Appendix 1.0-AC SRK, Liner Design and Construction Methodology for Tenas Management Pond Liners

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LIMITED

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FINAL

Technical Memo

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To	Dan Farmer, P.Eng., Allegiance Coal Limited
From	Kyle Scale, P.Eng., Ph.D.; Calvin Boese, P.Eng., M.Sc.
Subject	Liner Design and Construction Methodology for Tenas Management Ponds
Client	Telkwa Coal Ltd.
Project	2CT025.008.0300

1 Introduction

Telkwa Coal Ltd. (TCL) has retained SRK Consulting (Canada) Inc. (SRK) to design and provide a preliminary construction methodology for a liner system that will reduce seepage rates from the Tenas Management Ponds to below allowable thresholds defined in SRK's site water balance (SRK, 2020a). This liner assessment was initially conducted on four liner alternatives in the preliminary seepage assessment (Section 4.4.1); however, based on the performance and estimated costs, one of these liner alternatives was advanced to a focused seepage assessment (Section 4.4.2). The construction methodology for the selected liner alternative is detailed in Section 6 at an early design stage level.

This technical memo is divided into sections describing the Liner Design, Seepage Modeling, Construction Methodology, and Recommendations. The *Liner Design* section provides background on the seepage design criteria from SRK's site water balance, geometry of the PAG management ponds, and details the liner materials and liner system configurations. The *Seepage Modeling* section details the cross sections that serve as a basis for the seepage models, the assumptions and calibration of these models, and presents the results of the seepage assessment and presents a recommended liner option. The *Construction Methodology* section outlines the assumptions, material characteristics, execution of the liner system at an early design stage level, and quality control. The technical memo concludes with the *Recommendations* section, presenting SRK's recommendations for field and laboratory testing, construction methodology, and quality control of the recommended liner system.

2 Background

The Tenas Project is in central British Columbia, approximately 15 km south of Smithers and 2 km southwest of Telkwa. The Project site is located south of the Tenas River and the boundaries of the Project encompass the lower reaches of the Telkwa River, Goathorn Creek, and Pine Creek. The Tenas Project's total mine life is anticipated to be 22 years, including one year of pre-stripping and construction followed by 21 years of production. The mine plan was designed and scheduled in a manner that allows potentially-acid generating (PAG) rock to be deposited into management ponds (MP), including the East Management Pond (EMP), West Management Pond (WMP), and North Management Pond (NMP). These MP are above-ground PAG rock storage facilitates. The WMP consists of a portion that is an excavated pit (*Tenas Pit Phase 9*), referred to herein as '*In Pit*', and the remaining portion outside the pit referred to herein as '*Ex Pit*'.

Environmental containment is to be achieved with liner systems that are constructed along the bottom of the ponds and the upstream slopes of the perimeter dams.

3 Liner Design Basis

The following subsections describe the seepage design criteria, pond geometry, material properties, and liner configurations.

3.1 Seepage Design Criteria

A preliminary water balance provided design targets for the liner seepage analyses that evaluated seepage rates through the bottom of the MP and upstream slopes of the perimeter dams. The maximum allowable seepage through the MP catchments was determined to be 2,800 m^3/day from the site wide water balance (SRK, 2020a). This value represents the maximum seepage rate allowed to maintain a positive water balance over the PAG rock (e.g. maintain a minimum 1 m capping of ponded water).

This value is conservatively based on the "*10 Year Dry*" scenario. For the average year scenario, the allowable seepage rate through the management pond catchments increases to 4,260 m^3/day. For reference, the water quality target from the Definitive Feasibility Study (DFS) model was 1,700 m^3/day.

3.2 Pond Geometry and Potential Seepage Areas

Design elevations for the dam crests, freeboard, and areas pertinent to the seepage assessments are included in Table 1. Design revision 1 includes added capacity to account for the reduction in MP storage capacity due to the incorporation of a 1 m thick soil over-liner as the liner protective component (discussed in Section 4.4.2). This revision included raising the dam crests and freeboard elevations for the EMP, NMP, and WMP (Ex-Pit).

Table 1: Model Geometry for the TCL Management Ponds

Design Revision	Management Pond	Area Pond[1] (m^2)	Area Upstream Dam Slopes[1] (m^2)	Cumulative Area[1] (m^2)	Dam Crest Elev. (masl)	Freeboard Elev. (masl)
0	EMP	901,000	163,000	1,064,000	850	849
	WMP (Ex Pit)	371,600	122,000	493,600	850	849
	WMP (In Pit)	440,400	n/a	440,400	n/a	n/a
	NMP	76,900	184,500	261,400	830	829
1	EMP	961,939	180,136	1,142,075	852	851
	WMP (Ex Pit)	361,874	141,148	503,022	852	851
	WMP (In Pit)	533,548	n/a	533,548	n/a	n/a
	NMP	210,190	83,017	293,207	831	830

Notes:
(1) MP surfaces areas contributing to seepage through the liner system.
(2) Model geometry for Design Revision 1 provided by Telkwa on November 17, 2020.

3.3 Material Properties

Table 2 lists the materials that were modeled in the seepage assessment for the various liner design options. The high case for the native soils represents an increase of the base case hydraulic conductivities by a factor of 2.7 (SRK, 2020b).

Table 2: Materials Considered for the Liner Seepage Assessment

Material	Hydraulic Conductivity, k (m/s)	
	Base Case	High Case
Native soil (EMP)[1]	3.0E-6	8.1E-6
Native soil (NMP)[1]	1.9E-6	5.1E-6
Bentonite[2]	5.0E-11	-
Soil-bentonite mixture[2]	1.0E-9	-
Soil-bentonite mixture (optimized)[2]	1.0E-10	-
Skilhorn clay[3]	5.9E-9	-
Clay-bentonite mixture[2]	8.6E-10	-
Skeena Sedimentary Rock[4]	3.62E-7	-

Notes:
(1) Values for native soil derived from calibration with the site wide FEFLOW® groundwater model.
(2) Values for bentonite, soil-bentonite mixtures, and clay-bentonite mixtures assumed based on experience with previous projects.
(3) Values for Skilhorn measured in laboratory falling head hydraulic conductivity testing performed with a flexible wall permeameter.
(4) Values for Skeena sedimentary rock (bedrock) obtained from FEFLOW® groundwater model.

A hydraulic conductivity of 1.0E-9 m/s for the soil-bentonite mixture was calculated for a 5% (by volume) soil-bentonite mixture based an assumed hydraulic conductivity for bentonite of 5E-11 m/s. However, recent laboratory testing performed by Golder Associates on available bentonite are showing the hydraulic conductivity to be 3E-12 m/s. The calculated hydraulic conductivity of the soil-bentonite mixture, using the recent lab test value, equates to 6E-11 m/s. Based on the lab data and previous experience with a similar northern project, it is anticipated that a hydraulic conductivity value of 1E-10 m/s can be achieved and was therefore considered in the liner option assessment as an optimized value.

4 Seepage Model Development

Two-dimensional liner seepage analyses were carried out with GeoStudio's SEEP/W modeling software (Version 11.0.1.21429). The following subsections detail the cross-sections, model assumptions and calibration, and results of the seepage assessment.

4.1 Cross Sections

The cross sections shown in Figure 1 were developed into seepage models for the NMP, EMP, and WMP based on site topography, bedrock elevations, and perimeter dam designs. These cross sections were chosen along alignments that intersect the lowest topography in each pond as well as nearby creeks (*topographic lows*). Section 1 (1'-1') was used to develop the model for the NMP; Section 2 (2'-2') was used to develop the model for the EMP; and Sections 3 (3'-3') and 4 (4'-4') were used to develop models for the WMP.

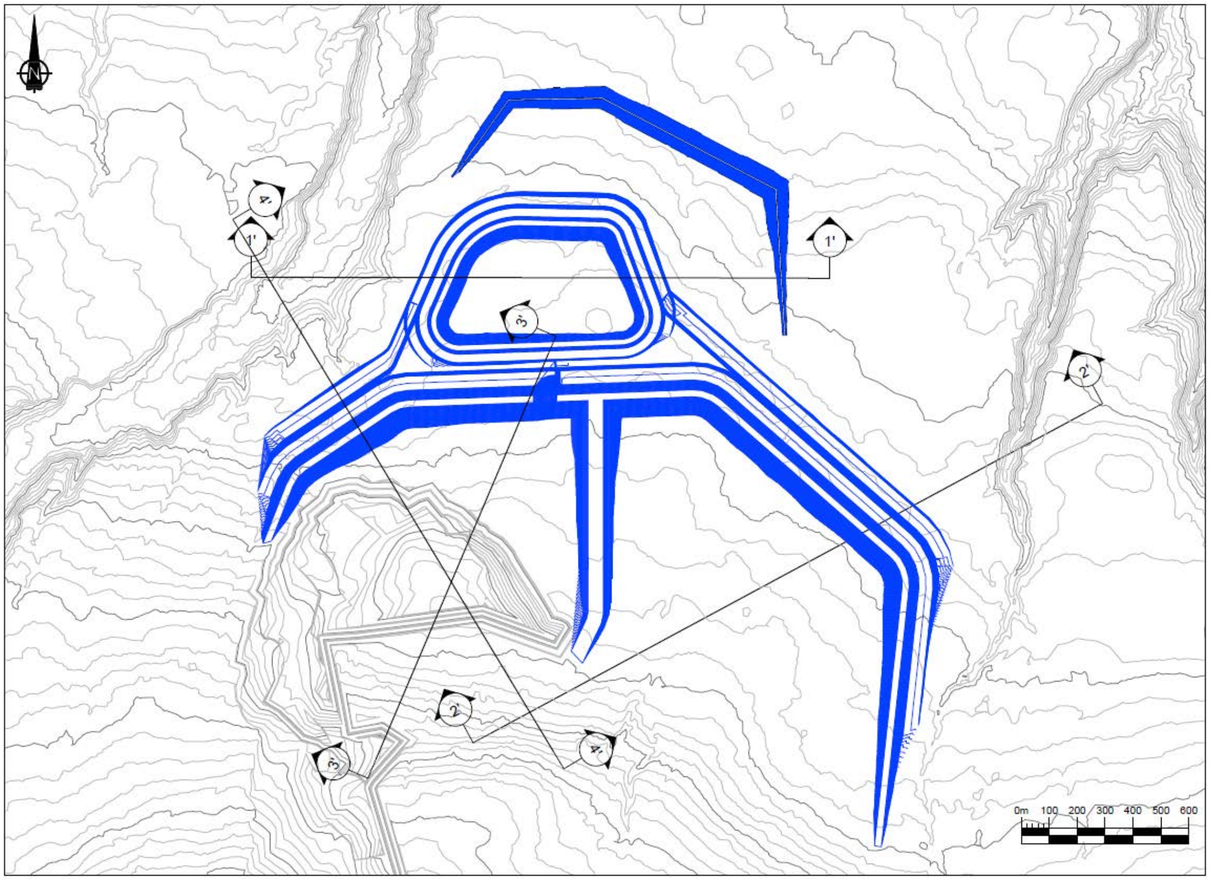

Figure 1: Cross sections of the North Management Pond (Section 1'-1'), the East Management Pond (Section 2'-2'), and the West Management Pond (Sections 3'-3' and 4'-4') that served as the basis for the seepage models

4.2 Model Assumptions

The seepage models for the EMP, WMP, and NMP were developed based on cross sections that included the site topography, bedrock elevations, and designs of the perimeter dams. For the preliminary seepage assessment only Section 1 for the NMP and Section 2 for the EMP were evaluated. At this early stage, seepage through the WMP was assumed to be equivalent to seepage through the EMP.

The seepage assessment for revision 1 included two additional sections for the WMP that spanned the *In Pit* and *Ex Pit* portions. Seepage through unlined portions of the WMP *In Pit* were determined using FEFLOW® groundwater modeling software by applying a total head of 851 masl (*the dam freeboard elevation*). The WMP *In Pit* portion is assumed to be graded at 2.5H:1V from the *Ex Pit* portion towards the south-southwest. This produces a portion of the north slope that is comprised of overburden and a portion that is a bedrock pit wall. Scenarios that involve lining the overburden slope and bedrock pit wall are discussed in Section 4.4.

Seepage models developed for the preliminary and revision 1 seepage assessments consider the uppermost soil layer to be unsaturated and the underlying soil (below the estimated water table) to be saturated.

4.3 Calibration

The site wide groundwater model was developed with FEFLOW® groundwater modeling software. This model utilized data from recent and historic drilling campaigns to distribute the native ground in the vicinity of the MP into *Silty Clay* and *Sand & Gravel*, with hydraulic conductivities of 2E-7 and 3E-6 m/s, respectively. These materials were used as a basis to calibrate the two-dimensional liner seepage models.

To accomplish this calibration, the hydraulic conductivity of the materials in the unlined two-dimensional seepage models were toggled until the seepage rates matched the rates measured with FEFLOW®. For the purposes of this calibration, the resulting material at the EMP and WMP were *Sand & Gravel*, with a hydraulic conductivity of 3E-6 m/s, and the material at the NMP was 40% *Clay* and 60% *Sand & Gravel,* with a hydraulic conductivity of 1.88E-6 m/s.

4.4 Liner Configurations

Four liner configurations were modeled as part of the preliminary seepage assessment (Design Revision 0) and one of these configurations was advanced to the focused seepage assessment (Design Revision 1).

4.4.1 Preliminary Seepage Assessment (Design Revision 0)

The liner options that were modeled in the two-dimensional SEEP/W (2020) for the preliminary seepage assessment are listed below:

1. Native soil with bentonite disked into the surface at 0.15 or 0.30 m.
2. Clay from Skilhorn Quarry placed to a depth of 1 to 2 m.
3. Clay from Skilhorn Quarry placed to a depth of 1 m with bentonite disked to a depth of 0.15 or 0.30 m.
4. Bentonite placed to a thickness of 0.15 or 0.30 m and covered with a minimum 0.15 m of native soil.

4.4.2 Focused Seepage Assessment (Design Revision 1)

The soil-bentonite liner system (Option 1 from Design Revision 0) was progressed to a focused liner seepage assessment in 0.15 and 0.30 m thicknesses with the optimized bentonite hydraulic conductivity of 1E-10 m/s. Table 3 presents the various configurations of the soil-bentonite liner system that were assessed.

Each configuration considers the WMP *Ex Pit* portion to be lined. Configurations 1 to 4 consider the overburden pit slope of the WMP *In Pit* portion to be lined. Configurations 5 to 8 consider the entire

WMP *In Pit* portion to be lined other than the subvertical bedrock cliff; this includes a 1.5 m thick layer *In Pit* soil liner overlying the bedrock. These configurations were modeled with the base and high case hydraulic conductivity values listed in Table 2.

Table 3: Soil-Bentonite Liner Systems Assessed as Part of the Focused Seepage Modeling

Configuration	Case	SB Thickness (m)	NMP	EMP	WMP Liner Configurations		
					OVB Slope Liner	In-Pit Liner	BR Pit Wall Slope Liner
1	BC	0.15	Y	Y	Y	N	N
2	BC	0.30	Y	Y	Y	N	N
3	HC	0.15	Y	Y	Y	N	N
4	HC	0.30	Y	Y	Y	N	N
5	BC	0.15	Y	Y	Y	Y	Y
6	HC	0.15	Y	Y	Y	Y	Y
7	BC	0.30	Y	Y	Y	Y	Y

Notes:
(1) BC = Base Case; HC = High Case; MP = Management Pond; BR = Bedrock; OVB = Overburden; SB = Soil-Bentonite.
(2) For the High Case, the hydraulic conductivity of the underlying soils has been increased by a factor of 2.7.
(3) The Soil-Bentonite material assumes an optimized hydraulic conductivity of 1E-10 m/s.

5 Seepage Model Results

Seepage rates were quantified through the surface areas corresponding to the upstream perimeter dam slopes and MP pond bottoms. Results of the preliminary seepage modeling (Design Revision 0) are presented in Section 5.1 and results of the focused seepage modeling (Design Revision 1) are presented in Section 5.2.

5.1 Results of the Preliminary Seepage Modeling (Design Revision 0)

Preliminary seepage modeling was conducted with the geometry shown in Table 1 for *Design Revision 0.* Only Section 1 for the NMP and Section 2 for the EMP were modeled at this stage and the *In Pit* portion of the WMP was not independently assessed. Based on FEFLOW® groundwater modeling, with a scenario considering a 0.5 m thick compacted clay liner, the seepage from the *Ex Pit* portion of the WMP would be 483 m^3/day. This seepage rate was factored into the seepage results calculated for the various liner systems with SEEP/W (2020).

Results of the two-dimensional liner seepage assessment are shown in Table 4 and plotted in Figure 2. Seven liner alternatives provided a seepage rate < 2,800 m^3/day, which corresponds to the maximum allowable seepage rate for the *10 Year Dry* scenario. Four of these alternatives barely met the design criteria. However, the design criteria was easily achieved for bentonite placed to a thickness of 0.15 or 0.30 m covered with a minimum 0.15 m of native soil, and the optimized native soil with bentonite disked into the surface at 0.15 m (soil-bentonite). Each of the liner alternatives listed below provide a seepage rate ≤ 4,260 m^3/day, which corresponds to the *Average Year* scenario.

Table 4: Results from the Two-dimensional Liner Seepage Assessment for the Various Liner Configurations Modeled in SEEP/W

Model	Seepage (m^3/day)	Seepage < 2800 m^3/day (Y/N)
No Liner	6,992	N
0.15m Soil-Bentonite	3,226	N
0.15m Soil-Bentonite (Optimized)	1,606	Y
0.3m Soil-Bentonite	2,779	Y
1m Skilhorn Clay	3,201	N
2m Skilhorn Clay	2,779	Y
1m Skilhorn Clay + 0.15m Clay-Bentonite	2,788	Y
1m Skilhorn Clay + 0.30m Clay-Bentonite	2,580	Y
0.15m Bentonite	1,204	Y
0.30m Bentonite	843	Y

Notes:
(1) Seepage limit based on the 10 Year Dry scenario developed in the site water balance is 2,800 m^3/day.
(2) Seepage limit based on the Average Year scenario developed in the site water balance is 4,260 m^3/day.

Results of the two-dimensional liner seepage assessment are plotted in Figure 2.

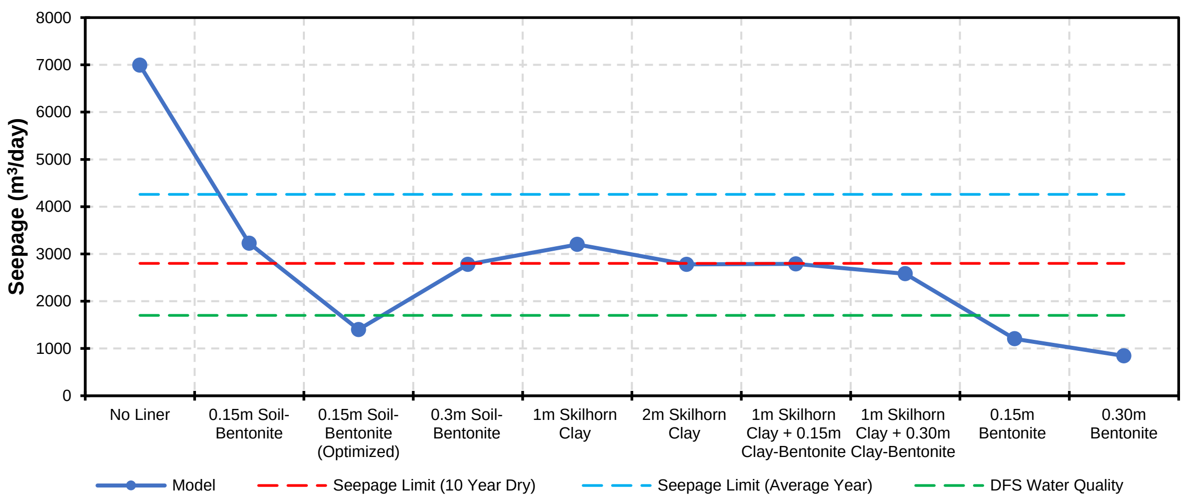

Figure 2: Results of the Preliminary Liner Seepage Assessment (Design Revision 0) for the Various Liner Configurations Modeled in SEEP/W

From these scenarios, the 0.15 m soil-bentonite liner system with the optimized bentonite hydraulic conductivity of 1E-10 m/s was advanced to the focused seepage modeling (Design Revision 1). The alternatives for the 0.15 m and 0.30 m pure bentonite were not advanced due to the costs being significantly higher compared to the other liner systems.

5.2 Results of the Focused Seepage Modeling (Design Revision 1)

The 0.15 m soil-bentonite liner system with the optimized bentonite hydraulic conductivity of 1E-10 m/s was subjected to a more detailed assessment as part of the focused seepage modeling (Design Revision 1). An additional 0.30 m soil-bentonite liner system with the optimized bentonite hydraulic conductivity of 1E-10 m/s was also incorporated into the focused seepage modeling. These seepage models were developed with the geometry shown in Table 1 for *Design Revision 1*.

5.2.1 WMP Liner Assessment

For the focused seepage modeling, two cross sections were modeled for the WMP (Section 3 and Section 4), in addition to the sections for the NMP and EMP. The new cross sections spanned the WMP *In Pit* and *Ex Pit* portions.

The results of the focused seepage assessment for all MPs with the geometry shown in Table 1 for *Design Revision 1* are listed in Table 5 and shown in Figure 3. The seepage rates for the WMP *In Pit* and *Ex Pit* portions are the average of Sections 3 and 4. As noted in Section 4.4.2, Configurations 1 to 4 consider the overburden pit slope of the WMP *In Pit* portion to be lined. Configurations 5 to 8 consider the entire WMP *In Pit* portion to be lined other than the subvertical bedrock cliff; this includes a 1.5 m thick layer *In Pit* soil liner overlying the bedrock to provide a bedding layer for the liner.

Table 5: Results of the Focused Liner Seepage Assessment for the NMP, EMP, and WMP *In Pit* and *Ex Pit* Conducted using the Geometry from Design Revision 1

Liner	Case	SB Thickness (m)	WMP Liner Configurations			Seepage Rates (m^3/day)				
			OVB Slope Liner	In-Pit Liner	BR Pit Wall Slope Liner	EMP	NMP	WMP (In-Pit)	WMP (Ex-Pit)	Cumulative
1	BC	0.15	Y	N	N	738	371	654	706	2,470
2	BC	0.30	Y	N	N	458	198	701	379	1,736
3	HC	0.15	Y	N	N	978	408	1441	778	3,605
4	HC	0.30	Y	N	N	535	210	1445	404	2,594
5	BC	0.15	Y	Y	Y	738	371	368	762	2,239
6	HC	0.15	Y	Y	Y	978	408	567	933	2,886
7	BC	0.30	Y	Y	Y	458	198	313	400	1,369
8	HC	0.30	Y	Y	Y	535	210	447	523	1,715

Notes:
(1) BC = Base Case; HC = High Case; MP = Management Pond; BR = Bedrock; OVB = Overburden; SB = Soil-Bentonite
(2) For the High Case, the hydraulic conductivity of the underlying soils has been increased by a factor of 2.7.
(3) The Soil-Bentonite material assumes an optimized hydraulic conductivity of 1E-10 m/s.

The results of the focused seepage assessment for all MPs with the geometry shown in Table 1 for *Design Revision 1* are shown in Figure 3.

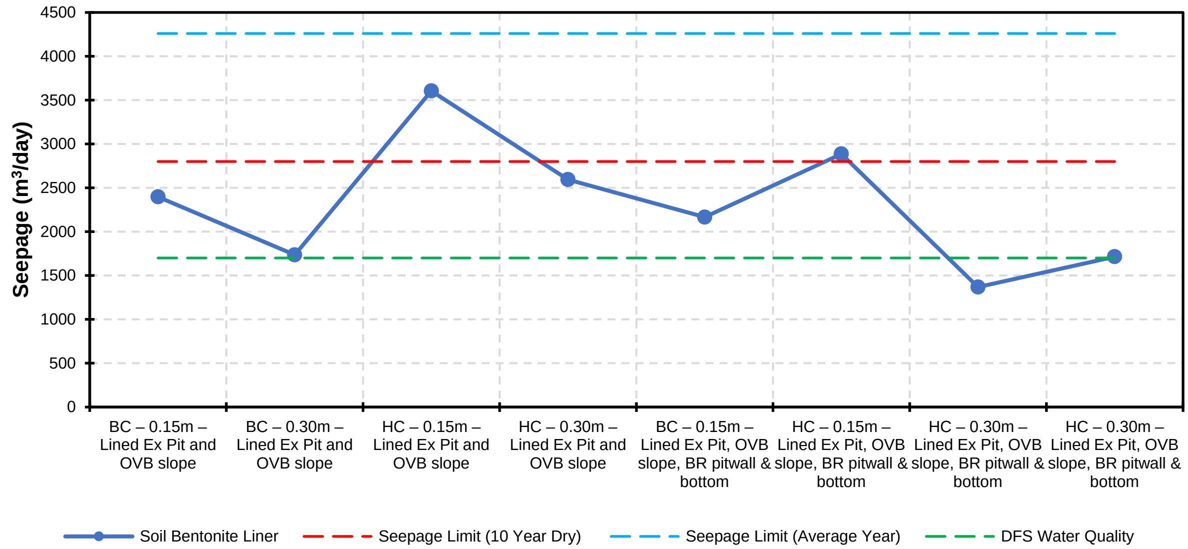

Figure 3: Results of the Focused Liner Seepage Assessment (Design Revision 1) for the Various Soil-bentonite Liner Configurations Modeled in SEEP/W

Each of the liner alternatives listed above provide a seepage rate ≤ 4,260 m^3/day, which corresponds to the *Average Year* scenario. The 0.3 m soil bentonite-liner provides seepage rates < 2,800 m^3/day for both the base and high cases, which corresponds to the maximum allowable seepage rate for the *10 Year Dry* scenario.

5.3 Recommended Liner Design

The recommended liner design is the 0.30 m soil-bentonite liner constructed in the NMP, EMP and over the *Ex Pit* portion of and the overburden pit slope of the WMP. This liner system provides a seepage rate ≤ 2,800 m^3/day for both the base and high cases, which corresponds to the maximum allowable seepage rate for the *10 Year Dry* scenario.

6 Construction Methodology

The following section details a preliminary construction methodology for the recommended 0.30 m soil-bentonite liner system that will be constructed in two 0.15 m lifts. This construction methodology was completed at an early design stage level and will be refined in greater detail in detailed design engineering.

6.1 Assumptions

It is assumed that construction of the embankments and buttresses are to be completed to the specifications in SRK (2021).

Table 6 lists the lined areas for the various MP that were evaluated in the preliminary cost estimate.

Table 6: Lined Areas for the Various Liner Alternatives

Design Revision[1]	Management Pond	Area Pond (m^2)	Area Upstream Dam Slopes (m^2)	Cumulative Area (m^2)
1	EMP	961,939	180,136	1,142,075
	WMP[2] (Ex Pit)	361,874	141,148	503,022
	NMP	210,190	83,017	293,207

Notes:
(1) Model geometry for Design Revision 1 provided by Telkwa on November 17, 2020.
(2) Lining of the WMP *In Pit* portion is not being considered for the construction methodology

Plan view of the areas requiring soil-bentonite liner is shown in Figure 4.

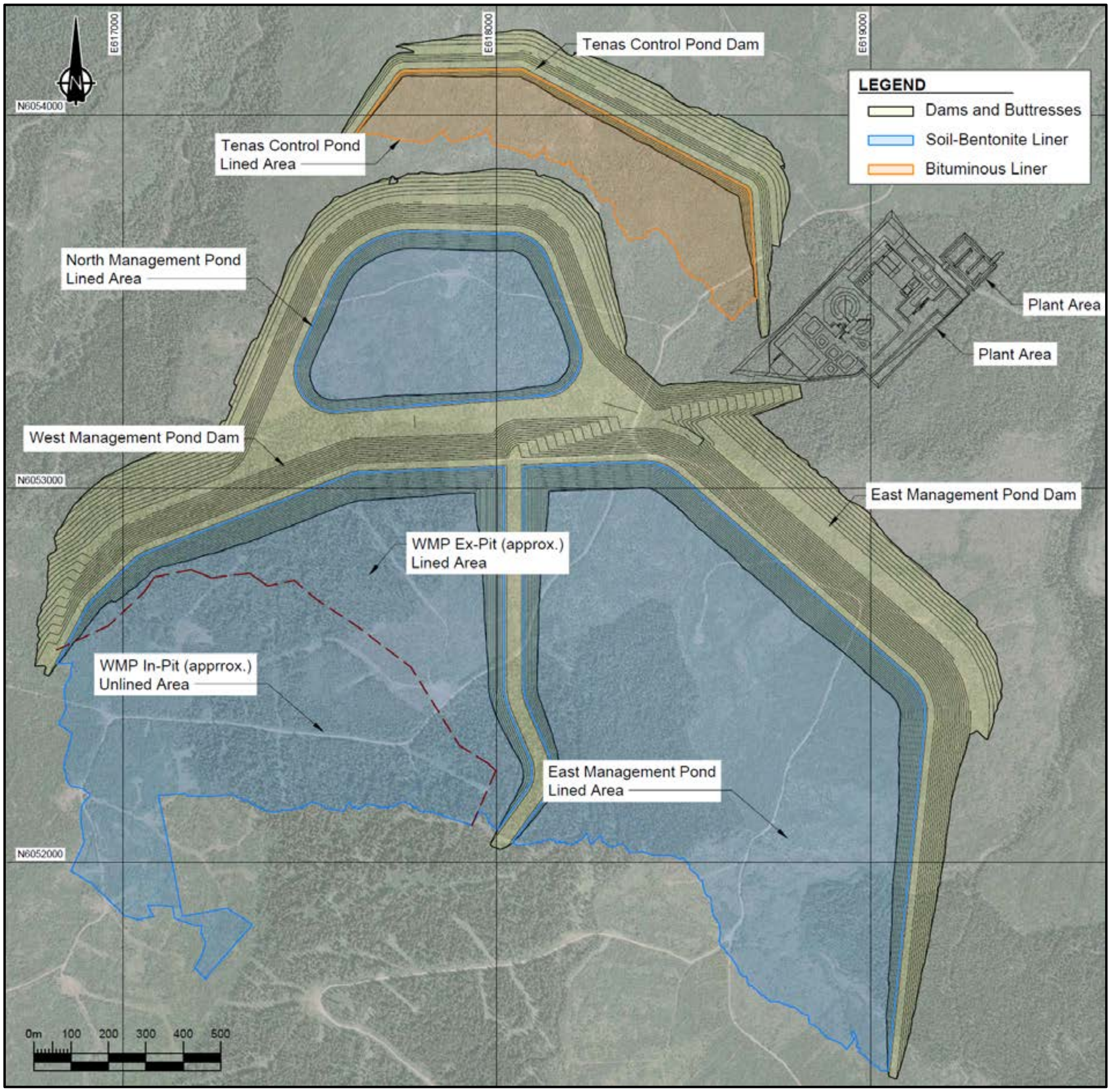

Figure 4: **Plan view of the lined surface areas of the Tenas Control Pond and PAG management ponds at the Tenas Project**

6.2 Material Characteristics

The blend of materials used for the soil-bentonite liner system (surface soils and bentonite) depend on the parameters adopted in the design, specifically the geotechnical parameters and hydraulic conductivity. The material characteristics and its adequacy to quality standards will need to be proven in laboratory testing and in the field.

Field obtained geotechnical parameters should be equal to or better than those adopted in the design. The *in-situ* hydraulic conductivity of the soil-bentonite liner should have a hydraulic conductivity $\leq 1 \times 10^{-10}$ m/s; therefore, a correct characterization of the geotechnical parameters (particle-size distribution and clay/bentonite content) and parameters associated with the condition of permeability (degree of compaction, *in-situ* hydraulic conductivity) will be required. Additional characteristic parameters are recommended to be evaluated during the construction works to check compliance with minimum material requirements during construction.

6.2.1 On-Site Soil

The selected area for the MP is located at the north and north-east of the projected Tenas open pit. The overburden material is composed principally of a very stiff to hard lean clay (CL), with low to medium plasticity, with intervals of high plasticity clay (CH), clayey silty sand (SC or SM) or gravel (GC or GM) at various depths (with an overburden total thickness equal or higher than 30 m in most of the extension).

Fine-grained and coarse-grained native soil utilized for the soil-bentonite liner system will be exposed during foundation preparation (described in Section 6.3.3). Coarser-grained granular particles such as cobbles and boulders should be removed. The native soil should be subjected to field and laboratory testing to verify the proportion of bentonite required to meet the target hydraulic conductivity $\leq 1 \times 10^{-10}$ m/s, which served as the basis of the liner design.

6.3 Execution of the Liner System

6.3.1 General

During the construction procedure (cleaning, excavation, embankment construction and operations), additional information related to foundation characteristics and slope materials can be obtained. This information can continue to inform and help to develop processes.

6.3.2 Equipment

Equipment options that can be considered for construction of the soil-bentonite liner system include haul trucks, haul trucks equipped with truck mounted spreaders or tractors pulling trailer mounted spreaders, smooth-drum and/or padfoot vibrating compactors, tractors (equipped with or) pulling trailer mounted rotovators or disc harrows, dozers, or graders. The most suitable equipment will be selected by Telkwa Coal based on the soil characteristics and construction requirements.

6.3.3 Foundation Preparation

In preparation for construction of the soil-bentonite liner system, clearing and grubbing should be completed until surface soils, trunks, roots, and topsoil materials have been removed and no appreciable content of organic matter remains:

- Clearing involves cutting of tree stumps and brush, and removal of snow and ice.
- Grubbing involves removal of tree stumps, shrubs, grasses, including their complete root system.

The terrain slope should be uniform for consistent pre-disking and subsequent application & mixing of bentonite.

6.3.4 Placement, Disking, and Compaction

In this section, preliminary placement, disking, and compaction specifications are provided. These will be further studied and updated during detailed design engineering.

Previous Studies

Placement, discing, and compaction equipment and use shall be determined from field studies in trial pads. From these studies, the optimum combination of type of equipment and operation shall be specified. The feasibility of pre-disking the upstream dam surface area shall be assessed on a trial embankment. However, it may be determined that instead of pre-disking, the upstream dam face should be scarified with a toothed excavator bucket or alternative methods.

Pre-Disking

Construction of the soil-bentonite liner system involves pre-disking the uppermost 0.15 m of soil to ensure hydraulic connectivity of the native soils and bentonite. This will take place following inspection and approval of preliminary foundation preparation (clearing and grubbing). The field engineer shall carry out visual inspection and approval of the pre-disked surface prior to advancing to bentonite placement. The number of passes required for pre-disking to is dependent on the prepared foundation conditions and selection of equipment.

Placement, Disking, and Compaction

Bentonite will be spread onto the uppermost 0.15 m of pre-disked surface soil. Spreading the bentonite may be accomplished from a haul truck mounted cement spreader or a tractor pulling a trailer mounted spreader. Equipment to consider for spreading bentonite are the Stoltz Site Spreader® mounted on a CAT® haul truck. The number of passes to dispense a sufficient quantity of bentonite is dependent on the selection of equipment. For the upstream dam faces it may be necessary to utilize an excavator to roughly dispense the bentonite from 1 m^3 bags, followed by manual smoothing/raking of the bentonite by laborers using manual tools such as rakes and shovels.

Following spreading of the bentonite, disking will be undertaken to mix the pre-disked native soil and bentonite. The maximum disking depth per pass is 0.15 m; hence, survey control will need to be achieved using either GPS, rod & level (horizontal levelling), or Total Station. The number of passes of the disking equipment to achieve adequate mixing will be based on the selection of equipment and informed by field studies on trial pads.

To achieve the 0.30 m soil-bentonite liner, a 0.15 m layer of local material will need to be placed prior to the second addition of bentonite. Placement of the native soil can be completed by hauling native soil with a haul truck, dumping the material in local stockpiles, and then spreading the soil to the target 0.15 m lift thickness with a dozer or grader. Similar to the first 0.15 m lift of the soil-bentonite liner system, bentonite will be spread onto the 0.15 m of native soil followed by disking to mix the native soil and bentonite.

Compaction of the 0.3 m soil bentonite will be accomplished with a vibratory smooth drum or sheepsfoot roller. The number of passes of the compactor will be dependent on dry density targets defined in the detailed design engineering and selection of equipment.

Grab samples of the surface soil, bentonite, and soil-bentonite mixture shall be collected and subjected to the testing procedures recommended in Section 6.4.2. Testing of the compacted soil-bentonite liner system *in-situ* shall be undertaken with the testing procedures recommended in Section 6.4.

6.3.5 Protective Component

Prior to placement of PAG material, the soil-bentonite liner system will require a protective component to protect the liners from being punctured by large waste rock, which could damage the integrity and functionality of the liner system. Two options were evaluated for this protective layer:

1. Placement of a 1 m thick over-liner layer of locally stockpiled soil.
2. Deployment of a 16 oz. non-woven geotextile.

A protective layer of 16 oz. non-woven geotextile was selected to be placed on top of the liner instead of a soil over-liner. Aside from being the lower cost of the two alternatives, the non-woven geotextile does not reduce the storage capacity of the MPs.

6.4 Quality Control and Quality Assurance

The development of an adequate geotechnical campaign, technical specifications for construction and quality controls mitigate the risk of requiring a re-design during construction. The definition of ranges for acceptable parameters ensures flexibility in design tolerances and enables foreseeing actions on possible variabilities in material quality. The design of adequate construction methodologies and its correct control can help prevent contingent quality defects due to negligence and the additional associated costs.

6.4.1 Weather Considerations

Weather and runoff conditions during construction can significantly affect the water content of the surface soil material or create hydraulic conditions different from those assumed, which could in turn cause changes in the liner design. For this reason, the project must be continuously evaluated to make sure that the conditions found during construction are compatible with the final design.

6.4.2 Recommended Testing

It will be necessary to maintain density control and verify the in-situ hydraulic conductivity of the soil-bentonite liner system to ensure the liner will perform to specification. This will involve a combination of laboratory testing on grab samples collected in the field and *in-situ* (field based) testing.

Routine Tests

The following routine testing and visual-manual inspection shall be performed to establish the soil type and *in-situ* condition:

- Natural moisture content testing according to standard ASTM D2216;
- Particle size distribution curves shall be obtained according to standards ASTM D0422 (granular material) and ASTM D2487 (fine material). These shall be obtained for samples of surface soils, bentonite, and soil-bentonite liner material; and
- Permeability tests shall be performed according to standards ASTM D2434 (granular material) and ASTM D5084 (fine material).

6.4.3 Compaction

The *in-situ* soil density can be measured by two methods:

- Sand-cone method (ASTM D1556): an excavation is made, and the weight of the extracted material is determined. The excavation volume is computed by filling the hole with sand using a calibrated recipient; and
- Nuclear methods (ASTM D2922, ASTM D3017): based on the interaction between gamma radiation and existing electrons in the soil particles. The difference between energy emitted and received is measured, which is proportional to the soil density.

A systematic on-site control program of the degree of compaction must be elaborated and implemented to determine the density and moisture content of the compacted material and compare the results with the specified limits.

The degree of compaction grade shall be verified in each lift. Control of the fill material shall be carried out continuously by visual inspection of the operations (unloading, spreading, humidification, mixing and compaction).

The number of control tests shall be determined for the detailed level design. No new lift shall be spread until the degree of compaction (moisture and density) has been tested and accepted.

6.4.4 Permeability Tests

The soil permeability governs the hydraulic performance of the soil-bentonite liner system. Permeability shall be verified by the use of trial pads, either prior to or during construction, by a Double Ring Infiltrometer, Guelph infiltrometer or *in situ* tests (ASTM D5126).

Permeability results for the soil bentonite liner must be less than or equal to $1x10^{-10}$ m/s in accordance with hypotheses made during the geotechnical design of the embankment.

7 Recommendations

- A 0.30 m soil-bentonite liner system with a hydraulic conductivity of 1E-10 m/s would be sufficient to reduce total seepage below the 2,800 m^3/day design criteria target for both the base and high cases.
- To perform a laboratory study to determine the optimal proportion of bentonite-soil blend to produce a soil-bentonite mixture with a hydraulic conductivity ≤ 1E-10 m/s.
- To perform field trials to refine the construction methodology and equipment selection, and verify the soil-bentonite liner system performs to specification with an *in-situ* hydraulic conductivity ≤ 1E-10 m/s.
- The preliminary construction methodology for the recommended 0.30 m soil-bentonite liner system will be constructed in two 0.15 m lifts:
  - Preliminary foundation preparation (clearing and grubbing) followed by pre-disking the native soil, spreading bentonite to meet the target ≤ $1x10^{-10}$ m/s hydraulic conductivity, and disking the first 0.15 m lift of soil-bentonite;
  - Placement of a 0.15 m lift of native soil, followed by application of bentonite to meet the target ≤ $1x10^{-10}$ m/s hydraulic conductivity, and disking the second 0.15 m lift of soil-bentonite; and
  - Lastly, compaction of the 0.30 m soil-bentonite liner system.
- Quality control and quality assurance procedures should be implemented to mitigate the risk of redesign and prevent quality defects. This includes proper oversight of weather and implementation of routine testing to establish the soil type and *in-situ* condition, as well as maintaining control of the degree of compaction and permeability of the soil-bentonite liner system.

8 Closure

This technical memo, “Liner System Seepage Assessment and Construction Methodology for Tenas Management Ponds”, was prepared by SRK Consulting (Canada) Inc. to provide recommendations for a liner system that will reduce seepage rates from the Tenas Management Ponds to below allowable thresholds defined in SRK’s site water balance (SRK, 2020a).

We trust the information included meets your present requirements. If you have any questions regarding the analyses or if you require additional information, please do not hesitate to contact the undersigned.

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The opinions expressed in this report have been based on the information available to SRK at the time of preparation. SRK has exercised all due care in reviewing information supplied by others for use on this project. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information, except to the extent that SRK was hired to verify the data.

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