not a "do-nothing" approach. It requires up-front planning and once implemented requires diligence and the presence of appropriate resources to implement the monitoring and reaction plan, if needed.

However, the "observational approach" does not address the current leakage and the facility will not meet all of the water licence effluent discharge requirements. Should this approach be selected, the discharge should be controlled, and directed away from the recreational area.

One significant short coming of a properly planned and implemented observational approach is that it is not suitable for rapid, catastrophic failure events. If the monitoring plan is not followed or the failure is not progressive, implementation of the prepared reaction may not be suitable or adequate.

4.3 TESTING AND MITIGATION APPROACH TO SHORT TERM REMEDIAL ACTION

If the observation approach is not implemented, then seepage from the lagoon should be controlled by immediately resolving integrity issues with the synthetic liner. Field testing to identify the source of the seepage is needed prior to developing a full mitigation strategy.

Intrusive investigation plans should be developed to examine the liner at locations where seepage is present. Test pits using mechanical and hand excavation should be considered for this investigation. Other investigative techniques may also be considered. Regardless of the investigative techniques, a lowering of water level in the pond will probably be required, and the treatment and discharge of the wastewater associated with the lowering of the water level will require the development of a plan for approval by the regulators and the water board.

4.4 WASTE WATER SAMPLING

In conjunction with the site inspection, water samples were taken in 2 locations. The first location was from the seepage at the toe of the south berm to ascertain if the seepage was originated from the lagoon itself. The second location was a point of the seepage flow approximately 120 metres downhill from the toe of the berm (See **Figure 9 and 10**). The testing of the water samples produced the following results (See **Appendix B** for details).

Seepage at Toe of Berm

Biochemical Oxygen Demand	185 mg/L (average of 2 samples)
Total Suspended Solids	12.9 mg/L (average of 2 samples)
MPN – Fecal Coliforms	15,500 MPN/100 mL (average of 2 samples)
Ammonia, Total	84.9 mg/L (average of 2 samples)

Seepage 120 metres from Toe of Berm

Biochemical Oxygen Demand	119 mg/L (average of 2 samples)
Total Suspended Solids	24.9 mg/L (average of 2 samples)
MPN – Fecal Coliforms	2000 MPN/100 mL (average of 2 samples)
Ammonia, Total	50.3 mg/L (average of 2 samples)

In reference to the water licence effluent quality criteria (See **Section 2** item 11), only the TSS meets the effluent quality standard at the toe of the berm. At a distance of 120 metres from the toe of the berm, Total Suspended Solids, and Fecal Coliforms meet the effluent quality standard. A notable improvement in the in the seepage occurs between the toe of the berm and the sample point 120 meters from the toe of the berm.

5.0 BERM STRUCTURE

5.1 COMPONENTS

Sewage containment is provided by a constructed berm along the north, west and south sides of the lagoon area. In several areas the berms augmented existing berm structure. Natural bedrock topography provides containment on the east side.

The berm characteristics and design features are understood to be as follows:

- Crest Length: 350 metres (approximately)
- Crest width: 4 metres (estimated)
- Base width: varies up to 50 metres (approximately)
- Berm height: 5 metres (from interior base of lagoon)
- Berm slopes: 3H:1V upstream and downstream
- Seepage barrier: Geosynthetic clay liner (1 to 1 slope), embedded into native materials in a cut-off trench
- Lagoon discharge: designed for a 300 mm pipe through the base of the berm with a control valve (and access vault) through the downstream berm section – pipe freezing necessitated use of pumping discharge

5.2 STRUCTURAL INTEGRITY

Stantec was provided a dam safety review report for the lagoon prepared by Exp, in 2014. A geotechnical site reconnaissance was conducted by Exp in late July 2014. No seepage from the lagoon was identified at the time of reconnaissance and interviews with Hamlet staff did not suggest any lagoon integrity issues.

Exp (2014) reported that the lagoon was constructed in 2007. Containment is understood to be provided by an impermeable liner vertically embedded within the berms. The base of the liner was to be anchored into sound bedrock at depth via a key trench with low permeability backfill or grout. The perimeter berms were constructed of local silty sand and gravel. Larger rip rap stone provides erosion protection on the face of the berms.

Lagoon discharge is via a designated outfall into a smaller downstream treatment cell.

As noted in **Section 4**, the absence of sagging, sloughing or other deformation of the perimeter berms suggests that the berms remain geotechnically stable. It is indeterminate how any instability may progress or over what timeframe. If seepage accelerates, the opportunity for material loss increases, which will negatively impact the geotechnical stability of the berms.

6.0 REMEDIAL WORK TO ELIMINATE SEEPAGE

6.1 BERM REPAIR OPTIONS

Several conceptual strategies have been developed to permanently address the seepage in the south berm:

- Placement of bentonite powder in seepage path.
- Installation of a vertical curtain wall to base of berm.
- Reconstruction of the entire berm.
- Passive sealing of seepage by accumulation of sewage sludge

Eliminating Seepage Using Bentonite

To execute this option, a quantity of bentonite powder would be released into the base of the near empty lagoon, in the vicinity where the seepage is believed to be originating. In principal, the bentonite would migrate into the containment structure, carried by the hydraulic head of the seeping water. Once inside the containment structure the bentonite would hydrate, expand and plug the seepage pathways.

A primary advantage of this option is that it may require little or no specialized equipment or trained personnel. Bentonite is understood to be a low level health hazard, addressed with minimal personal protective equipment. However in order to apply this option, the lagoon must be emptied, and the biosolids accumulation must be removed from the lagoon. Alternatively a temporary berm could be utilized to isolate the area for the bentonite application. An alternate wastewater treatment process may be required because the lagoon will be out of services.

The primary unknowns for this option are whether the bentonite would hydrate before being carried into the seepage channels within the containment berm (if hydration did not occur upstream or within the seepage channels then a seal may not be provided) and the uncertain effects of the hydraulic gradient on the bentonite-sealed seepage pathways. Another issues with this option is the influence of any residual biosolids accumulation in the area where the bentonite would be applied. A subsequent performance question is whether seepage pathways sealed under a low hydraulic gradient would remain sealed under the considerably higher hydraulic gradient of an operating lagoon.

The bentonite addition within this option should be incremental and assess whether leakage is slowing down or stopping. Measures should be taken to prevent the scenario where the leakage is stopped and the lagoon is filled with a water/bentonite mixture (bentonite is not likely to settle before seasonal discharge).

There is no assurance that this scheme will achieve the desired results. There may also be regulatory issues associated with discharging the bentonite-water mixture at the end of the summer.

Table 6.1: Opinion of Probable Cost for Application of Bentonite for Eliminating Seepage

Description	Units	Quantity	Unit Cost	Estimated Cost
Mobilization and Demobilization	Lump sum	1	$20,000	$20,000
Bentonite addition	Lump sum	1	$25,000	$35,000
Monitoring of conditions	Lump sum	1	$30,000	$30,000
Biosolids removal	Lump Sum	1	$30,000	$100,000
Temporary waste water treatment (supply)	Lump sum	1	$325,000	$325,000
Temporary wastewater treatment (operation)	Lump sum	1	$320,000	$320,000
Contingency (40%)				$332,000
Total				**$1,160,000**

6.1.1 Eliminating Seepage with Installation of Vertical Curtain

The execution of this option has a number of similar schemes to provide a vertical barrier to water seepage. Potential schemes include the following:

- Trenched liner or synthetic clay liner
- Slurry trench wall
- Jet/pressure grouting
- Sheet pile cut-off wall

The most important aspect of this option is the need to ensure that a good seal is provided at an impermeable layer at depth. As the current seepage is suspected as occurring along the interface between the containment structure and the native subgrade, excavation into the native subgrade to some depth to form a cut-off is considered critical. This may require physical excavation into the native subgrade to construct a cut-off trench.

The execution of the trenched liner or slurry trench wall requires a relatively narrow trench excavation through the containment structure and into the underlying bedrock or permafrost soils. The trench is then backfilled with a liner or bentonite slurry that would provide an impermeable barrier to water migration.

The execution of the jet/pressure grouting involves the insertion of an injection nozzle into the ground, either through driving or drilling to a desired depth and injecting a bentonite and/or cementitious grout under high pressure. The injection nozzle is slowly withdrawn upwards forming a vertical impermeable column. The injection nozzle is then re-inserted a short distance away and the procedure repeated until a continuous barrier wall is formed. Some alternate methods include cutting and mixing tips so the grout is mixed with the native soils at depth.

A sheet pile wall may be a more practical alternative to the slurry or liner curtain because a minimal depth of excavation is needed to seal the sheet piles. The potential issue with sheet piles is to ensure an adequate seal at the base of the wall within the native soils is achieved. Sheet piles may be either steel or synthetic materials.

The installation of a vertical curtain is an option which has a moderate to high expense, in the $1 to $4 million dollar order of magnitude cost. It will require specialized equipment and experienced personnel. Given the potential depth of the excavation, trench wall shoring will likely be required.

The application of this solution would require the implementation of an alternate sewage treatment process during the sealing work. Alternatively a temporary berm could be utilized to isolate the area for the bentonite application.

6.1.2 Eliminating Seepage with Containment Berm Reconstruction

The only assured option for providing a sealed containment structure is to completely reconstruct the entire south containment structure. This option would require the following tasks:

- Excavation and stockpiling of the majority of the containment berm,
- Exposure of the native subgrade,
- Sealing of the subgrade. This may include pressure grouting, construction of a key trench or other means,
- Re-construction of the containment berm including a vertical seepage barrier.

Table 6.2: Opinion of Probable Cost for Reconstruction of Containment Berm

Description	Units	Quantity	Unit Cost	Estimated Cost
Mobilization and Demobilization	Lump sum	1	$100,000	$100,000
Excavate and stockpile berm material	m^3	5,000	$125	$625,000
Rebuild berm (incl. vertical seepage barrier)	m^3	5,000	$225	$1,125,000
Temporary waste water treatment (supply)	Lump sum	1	$325,000	$325,000
Temporary wastewater treatment (operation)	Lump sum	1	$320,000	$320,000
Contingency (40%)				$848,000
Total				**$3,490,000**

6.1.3 Eliminating Seepage with Sealing by Accumulation of Sewage Solids

The passive sealing of seepage by the accumulation of sewage biosolids is similar to the sealing of the seepage with bentonite, with the solids in the in the sewage eventually sealing the berm. However, since an accumulation of biosolids has already occurred with the operation of the facility to date, the potential success of the option may be have already been demonstrated.

In principle, the sewage solids would carry into the berm structure by the seeping water under hydraulic head and could conceivably plug small seepage pathways, eventually forming a low permeable structure. The characteristic of sewage solids sealing off a low permeable material is a well-documented phenomenon that has been particularly well documented in the soil disposal of sewage with the formation of a layer of material referred to as a "schmutzdecke".

The primary advantage of this option would be the cost. There is no direct cost associated with this option as it involves gradual plugging of the berm leak over time by solids that are inherence to the effluent discharge from the lagoon. There are a number of disadvantages and challenges associated with this option. The first challenge may be the acceptability by regulatory agencies for the continuing seepage of effluent through the lagoon until the blockage develops. The second challenge is that the effectiveness of this sealing option is impossible to predict. If the natural sealing of seepage paths does not occur, poorly treated effluent would continue to seep out of the lagoon.

6.2 COMPARISON OF REMEDIAL WORK TO ELIMINATE SEEPAGE

Table 6.3: Comparison of Lagoon Remedial Options to Eliminate Seepage

Criteria	Seal Berm with Bentonite	Install Vertical Curtain	Containment Berm Reconstruction	Natural Sealing of Leaks by Effluent
Opinion of Probable Cost	$985,000	$1,000,000 to $4,000,000	$2,970,000	$0
Regulatory Acceptance	Unknown if this will be acceptable (unproven technique)	Acceptable	Acceptable	Unknown if this will be acceptable (unproven technique)
Environmental Risk	Highest risk: risk that berm seepage will continue	Existing leak should be fixed but risk of future berm leakage	Existing leak should be fixed but risk of future berm leakage	Highest risk: risk that berm seepage will continue
Constructability	Easiest to implement	Most difficult to construct (deep excavation, specialized equipment and personnel)	Difficult construction: specialized techniques required	No work required to implement
Operations	Will require monitoring	Routine inspection	Routine inspection	Will require monitoring
Potential Success	Low to medium	High	High	Very low

7.0 REMEDIAL WORK TO MANAGE LEAKAGE

An alternative approach to address the seepage concerns would be to manage the seepage with either a seepage control pond, a seepage filter, or a seepage diversion channel to direct the flow to the existing wetland area. The existing seepage would be allowed to remain, earth structures would be constructed to intercept the seepage, and the existing berm structure should be reinforced to provide a long term stability. These approaches would require discussion and negotiation with the regulators to gain their acceptance.

7.1 SEEPAGE CONTROL POND

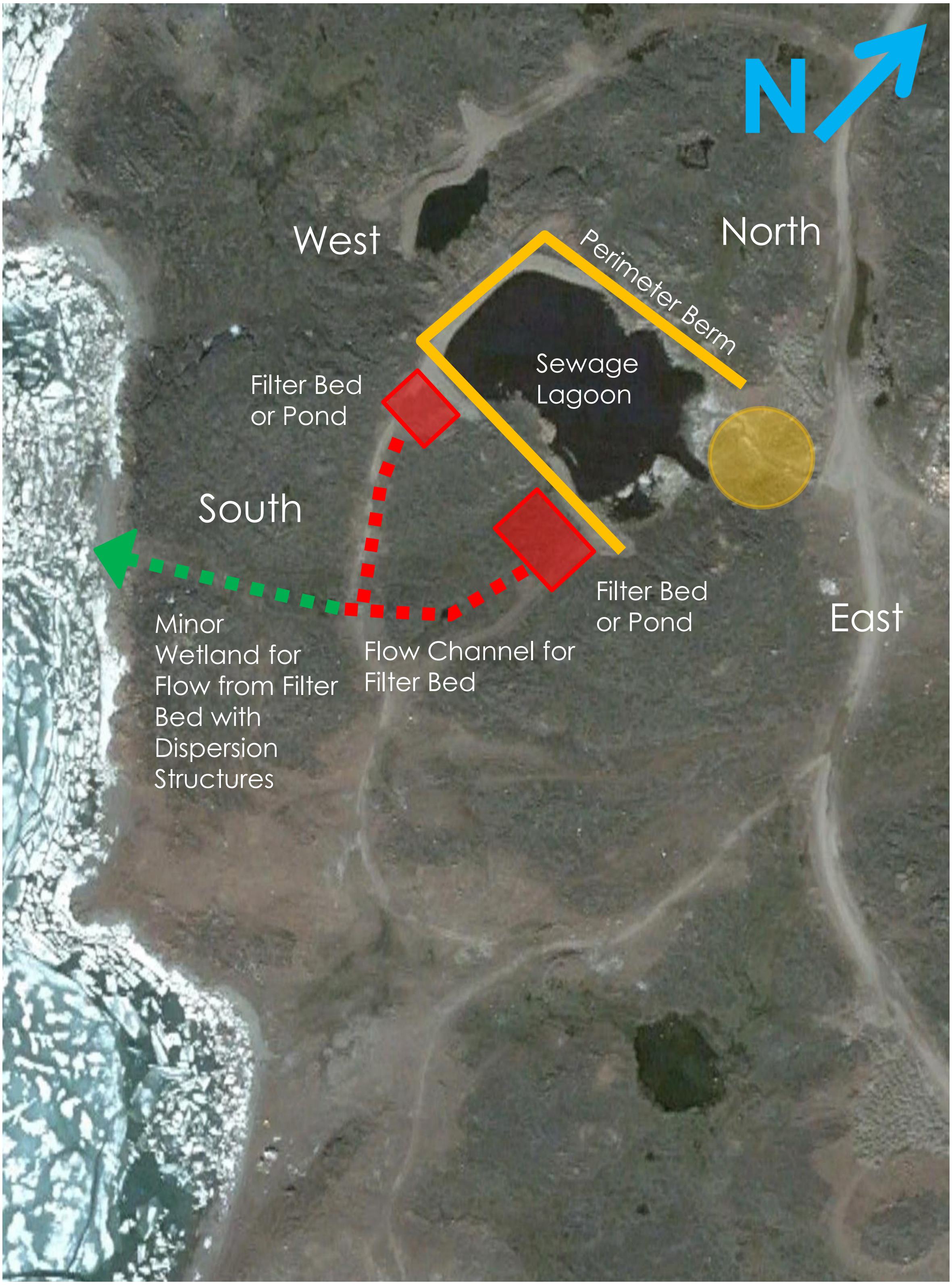
A seepage control alternative could be to add a small engineered pond below the seepage areas to control the seepage for either pumping back into the lagoon, or discharge into a channel that would ultimately direct the seepage accumulation into the ocean (See **Figures 12, 13, and 15**).

Table 7.1: Opinion of Probable Cost for Construction of Seepage Control Pond

Description	Units	Quantity	Unit Cost	Opinion of Probable Cost
Mobilization and Demobilization	Lump sum	1	$100,000	$100,000
Excavate of Pond	m^3	800	$100	$80,000
Build Perimeter Berm (incl. vertical seepage barrier)	m^3	2400	$175	$420,000
Reinforce existing berm	m^3	1000	$150	$150,000
Contingency (40%)				$300,000
Total				**$1,050,000**

7.2 SEEPAGE FILTER

A seepage filtration alternative would add a small engineered filter below the seepage areas to provide and filtration flow path through soil prior to a discharge into a channel that would ultimately direct the seepage accumulation into the ocean (See **Figures 12, 14, and 15**). Soil filtration would improve the effluent quality beyond what has been observed in the seepage through the existing berm structure as noted in **Section 4.4**. The filter will likely freeze during the winter months, and therefore not function to filter any seepage through the berm that continues during the winter months.



Hamlet of Kugaaruk, Nunavut

Sewage Lagoon Assessment

FIGURE 12. Seepage Pond/Filter

Prepared by Ken Johnson, RPP, P.Eng. 2016 05 20

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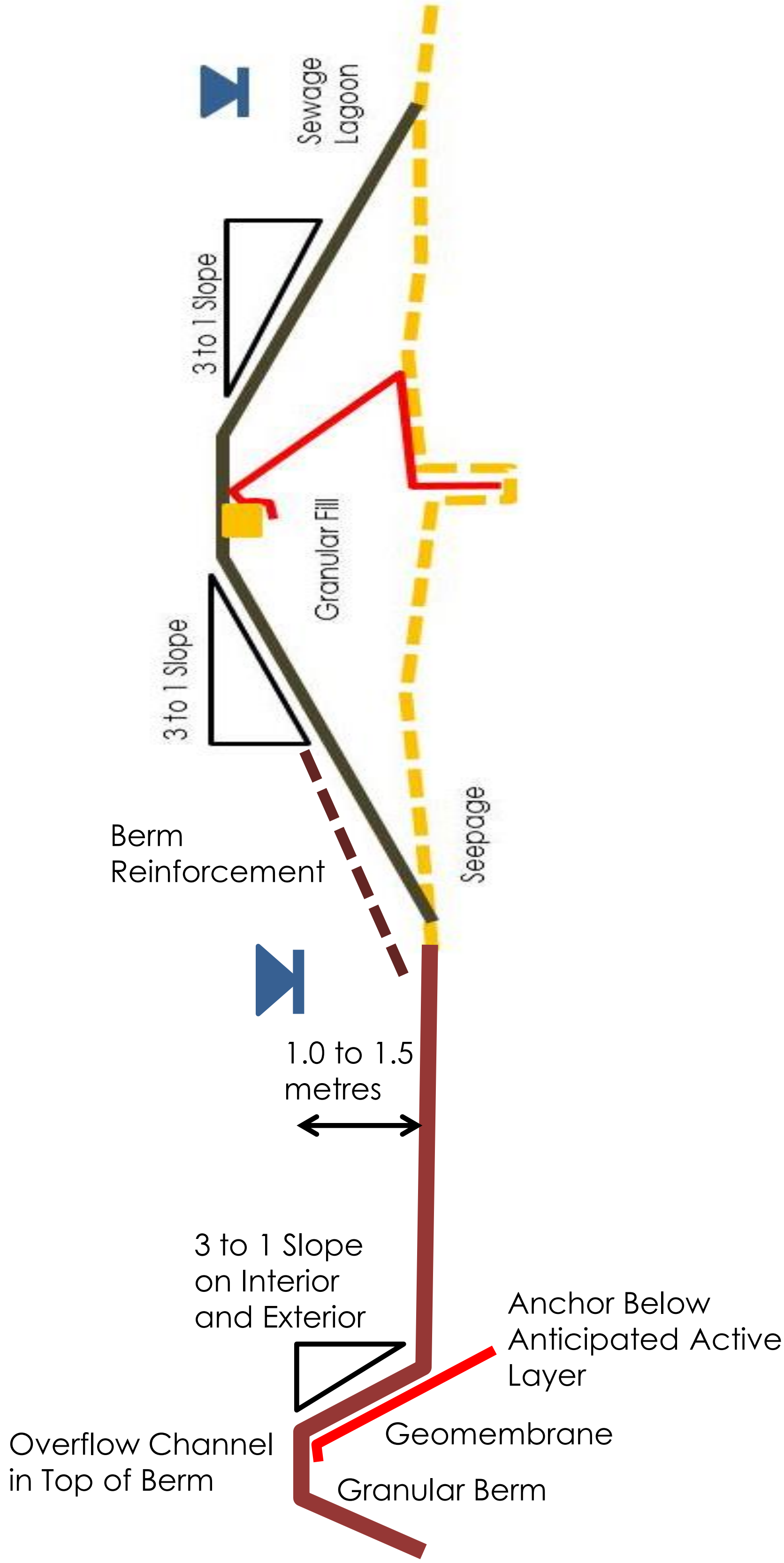

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FIGURE 13. Seepage Ponds - Profile

Prepared by Ken Johnson, RPP, P.Eng. 2016 05 20

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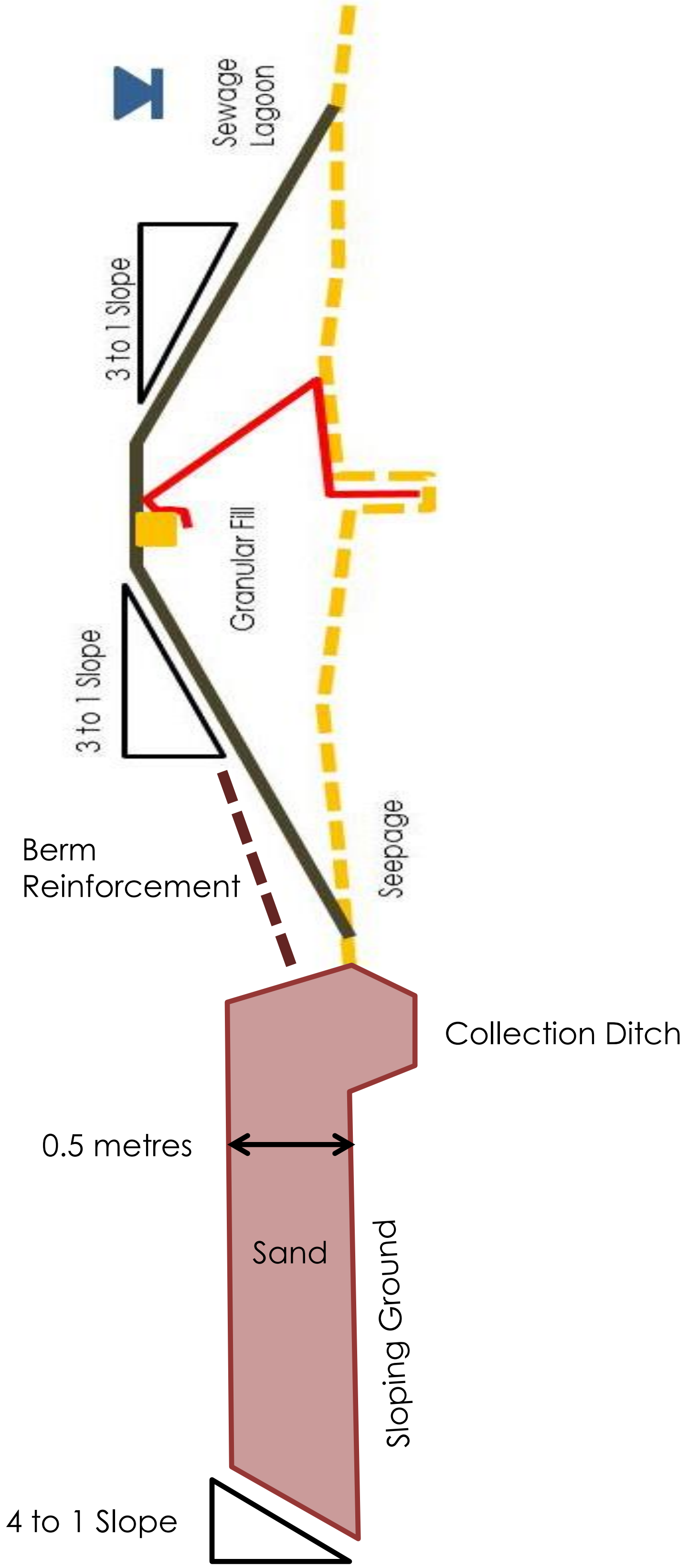

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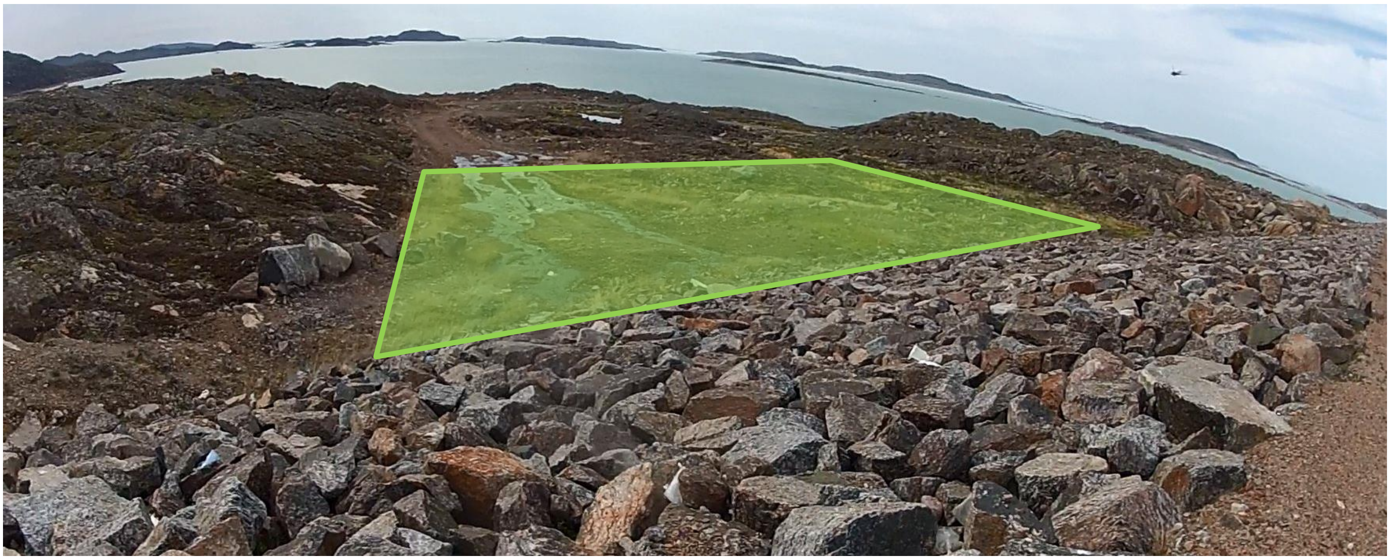
FIGURE 14. Seepage Filters - Profile

Prepared by Ken Johnson, RPP, P.Eng. 2016 05 20



South East Seepage Area

Southwest Seepage Area

Hamlet of Kugaaruk, Nunavut

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FIGURE 15. Pond and Filter Areas

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Table 7.2: Opinion of Probable Cost for Seepage Filter

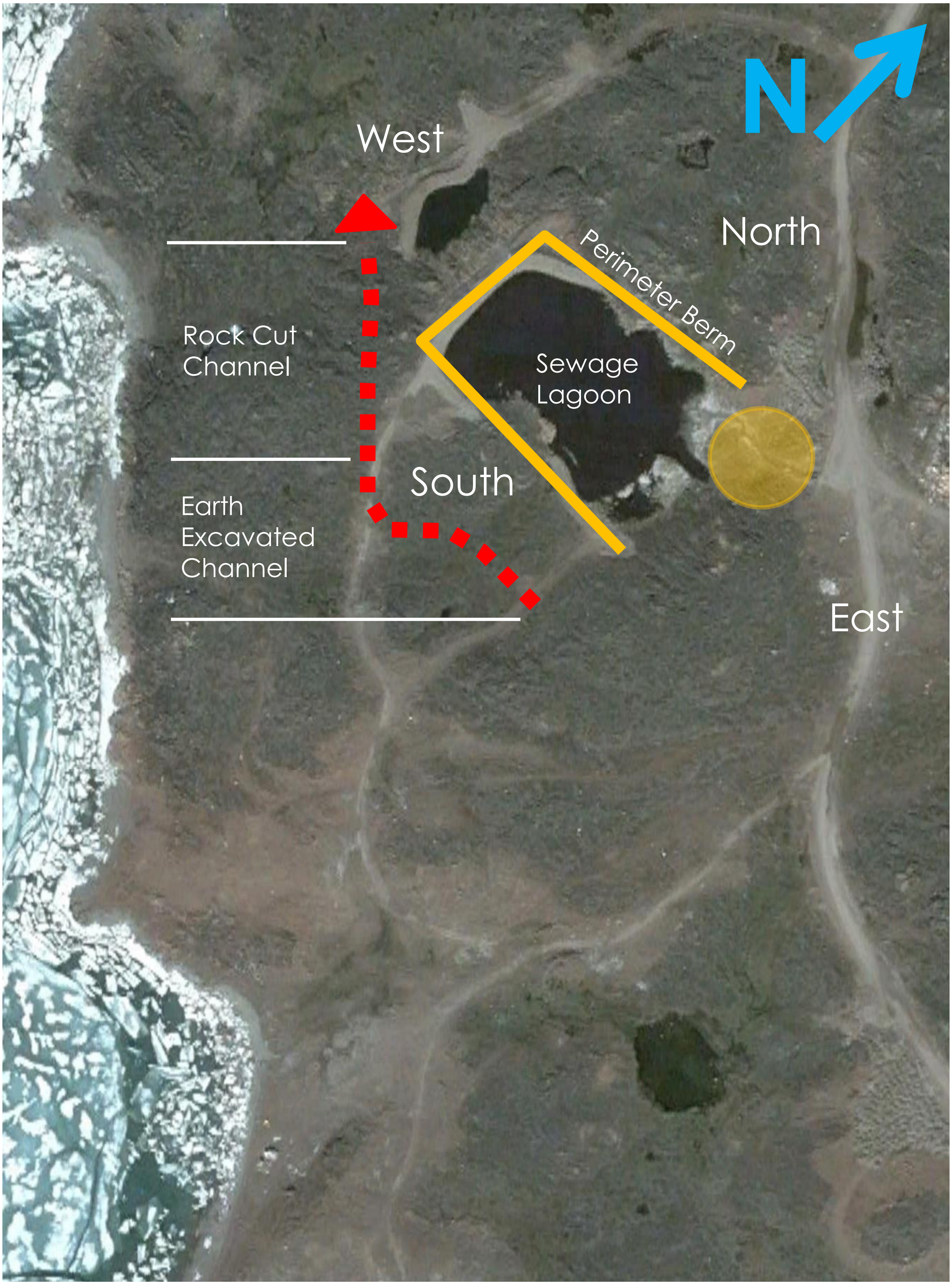
Description	Units	Quantity	Unit Cost	Opinion of Probable Cost
Mobilization and Demobilization	Lump sum	1	$100,000	$100,000
Prepare Subgrade	m^2	800	$25	$20,000
Construct Filter	m^3	1200	$125	$150,000
Excavate Flow Channel	m	200	$100	$20,000
Dispersion Berms in Wetland	Lump sum	2	$10000	$20,000
Reinforce Existing Berm	m3	1000	$150	$150,000
Contingency (40%)				$184,000
Total				**$644,000**

7.3 SEEPAGE DIVERSION

A seepage diversion alternate would create a channel from the seepage area to the wetland area (See **Figure 16**). A channel is possible in principle, but it could involve a significant rock cut to create a channel that could discharge into the wetland area. **Figure 17** shows the channel concept in a series of 3 photos. The top photo shows the main seepage area and a channel that would traverse the edge of a bedrock ridge to the second seepage area (middle photo). From the second seepage area, the channel would require a rock cut through a second bedrock ridge to direct the flow to the vicinity of the lagoon discharge area. Beyond the rock cut channel into the bedrock a flume may be necessary (bottom photo) to direct the flow into the lagoon discharge.

Table 7.3: Opinion of Probable Cost for Seepage Diversion

Description	Units	Quantity	Unit Cost	Opinion of Probable Cost
Mobilization and Demobilization	Lump sum	1	$100,000	$100,000
Channel Excavation in Earth	m	110	$500	$55,000
Channel Excavation in Rock	m^3	1000	$300	$300,000
Flume Discharge	Lump sum	1	$25,000	$25,000
Contingency (40%)				$192,000
Total				**$672,000**



Hamlet of Kugaaruk, Nunavut

Sewage Lagoon Assessment

FIGURE 16. Seepage Channel Alignment

Prepared by Ken Johnson, RPP, P.Eng. 2016 05 20

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FIGURE 17. Seepage Channel Features

Prepared by Ken Johnson, RPP, P.Eng. 2016 05 20

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7.4 COMPARISON OF REMEDIAL WORK TO MANAGE SEEPAGE

Table 7.4: Comparison of Lagoon Remedial Options to manage Seepage

Criteria	Seepage Pond	Seepage Filter	Seepage Diversion
Opinion of Probable Cost	$1,050,000	$644,000	$672,000
Regulatory Acceptance	Unknown if this will be acceptable	Unknown if this will be acceptable	Unknown if this will be acceptable
Environmental Risk	Seepage will be managed, and discharge eliminated with pumping back into sewage lagoon	Discharge quality will be improved during summer months, but little or no discharge quality improvement during winter months	Discharge quality will be improved during summer months, but little or no discharge quality during winter months
Constructability	Routine earthworks construction	Routine earthworks construction	Approximately ½ routine earthworks construction and ½ rock blasting; potential need for flume structure.
Operations	Ongoing inspection for filling of pond and periodic pumping of pond back into lagoon; will require winter access for potential pumping.	Ongoing inspection for filter integrity and performance; will require winter access for potential pumping.	Minimal inspection for channel operation.

8.0 CONCLUSIONS

The main conclusions from the feasibility study are:

- Two existing segments of the south berm have seepage of sewage at the base of the berm structure.
- The south berm appears to be geotechnically stable under the current seepage conditions.
- The seepage appears to originate from the toe of the berm, and may be the result of seepage at the base of internal impermeable liner system, where it keys into bedrock and permafrost.
- The seepage from the lagoon is not meeting the effluent quality criteria in the current water licence.
- The seepage is naturally flowing toward the ocean.
- There are several methods available to bring the facility to a reasonable level of complete containment.
- There are several methods available to manage the seepage from the lagoon.

9.0 RECOMMENDATIONS

The recommendations are as follows:

The GN should continue monitor the berm to determine any evidence of berm deterioration.

The GN should prepare a plan going forward that will address the management of the seepage from the toe of the berm to satisfy the current concerns of the regulators.

The GN should undertake a dialogue with the Nunavut Water Board for the consideration of a continual discharge lagoon facility, and the associated effluent quality considerations from the continual discharge.

The GN should remediate the facility to provide full retention of the sewage, **if required to meet the effluent quality standards.**

The GN should undertake additional topographic data collection on the south and west portions of the lagoon to develop a more accurate estimate of the earth work, and rock work necessary to design and construct a seepage diversion management option, **if a relaxation of the effluent quality standards is accepted, and the seepage management concept is accepted.**

Summary of opinion of probable costs as follows:

Table 9.1: Summary of Options, and Opinion of Probably Cost

Option	Description	Opinion of Probable Cost
1	Complete bentonite berm sealing (requires emptying of lagoon and provision of alternated treatment system)	$ 1,160,000
2	Construct vertical curtain (specialized construction)	$1,000,000 to $4,000,000
3	Reconstruct berm in area of seeping (requires emptying of lagoon and provision of alternated treatment system)	$3,490,000
4	Allow passive biosolids sealing (unknown timeline for sealing to occur, and unknown for ultimate success)	$0
5	Construct seepage control pond requires consultation with regulators, and potential change in effluent quality criteria)	$1,050,000
6	Construct seepage filter (requires consultation with regulators, and potential change in effluent quality criteria)	$644,000
7	Construct seepage diversion channel (current opinion of probable cost is order of magnitude only)	$672,000

Appendix A INTERIM TECHNICAL MEMO

Stantec Memo

To:	Shah Alam, Planning Engineer, Government of Nunavut Cambridge Bay , Nunavut	From:	Ken Johnson, RPP, P.Eng. Planner and Engineer Edmonton AB
File:	Kugaaruk Sewage Lagoon Assessment	Date:	October 8, 2015

Reference: Kugaaruk Sewage Lagoon Assessment, and Interim Report Concerning Remedial Action

Introduction

Stantec has been retained to provide an assessment and planning report on remedial work to the Kugaaruk sewage lagoon in response to a specific seepage issue in the berm structure that has occurred over the course of past year (see **Figure 1**). With the potential need for short term remedial work in the 2015 construction season, Stantec has prepared this interim report concerning short term remedial action to address the seepage in the south berm of the facility.

The sewage lagoon serving the Hamlet of Kugaaruk is a granular earth berm structure, with a rectangular shape approximately 150 metres long and 90 metres wide, and an impermeable bentonite membrane integral within the berm structure. The facility was commissioned in 2007, and it has been operating almost continuously since then.

It was reported in 2014, that there was seepage from the toe of the lagoon berm along the southern edge. No other deterioration in the berm structures was reported. The complete assessment and planning report with the identification of short term and long term remedial work will be submitted at a later date.

Site inspection

A site inspection of the Kugaaruk sewage lagoon was completed in July 20, 21, 22, and 23, 2015 by Ken Johnson, M.A.Sc., P.Eng.; several strategic photographs concerning the lagoon and elements of the inspection are presented in **Figure 2.** A synopsis of the inspection and the notable features of the facility are presented in **Figure 3.** The inspection was completed with walking excursions along the top of the berm (walking in both directions), and along the exterior base of the south berm (walking in both directions). The excursions were documented with high definition (1080p) video, and digital photographs.

Some infrared photos were taken, as well, above the seepage points in the berms as a potential means to collect supplementary information on the origin of the seepage in the berm structure. However, the rip rap armouring shielded the granular surface of the berm from any meaningful infrared imagery, and the results were inconclusive.

Concerning the top of the berm, there was no visible deterioration in the berm structures along the north, west and south berms. The east berm, where the truck discharge is located, shows visible bedrock and riprap armouring where the truck discharge is located. The proximity to bedrock is evident with visible bedrock outcrops in several locations around the lagoon perimeter, specifically in the east segment of the lagoon. The top of the berm structures have a 4 meter wide gravel surface. This gravel surface shows very little, if any, deterioration from surface erosion or other factors. The interior and exterior slopes are armoured with riprap with sizes generally greater than 30 cm in diameter.

The discharge structure for the lagoon is a pipe on the west side of the lagoon which discharges into a flow dispersion structure and ultimately into a wetland. An overflow structure is also located on the west berm beside the discharge structure.

A notable flow from the base of the lagoon on the south side was clearly visible. The flow originates from two general areas on the south berm, and from specific flow points in each area. The flow area in the south east corner has 4 distinct points of flow (**See Figure 2**), with varying degrees of flow that contribute to two channels of flow immediately downstream, that form one channel of flow. A single point of minor flow was observed in the south west corner, and this flow infiltrates into the ground within 20 metres of the toe of the berm.

Further downstream, the flows from the south east corner separates into 2 channels once again **(See Figure 4)** with the majority of the flow travelling southwest and a minor flow travelling southeast. The flow travelling southwest ultimately discharges into the ocean, and the flow travelling southeast also discharges into the ocean. The ocean discharge of the southeast flow appears to be an area used for camping.

Concern with Seepage and the Potential Deterioration of the Berm Structure

The seepage from the perimeter berm was confirmed to be sewage with several samples taken and tested. The test results indicate that the seepage is above the effluent quality parameters for the facility, which is a non compliance issue in the context of the water licence. The seepage may also be an environmental and public health concern with its discharge into the ocean, particularly with the discharge path in proximity to an area that may be used for camping and recreation.

The presence of seepage from the perimeter berms reflects a loss of containment by the synthetic liner and/or its cut-off trench and not a containment failure of the perimeter berm itself. The presence of seepage through the berms raises geotechnical integrity concerns for the berms as the seepage may lead to ground loss (piping) that could weaken or undermine the perimeter berms or reduce the geotechnical stability of the perimeter berms.

The absence of sagging, sloughing or other deformation of the perimeter berms suggests that the berms remain geotechnically stable. It is indeterminate how any instability may progress or over what timeframe. If seepage accelerates, the opportunity for material loss increases, which will negatively impact the geotechnical stability of the berms.

Influencing Factors to Flow from Toe of South Berm

The design of the geosynthetic clay liner is shown in **Figure 5**; the design elements associated with the containment system are the liner itself, the liner keyed into bedrock and permafrost at the base, and an anchor trench at the top of the liner. The potential sources of leakage with this configuration may be a fault in the liner itself due to damage, or improper installation between panels of the liner, or a fault in the in the impermeability of the liner / bedrock / permafrost system at the base of the berm.

Short Term Remedial Action

The observed seepage is of concern from a geotechnical perspective in terms of potential impacts on perimeter berm stability. Application of the so-called "observational approach" to the perimeter berm stability is one potential approach. The observational method is based on two important principles:

- Regular and thorough inspections of critical components of the system.
- Advance preparation of a reaction plan (emergency response plan) and implementation of the plan should circumstances change and stability conditions deteriorate.

The value of the observational approach is that it may defer any costly intrusive investigations and remediation for many years. It is critical to recognize that the observational approach is not a "do-nothing" approach. It requires up-front planning and once implemented requires diligence and the presence of appropriate resources to implement the monitoring and reaction plan, if needed.

However, the "observational approach" does not address the current leakage and the facility will not meet all of the water licence effluent discharge requirements. Should this approach be selected, the discharge should be controlled, and directed away from the recreational area. The testing of the leakage at the time of the site inspection produced results of 177 to 193 mg/L for BOD; 12.7 to 13.1 mg/L for TSS; and 14,000 to 17,000 MPN /100 mL for fecal coliforms. These values exceed the effluent quality parameters for BOD (120 mg/L) and fecal coliforms (10,000 CFU/100 mL). The effluent quality improved as the overland flow approached the ocean.

If the Government and Community are accepting of the above principles, Stantec can assist in developing the necessary inspection and reaction plans.

One significant short coming of a properly planned and implemented observational approach is that it is not suitable for rapid, catastrophic failure events. If the monitoring plan is not followed or the failure is not progressive, implementation of the prepared reaction may not be suitable or adequate.

If the Government and Community is not prepared to accept the implementation of the observational approach, then seepage from the lagoon should be primarily controlled by immediately resolving integrity issues with the synthetic liner. Field testing to identify the source of the seepage is needed prior to developing a full mitigation strategy.

Mitigation strategies may include excavation and repair of the liner, if liner seepage is at mid-height in the berm, or pressure grouting with bentonite slurry if the seepage is through the bedrock cut-off trench.

Intrusive investigation plans should be developed to examine the liner at locations where seepage is present. Test pits using mechanical and hand excavation should be considered for this investigation. Other investigative techniques may also be considered.

Closure

The absence of any observable deterioration in the berms structure of the Kugaaruk sewer lagoon indicate a stable structure in the short term, however the seepage from the base of the structure suggests an opportunity for deterioration to occur in the future. The continuing observation and reporting on the condition of the berms is an appropriate response at this time to allow for the development of a long term remedial action plan. The seepage is non compliant with the water licence, and therefore a dialogue with the water board is necessary to advise them of the situation and the action plan. A channeling of the flow in a direction away from the beach where camping and other recreation may occur will reduce the public health risk.

STANTEC CONSULTING LTD.

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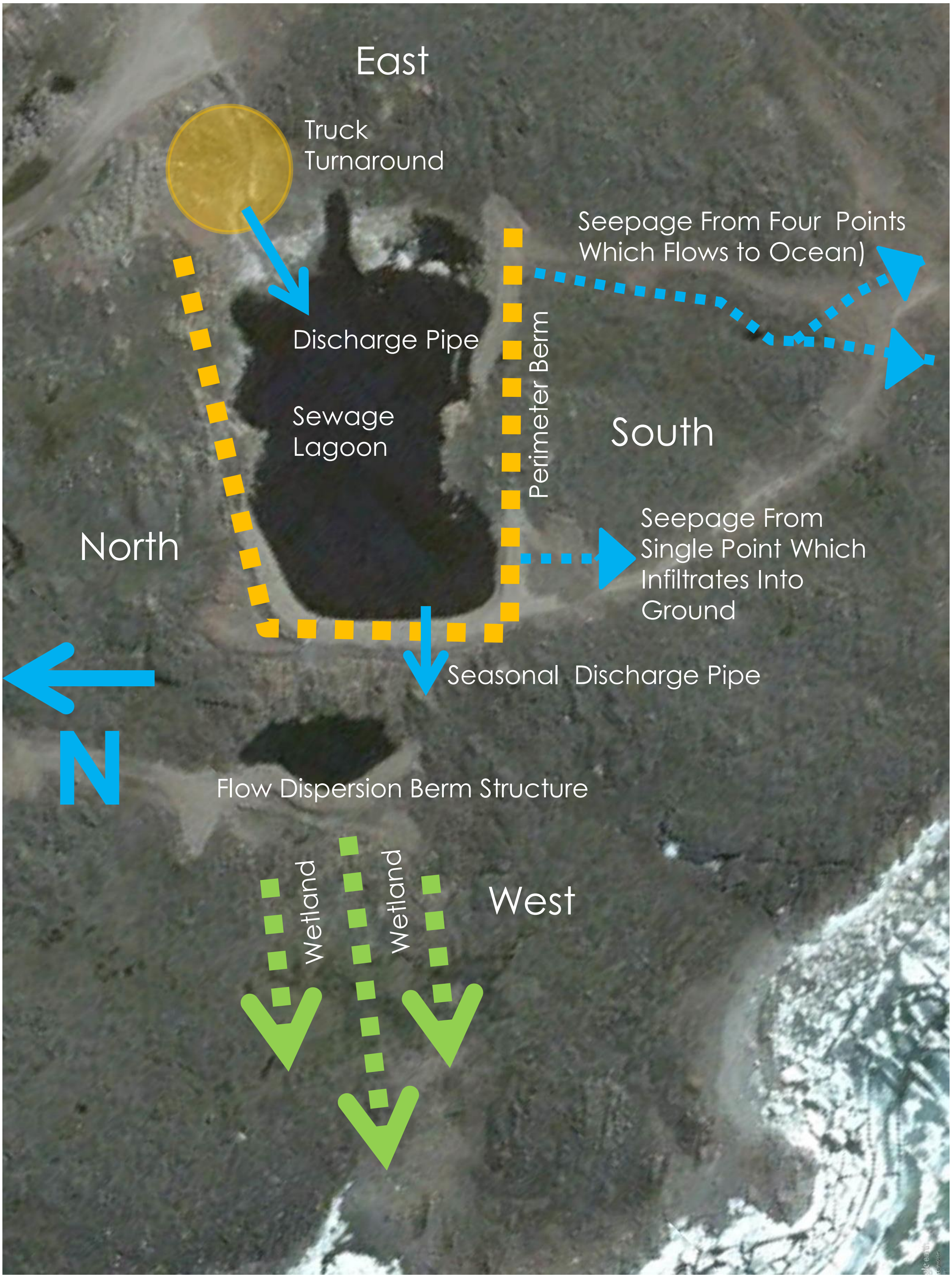
REGISTERED PROFESSIONAL ENGINEER
K.R. JOHNSON
NWT/NU

OCT 0 8 2015

Attachments:

1. Figures 1 to 5
2. Preliminary Geotechnical Assessment



Hamlet of Kugaaruk, Nunavut

Sewage Lagoon Assessment

FIGURE 1. Satellite Image

Prepared by Ken Johnson, RPP, P.Eng. 2015 09 29

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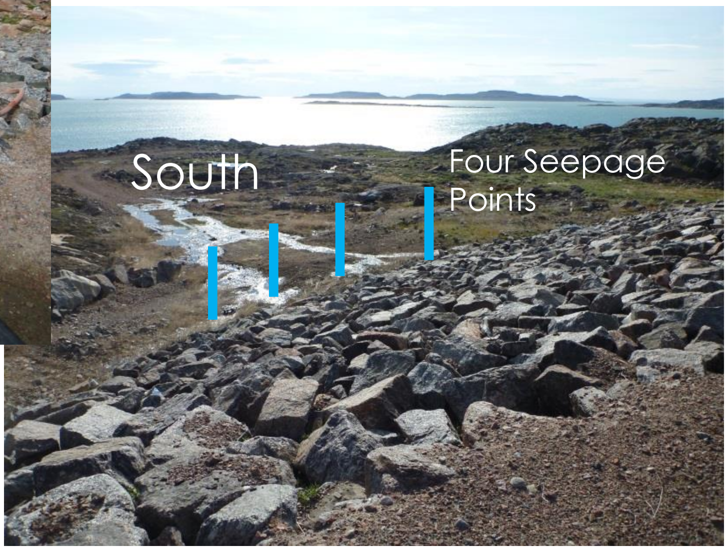
Northwest corner looking southeast

Discharge control manhole on west side flowing onto flow dispersion berm structure

Seepage from toe of south berm



Hamlet of Kugaaruk, Nunavut

Sewage Lagoon Assessment

FIGURE 2. Site Photographs

Prepared by Ken Johnson, RPP, P.Eng. 2015 09 29

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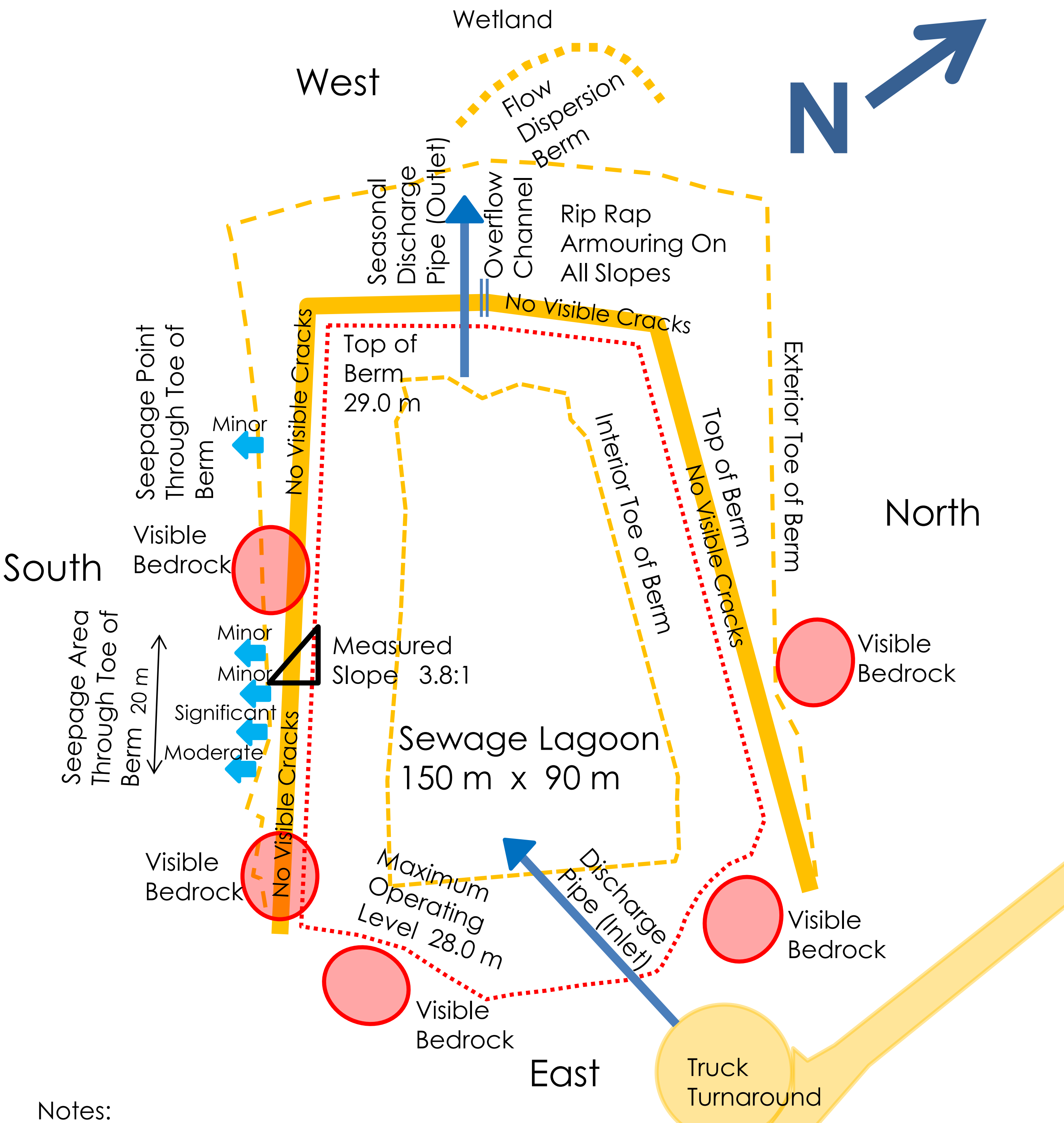

Notes:

1. No visible seepage along toes of north and west perimeter berms.
2. Five seepage points observed.

Hamlet of Kugaaruk, Nunavut

Sewage Lagoon Assessment

FIGURE 3. Field Inspection Synopsis

Prepared by Ken Johnson, RPP, P.Eng. 2015 09 29

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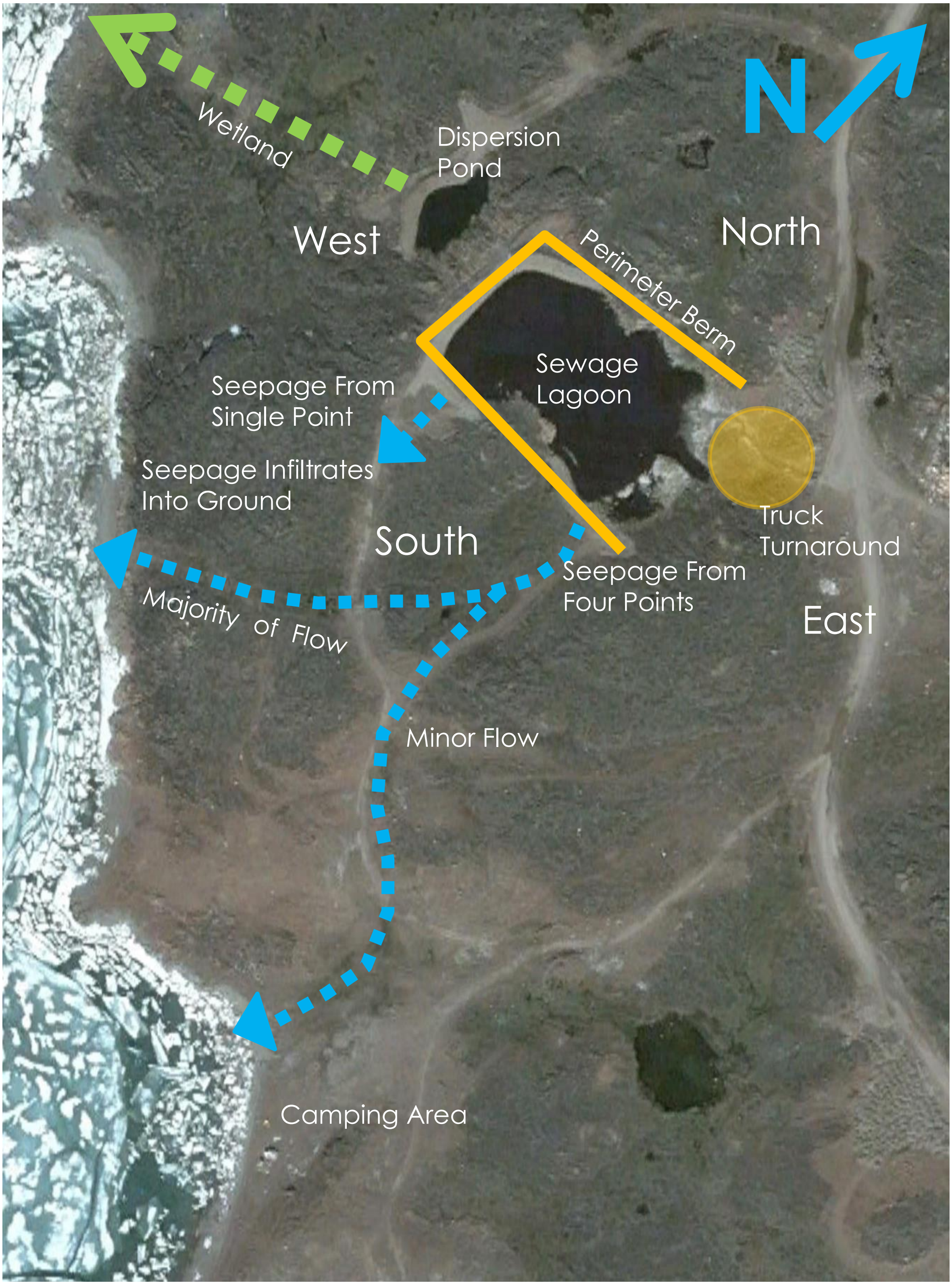

Hamlet of Kugaaruk, Nunavut

Sewage Lagoon Assessment

FIGURE 4. Route of Seepage to Ocean

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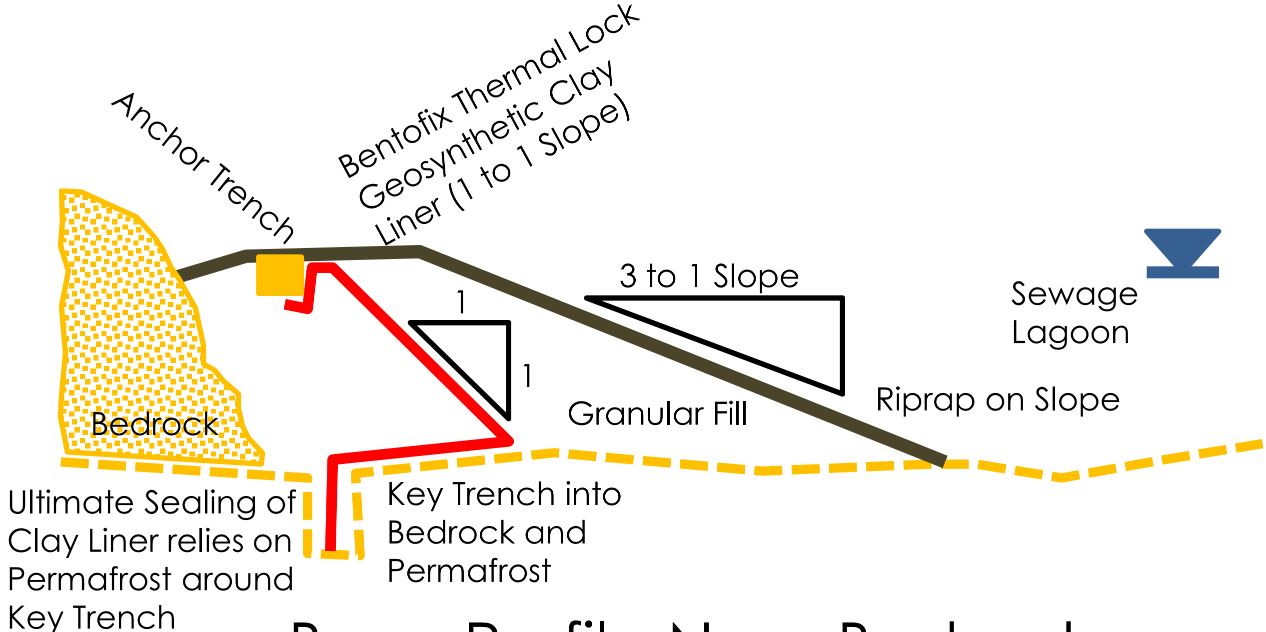
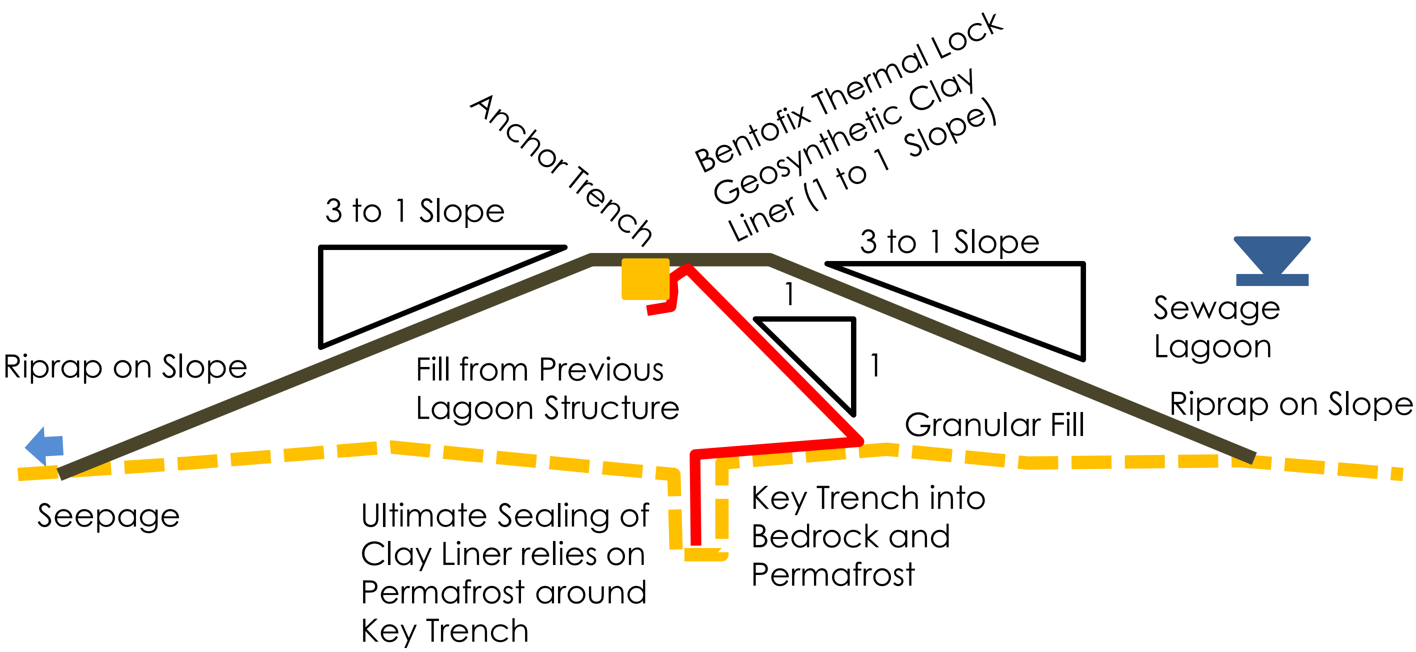


Berm Profile Near Bedrock



General Berm Profile

Note: 3.8 to 1 exterior slope measured on southeast segment of berm.

Hamlet of Kugaaruk, Nunavut

Sewage Lagoon Assessment

FIGURE 5. Potential Influencing Conditions

Prepared by Ken Johnson, RPP, P.Eng. 2015 09 29

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Memo

To:	Ken Johnson, P.Eng. Project Manager Stantec, Edmonton	From:	Jim Oswell, PhD., P.Eng Geotechnical and Permafrost Engineer Stantec Calgary
File:	110126041	Date:	October 8, 2015

Reference: Preliminary Geotechnical Assessment: Kugaaruk, NU Waste Water Treatment Lagoon

Prepared by: Jim Oswell, Ph.D., P.Eng Reviewed by Thomas Crilly, M.Sc., P.Eng

IMPORTANT NOTICE

This assessment is based solely on notes, photographs and videos made by a northern municipal engineering specialist from Stantec during a site visit on July 20, 2015. No geotechnical engineering professional from Stantec visited the site as part of this assessment, and limited design drawings, construction photographs, as-built drawings or other design or construction information has been provided to Stantec as part of this evaluation, except as noted.

All comments, opinions and recommendations provided herein must be considered preliminary and subject to change and verification as more information is provided. The Government of Nunavut is cautioned to carefully evaluate any recommendations provided herein and their implications relative to the Government's or Community's ability to effectively implement them and any repercussions that might arise relative to regulatory agencies and boards.

Any recommendations and comments provided herein with respect to mitigation or intervention do not constitute an engineered design.

INTRODUCTION

This memorandum provides a preliminary geotechnical assessment of the perimeter berms for the Kugaaruk, NU waste water treatment lagoon (the "lagoon").

During a site visit to address performance issues with the lagoon, Stantec identified seepage from the lagoon in several locations. Figure 1 presents a sketch of the lagoon, annotated with comments from the site visit.

SITE OBSERVATIONS

Seepage was observed flowing from the south perimeter berm at several locations.

Figure 2 and **Figure 3** presents photographs of the seepage at two locations as noted in **Figure 1**.

No slumping or visual evidence of perimeter berm instability was noted at the time of the site visit.

SITE OBSERVATIONS BY OTHERS

Stantec was provided dam safety review reports for the lagoon prepared by AMEC Earth and Environmental (AMEC, 2010) and Exp (Exp, 2014).

AMEC (2010)

The AMEC dam inspection report of 2010 references a geotechnical investigation from 2005 prepared for the initial lagoon design by Dillon Consulting Inc. Salient information from the 2005 report, as stated by AMEC in their 2010 dam safety review includes:

- Lagoon site covered with organic mat, typically 50 mm to 100 mm thick.
- Subsoils comprise poorly drained, saturated fine grained marine deposits of sand and silt with gravel, and inclusions of cobbles and boulders.
- Mean annual ground temperature of about -10 °C at about 15 m depth. Kugaaruk is located in the continuous permafrost zone.
- Active layer (seasonal thaw) thickness of 0.7 m to 1.0 m.
- A containment design comprising a cut-off trench and liner was adopted for the design. The cut off trench was originally proposed to comprise fine grained soils, but was substituted with sand backfill. This substitution was predicated on the assumption that the cut-off trench would remain frozen, and thus essentially impermeable, over the life of the containment structure.
- The liner comprises a Bentofix thermal lock geosynthetic clay liner.

AMEC provided construction monitoring of the cut-off trench. AMEC states that "practically the entire cut-off trench is situated atop granite gneiss that is weathered, jointed, and foliated extensively". Furthermore, the cut-off trench was excavated by the drill and blast method "into the competent granite in which most of the cut-off trench was constructed".

AMEC stated in their 2010 report: "It is anticipated that the [cut-off] trenches will perform as designed, provided that the soils surrounding cut-off trench remain in a frozen state."

The 2010 AMEC dam safety inspected did not identify any seepage on the exterior side of the perimeter berm, either at the time of the inspection or in the past, when "the effluent level in the lagoon was considerably higher". No settlement or depressions were observed in the crest of the perimeter berms.

Exp (2014)

A geotechnical site reconnaissance was conducted by Exp in late July 2014. No seepage from the lagoon was identified at the time of reconnaissance and interviews with Hamlet staff did not suggest any lagoon integrity issues.

CONTAINMENT DESIGN

Exp (2014) reported that the lagoon was constructed in 2007. Containment is understood to be provided by an impermeable liner vertically embedded within the berms. The base of the liner was to be anchored into sound bedrock at depth via a key trench with low permeability backfill or grout. The perimeter berms were constructed of local silty sand and gravel. Larger rip rap stone provides erosion protection on the face of the berms.

Lagoon discharge is via a designated outfall into a smaller downstream treatment cell.

PRELIMINARY GEOTECHNICAL ASSESSMENT OF PERIMETER BERMS

Seepage from the perimeter berms likely reflects a loss of containment by the synthetic liner and/or its cut-off trench and not a containment failure of the perimeter berms. Because the perimeter berms were not designed to contain waste water, any leakage through the liner system will seep through the berms relatively unobstructed. If seepage is occurring through the cut-off trench, this indicates thawing of the permafrost within the trench.

Seepage through the berms raises geotechnical integrity concerns for the berms as the seepage may lead to ground loss (piping) that could weaken or undermine the berms or reduce the geotechnical stability of the perimeter berms.

The absence of sagging, sloughing or other deformation of the perimeter berms suggests that the berms are still geotechnically stable. It is indeterminate how instability may progress or over what timeframe. If seepage accelerates, the opportunity for ground loss increases, which will negatively impact the geotechnical stability of the berms.

PRELIMINARY INTERVENTION STRATEGY

The observed seepage is of concern from a geotechnical perspective in terms of potential impacts on perimeter berm stability. Addressing treatment or other issues of the seepage is beyond the scope of this assessment.

Application of the so-called “observational approach” to the perimeter berm stability is one potential approach. The observational method is based on two important principles:

- Regular and thorough inspections of critical components of the system.
- Advance preparation of a reaction plan (emergency response plan) and implementation of the plan should circumstances change and stability conditions deteriorate.

The value of the observational approach is that it may defer any costly intrusive investigations and remediation for many years. It is critical to all parties to recognize that the observational approach is not a “do-nothing” approach. It requires up-front planning and once implemented requires diligence and the presence of appropriate resources to implement the monitoring and reaction plan, if needed.

Reference: Preliminary Geotechnical Assessment: Kugaaruk, NU Waste Water Treatment Lagoon

If the Government and Community are accepting of the above principles, Stantec can assist in developing the necessary inspection and reaction plans.

One significant short coming of a properly planned and implemented observational approach is that it is not suitable for rapid, catastrophic failure events. If the monitoring plan is not followed or the failure is not progressive implementation of the prepared reaction may not be suitable or adequate.

If the Government and Community is not prepared to accept the implementation of the observational approach, then seepage from the lagoon should be primarily controlled by immediately resolving integrity issues with the synthetic liner. Field testing to identify the source of the seepage is needed prior to developing a mitigation strategy

Mitigation strategies may include excavation and repair of the liner, if liner seepage is at mid-height in the berm, or pressure grouting with bentonite slurry if the seepage is through the bedrock cut-off trench.

Intrusive investigation plans should be developed to examine the liner at locations where seepage is present. Test pits using mechanical and hand excavation should be considered for this investigation. Other investigative techniques may also be considered.

CLOSURE

This memorandum provides a preliminary geotechnical assessment of the perimeter berm for the Kugaaruk sewage lagoon. It is considered that the perimeter berms are presently geotechnically stable, although stability could degrade if the existing seepage is not mitigated. The observational method may be an effective strategy to address potential berm instability, subject to development and implementation of an appropriate monitoring and emergency response plan.

REFERENCES

AMEC Earth & Environmental. 2010. Dam safety review for the Kugaaruk sewage lagoon. Prepared for Dillon Consulting Limited. Project number YX00828. Letter report dated November 24, 2010. 10 pgs.

Exp Services Inc. 2014. Hamlet of Kugaaruk: Dam safety review. Project Number: OTT-00219538-40. Dated November 14, 2014. 24 pgs.

Reference: Preliminary Geotechnical Assessment: Kugaaruk, NU Waste Water Treatment Lagoon

STANTEC CONSULTING LTD.

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Geotechnical and Permafrost Engineer
Stantec Consulting Ltd.
Calgary
Phone: (403) 880-6791

Attachment: Figures 1 - 3

Reference: Preliminary Geotechnical Assessment: Kugaaruk, NU Waste Water Treatment Lagoon

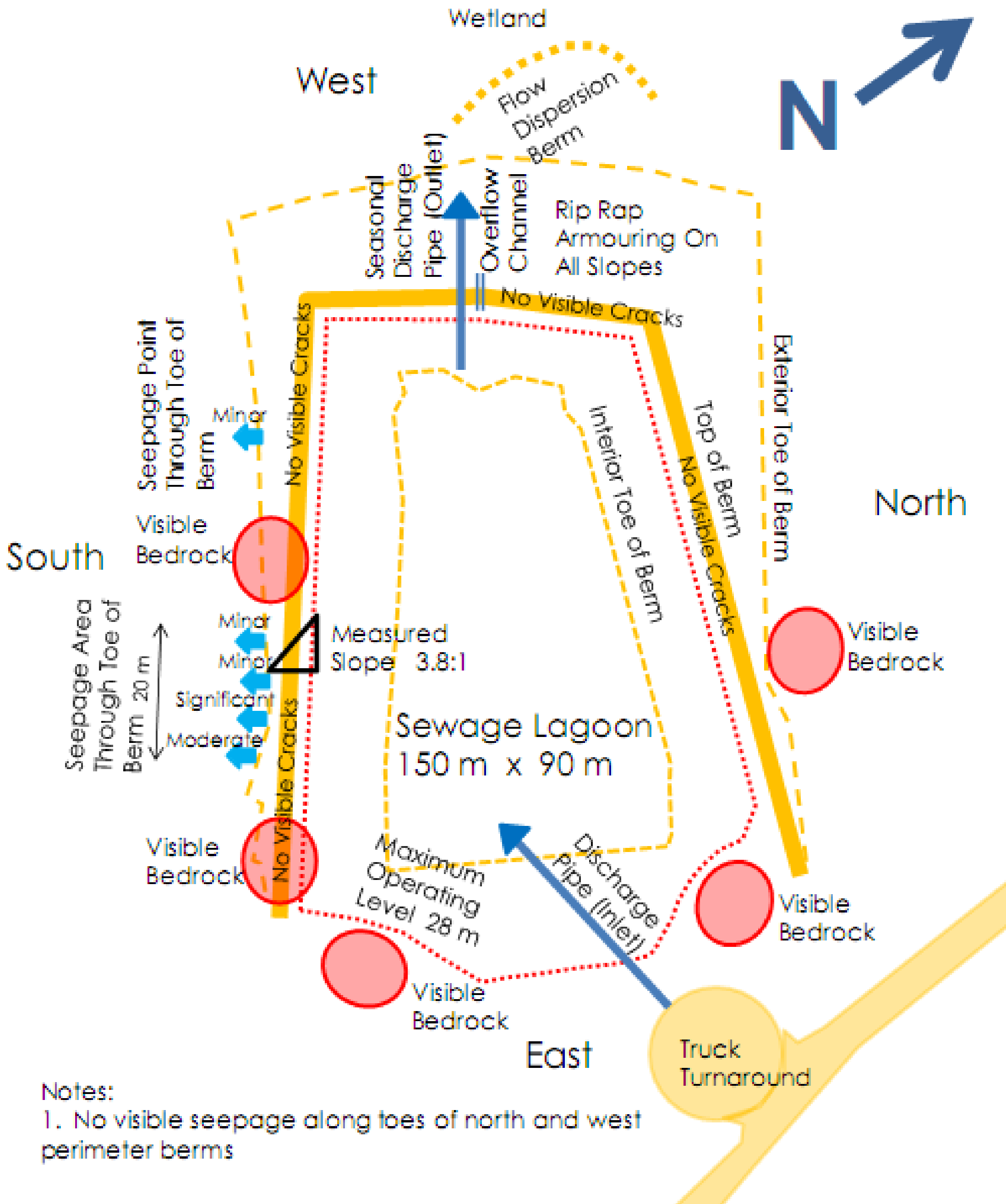

Figure 1: Sketch Kugaaruk waste water treatment lagoon (dated July 20, 2015), showing locations of observed seepage from the containment berm and other features.

Reference: Preliminary Geotechnical Assessment: Kugaaruk, NU Waste Water Treatment Lagoon

Figure 2: Seepage from south perimeter berm, Kugaaruk waste water lagoon

Figure 3: Seepage from south perimeter berm, Kugaaruk waste water lagoon

Appendix B WATER SAMPLE RESULTS

Stantec Consulting Ltd.
ATTN: KENNETH JOHNSON
10160 112 St.
Edmonton AB T5K 2L6

Date Received: 23-JUL-15
Report Date: 30-JUL-15 16:03 (MT)
Version: FINAL

Client Phone: 780-984-9085

Certificate of Analysis

Lab Work Order #: L1647361

Project P.O. #: NOT SUBMITTED
Job Reference: 110126041
C of C Numbers: 14-440551
Legal Site Desc:

Jessica Spira, Env. Tech. DIPL
Senior Account Manager

ALS ENVIRONMENTAL ANALYTICAL REPORT

Sample Details/Parameters	Result	Qualifier*	D.L.	Units	Extracted	Analyzed	Batch
L1647361-1 BERM TOE							
Sampled By: CLIENT on 23-JUL-15 @ 10:00							
Matrix: GRAB							
Miscellaneous Parameters							
Ammonia, Total (as N)	85.5		0.050	mg/L		30-JUL-15	R3235336
Biochemical Oxygen Demand	177		2.0	mg/L		24-JUL-15	R3234788
MPN - Fecal Coliforms	17000	DLA	100	MPN/100mL		24-JUL-15	R3232836
Total Suspended Solids	12.7		3.0	mg/L		25-JUL-15	R3232874
L1647361-2 BERM TOE DUPLICATE							
Sampled By: CLIENT on 23-JUL-15 @ 10:00							
Matrix: GRAB							
Miscellaneous Parameters							
Ammonia, Total (as N)	84.3		0.050	mg/L		30-JUL-15	R3235336
Biochemical Oxygen Demand	193		2.0	mg/L		24-JUL-15	R3234788
MPN - Fecal Coliforms	14000	DLA	100	MPN/100mL		24-JUL-15	R3232836
Total Suspended Solids	13.1		3.0	mg/L		25-JUL-15	R3232874
L1647361-3 DOWNSTREAM BERM							
Sampled By: CLIENT on 23-JUL-15 @ 10:00							
Matrix: GRAB							
Miscellaneous Parameters							
Ammonia, Total (as N)	51.9		0.050	mg/L		30-JUL-15	R3235336
Biochemical Oxygen Demand	115		2.0	mg/L		24-JUL-15	R3234788
MPN - Fecal Coliforms	1700	DLA	100	MPN/100mL		24-JUL-15	R3232836
Total Suspended Solids	29.8		3.0	mg/L		25-JUL-15	R3232874
L1647361-4 DOWNSTREAM BERM DUPLICATE							
Sampled By: CLIENT on 23-JUL-15 @ 10:00							
Matrix: GRAB							
Miscellaneous Parameters							
Ammonia, Total (as N)	48.6		0.050	mg/L		30-JUL-15	R3235336
Biochemical Oxygen Demand	123		2.0	mg/L		24-JUL-15	R3234788
MPN - Fecal Coliforms	2300	DLA	100	MPN/100mL		24-JUL-15	R3232836
Total Suspended Solids	19.9		3.0	mg/L		25-JUL-15	R3232874

* Refer to Referenced Information for Qualifiers (if any) and Methodology.

Reference Information

Sample Parameter Qualifier Key:

Qualifier	Description
DLA	Detection Limit adjusted for required dilution

Test Method References:

ALS Test Code	Matrix	Test Description	Method Reference**
BOD-ED	Water	Biochemical Oxygen Demand (BOD)	APHA 5210 B-5 day Incub.-O2 electrode
FCOLI-MPN-ED	Water	Thermotolerant Coliforms by MPN	APHA 9223B, 2004 Enzyme Substrate Method

Analysis is carried out using procedures adapted from APHA 9223 "Enzyme Substrate Coliform Test". Fecal Coliform (Thermotolerant) bacteria are determined by mixing sample with a mixture of hydrolyzable substrates and then sealed in a multi-well packet. The packet is incubated for 18-24 hours and the number of wells exhibiting a positive response are counted. The final result is obtained by comparing the positive responses to a probability table.

ALS Test Code	Matrix	Test Description	Method Reference**
NH3-CFA-ED	Water	Ammonia in Water by Colour	APHA 4500 NH3-NITROGEN (AMMONIA)

This analysis is carried out using procedures adapted from APHA Method 4500 NH3 "NITROGEN (AMMONIA)". Ammonia is determined using the automated phenate colourimetric method.

ALS Test Code	Matrix	Test Description	Method Reference**
SOLIDS-TOTSUS-ED	Water	Total Suspended Solids	APHA 2540 D-Gravimetric

Gravimetric determination of solids in waters by filtration and drying filter at 104 degrees Celsius.

** ALS test methods may incorporate modifications from specified reference methods to improve performance.

The last two letters of the above test code(s) indicate the laboratory that performed analytical analysis for that test. Refer to the list below:

Laboratory Definition Code	Laboratory Location
ED	ALS ENVIRONMENTAL - EDMONTON, ALBERTA, CANADA

Chain of Custody Numbers:

14-440551

GLOSSARY OF REPORT TERMS

Surrogates are compounds that are similar in behaviour to target analyte(s), but that do not normally occur in environmental samples. For applicable tests, surrogates are added to samples prior to analysis as a check on recovery. In reports that display the D.L. column, laboratory objectives for surrogates are listed there.
mg/kg - milligrams per kilogram based on dry weight of sample
mg/kg wwt - milligrams per kilogram based on wet weight of sample
mg/kg lwt - milligrams per kilogram based on lipid-adjusted weight
mg/L - unit of concentration based on volume, parts per million.
< - Less than.
D.L. - The reporting limit.
N/A - Result not available. Refer to qualifier code and definition for explanation.

Test results reported relate only to the samples as received by the laboratory.
UNLESS OTHERWISE STATED, ALL SAMPLES WERE RECEIVED IN ACCEPTABLE CONDITION.
Analytical results in unsigned test reports with the DRAFT watermark are subject to change, pending final QC review.

Quality Control Report

Workorder: L1647361 Report Date: 30-JUL-15

Client: Stantec Consulting Ltd.
10160 112 St.
Edmonton AB T5K 2L6
Contact: KENNETH JOHNSON

Test	Matrix	Reference	Result	Qualifier	Units	RPD	Limit	Analyzed
BOD-ED	**Water**							
Batch R3234788								
WG2135712-2 LCS								
Biochemical Oxygen Demand			99.8		%		85-115	24-JUL-15
WG2135712-3 MB								
Biochemical Oxygen Demand			<2.0		mg/L		2	24-JUL-15
FCOLI-MPN-ED	**Water**							
Batch R3232836								
WG2135850-1 MB								
MPN - Fecal Coliforms			<1		MPN/100mL		1	24-JUL-15
NH3-CFA-ED	**Water**							
Batch R3235336								
WG2139580-2 LCS								
Ammonia, Total (as N)			100.2		%		85-115	30-JUL-15
WG2139580-8 LCS								
Ammonia, Total (as N)			102.4		%		85-115	30-JUL-15
WG2139580-1 MB								
Ammonia, Total (as N)			<0.050		mg/L		0.05	30-JUL-15
WG2139580-6 MB								
Ammonia, Total (as N)			<0.050		mg/L		0.05	30-JUL-15
SOLIDS-TOTSUS-ED	**Water**							
Batch R3232874								
WG2136431-6 DUP		**L1647361-1**						
Total Suspended Solids		12.7	13.7		mg/L	7.6	20	25-JUL-15
WG2136431-2 LCS								
Total Suspended Solids			98.8		%		85-115	25-JUL-15
WG2136431-5 LCS								
Total Suspended Solids			100.4		%		85-115	25-JUL-15
WG2136431-1 MB								
Total Suspended Solids			<3.0		mg/L		3	25-JUL-15
WG2136431-4 MB								
Total Suspended Solids			<3.0		mg/L		3	25-JUL-15

Legend:

Limit	ALS Control Limit (Data Quality Objectives)
DUP	Duplicate
RPD	Relative Percent Difference
N/A	Not Available
LCS	Laboratory Control Sample
SRM	Standard Reference Material
MS	Matrix Spike
MSD	Matrix Spike Duplicate
ADE	Average Desorption Efficiency
MB	Method Blank
IRM	Internal Reference Material
CRM	Certified Reference Material
CCV	Continuing Calibration Verification
CVS	Calibration Verification Standard
LCSD	Laboratory Control Sample Duplicate

Hold Time Exceedances:

All test results reported with this submission were conducted within ALS recommended hold times.

ALS recommended hold times may vary by province. They are assigned to meet known provincial and/or federal government requirements. In the absence of regulatory hold times, ALS establishes recommendations based on guidelines published by the US EPA, APHA Standard Methods, or Environment Canada (where available). For more information, please contact ALS.

The ALS Quality Control Report is provided to ALS clients upon request. ALS includes comprehensive QC checks with every analysis to ensure our high standards of quality are met. Each QC result has a known or expected target value, which is compared against pre-determined data quality objectives to provide confidence in the accuracy of associated test results.

Please note that this report may contain QC results from anonymous Sample Duplicates and Matrix Spikes that do not originate from this Work Order.

ALS Environmental
www.alsglobal.com

Chain of Custody (COC) / Analytical Request Form

Canada Toll Free: 1 800 668 9878

Affix ALS barcode label here (lab use only)

COC Number: 14 - 440551

Page 1 of 1

Report To	KENNETH JOHNSON
Company:	STANTEC
Contact:	KEN JOHNSON
Address:	10160 112 ST EDMONTON
Phone:	780 984 9085

Report Format / Distribution

Select Report Format: [x] PDF [ ] EXCEL [ ] EDD (DIGITAL)

Quality Control (QC) Report with Report [ ] Yes [ ] No

[x] Criteria on Report - provide details below if box checked

Select Distribution: [x] EMAIL [ ] MAIL [ ] FAX

Email 1 or Fax: KENNETH.JOHNSON@STANTEC.COM

Email 2

Select Service Level Below (Rush Turnaround Time (TAT) is not available for all tests)

- R [x] Regular (Standard TAT if received by 3pm)
- P [ ] Priority (2-4 business days if received by 3pm)
- E [ ] Emergency (1-2 business days if received by 3pm)
- E2 [ ] Same day or weekend emergency if received by 10am – contact ALS for surcharge.

Specify Date Required for E2,E or P:

Invoice To

Same as Report To [x] Yes [ ] No

Copy of Invoice with Report [x] Yes [ ] No

Company:

Contact:

Invoice Distribution

Select Invoice Distribution: [ ] EMAIL [ ] MAIL [ ] FAX

Email 1 or Fax

Email 2

Project Information

ALS Quote #:

Job #: 110126041

PO / AFE:

LSD:

Oil and Gas Required Fields (client use)

Approver ID: | Cost Center:

GL Account: | Routing Code:

Activity Code:

Location:

ALS Lab Work Order # (lab use only): L1647361

ALS Contact:

Sampler:

Analysis Request

Indicate Filtered (F), Preserved (P) or Filtered and Preserved (F/P) below

ALS Sample # (lab use only)	Sample Identification and/or Coordinates (This description will appear on the report)	Date (dd-mmm-yy)	Time (hh:mm)	Sample Type	BOD	TSS	FECAL COL	AMMONIA	Number of Containers
	BERM TOE	23.07	10:00	GRAB	✓	✓	✓	✓	
	BERM TOE DUPLICATE	↓	↓	↓	✓	✓	✓	✓	
	DOWNSTREAM BERM	↓	↓	↓	✓	✓	✓	✓	
	DOWNSTREAM BERM DUPLICATE	↓	↓	↓	✓	✓	✓	✓	

L1647361-COFC

Drinking Water (DW) Samples[1] (client use)

Are samples taken from a Regulated DW System? [ ] Yes [x] No

Are samples for human drinking water use? [ ] Yes [x] No

…rt (client Use)

SAMPLE CONDITION AS RECEIVED (lab use only)

Frozen [ ] SIF Observations Yes [ ] No [ ]

Ice packs Yes [ ] No [ ] Custody seal intact Yes [ ] No [ ]

Cooling Initiated [ ]

INITIAL COOLER TEMPERATURES °C: 12.4°C

FINAL COOLER TEMPERATURES °C:

SHIPMENT RELEASE (client use)			INITIAL SHIPMENT RECEPTION (lab use only)			FINAL SHIPMENT RECEPTION (lab use only)		
Released by: [signature]	Date:	Time:	Received by: [signature]	Date: 7/23/2015	Time: 9:58pm	Received by:	Date:	Time:

REFER TO BACK PAGE FOR ALS LOCATIONS AND SAMPLING INFORMATION

WHITE - LABORATORY COPY YELLOW - CLIENT COPY

Failure to complete all portions of this form may delay analysis. Please fill in this form LEGIBLY. By the use of this form the user acknowledges and agrees with the Terms and Conditions as specified on the back page of the white - report copy.

1. If any water samples are taken from a Regulated Drinking Water (DW) System, please submit using an Authorized DW COC form.