NYRSTAR MYRA FALLS MINE
LYNX TDF DAM FACE CLOSURE COVER
PERMIT LEVEL DESIGN

Submitted to:
Nyrstar Myra Falls Ltd.

Submitted by:
Amec Foster Wheeler Environment & Infrastructure,
a Division of Amec Foster Wheeler Americas Limited
Burnaby, BC

16 December 2016

NX14001K.2

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Nicole Pesonen
Environmental Manager
Nyrstar Myra Falls Ltd.
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Campbell River, BC V9W 5E2

Dear Ms. Pesonen:

Re: Lynx TDF Dam Face Closure Cover Permit Level Design Report

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Enclosed please find two copies of the report titled "Nyrstar Myra Falls Mine Lynx TDF Dam Face Closure Cover Permit Level Design Report" dated 15 December 2016.

Please contact the undersigned at (250) 758-1887 should you have any questions or wish to discuss any aspects of the report.

Yours truly,

Amec Foster Wheeler Environment & Infrastructure,
a Division of Amec Foster Wheeler Americas Limited

Original hard copies signed by
Dan Hughes-Games, P.Eng.

Dan Hughes-Games, P.Eng.
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cc: Nyrstar DL

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EXECUTIVE SUMMARY

Amec Foster Wheeler Environment & Infrastructure (Amec Foster Wheeler) was retained by Nyrstar Myra Falls Ltd. (NMF) to develop a permit level closure cover design for the outside dam face of the Lynx Tailings Disposal Facility (Lynx TDF) at Nyrstar Myra Falls Mine, located within Strathcona Provincial Park, approximately 60 km southwest of Campbell River, British Columbia.

The Lynx TDF dam has been sequentially raised over the years chiefly using potentially acid-generating (PAG) mine waste materials as dam fill. It has a final design crest elevation of 382.5 m corresponding to a maximum height of approximately 57 m and a downstream face with 2H:1V slope ratio. NMF wishes to proceed with the progressive reclamation of Lynx TDF as the ultimate dam envelope is constructed. The closure cover design presented in this report is limited to the downstream face of the dam in its ultimate configuration. Shallow groundwater is impacted by mine waste in the vicinity of Lynx TDF and the closure plan for the facility also includes a shallow groundwater interception system, to be designed by others.

The Lynx TDF dam face cover was designed to meet the following main goals:

- Provide a growth medium for establishment of vegetation; and
- Reduce contaminant generation and release by reducing total infiltration.

Water balance modelling carried out by Robertson GeoConsultants Inc. (RGC) concluded that although covering the Lynx TDF dam with a low permeability liner to reduce infiltration and oxygen ingress would significantly reduce metal loadings to groundwater, the shallow groundwater interception system would still be required to achieve water quality objectives for Myra Creek. They also concluded that even a cover with moderate percolation will still improve site groundwater chemistry relative to existing conditions and is considered acceptable from a long-term water quality perspective.

Various cover alternatives were considered for the Lynx TDF, such as a rock cover or a geomembrane cover; however, NMF selected the following cover sequence:

- 300 mm of growth medium (till and/or topsoil) with shrub and tree vegetation;
- 700 mm of compacted till; and
- 450 mm of select non-PAG quarry run blast rock having less than 5% fines.

The closure cover will be constructed directly upon the compacted waste rock dam fill (300 mm minus, well-graded mine waste rock with less than 20% fines). The layer of select quarry run blast rock will create a capillary break to prevent lateral seepage from the dam into the compacted till layer. A rock drain will intercept seepage at the toe of the cover and convey seepage waters to treatment. This toe drain is sized to convey a flow rate of 0.1 m^3/s and will connect to the existing Lynx TDF Dam foundation underdrain near its outlet point in the existing shotcrete ditch upstream of the treatment system (Super Pond).

Local till was selected to compose a fine-grained layer intended to reduce infiltration into the underlying waste materials and support vegetation growth. The till was selected for its low hydraulic conductivity in the compacted state (estimated average hydraulic conductivity of $5x10^{-6}$ m/s). Use of additional till as the primary growth media is proposed both for its relatively good erosion resistance and moisture retention characteristics. The relative thickness of the compacted till and growth medium layers are subject to verification during field trials and detailed design. This will occur during detailed design, and through the first years of construction, to achieve a good balance between cover performance, veneer stability, and vegetation requirements.

Vegetation prescriptions are according to those formulated by the Integral Ecology Group (IEG, 2014), and consist of a relatively dense planting of red alder at approximately two to five thousand stems per hectare. Amec Foster Wheeler also recommends inclusion of other shrubs listed by IEG during initial planting, particularly those with good local stability and erosion control potential such as willows. Organic amendments and mulching will be applied to the growth medium if needed.

Runoff from the closure cover will report to a ditch along the slope toe perimeter. The toe ditch will convey water to a control structure where the flow can be transferred to the Super Pond or routed towards the environment (Myra Creek) depending on water quality. A simple hydrological model estimated discharge of 2.4 m^3/s associated with the Probable Maximum Precipitation for a single drainage area of 7.2 ha. The proposed ditch cross section will consist of a 300 mm compacted till bedding covered with a high-density polyethylene geomembrane liner, heavyweight geotextile and a 500 mm thick armour of riprap.

Cover construction will be carried out stepwise and in the first construction stages, a relatively small area will be covered. During the early construction process, the cover toe ditch may be used to manage contact waters and divert impacted runoff away from the covered surfaces. In this case, the mix of non-contact and contact waters would be routed to the appropriate water management/treatment infrastructure. Some erosion of the cover is also anticipated until the vegetation is established. To prevent contamination of the toe ditch riprap by contact water or suspended solids, the placement of riprap in the toe ditch should be delayed until vegetation is firmly initiated and water flowing in the ditch meets release objectives. Until this time, the toe ditch will remain lined with the exposed HDPE membrane.

Stability analyses were performed and indicated acceptable factors of safety except in the case of a fully-saturated cover, where uncompacted material may develop a shallow failure parallel to the surface (i.e. veneer failure). The highest risk of saturated conditions would occur during high intensity rainfall and/or snowmelt. Once a good vegetative cover and deep root system is established, this vulnerability period is usually safely passed. Cover performance monitoring is proposed as part of staged construction to validate this approach.

Onsite experience at the Old TDF Seismic Upgrade Berm has demonstrated that compacted till slopes slightly steeper than 2H:1V *without* underdrainage are stable and relatively erosion resistant (i.e. self-armouring).

Amec Foster Wheeler recommends that the friction angle, compaction characteristics and permeability of till materials be confirmed by laboratory and/or field testing prior to initial construction. Progressive reclamation and cover construction in stages/benches will reduce the incremental surface area of un-vegetated slope constructed at any one time while providing opportunity to monitor cover performance and refine the design between subsequent stages.

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IMPORTANT NOTICE

This report was prepared exclusively for Nyrstar Myra Falls Ltd. by Amec Foster Wheeler Environment & Infrastructure, a wholly owned subsidiary of Amec Foster Wheeler Americas Limited. The quality of information, conclusions and estimates contained herein is consistent with the level of effort involved in Amec Foster Wheeler services and based on: i) information available at the time of preparation, ii) data supplied by outside sources, and iii) the assumptions, conditions and qualifications set forth in this report. This report is intended to be used by Nyrstar Myra Falls Ltd. only, subject to the terms and conditions of its contract with Amec Foster Wheeler. Any other use of, or reliance on, this report by any third party is at that party's sole risk.

1.0 INTRODUCTION

Amec Foster Wheeler Environment & Infrastructure (Amec Foster Wheeler) was retained by Nyrstar Myra Falls Ltd. (NMF) to develop a permit level closure cover design for the outside dam face of the Lynx Tailings Disposal Facility (Lynx TDF) at Myra Falls Mine. The scope of this work assignment is described in the Amec Foster Wheeler proposal to NMF dated 8 September 2016.

The Lynx TDF needs a closure cover design completed to meet the requirements of the site-wide closure plan update being prepared by NMF. A conceptual closure plan was presented in the 2008 Lynx TDF design report (AMEC 2008), but the concept was not well-developed or evaluated and no engineering design was performed at that time. NMF intends to proceed with the progressive reclamation of Lynx TDF as the ultimate dam envelope is constructed. The closure cover design presented in this report is limited to the downstream face of the dam in its ultimate configuration, from the toe to the crest, but excluding the dam crest and tailings area. The final overall closure concept for Lynx TDF will include the crest of the dam, the tailings area and upstream areas, but a closure cover design for these areas cannot be completed at this time without further assessment and Nyrstar input.

This report presents the preliminary design of Lynx TDF dam face cover, the criteria and assumptions, aspects and components of the design such as the cover sequence, geotechnical stability, dam seepage and surface water management, revegetation plan, erosion protection measures, and the supporting engineering analyses and calculations. A discussion on construction considerations, and recommendations for further work to support detailed engineering design are briefly covered.

1.1 Site Background

Nyrstar Myra Falls Mine is an underground polymetallic base metal mine located within Strathcona Provincial Park, approximately 60 km southwest of Campbell River, British Columbia. Historical open pit mining activities at the mine generated substantial amounts of sulphide and metal-bearing waste rock that were stockpiled around the Lynx Pit. In 2006, construction of an earthfill dam began around the Lynx Pit to convert it into a paste tailings disposal facility known as the Lynx TDF. The dam has been sequentially raised over the years to an elevation of 356.8 m (3404.3 m local mine grid), chiefly using potentially acid-generating (PAG) mine waste materials as dam fill. The Lynx TDF dam has a final proposed design elevation of 382.5 m (3430 m local) corresponding to a maximum height of approximately 57 m.

The Lynx TDF has been the active tailings disposal facility on site until June 2015 when milling operations were halted. Although it has not received paste tailings since then, it has been used to store dredged sediments and sludge from the various onsite treatment and polishing ponds. Excavated tailings materials from the Reclaim Sand Area (now the Old TDF Surge Pond) were also deposited in Lynx TDF.

The Lynx TDF dam currently has a nominal crest elevation of 356.8 m and the facility is filled with fine tailings up to an elevation of approximately 353.8 m. Lynx TDF Dam is built out of two main materials:

- Zone A, 0-300mm well-graded compacted mine waste rock with less than 20% fines (particles finer than 0.075 mm) composing the outer shell and upstream buttress;

- Zone J, 0-300mm well-graded compacted mine waste rock with 10-40% fines forming a 6-m wide filter zone to retain paste tailings. This material is typically produced by mixing mine waste and coarse tailings (reclaim sand/cyclone underflow).

For some dam raises, the upstream buttress has been built with coarse tailings or with uncompacted Zone J material on top of paste tailings. The upstream buttress is more permeable than the tailings mass or the Zone J and is one principal seepage path. The Lynx TDF dam also has a 13 to 19 m wide foundation underdrain located at Station 0+380 (see Drawings C-1001 and C-1003) and running from the upstream base of the starter dam to the downstream toe of the ultimate dam, exiting into the Super Pond 'In' shotcrete ditch.

Groundwater springs are present on the Lynx open pit northeast wall and the lower springs were captured with a rock drain running along the northeast pit wall and under the east arm of the dam at approximately El. 347 m. The Lynx Springs Drain has a longitudinal slope of 3% and terminates at the toe of the existing dam in waste rock fill that was placed in 2014. The Lynx Springs Drain will need to be extended to the downstream toe of the ultimate dam envelope. The detailed design for the termination of the drain has not yet been finalised at the time of writing this report but the drain outfall is proposed to empty into a concrete sump from which the flow can either be directed to treatment through a dedicated pipeline connected to the existing Old TDF Surge Pond Pipeline at Manhole No.2 or routed towards Myra Creek depending on water quality testing results.

Pore pressures and groundwater levels in the Lynx TDF dam and the underlying soils are monitored daily through an automated piezometer network. The site is also equipped with an automated weather station located near the Paste Plant. Instrumentation also includes several slope inclinometer casings through the dam fills into the foundation soils. Further design details and monitoring information about Lynx TDF can be found in the following reports:

- 2015 Annual Dam Safety Inspection Report (Amec Foster Wheeler, 2016d).

- Lynx TDF Stability Assessment and Design Update Report (Amec Foster Wheeler, 2015a).

1.2 Previous Closure Studies

The facility design report (AMEC 2008) included a rough closure concept. In recent years, NMF contracted other consultants to provide additional input on various site closure aspects. These have included: O'Kane Consultants Inc. (OKC), Marsland Environmental Associates (MEA), Robertson GeoConsultants Inc. (RGC), and Integral Ecology Group (IEG). The results of these further studies have been incorporated into this document and are referenced in the appropriate sections.

1.3 Site Visit

A site visit was carried out on 20 September 2016 during which Amec Foster Wheeler's design engineers Dan Hughes-Games, Greg Standen, Dean Wall and Frederic Besozzi, and project manager Christine Peters visited the mine and toured Lynx TDF. A meeting was held on site the same day to clarify the project scope and discuss the cover concept for Lynx TDF with NMF and RGC's representatives.

1.4 Spatial Information

Topographical data and surveys were used in the areas specified below:

- Topographical data from an airborne LiDAR survey carried out on 29 June 2015 by McElhanney Consulting Services Ltd. was used as the primary base.
- Where available, the most current as-built surveys provided by NMF were used (2015 construction as-built surveys received on 05 December 2015) and,
- The proposed design surfaces were used where as-built surveys for construction works are not yet available and the construction needs to be considered (latest updates of Lynx TDF Dam and Springs Drain designs).

Detailed design should be carried out using detailed as-built survey data to supplement those areas that have significantly changed since the LiDAR survey.

2.0 APPLICABLE STANDARDS AND REGULATIONS

The list below summarises the applicable standards and regulations governing the design of the closure cover:

- Dam Safety Guidelines (2007, Revised 2013, Canadian Dam Association, guidelines for Closure – Active Care)
- 2014 Technical Bulletin: Application of Dam Safety Guidelines to Mining Dams (Canadian Dam Association)
- Health, Safety and Reclamation Code for Mines in British Columbia (Ministry of Energy and Mines)
- Guidelines for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia (Ministry of Energy and Mines)

3.0 DESIGN CRITERIA

The design criteria presented in the following sections are based upon the applicable standards and regulations listed in Section 2.0. These must to be met in order to satisfy industry state of practice and governmental requirements. The relevant site data used in the design are also presented.

3.1 Cover Design Objectives

The cover design is intended to meet the following goals:

- Physical stabilization:
  - Provide dust and erosion control;
  - Separate geochemically clean soils from mine waste rock; and
  - Prevent direct contact of the waste by flora and fauna.
- Chemical stabilization:
  - Promote chemical stabilization of the waste by reducing oxygen and water ingress; and
  - Reduce contaminant generation and release by reducing total infiltration (reduce contact water inputs to shallow groundwater and the water treatment system).
- Land use and societal values:
  - Provide a growth medium for establishment of vegetation; and
  - Facilitate reclamation of the area in a manner consistent with post-closure land uses.

3.2 Lynx TDF Classification and Phase

The Lynx TDF is classified as a high consequence dam consistent with guidance provided by the Canadian Dam Association's (CDA) 2014 Technical Bulletin: Application of Dam Safety Guidelines to Mining Dams. The seismic and hydrological design criteria for "Operations, Transition, Active Closure" described in CDA's Technical Bulletin have been applied to Lynx TDF. The Lynx TDF is expected to remain active for an extended period of time during which the dam and cover will be progressively built, and monitoring and maintenance activities will be carried out as the dam is being raised, until the facility approaches its ultimate tailings storage capacity. The Lynx TDF is then expected to transition into the Closure – Active Care phase, followed by the Passive Closure phase when surveillance activities will become less frequent.

The current design objective is to achieve a closure cover design consistent with the requirements for Active Care. It is understood that the facility will likely remain in Active Care for the foreseeable future due to water management obligations.

3.3 Seismic Criteria

The target level for earthquake hazard for Closure – Passive Care for a high consequence dam consists of a seismic event one-half between the 1/2475 AEP event and either the 1/10,000 AEP event or the Maximum Credible Earthquake. The AMEC (2008) Lynx TDF design report specifies a maximum permissible post-seismic displacement of 3 m under closure conditions. These criteria are developed for reasons of dam safety and apply to the dam as a whole.

The consequences of sliding or deformation of cover components due to seismic loading would be limited in comparison to failure of the dam. For this reason the 1/2475 AEP event was used to develop preliminary estimates of post-seismic displacements of the cover itself. For larger earthquakes it is anticipated that the cover would deform conformably with the overall dam structure.

A site-specific seismic hazard evaluation was completed for the Myra Falls tailings disposal facilities in 2015 (Amec Foster Wheeler, 2016a). The spectral accelerations for the 1/2475 AEP event (mean hazard) for soft rock (Vs_{30}=450 m/s) are provided in Table 3.1. The reader is referred to the site-specific hazard evaluation for a detailed discussion of the seismicity and seismic hazards of the Nyrstar Myra Falls Mine area.

Measurements reported by Amec Foster Wheeler (2016b) indicate shear wave velocities between approximately 350 and 700 m/s in the upper 40 m of the glaciofluvial deposits below the base of the Lynx TDF dam. Shear wave velocities for the unsaturated dam fill were estimated to range between 316 and 460 m/s.

Table 3.1: Spectral Accelerations for the 1/2475 AEP Seismic Event

Period (seconds)	Spectral Acceleration (g)
0.01 (PGA)	0.55
0.05	0.56
0.1	0.88
0.2	1.15
0.5	1.07
1	0.66
2	0.28
5	0.08
10	0.02

3.4 Geotechnical Criteria

For Lynx TDF, the geotechnical criteria for slope stability assessments provided for Construction, Operation and Transition Phases are applicable. The target levels for static and post-earthquake slope stability assessments can be found in CDA's Technical Bulletin. Again, those criteria apply to the overall dam structure for reasons of dam safety. The conformal cover is thin compared to the dam and therefore has little influence on the overall dam stability. Amec Foster Wheeler considers that the most recent stability and seismic deformation analysis results are valid with respect to Lynx TDF dam stability and safety with the addition of a cover (Amec Foster Wheeler, 2015a, 2016c).

A long-term target static factor of safety of 1.5 was considered for the dam design and the cover was checked relative to these values. The stability of a partially and fully-saturated cover was assessed but with no specific target factor of safety.

The following assumptions were applied to geotechnical aspects of the cover design:

- Existing subsurface information is sufficient to inform the design and no additional subsurface investigations were required;

- Deformation of the dam face due to long-term settlement will be small enough that it will not influence cover design.

- Toe drain design is not dependent on outcomes of the shallow groundwater interception system to be designed by others (RGC) and can proceed in parallel;

3.5 Hydrologic and Hydraulic Criteria

As outlined in the Technical Bulletin (CDA, 2014), the IDF for Closure – Active Care for a high consequence dam is one-third between a 1/1000 AEP event and the Probable Maximum Flood (PMF). For Closure – Passive Care, the IDF increases to two-thirds between a 1/1000 AEP event and the PMF. The PMF was considered as a first-pass design target because the catchment area of the dam face is relatively small and the design flows are accordingly likely to be manageable with relatively small structures.

The design of the cover water management structures has been carried out based on a 24-hour Probable Maximum Precipitation (PMP) design event of 635 mm in 24-hours (AMEC 2012), using a Soil Conservation Service Type 1A rainfall distribution.

For comparison purposes, Table 3.2 shows precipitation total for various annual exceedance probabilities (AEPs) and design levels as described above. The values are based on AMEC 2012. Because the catchment area of the cover is small, the attenuation times are short and design peak flood flows are roughly proportional to the size of the precipitation events.

Table 3.2: Myra Falls 24-hour Precipitation Events

Event	Precipitation (mm)
Snowmelt	17
1/200 AEP + snowmelt	237
1/1000 AEP + snowmelt	253
1/3 between 1/1000 AEP and PMP	369
2/3 between 1/1000 AEP and PMP	502
Probable Maximum Precipitation	635

The following assumptions were applied to hydrologic aspects of the cover design:

- Runoff from covered areas is considered to be non-contact water. Non-contact water may be released untreated to the environment.
- Runoff in the areas of Lynx TDF dam where the cover is not completed is considered contact water and must be routed to water treatment.
- The toe ditch will only need to convey runoff from the covered dam face. Water from the future closure configuration of the dam crest and other areas will be routed separately.
- Cover construction will be carried out stepwise and in the first construction stages, a relatively small area will be covered. During the early construction process, the cover toe ditch may be used to manage contact waters and divert impacted runoff away from the covered surfaces. In this case, the mix of non-contact and contact waters would be routed to the appropriate water management/treatment infrastructure.

The design of the cover shall promote sheet flow on the cover surface, rather than rill flow or channelized flow to minimize the potential for erosion. The sheet flow will be collected in a toe ditch at the base of the dam.

3.6 Environmental Criteria

The Lynx TDF cover will have the following functions:

- Provide a vegetated surface to minimize erosion, enhance cover stability, and improve aesthetics;
- Separate clean soils from mine waste rock; and
- Promote surface and near-surface runoff of precipitation in order to reduce infiltration and associated geochemical loadings to shallow groundwater.

The cover materials will:

- Meet the applicable soil quality guidelines for the post-closure land use;
- Be geochemically stable (i.e. non-PAG);
- Consist of geological material with low erosion susceptibilities;
- Consist of geological materials where available at the onsite borrow areas and quarries, overburden and organic material stockpiles, or at existing nearby borrow areas and quarries if practical; and
- Consist of geosynthetic materials where they provide acceptable long-term performance, similar to geologic materials, and are cost effective.

With respect to the hydrogeological aspects of the cover design, the following is understood:

- Shallow groundwater is impacted by mine waste in the vicinity of Lynx TDF and the closure plan for the facility also includes a shallow groundwater interception system, to be designed by others (RGC).
- Water balance modelling carried out by RGC (Paul Ferguson, personal communication, 3 November 2016) concluded that although covering the Lynx TDF dam with a low permeability liner to reduce infiltration and oxygen ingress would significantly reduce metal loadings to groundwater, the shallow groundwater interception system would still be required to achieve water quality objectives for Myra Creek. They also concluded that even a cover with moderate percolation (e.g. from penetration by tree roots, weathering, or other pathways) will still improve site groundwater chemistry relative to existing conditions and is considered acceptable from a long-term water quality perspective, provided additional recommended control measures remain in place (i.e. the shallow groundwater interception system).

3.7 Materials Availability

The granular materials proposed for construction purposes are:

- Non-PAG quarry rock, clean stone, riprap and granular filters produced by sorting, crushing and/or screening; and
- Well graded silty sand and gravel (glacial till).

All materials above are assumed to be available to NMF and in sufficient quantities.

4.0 LYNX TDF COVER DESIGN

4.1 Closure Concept Overview and Alternatives Studied

Lynx TDF dam face closure concept is shown on Drawing C-1001 in Appendix A. The concept consists of capping the downstream slope of the Lynx TDF dam with a clean material, forming a clean catchment area whose runoff will drain into a perimeter ditch constructed along the toe of the cover. This toe ditch will consist of two segments, collecting the runoff from the east and west sides of the Lynx TDF, respectively. At the confluence of these two ditch segments, a concrete headwall or pipe drop structure and pipeline will be used to route collected runoff to Myra Creek or to the Super Pond "in" channel depending on water quality. The exit route for "clean" runoff has not yet been determined but it could be routed to Myra Creek through the proposed Lynx TDF spillway outlet.

A conceptual alignment for Lynx TDF spillway is presented on the closure concept drawings for illustrative purposes. The Lynx TDF spillway design is not part of this cover design scope.

Three reclamation alternatives were considered for the cover:

1. A Non-PAG rock cover: Cover the Lynx TDF Dam with a 1 m thick layer of non-PAG waste rock after each dam raise.
2. A Till and Non-PAG rock cover: Cover the Lynx TDF Dam with 1 m of compacted till and/or non-PAG waste rock after each dam raise.
3. A Geomembrane Liner cover: Cover the dam slope with a geomembrane liner after each dam raise. Then cover the liner with 1 m of till to allow re-vegetation.

Based on chemical loading calculations and long term performance conducted by RGC (Paul Ferguson, personal communication, 5 October 2016), Nyrstar chose the compacted till and non-PAG rock cover option for the permit level design.

4.2 Cover Design

Details of the cover design are shown on Drawings C-1002 to C-1004 and C-1101, as well as in Figure 4.1 below. The cover will be constructed directly upon the Zone "A" fill used to construct the dam. Cover thicknesses will be finalized during detailed design. The preliminary cover design consists of a 1450 mm thick cover on a 2H:1V slope comprised of:

- a 300 mm top layer of growth medium (till and/or topsoil) that will be allowed to naturally vegetate supplemented with planting;
- a 700 mm layer of compacted till; and
- a 450 mm seepage collection layer composed of non-PAG quarry run blast rock having less than 5% fines, placed on the Zone "A" fill.

A detailed description of technical characteristics of each layer is presented in the following sections. The gradation specifications for all cover materials are presented in Appendix C.

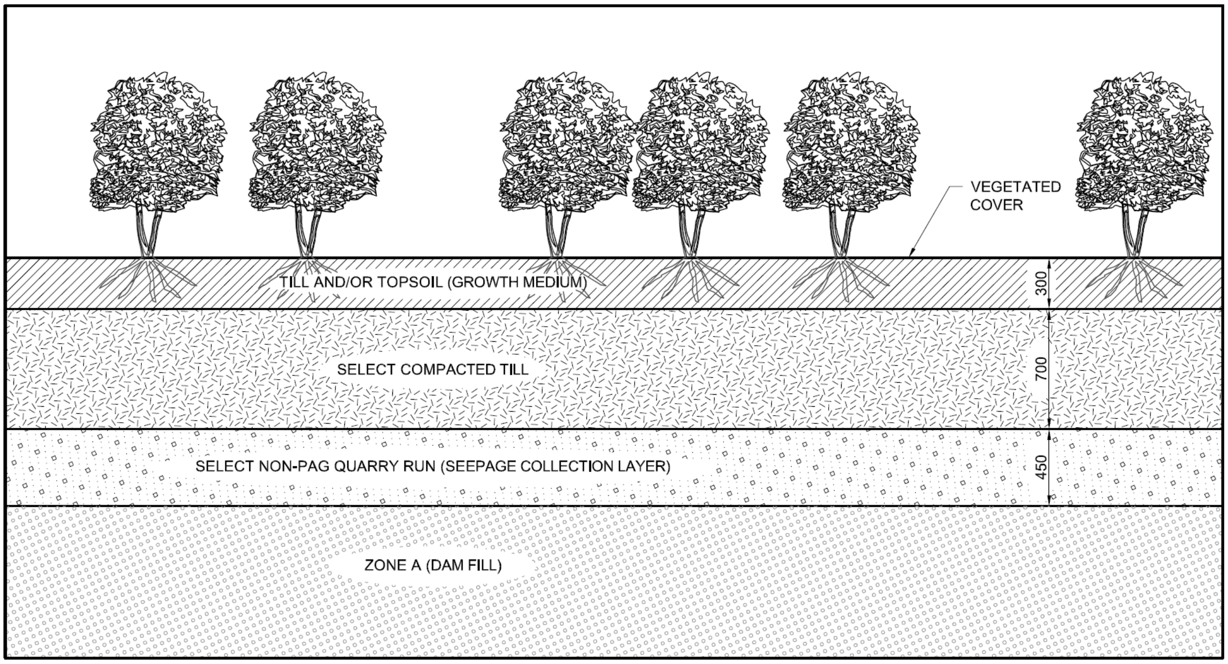

Figure 4.1: Proposed Cover Design

4.2.1 Seepage Collection Layer

Preferential horizontal seepage has been observed in the existing dam face presumably along more compacted or finer-grained planes within the dam fill. The seepage collection layer would intercept those horizontal seepage sources to prevent them from permeating the cover material, and convey the contact water to the toe drain. It will also provide a granular filter transition between the till and PAG waste rock material. The seepage collection layer will be placed directly above the PAG waste rock of the dam shell.

The proposed material for the seepage collection layer is select non-PAG quarry rock. The material must have sufficiently low fines content to be significantly more permeable than Zone A or till material and have sufficient sand-sized fraction to retain fines and behave as a filter. It is estimated that the material must have less than 5% fines (material smaller than 0.075 mm) and approximately 30% material smaller than 4.75 mm to meet these objectives. Use of non-PAG materials is recommended for resistance to material degradation/clogging by acid rock drainage processes.

Amec Foster Wheeler estimates that the transmissivity of a 450 mm thick seepage collection layer is approximately $9x10^{-5}$ m^3/s per linear meter of cover, measured perpendicular to the direction of flow. It is anticipated that the transmissivity is sufficient such that the overlying compacted till layer will remain unsaturated under most circumstances. This will have the effect of lowering the effective permeability of the cover system by reducing the unsaturated permeability of the till layer. At the toe of the cover, the seepage collection layer ties in to a subsurface toe drain located below the toe ditch.

4.2.2 Compacted Till Layer

Till was selected as a suitable cover material since it provides moisture retention and root growth media to the vegetation and its relatively low hydraulic conductivity will reduce infiltration into the PAG waste rock (Zone A material) forming the bulk of the tailings dam.

The Core Rack Area Borrow (CRAB) till material is typically described as either sandy or silty depending on the fines content which varies between about 7% and 29%. The material is well graded with a wide distribution of particle sizes spanning fines to boulders. OKC (2014) estimated an average saturated hydraulic conductivity for the CRAB till of $5x10^{-6}$ m/s using the available particle size distribution data set for this material used for the construction of the Old TDF Seismic Upgrade (see Figure 1, Appendix C). Amec Foster Wheeler developed hydraulic conductivity estimates for the proposed cover materials, which are presented in Table 4.1. The range of fines content of the till results in estimated permeabilities that vary over approximately two orders of magnitude. Siltier till would be would be preferable over sandy till for use as a growth media. The silty till would also be a good prospect for use as a low-permeability material.

Table 4.1: Hydraulic Conductivity of Cover Materials

Material	Saturated Hydraulic Conductivity (m/s)
Medium Dense Till[1,2]	3×10^{-6} to 3×10^{-4}
Compacted Till[1,2]	6×10^{-7} to 7×10^{-5}
Select Quarry Run Blast Rock [3]	3×10^{-4}
Compacted Zone A Fill[4]	4×10^{-6} to 4×10^{-5}

Notes:

(1) *Range of values estimated for silty and sandy CRAB till by Amec Foster Wheeler based on gradational data using Kozeny-Carman equation (silt and clay distribution estimated graphically, fine content ranging from 7 to 29%).*

(2) *Medium dense and compacted till porosities assumed as 30% and 20% respectively.*

(3) *Minimum design value based on proposed material gradation.*

(4) *Calibrated values for waste rock from 3D groundwater model by Marsland Environmental Associates (MEA) (2011).*

Permeability estimates confirm that CRAB till needs to be densified to match hydraulic conductivity assumptions previously made by OKC. A material testing program to confirm the gradational, compaction, mechanical, and permeability characteristics of representative till samples from the proposed borrow source(s) is recommended during detailed engineering and prior to construction.

4.2.3 Growth Medium Layer

A growth medium layer will be required within or above the compacted till surface to support shrub and tree vegetation. The growth medium material will require sufficient fines content to provide adequate moisture retention for plants, and sufficient gravel and cobble content to provide adequate resistance to soil erosion. It may consist of local till and/or topsoil and will be placed to enhance vegetation establishment. A thickness of 300 mm for the growth medium layer is consistent with the 2008 design but IEG (2014) suggests that 500 mm to 750 mm is preferred. The need for establishing vegetation must be balanced with veneer stability of the sloping cover during periods of wet weather.

The thickness of the compacted till and growth medium layers are preliminary and will be refined during detailed design. Field trials may be conducted to establish both stability, required degree of compaction, and associated reduction of infiltration of various thicknesses of compacted till and growth medium. As part of phased construction, cover performance should be evaluated and adjusted if needed prior to implementation of each subsequent construction phase.

Locally available till has been shown to successfully support revegetation (e.g. Old TDF Seismic Upgrade Berm). However, using organic amendments such as compost or even a thin layer of organic soil, would increase the nutrient content and water holding capacity of the growth medium, and promote the re-establishment of soil microorganisms that are critical to soil nutrient cycling. Fertilizer may be added to supply macronutrients to plants in supplement of other organic amendments used. The type and amount of amendments will be determined as part of final design once the nutrient content of the till is determined and available organic amendments are identified.

4.2.4 Surface Vegetation

The revegetation prescription for the Lynx TDF dam face cover will be based on the prescription for revegetation treatment proposed for the Myra Falls Mine site by OKC (2014) and IEG (2014), which are understood to be adequate for the cover vegetation. The prescription proposed by IEG consists of a relatively dense planting of red alder at approximately 2,000 to 5,000 stems per hectare, followed by additional planting of native species based on assessment of natural regeneration and on revegetation needs, approximately 5 to 15 years after initial red alder planting. The IEG report contained a list of locally appropriate candidate vegetation species in addition to red alder, derived using information from Nyrstar (2012), an identification guide by Green and Klinka (1994), and from the observation of species present in reclaimed areas of the site and the adjacent natural ecosystems. OKC recommended bioengineering techniques using selected willow species for the areas with higher erosion potential.

Previous experience on the mine site indicates natural revegetation will need to be supplemented with planting. Based on the recommendations of OKC and IEG, and considering the characteristics of a 2H:1V slope on the Lynx TDF dam face, Amec Foster Wheeler recommends including other shrubs listed by IEG (2014) during initial planting, particularly those with good erosion control potential such as willows. The exact prescription will be determined as part of final design. Amec Foster Wheeler recommends that the planting prescription be updated between construction phases based on field results during the phased construction of the cover.

Additionally, IEG suggested a grass seed mix to be applied as an interim treatment if erosion/sediment-control measures are needed. Applying a low rate of the interim erosion and sediment control seed mix is also considered appropriate, especially on the upper and middle section of the 2H:1V slope. Attempts would be made to transition to woody vegetation communities in those areas.

4.3 Cover Geotechnical Stability

The cover layer thickness has been integrated into the final dam geometry (below the final envelope surface indicated on the facility design) rather than being added over top of it. The cover is a relatively thin surface feature compared to the embankment volume and therefore does not materially influence the overall embankment design or geotechnical stability. As mentioned above, the most recent stability analysis results (Amec Foster Wheeler, 2015a, 2016c) are still valid with respect to the overall stability of the dam.

4.3.1 Limit Equilibrium Analysis

Static and pseudo-static stability analyses were performed for the cover using the Slope/W module of GeoStudio 2012 software (August 2015 Release, version 8.15.5.11777) by GEO-SLOPE International Ltd. (2015), the Morgenstern-Price limit equilibrium method, and the geotechnical parameters shown in Table 4.2.

A literature review was carried out to select appropriate material parameters in the analysis. For silty gravels (i.e. till), shear friction angles were found to range from 30 to 40, with most values falling between 34 and 38, with the higher shear friction angles applicable to cleaner (low fines), angular and well-graded materials.

Cohesion is generally neglected when considering long-term, deep-seated stability; however in the case of a thin veneer, small cohesion forces may be significant compared to frictional resistance to sliding. Parametric analysis was carried out in order to assess the benefit of small amounts of cohesion.

Literature review found cohesion values for low-plasticity tills were in the 2 to 10 kPa range; however these values likely represent intact, undisturbed, natural materials. Remolded and compacted till materials may achieve apparent cohesion through matrix suction forces in a damp but unsaturated soil mass, but this type of cohesion is effectively eliminated during saturation and cannot be relied on for stability. The material may also develop true cohesion over time due to cementation processes (the natural tills in the area are weakly cemented), but the effect may take a long time to occur to significant degree and may be reduced or destroyed by contact with acidic or metal rich porewater. For these reasons, relying on cohesion forces inherent to the till and growth media soil materials is not recommended.

The presence of vegetation will materially improve shallow factors of safety by adding root cohesion; however, the effect is difficult to quantify analytically. Research suggests the effective root-zone cohesion of a disturbed and then revegetated slope is between about 1.5 and 6.7 kPa within 11 years after revegetation, and may continue to improve with time to values up to about 25 kPa for a "mature", reforested, disturbed slope (Schmidt et al. 2001). The value of cohesion used in the parametric analysis represents a reasonable lower-bound value for root cohesion.

Site experience along the toe of the Old TDF Seismic Upgrade Berm has demonstrated that compacted local till placed at slopes slightly steeper than 2H:1V is not subject to widespread surficial instability issues. Testing is recommended at the time of detailed engineering or prior to construction to confirm that the proposed construction materials have similar or stronger strength characteristics.

Table 4.2: Geotechnical Strength Parameters for Cover Materials

Layer – Function	Thickness	Description	Strength Model	Unit Weight (kN/m^3)	ϕ
Growth Medium	300 mm	Medium Dense Glacial Till	Mohr-Coulomb	19.5 moist 22.5 saturated	34°
Compacted Till	700 mm	Dense	Mohr-Coulomb	23 moist 25 saturated	37°
Seepage Collection	450 mm	Quarry Run Blast Rock	Mohr-Coulomb	21	38°
Dam Shell	Variable	Compacted Zone A (PAG waste rock)	Leps (1970) lower bound(1)	23.6	Ranging from ~37° to ~41° in the zone of influence

Notes:
ϕ = soil peak drained friction angle using Mohr-Coulomb shear strength theory
(1) Used Leps (1970) lower bound curve for rockfill relating friction angle to effective normal stress with friction angle decreasing with increasing stress level.

A cover model was developed for the tallest section of the dam, where the ultimate dam is 59 m higher than the toe. A series of various cover stability scenarios were considered as follows:

Failure mode:

- Circular failure plane of a minimum depth of 0.8 m through the cover soils;
- Fully-specified "veneer" failure surface at the interface between the compacted till and the seepage collection layer composed of quarry rock;

Porewater scenarios:

- Assuming cover materials are moist but unsaturated;
- Assuming a phreatic surface at half the cover thickness (water table 500 mm above the base of the compacted till), but with the underlying seepage collection layer drained;
- Assuming the compacted till and growth media layers are fully saturated, but with the underlying seepage collection layer drained;

Cohesive forces:

- Neglecting the effect of cohesive forces on the shear strength of cover materials; and
- Assigning a cohesion of 2 kPa to represent future root cohesion in the compacted till and growth medium layers.

The resulting minimum factors of safety (FoS) for the different cases are presented in Table 4.3. Examples of the slope stability analyses performed are shown on Figures 1 to 6 in Appendix B. Pseudo-static analyses were carried out for the "wet materials" assumption to determine the yield coefficient, i.e. the horizontal acceleration leading to a FoS of unity, expressed as a fraction of gravity. The resulting yield coefficients are also summarized in Table 4.3.

Table 4.3: Minimum Limit-Equilibrium Factor of Safety

Scenarios	Unsaturated	Half-saturated	Fully Saturated	Pseudo-Static
Veneer Failure no cohesion	1.5	1.1	0.8	0.19 g
Circular Failure no cohesion	1.5	1.2	0.7	0.18gg
Veneer Failure 2kPa cohesion	1.7	1.3	0.9	0.25 g
Circular Failure 2kPa cohesion	1.6	1.5	1.0	0.23 g

Factors of safety for the unsaturated, static case are 1.5 or higher for all cases. This suggests the proposed cover meets the target static factors of safety provided it is maintained in a drained condition. Factors of safety improve by 7 to 13% with the addition of 2 kPa cohesion.

Factors of safety for the half-saturated case without cohesion were between 1.1 and 1.2. This suggests the cover would be stable if half-saturated, but might not initially achieve the desired factor of safety until such time as vegetation is established. Addition of cohesion increased the factor of safety by around 20% to between 1.3 and 1.5. This suggests significantly improved stability with the addition of cohesion and that additional gain in root cohesion with time will likely improve long-term factors of safety to target levels.

Factors of safety for the fully saturated case without cohesion were below unity, suggesting the cover would not be stable if fully saturated. Addition of cohesion improved factors of safety by between about 15 and 40%, though the factor of safety values were still at or below unity. This suggests the cover is unlikely to be stable if fully saturated even with the addition of low to moderate levels of root cohesion.

Although failure of the cover would not compromise the dam's integrity, the select cases that have low factors of safety demonstrate that there is a potential for movement of the cover veneer during periods of extremely intense precipitation and/or snow melt. Once the vegetative cover and deep root system is established, factors of safety are likely to be improved such that the cover will be stable even during wet weather. This highlights the importance of proactively establishing vegetative cover as soon as practical during construction.

Onsite experience at the Old TDF Seismic Upgrade Berm has demonstrated that compacted till slopes steeper than 2H:1V *without* shallow underdrainage are stable and relatively erosion resistant (i.e. self-armouring). Shallow instability has not been an issue on those slopes, despite being subjected to very high intensity precipitation (at least 1/50 AEP). These slopes were generally built out in horizontal lifts compacted with a vibratory smooth-drum roller. It is presumed that the outer half-metre of the slope was not well compacted with the roller due to lack of confinement at the lift edge, but may have been nominally packed with the excavator bucket. This outer layer may represent an analogue to the proposed "growth media". The potential for saturation of the surface of the relatively deep cover on the Old TDF would be higher than the potential for saturation of the proposed cover, which includes a shallow underdrainage layer. This suggests either that the till is sufficiently permeable to prevent occurrence of full saturation, or that the frictional and/or cohesive properties of the till have been underestimated in the modelling. Similar or better performance would be anticipated from the proposed cover design.

Field trials are recommended to demonstrate that acceptable stability can be achieved through the rainy season using the proposed design and available borrow materials. Progressive reclamation and cover construction in stages/benches will reduce the length and surface area of un-vegetated slope exposed while providing time to make those trials and monitor cover performance. Exposed till, if used as the growth medium is anticipated to be erosion-resistant. However, as outlined by stability analysis results under saturated conditions, the cover will need to be actively revegetated through seeding and planting to accelerate the establishment of vegetation and monitored for erosion. Additional measures that could be incorporated to improve stability if issues develop include geosynthetic reinforcement or additional drainage layers.

4.3.2 Seismic Deformation Analysis

Amec Foster Wheeler used a simplified one-dimensional displacement model developed by Bray and Travasarou (2007) to estimate post-seismic displacements for the proposed cover. The method assumes a flexible sliding mass above a slide plane and relates post-seismic downstream displacements of that slide mass to the input ground motion characteristics and the design earthquake moment magnitude. Displacements are based on a statistical analysis of a variety of horizontal earthquake motions expressed in terms of an elastic response spectrum at the ground surface beyond the dam toe. Other key parameters in the analysis include the fundamental dam period, the yield coefficient for a critical slip surface of interest defined as the horizontal acceleration that must be applied to the limit equilibrium model to reduce the factor of safety to 1.

Site response characteristics were assumed using a Site Class D (stiff) soil classification, as defined by the “2010 National Building Code of Canada” (National Research Council of Canada, 2010). The adjusted response spectrum for the 1/2475 AEP seismic hazard at Myra Falls mine published by Amec Foster Wheeler (2016a), for which a magnitude 7.4 event was considered. An average shear wave velocity of 435 m/s was considered for the dam fill in the analysis and a fundamental period of 0.34 seconds was found. Critical yield coefficients computed for the cover failure were used in the deformation analysis.

Permanent horizontal displacements at the end of earthquake shaking for three probabilities of exceedance are presented in Table 4.4. Values for the scenario with cohesion show both better resistance to sliding and lesser estimated horizontal displacements.

Table 4.4: Estimated Horizontal Post-Seismic Displacements

Scenario	Yield Coefficient	Probability of Exceedance		
		84%	50%	16%
No cohesion	0.19	0.19 m	0.36 m	0.70 m
2kPa cohesion	0.24	0.13 m	0.24 m	0.47 m

Notes:
Bray and Travasarou (2007) method. 1/2475 AEP, mean seismic hazard, moment magnitude M7.4, Seismic response spectrum for NBCC Site Class D (stiff soil), fundamental period of 0.34 sec., spectral acceleration for degraded period of 0.51 sec (Sa(1.5Ts)) of 1.15g.

A maximum displacement of 0.7 m would be exceeded only 16% of the time for the case without cohesion and a yield coefficient of 0.19. In comparison, for the Lynx TDF dam, Amec Foster Wheeler (2015a) calculated horizontal displacements of 1.3 m (16% exceedance probability) for Operational Conditions (1/2475 AEP earthquake). As the displacement estimates for the cover are of similar magnitude, it is likely that the dam and cover would deform conformably as a unit. If the cover deforms separately, the values suggest there may be some local damage, but no catastrophic collapse of the cover veneer.

4.4 Toe Drain

The proposed cover toe drain is shown on Drawings C-1003, C-1004, and C-1101. The main purpose for the toe drain is to intercept seepage from the seepage collection layer at the bottom of the covered slope and convey it to treatment. It is separate and distinct from the dam foundation underdrain. The toe drain could also be designed to route springs and other discrete seepage sources in the dam face and along the dam toe but would need to be enlarged accordingly. Available piezometer data for Lynx foundation soils were reviewed and it was determined that even if the toe drain was to be built at the elevation of the subgrade, it would not collect static groundwater as it would remain several meters above the maximum groundwater levels observed to date. The groundwater levels may change in the future as the dam and tailings configuration evolves towards the ultimate configuration.

The toe drain is divided in two branches that will tie in to the existing Lynx TDF Dam foundation underdrain located along Section B (Sta. 1+490), which exits at the upstream end of the Super Pond ‘in’ existing shotcrete ditch (see Drawing C-1001). Drawing C-1002 shows the longitudinal profile of the toe drain. The toe drain invert follows under the toe ditch at a constant vertical offset. The south arm portion of the toe drain has a greater cross-sectional area than the west and east branches because the longitudinal slope is minimal. The dam underdrain would be extended into the shotcrete ditch to allow construction of an access road.

4.4.1 Construction Materials

The toe drain design will be similar in many respects to that of the Lynx Springs Drain, albeit the structure is much smaller. The gradation specifications for toe drain materials are presented in Appendix C. The drain rock zone will to be composed of highly permeable, non-PAG rock fragments up to 300 mm in particle size and is designed to convey the majority of the flow.

The coarse filter zone is also to be composed of non-PAG rock fragments, but with a smaller size than the core zone. It is intended to prevent migration of the other filter materials (i.e. liner bedding, till or select quarry run blast rock) into the large voids of the drain rock zone. It also acts as a secondary flow conveyance zone.

The liner bedding (select till or select quarry run blast rock) is designed as a non-PAG filter layer to separate the coarse filter zone from the dam fill (Zone A), existing mine waste fill or native soils, and provide adequate liner bedding.

The textured high-density polyethylene (HDPE) liner is intended to avoid seepage loss through pervious dam fill. The lined surface is open on the upstream side to allow lateral seepage to flow towards the drain. Where the toe drain is excavated in fine-grained native soils (e.g. glacial till), a liner would not be needed. The liner will be heavy-weight in order to reduce the requirements for select bedding materials.

4.4.2 Estimated Flow Capacity

Myra Falls mine receives about 2500 mm of precipitation per year on average, most of it through the rainy season extending from October through the winter months. The equivalent annual infiltration rates through waste rock was estimated by MEA (2011) to vary from approximately 300 mm/year for the driest month (July) to 3000 mm/year for the wettest month (November), corresponding to an infiltration of 55% of the total precipitation. Once the proposed cover is in place, the infiltration is anticipated to be further reduced.

The toe drain was sized to convey 0.1 m^3/s, a flow rate corresponding to about 12.5 times the estimated annual infiltration through waste rock in the 8 ha ultimate footprint of the downstream shell for the wettest month of the year (3000 mm per year, resulting in 8 L/s on average). The potential amount of horizontal seepage through the exposed dam fill is unknown but seepage flows observed to date on the lower dam benches were relatively minor and the selected design flow rate for the toe drain is considered sufficient. The selected design flow rate applies to the operation period and reflects current dam seepage observations and potential infiltration in exposed dam fills during this period. At closure of the facility when the dam crest and tailings area will be capped, it is anticipated that the amount of seepage reporting to the drain will be significantly lower.

The permeability of the drain rock and coarse filter zones is difficult to quantify but flow capacity estimates can be developed using Wilkins equation, which was developed to calculate flow through rockfill dams, i.e. turbulent flow through porous media that cannot be estimated using Darcy's equation for laminar flow. Wilkins equation relates on the concept of hydraulic mean radius that can be derived from the void ratio and specific surface area of the voids.

Mean specific surface areas of 90 m^2/m^3 and 550 m^2/m^3 were estimated for the proposed 25-300 mm drain rock and 5-75 mm coarse filter material using a method proposed by Garga et al. (1990). The method considers the center of the specified gradation envelope and a shape factor reflecting the angularity of particles. For the proposed 25-300 mm clean drain rock and 5-75 mm clean coarse filter material, an average porosity of 0.45 and void ratio of 0.8 were assumed for both materials. Hydraulic radii of 9 mm and 1.5 mm were calculated for the drain rock and coarse filter, respectively.

Bulk velocities of 0.018 m/s and 0.049 m/s in the drain rock material were calculated using Wilkins equation for longitudinal drain slopes (i.e., hydraulic gradients) of 1% and 5%, respectively. To meet the design capacity of 0.1 m^3/s, the cross-sectional areas of the drain rock zone had to be greater than 5.5 m^2 and 2.0 m^2 for longitudinal drain slopes of 1% and 5%, respectively. Accounting for the flow capacity of the surrounding 500-mm thick coarse filter zone, the required cross-sectional areas of the drain rock zone could be further reduced to 4.2 m^2 and 0.7 m^2 for the same longitudinal slopes for total cross-sectional areas of 13 m^2 and 8.25 m^2, respectively. The geometry of the south arm toe drain has been optimized to meet the design flow capacity but the size of west and east arm toe drains may be reduced further at the detailed engineering stage.

Consideration could be given to supplementing flow through rock drains with pipe conduits; however, this is only recommended if the pipe conduits can be constructed in a location where they can be excavated and replaced in the future, should need arise. The configuration selected for this preliminary design does not support this flexibility as the underdrain is within the toe of the dam, below material that contributes to the dam structural stability.

The toe drain is sized conservatively for operations. However, should the toe drain become inefficient, either through infiltration of fines or formation of precipitates, the seepage water would overflow into the dam fill, percolate the foundation soils, report to the shallow aquifer and be collected by the seepage interception system. Geochemical and gradational properties of construction materials, as well as zoning with filter-compatible materials, are designed to minimize “siltation” of the drains and chemical precipitation. If future plugging becomes a concern during detailed design, the toe drain could be modified to include sediment traps, or to add redundant perforated pipe capacity with clean-outs.

4.5 Surface Water Management Plan

Runoff from the closure cover will report to a ditch along the slope toe perimeter. The layout of the toe ditch is shown on Drawing C-1001. The ditch will be comprised of two segments, one collecting the runoff from the east and south side of the Lynx TDF, while the other collects the runoff from the west side. The two ditches will meet at a common low point at Station 1+475 of the west arm of the toe ditch, where the collected water will be transferred to the Super Pond “in” channel via a concrete headwall pipe drop structure. The profiles of the toe ditch are shown on Drawing C-1002.

4.5.1 Hydrological Modeling

A HEC-HMS hydrological model of the closure cover was used estimate the anticipated peak flow in the Toe Ditch. A single drainage area of 7.2 ha was used to calculate conservative design flows for the toe ditch. A curve number of 80 was assumed for the closure cover. An SCS Type 1A storm distribution was used. The resulting calculated flows for the precipitation events are provided in Table 4.5.

Table 4.5: Toe Ditch Peak Discharge Rates

Calculated Flows	Discharge (m^3/s)
1/200 AEP plus snowmelt	0.75
PMF	2.4

4.5.2 Toe Ditch Design

Similar to the toe drain, the toe ditch consists of two sections each running towards a central catchment point near the centre of the south arm of the dam. The ditch cross section, shown on Drawing C-1101 of Appendix A, will consist of a 300 mm compacted till lining covered with an HDPE geomembrane liner, heavyweight geotextile and a 500 mm thick armour of riprap. During the initial construction stages of the closure cover, the toe ditches may be used to manage contact waters and divert impacted runoff away from the covered surfaces as shown on Drawing C-1201. To prevent contamination of the toe ditch riprap by contact water or suspended solids, the placement of riprap in the toe ditch should be delayed until vegetation is firmly initiated and water flowing in the ditch is clean. Until this time, the toe ditch would only be lined with the exposed HDPE membrane (see Drawing C-1202).

Estimated flows and other design parameters related to conveyance of the PMF are presented in Table 4.6.

Table 4.6 Toe Ditch Design Segments

Station From	Station To	Design Slope (%)	Manning's 'n'	Flow Depth (m)	Flow Velocity (m/s)
West Arm					
1+031.74	1+110.00	24.2	0.035	0.24	4.6
1+110.00	1+475.00	5.7	0.035	0.36	2.7
South Arm					
1+475.00	1+739.07	1.0	0.035	0.57	1.5
East Arm					
1+739.07	2+006.62	18.4	0.035	0.26	4.2

The ditches have been sized for the PMF event. There is a minimum of 0.4 m of freeboard, which is considered reasonable for this size of ditch.

In steeper sections (slope of 18.4% or 24.2%), a class 50 kg riprap with a d_{50} of 330 mm is recommended, based on the full flow at the maximum flow cross section. For the reach with a slope of 5.7%, a class 25 kg riprap with a d_{50} of 260 mm is recommended. In the shallower sections (slope of 1.0%), a pitrun of the till available on site is recommended. The specifications for the proposed riprap armouring and compacted till are presented in Appendix C. These values may be refined during detailed design to size riprap for each section based on the flow at that section.

For maintenance and inspection purposes, a 6 m wide access road will be constructed alongside and downstream of the toe ditch.

5.0 CLIMATIC LIMITATIONS ON CONSTRUCTION SCHEDULE

The climate at Myra Falls varies distinctly between a wet, cool “rainy season” spanning mid-September to May, and a hot, dry “summer season” spanning June to early September. During the rainy season, the low temperatures and extremely high ambient humidity (generally 93% or higher) preclude effective drying of earth materials, even on sunny days. In addition, the high elevation and close proximity of Mt. Myra to the south of the site mean that all but the highest elevation areas of the site are permanently in shade through most of the rainy season.

The preferred construction weather window at Myra Falls Mine is limited to mid-July through early September. The construction window lags behind the advent of good summer weather by as much as about 6 weeks as it takes considerable time for the soil materials on site to dry following the rainy season. The limitations on practical construction window may affect the final design and/or schedule of any particular raise of the cover sequence.

Meeting construction specifications for waste rock derived dam fills outside ideal construction weather window has been historically difficult, to the degree that achieving acceptable finished compaction standards for densified zones should be generally be considered impractical. Other work such as preparatory excavation, material production, material stockpiling, etc. can be considered outside the preferred weather window.

Placement and compaction of the local till is not practical during periods of wet weather, as the disturbed material readily absorbs precipitation and quickly exceeds the range of workable moisture contents. Disturbed till materials and stockpiles left unprotected through the rainy season are typically too wet to be placed and compacted until late July or early August. Placement of uncompacted cover materials during the wet season is not recommended.

6.0 RECOMMENDATIONS AND COMPLEMENTARY STUDIES

Recommendations for further work to address data gaps are provided below and this work will need to be completed prior to construction:

- The permeability of compacted and uncompacted till materials should be assessed with appropriate lab/field testing. This information should be used to further assess the potential for saturation of the cover layers and the performance of the cover with respect to reducing net infiltration.

- The geotechnical strength parameters for compacted and uncompacted till materials should be confirmed with appropriate lab/field testing. This information should be used to update and/or supplement the limit equilibrium analysis for the cover stability.

- The cover performance with respect to initial reduction of net infiltration and geotechnical stability should be assessed through short-term field trials for varying the layer thickness and compaction levels in the compacted till and growth medium layers. This should take place prior to initial placement of the cover in the first construction phase.

- The cover performance should be formally monitored and evaluated over time. As the dam face cover will be built gradually in stages, there is excellent opportunity in the short term to learn from cover performance and to institute amendments, if required, in order to improve stability and erosion resistance, success of vegetation, and reduce maintenance requirements in the long term.

7.0 LIMITATIONS & CLOSING REMARKS

Recommendations presented herein are based on a geotechnical evaluation of the findings of the site investigation noted. If conditions other than those reported are noted during subsequent phases of the project, Amec Foster Wheeler should be notified and be given the opportunity to review and revise the current recommendations, if necessary. Recommendations presented herein may not be valid if an adequate level of review or inspection is not provided during construction.

This report has been prepared for the exclusive use of Nyrstar Myra Falls Ltd. for specific application to the area within this report. Any use which a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. Amec Foster Wheeler accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report. It has been prepared in accordance with generally accepted soil and foundation engineering practices. No other warranty, express or implied, is made.

Respectfully submitted,

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Appendix A

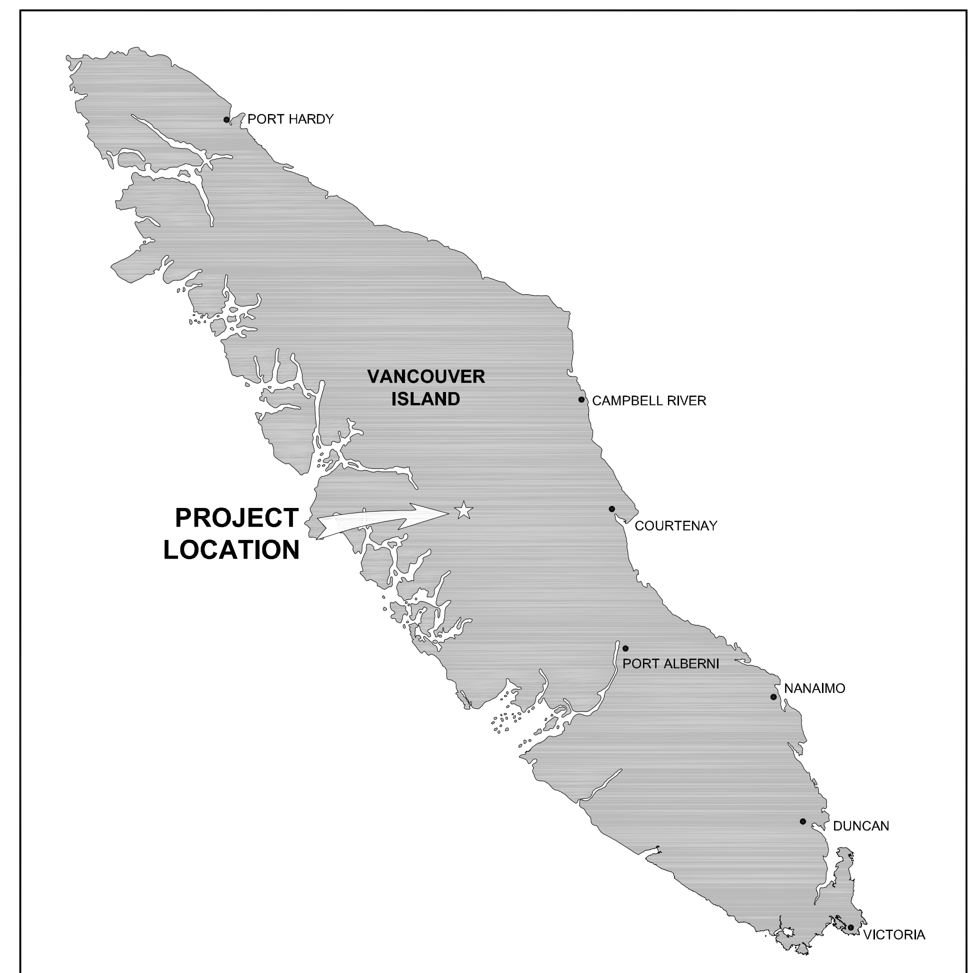
Drawings

NYRSTAR - MYRA FALLS

nyrstar

MYRA FALLS LYNX TDF DAM FACE CLOSURE COVER DESIGN

LIST OF PROJECT DRAWINGS



PROJECT LOCATION

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ISSUE DATE: 2016-12-15

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Set No.: ____________

PROJECT NUMBER	DRAWING NUMBER	ISSUE/REVISION
NX14001K.2	C-0001	B

GENERAL NOTES

1. THIS DRAWING SHOULD BE READ IN CONJUNCTION WITH THE AMEC FOSTER WHEELER ENVIRONMENT & INFRASTRUCTURE REPORT NO. NX14001K.2, "MYRA FALLS LYNX TDF DAM FACE COVER PERMIT LEVEL DESIGN", DATED 16 DECEMBER 2016.
2. SURFACE TOPOGRAPHY FOR "EXISTING GROUND PRE 2015 CONSTRUCTION" BASED ON LIDAR SURVEY FLOWN IN JUNE 2015 (FILES DATED 24 JUNE 2016) SUPPLIED BY CLIENT. SURFACE TOPOGRAPHY FOR "EXISTING GROUND POST 2015 CONSTRUCTION" SUPPLIED BY CLIENT ON 05 DECEMBER 2015. SURFACE TOPOGRAPHY FOR "OLD TDF SURGE POND AND DECANT PIPELINE" BASED ON RE-ISSUED FOR CONSTRUCTION DRAWING SET ISSUED JULY 8, 2016. SURFACE TOPOGRAPHY FOR APA TDF BERM BUTTRESS BASED ON ISSUED FOR PER DRAWING SET ISSUED 2016-08-26.
3. UTILITY INFORMATION SUPPLIED BY CLIENT ON MAY 22, 2015.
4. THIS SURVEY IS REFERENCED TO HORIZONTAL DATUM NAD 83(CSRS)3.0.0BC.1.NVI. VERTICAL DATUM IS CGVD2013.
5. COORDINATES PROJECTED IN UTM ZONE 10.
6. ALL DIMENSIONS ARE IN MILLIMETRES AND ELEVATIONS ARE IN METRES UNLESS OTHERWISE NOTED. ELEVATIONS REPRESENT FINISHED GRADE ELEVATIONS UNLESS OTHERWISE NOTED.
7. LYNX SPRINGS DRAIN DESIGN REFERENCES:
   AMEC ENVIRONMENT AND INFRASTRUCTURE, 2014. "LYNX SPRINGS DRAIN CONSTRUCTION NOTES". DESIGN DRAWINGS AND SPECIFICATIONS ISSUED TO NYRSTAR MYRA FALLS, MAY 23, 2014
   AMEC ENVIRONMENT AND INFRASTRUCTURE, 2013. "LYNX TAILINGS DISPOSAL FACILITY, CONCEPTUAL DESIGN FOR SEEPAGE INTERCEPTOR DRAIN, MYRA FALLS MINE, BC". LETTER REPORT TO NYRSTAR MYRA FALLS, SEPTEMBER 10, 2013.

ABBREVIATIONS

N	NORTHING	U/S	UPSTREAM
E	EASTING	D/S	DOWNSTREAM
APP	APPROXIMATE	c/w	COMPLETE WITH
STA	STATION	c/c	CENTER TO CENTER
EL	ELEVATION	HWL	HIGH WATER LEVEL
WL	WATER LEVEL	PWL	PERMANENT WATER LEVEL (NO FLOW)
PI	POINT OF INTERSECTION	NWL	NORMAL WATER LEVEL
BC	BEGINNING OF CURVE	SPMDD	STANDARD PROCTOR MOISTURE DRY DENSITY
EC	END OF CURVE	MH	MANHOLE
R	RADIUS	PAG	POTENTIALLY ACID GENERATING (WASTE ROCK)
CL	CENTERLINE	NON-PAG	NON POTENTIALLY ACID GENERATING (ROCK)
DIA	DIAMETER	HDPE	HIGH DENSITY POLYETHYLENE
MIN	MINIMUM	LLPE	LINEAR LOW DENSITY POLYETHYLENE
TYP	TYPICAL		
THK	THICK		

MATERIAL HATCHING LEGEND

MATERIAL TYPE	SPECIFICATION	HATCH PATTERN
FILL	SELECT COMPACTED TILL	
FILTER MATERIAL	COARSE FILTER (NON-PAG)	
	CLEAN DRAIN ROCK (NON-PAG)	
GRAVEL MATERIAL	SELECT QUARRY RUN BLAST ROCK (NON-PAG)	
ROAD BASE	COMPACTED CRUSHED GRAVEL	
BEDDING MATERIAL	LINER BEDDING MATERIAL	
RIPRAP	CLASS 50 RIPRAP	
	CLASS 10 RIPRAP (NON-PAG)	
GROWTH MEDIUM	TILL AND/OR TOPSOIL	
	UNDISTURBED GROUND	
DAM FILL	ZONE A (PAG)	
	ZONE J (PAG)	
	TAILINGS	

LINETYPE LEGEND

ROAD
CREEK
POWERLINE (OVERHEAD/UNDERGROUND) — E —
WATERLINE (UNDERGROUND) — W —
UTILITY PIPELINE

EXISTING LINETYPES
PROPOSED LINETYPES

HDPE LINER
GEOTEXTILE
DITCH FLOW

SYMBOL LEGEND

POWERPOLE
WATER BODY
CULVERT
DITCH INVERT ELEVATION
FILL ELEVATION
SURFACE FLOW (RUNOFF)

EXISTING SYMBOLS
PROPOSED SYMBOLS

SLOPE INDICATOR
ELEVATION MARKER
DETAIL / SECTION MARKER
(Top # Denotes Detail / Section Number)
(Bottom # Denotes Reference Drawing Location

SCALE

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B	16	12	15	ISSUED FOR PERMIT	MH	DH	FB	DHG
A	16	11	07	ISSUED FOR CLIENT REVIEW	MH	DH	FB	DHG

amec foster wheeler

CLIENT
nyrstar

PROJECT NAME
MYRA FALLS LYNX TDF DAM FACE CLOSURE COVER DESIGN

SHEET TITLE
LEGEND

PROJECT NUMBER
NX14001K.2

DRAWING NUMBER
C-0002

ISSUE/REVISION
B

ANSI D 864mm x 559mm
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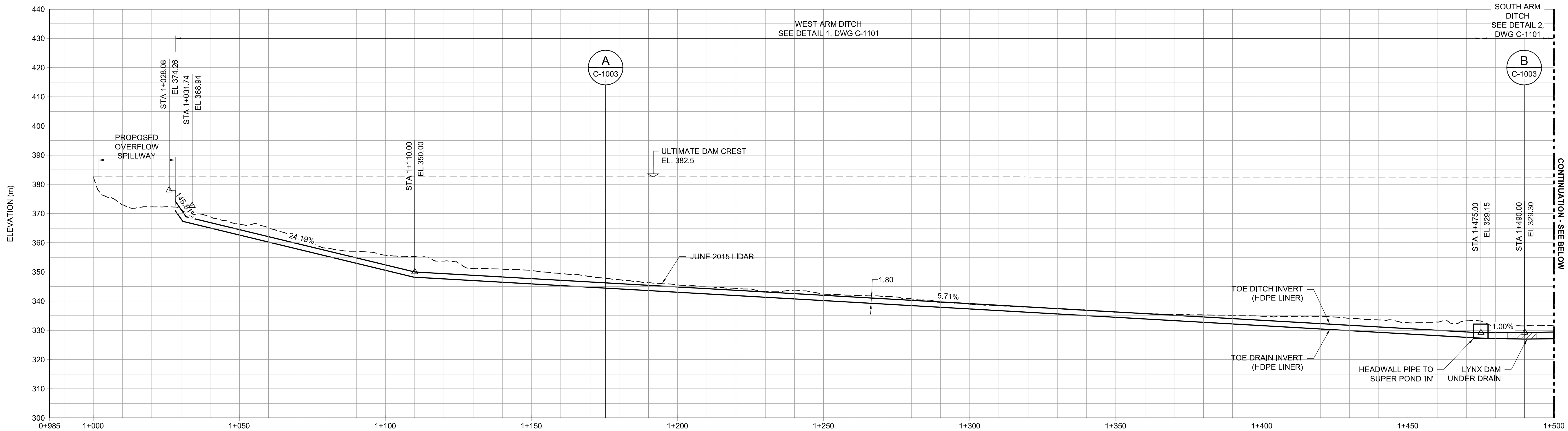
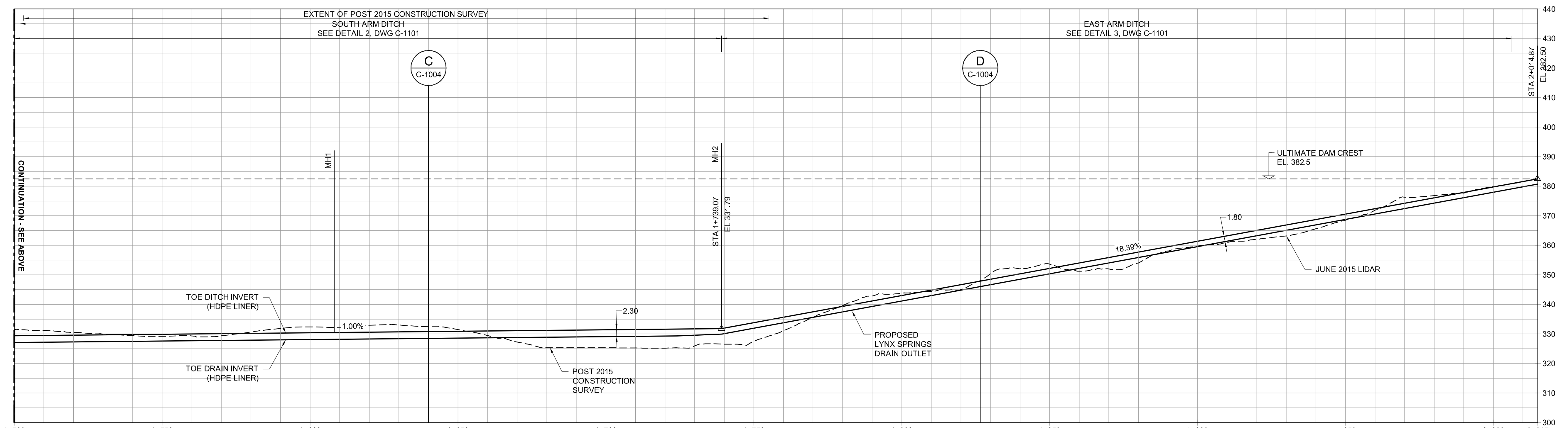


TOE DITCH PROFILE

STA. 1+000 TO 1+500 Scale 1:750



TOE DITCH PROFILE

STA. 1+500 TO 2+015 Scale 1:750

NOTES:

1. FOR ALL COMMON LEGEND AND NOTES, SEE DRAWING C-0002.

SCALE 0 18.75 37.5 1:750 Meters

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A	16	11	07	ISSUED FOR CLIENT REVIEW	MH	DH	FB	DHG

amec foster wheeler

CLIENT: nyrstar

PROJECT NAME: MYRA FALLS LYNX TDF DAM FACE CLOSURE COVER DESIGN

SHEET TITLE: TOE DITCH PROFILE

PROJECT NUMBER: NX14001K.2

DRAWING NUMBER: C-1002

ISSUE/REVISION: B

ANSI D 864mm x 559mm

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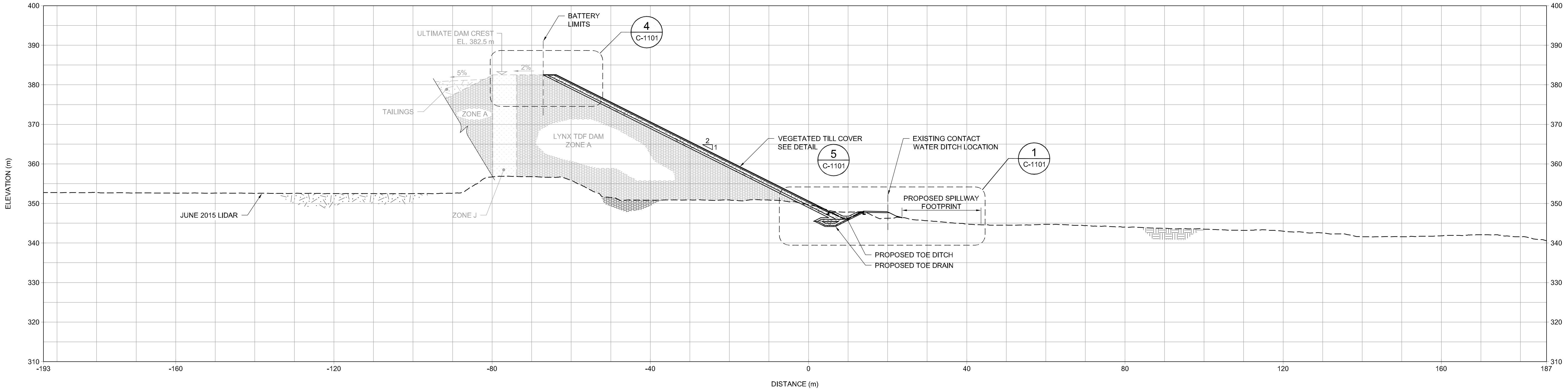
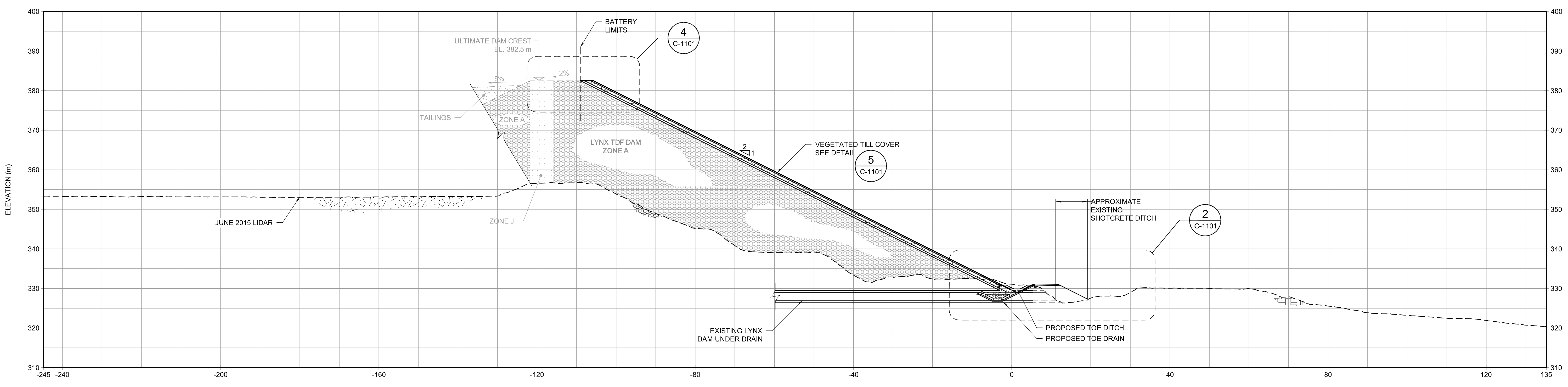


A C-1001 **TYPICAL SECTION**
STA. 0+185 Scale 1:500



B C-1001 **TYPICAL SECTION**
STA. 0+380 Scale 1:500

NOTES:

1. FOR ALL COMMON LEGEND AND NOTES, SEE DRAWING C-0002.
2. THE UPSTREAM SIDE OF THE BATTERY LIMITS, CREST AND TAILINGS POND ARE NOT IN THIS SCOPE OF WORK.

SCALE 0 10 20 1:500 Meters

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CLIENT nyrstar

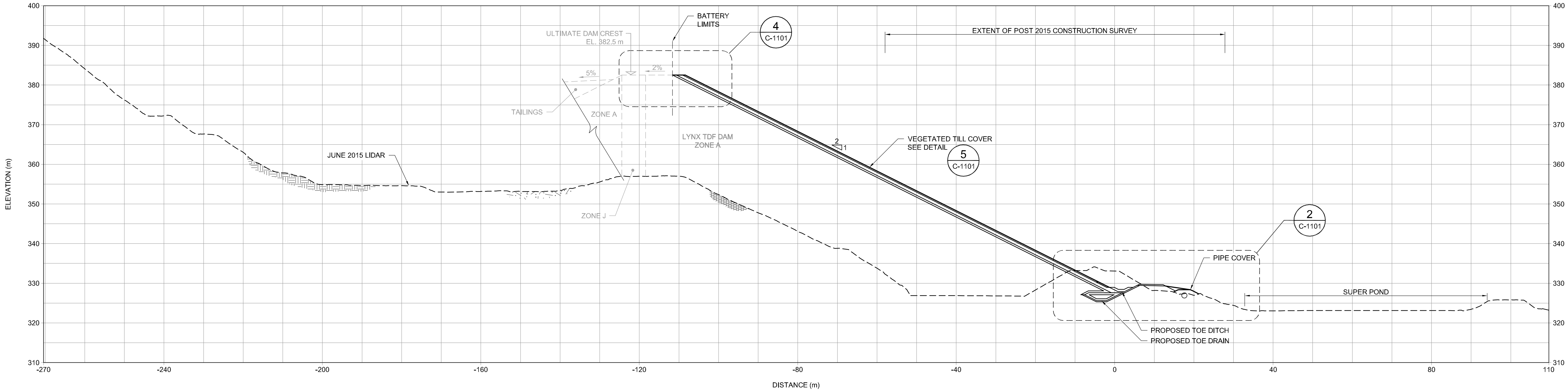
PROJECT NAME: MYRA FALLS LYNX TDF DAM FACE CLOSURE COVER DESIGN

SHEET TITLE: SECTIONS A & B

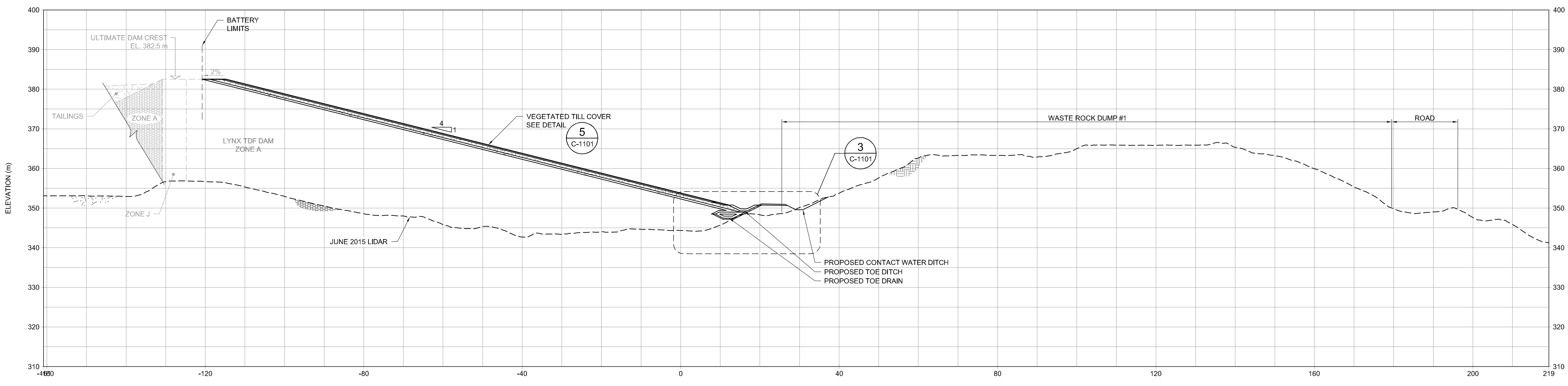
PROJECT NUMBER: NX14001K.2

DRAWING NUMBER: C-1003

ISSUE/REVISION: B



C C-1001 **TYPICAL SECTION**
STA. 0+530 Scale 1:500



D C-1001 **TYPICAL SECTION**
STA. 0+550 Scale 1:500

NOTES:

1. FOR ALL COMMON LEGEND AND NOTES, SEE DRAWING C-0002.
2. THE UPSTREAM SIDE OF THE BATTERY LIMITS, CREST AND TAILINGS POND ARE NOT IN THIS SCOPE OF WORK.

SCALE 0 10 20 1:500 Meters

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CLIENT nyrstar

PROJECT NAME: MYRA FALLS LYNX TDF DAM FACE CLOSURE COVER DESIGN

SHEET TITLE: SECTIONS C & D

PROJECT NUMBER: NX14001K.2

DRAWING NUMBER: C-1004

ISSUE/REVISION: B

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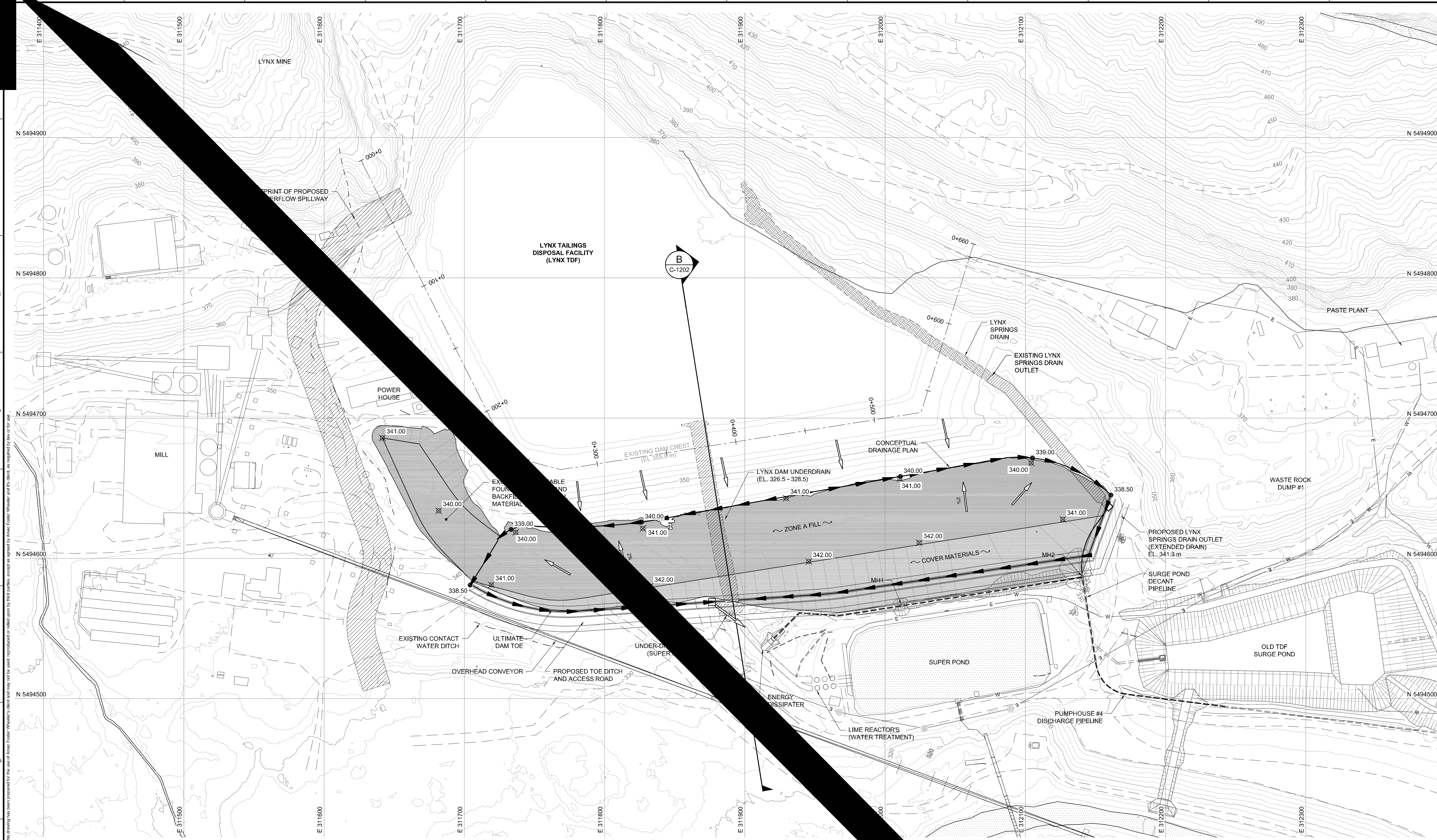

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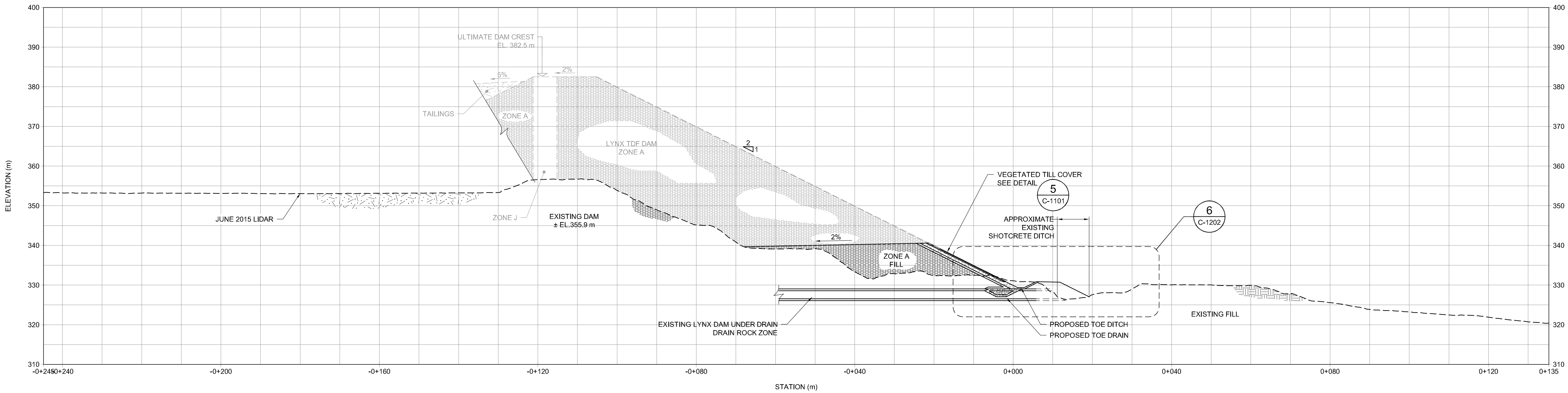
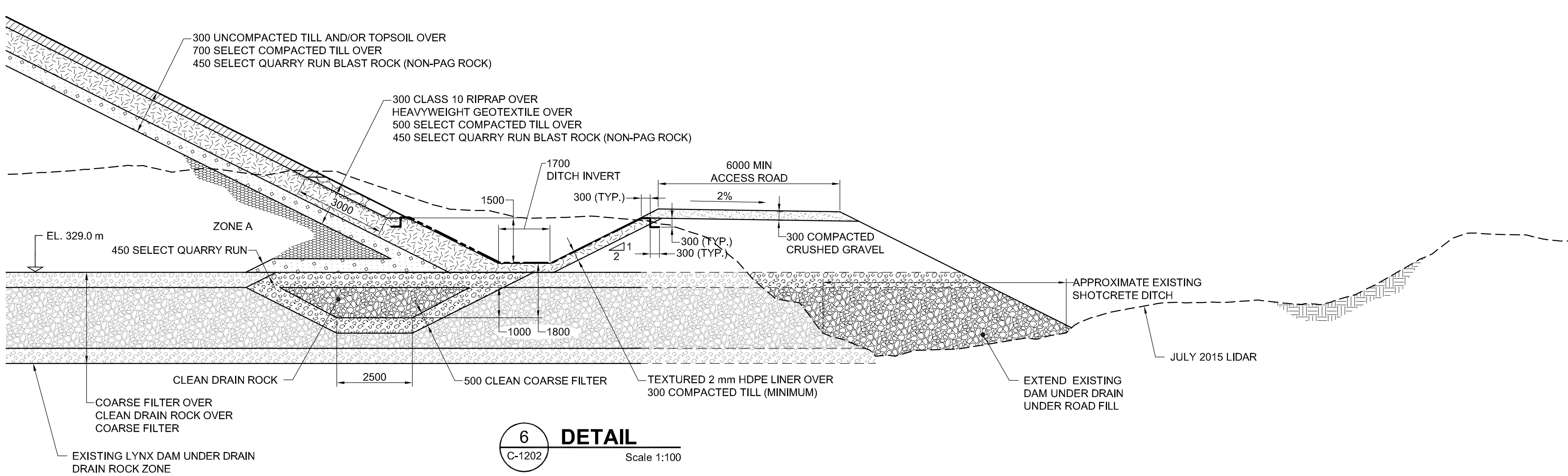


B
C-1201

SECTION

INTERIM CONSTRUCTION STAGE Scale 1:500



6
C-1202

DETAIL

Scale 1:100

NOTES:

1. FOR ALL COMMON LEGEND AND NOTES, SEE DRAWING C-0002.

SCALE: 0 10 20 1:500 Meters; 0 2 4 1:100 Meters

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amec foster wheeler

CLIENT: nyrstar

PROJECT NAME: MYRA FALLS LYNX TDF DAM FACE CLOSURE COVER DESIGN

SHEET TITLE: INTERIM CONSTRUCTION STAGE SECTION AND DETAILS

PROJECT NUMBER: NX14001K.2

DRAWING NUMBER: C-1202

ISSUE/REVISION: B

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ANSI D 864mm x 559mm

Appendix B

Figures

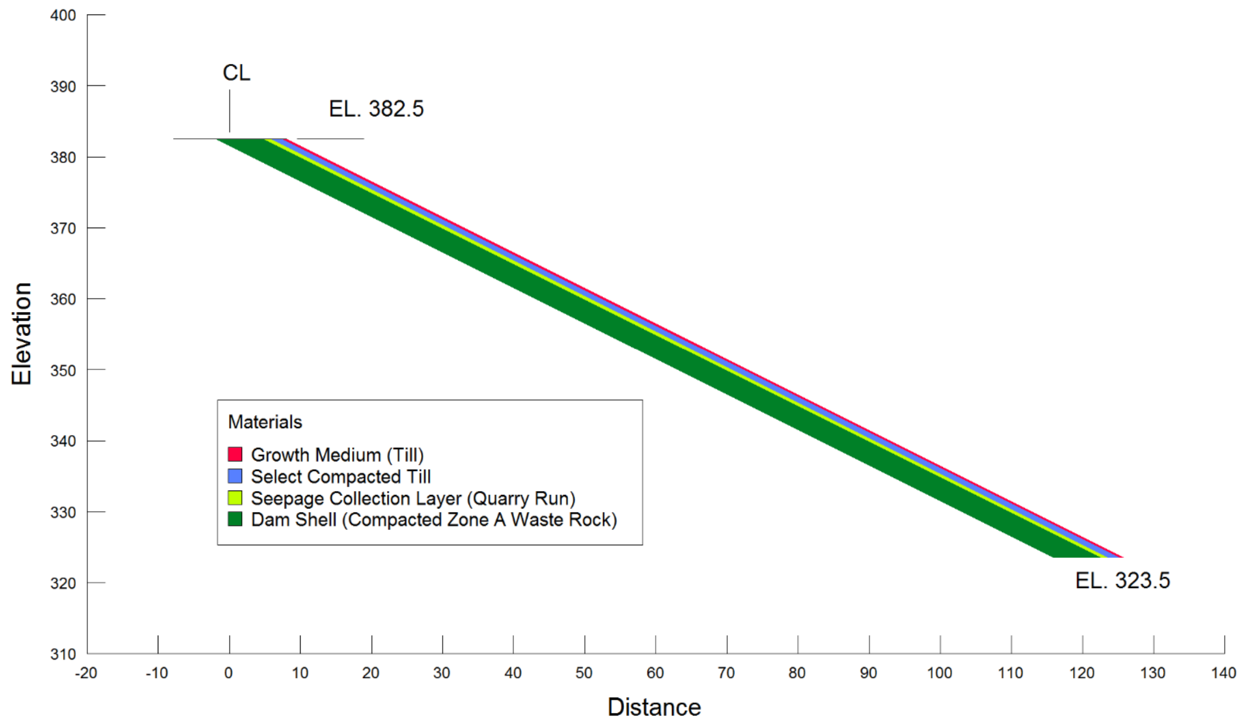

Figure 1: Cover stability model

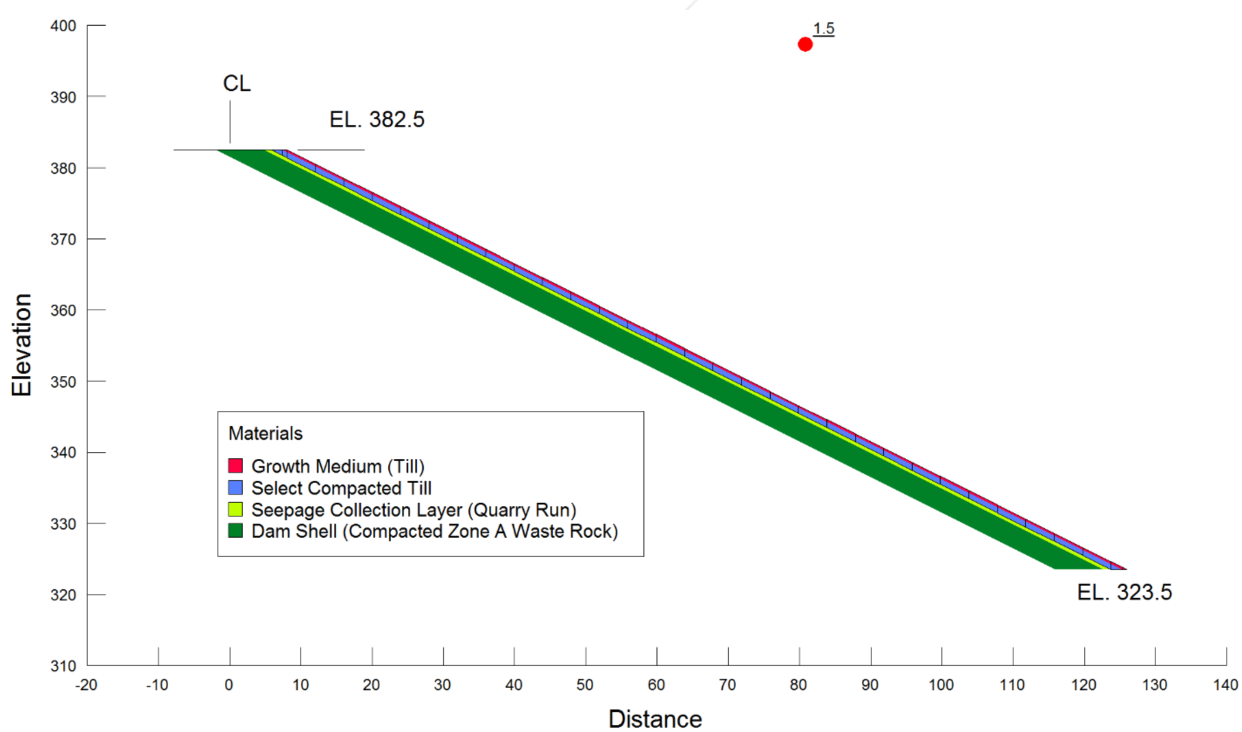

Figure 2: Static stability of unsaturated cover materials

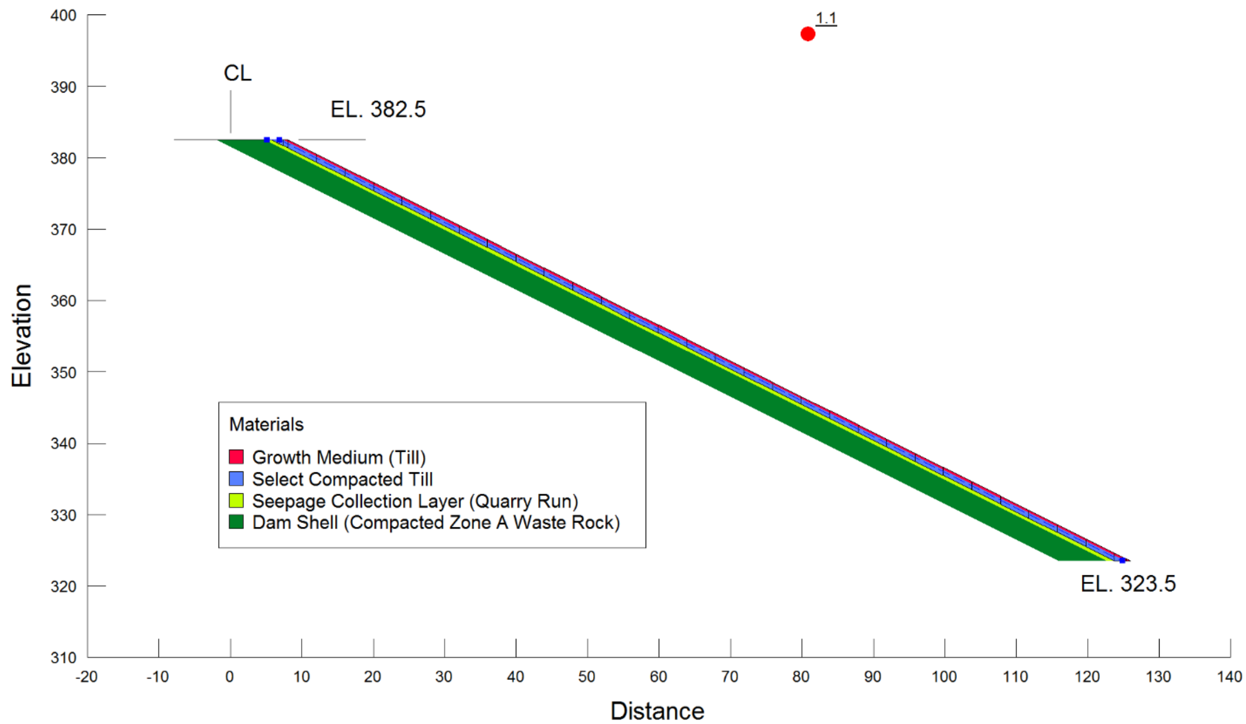

Figure 3: Static stability of half-saturated cover materials

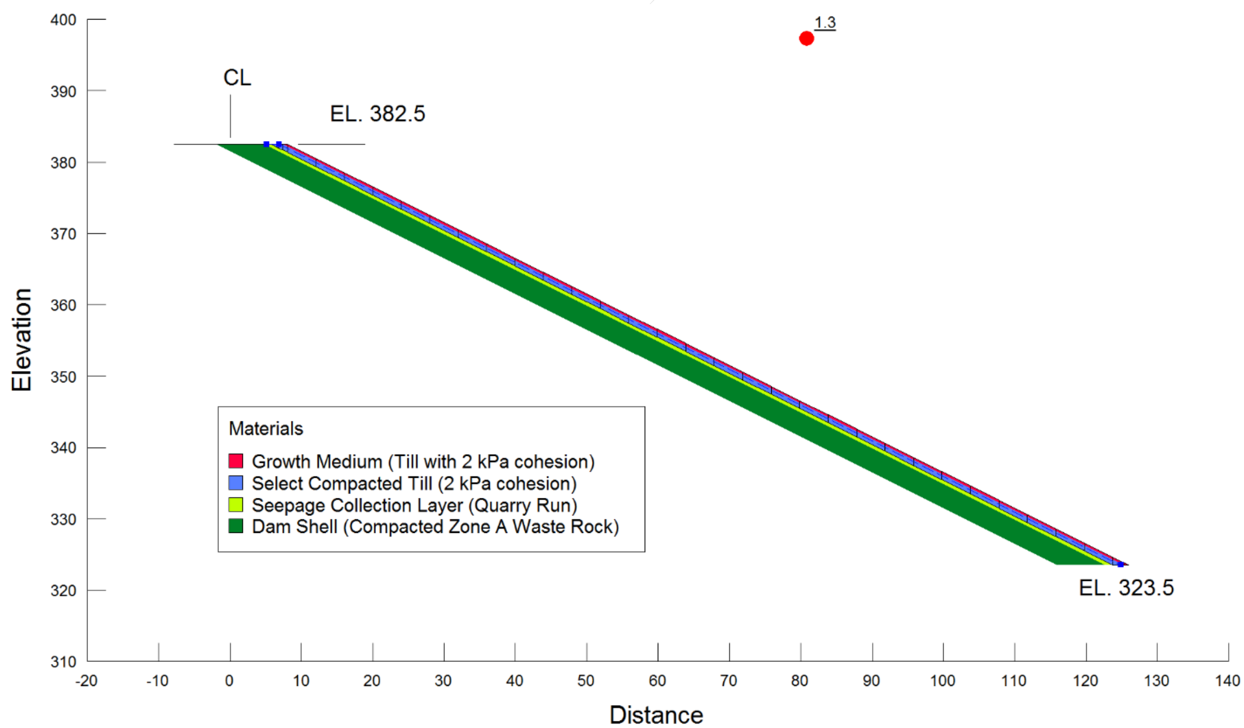

Figure 4: Static stability of half-saturated cover materials (with 2 kPa cohesion)

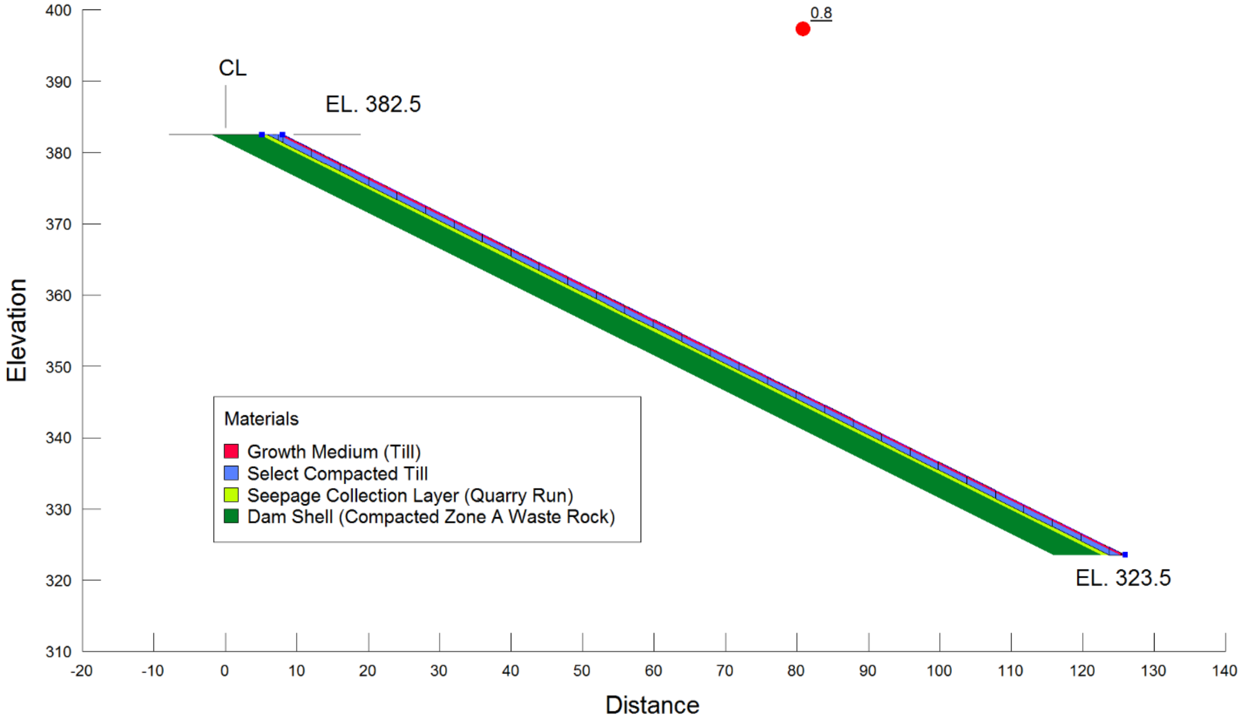

Figure 5: Static stability of fully-saturated cover materials

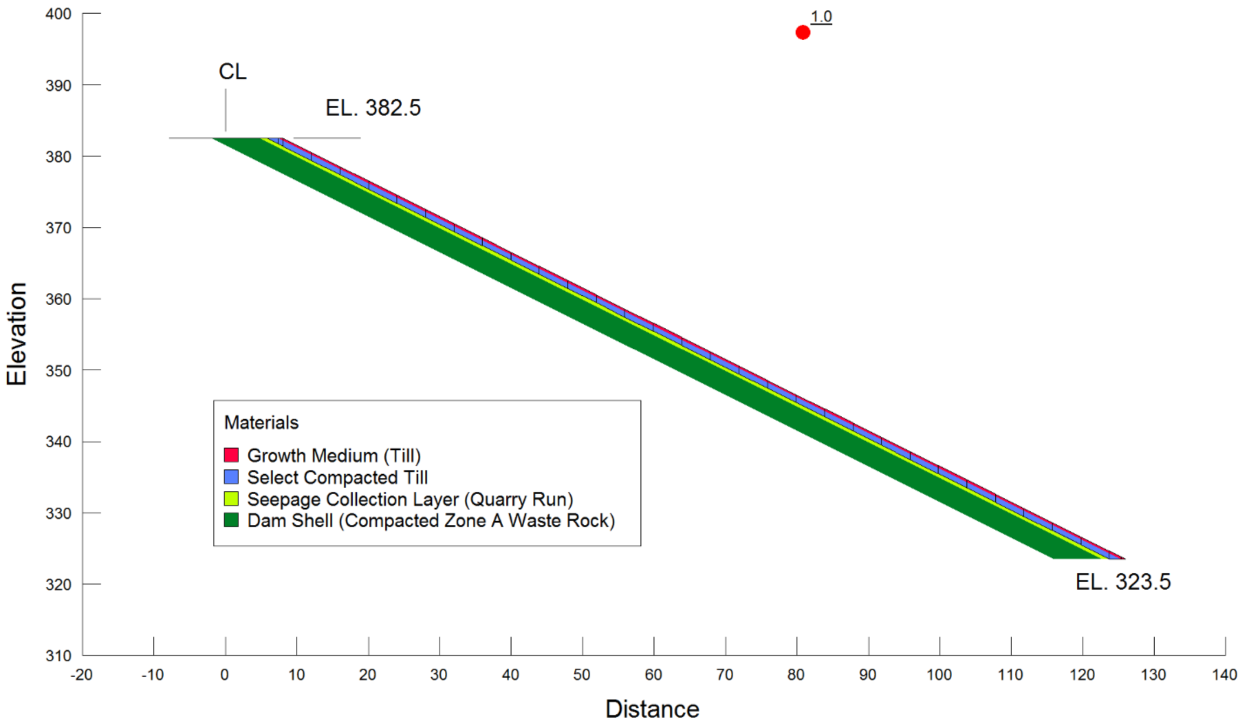

Figure 6: Pseudo-static stability of wet cover materials (yield coefficient of 0.19)

Appendix C

Material Specifications

Table 1: Myra Falls Lynx TDF Dam Face Closure Cover Design Granular Material Technical Specifications

Material	Description	Gradation[1]	
Class 10 Riprap	Non-PAG, well graded, angular, sound, hard, durable particles, free from silt, clay, shale, sandstone, flaky particles, topsoil, organic matter, and other deleterious materials	Fraction	Nominal Mass (Nominal Diameter[2])
		0% heavier than	50 kg (330 mm)
		15% heavier than	30 kg (280 mm)
		50% heavier than	10 kg (195 mm)
		85% heavier than	1 kg (90 mm)
Class 25 Riprap	Non-PAG, well graded, angular, sound, hard, durable particles, free from silt, clay, shale, sandstone, flaky particles, topsoil, organic matter, and other deleterious materials	Fraction	Nominal Mass (Nominal Diameter[2])
		0% heavier than	125 kg (450 mm)
		15% heavier than	75 kg (380 mm)
		50% heavier than	25 kg (260 mm)
		85% heavier than	2.5 kg (120 mm)

Table 1: Myra Falls Lynx TDF Dam Face Closure Cover Design Granular Material Technical Specifications (Cont'd)

Material	Description	Gradation[1]	
Class 50 Riprap	Non-PAG, well graded, angular, sound, hard, durable particles, free from silt, clay, shale, sandstone, flaky particles, topsoil, organic matter, and other deleterious materials	Fraction	Nominal Mass (Nominal Diameter[2])
		0% heavier than	245 kg (565 mm)
		15% heavier than	150 kg (475 mm)
		50% heavier than	50 kg (330 mm)
		85% heavier than	5 kg (150 mm)
Clean Coarse Filter	Non-PAG clean gravel	Particle size (mm)	% Passing
		75	100
		25	45 - 100
		9.5	0 - 40
		4.75	0 - 2
Clean Drain Rock	Non-PAG clean gravel and cobbles	Maximum particle size of 300 mm Maximum fraction >150 mm of 50%	
		Gradation of material <150 mm:	
		Particle size (mm)	% Passing
		150	50 - 100
		75	0 - 60
		37.5	0 - 25
		25	0 - 2

Table 1: Myra Falls Lynx TDF Dam Face Closure Cover Design Granular Material Technical Specifications (Cont'd)

Material	Description	Gradation[1]	
Compacted Till	Non-PAG, well graded, silt to cobbles	Maximum particle size of 200 mm Maximum fraction >150 mm of 10%	
		Gradation of material <150 mm:	
		Particle size (mm)	% Passing
		150	90 - 100
		37.5	70 - 100
		4.75	40 - 75
		0.425	20 - 50
		0.075	10 - 40
Growth Medium	As per Nyrstar direction	-	
Select Quarry Run (Blast Rock)	Non-PAG, well graded blasted quarry rock, sand to cobbles (low fines)	Particle size (mm)	% Passing
		200	100
		37.5	40 - 100
		4.75	20 - 60
		0.425	0 - 25
		0.075	0 - 5
		Maximum particle size of 200 mm	

Notes:

1. Gradation testing shall be defined in ASTM C136 and ASTM C117. Aggregates shall have a gradation that defines a curve (% passing versus log sieve size) with a slope between adjacent sieves, equal or intermediate to the corresponding slopes of the boundary curves defined by the specification.
2. Percentages quoted by mass. Sizes quoted are equivalent spherical diameters assuming a specific gravity of 2.64, and are for guidance only.

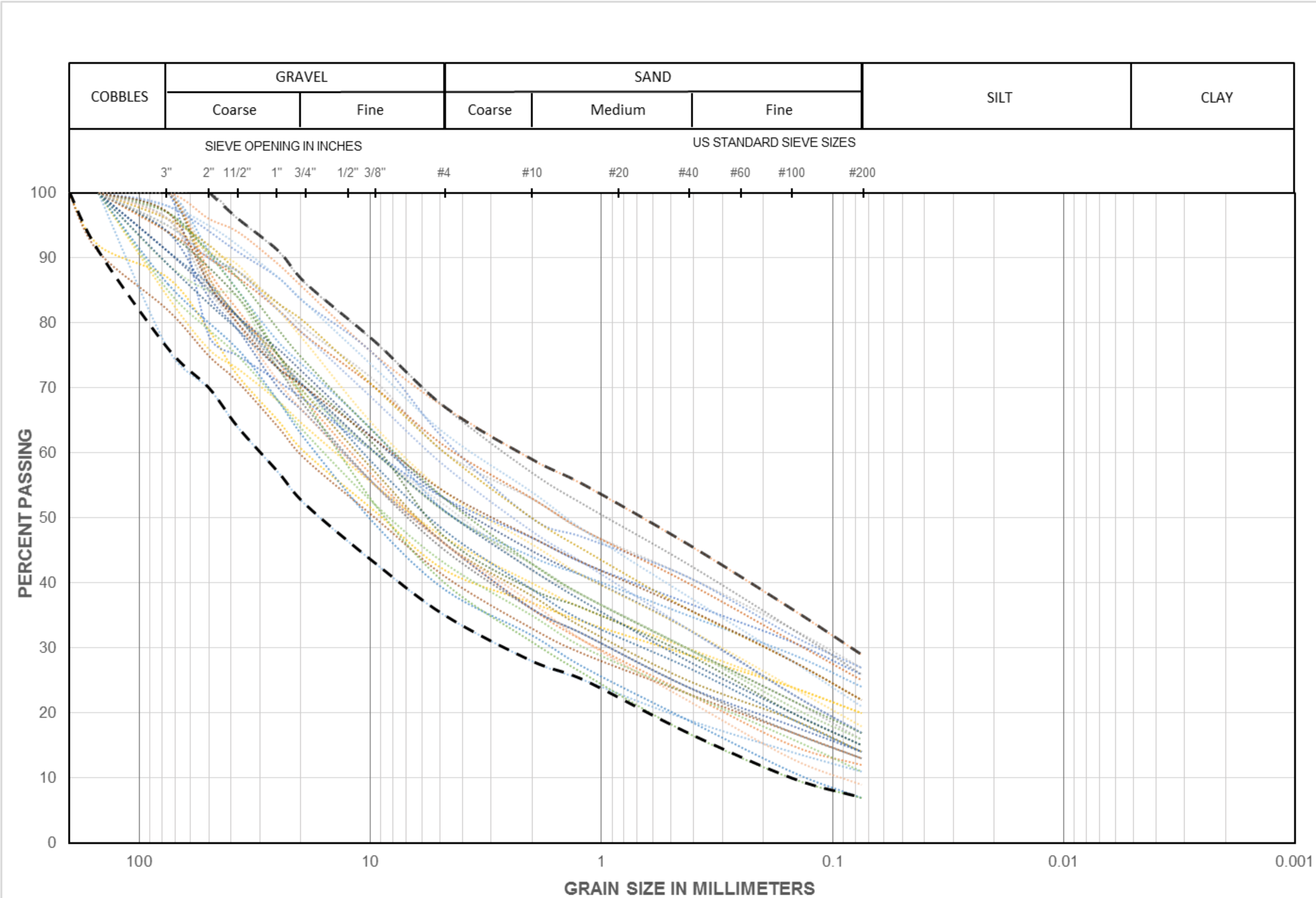

Figure 1: CRAB Till Gradation from Seismic Upgrade Berm Construction (Amec, 2013)