Clinton Creek Remediation Project

10% Design Phase Report
Project # VE52705E.100.2

Prepared for:

Government of Yukon-Energy, Mines and Resources
Assessment and Abandoned Mines

2C – 4114 4th Avenue, Whitehorse, Yukon, Y1A 4N7

November 2019

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November 2019

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List of Acronyms and Abbreviations

AACE	American Association of Cost Engineers
AAM	Assessment and Abandoned Mines (Yukon Government)
BCMOE	British Columbia Ministry of the Environment
CIRNAC	Crown-Indigenous Relations and Northern Affairs Canada
CC	Clinton Creek
CCME	Canadian Council of Ministers of the Environment
CCRP	Clinton Creek Remediation Project
CDA	Canadian Dam Association
CoC	Contaminants of Concern
DBA	Dam Breach Assessment
DBM	Design Basis Memorandum
ERT	Electrical Resistivity Tomography
FAL	Freshwater Aquatic Life
HHERA	Human Health and Ecological Risk Assessment
IDF	Inflow Design Flood
IPRP	Independent Project Review Panel
LCCA	Life Cycle Cost Analysis
PPSS	Porcupine Pit Spoil Structure
PMF	Probable Maximum Flood
TA	Task Authorization
TH	Tr'ondëk Hwëch'in
WC	Wolverine Creek
Wood	Wood Environment & Infrastructure Solutions, a Division of Wood Canada
YESAB	Yukon Environmental and Socio-Economic Assessment Board
YG	Yukon Government

1.0 Introduction

1.1 Site Description

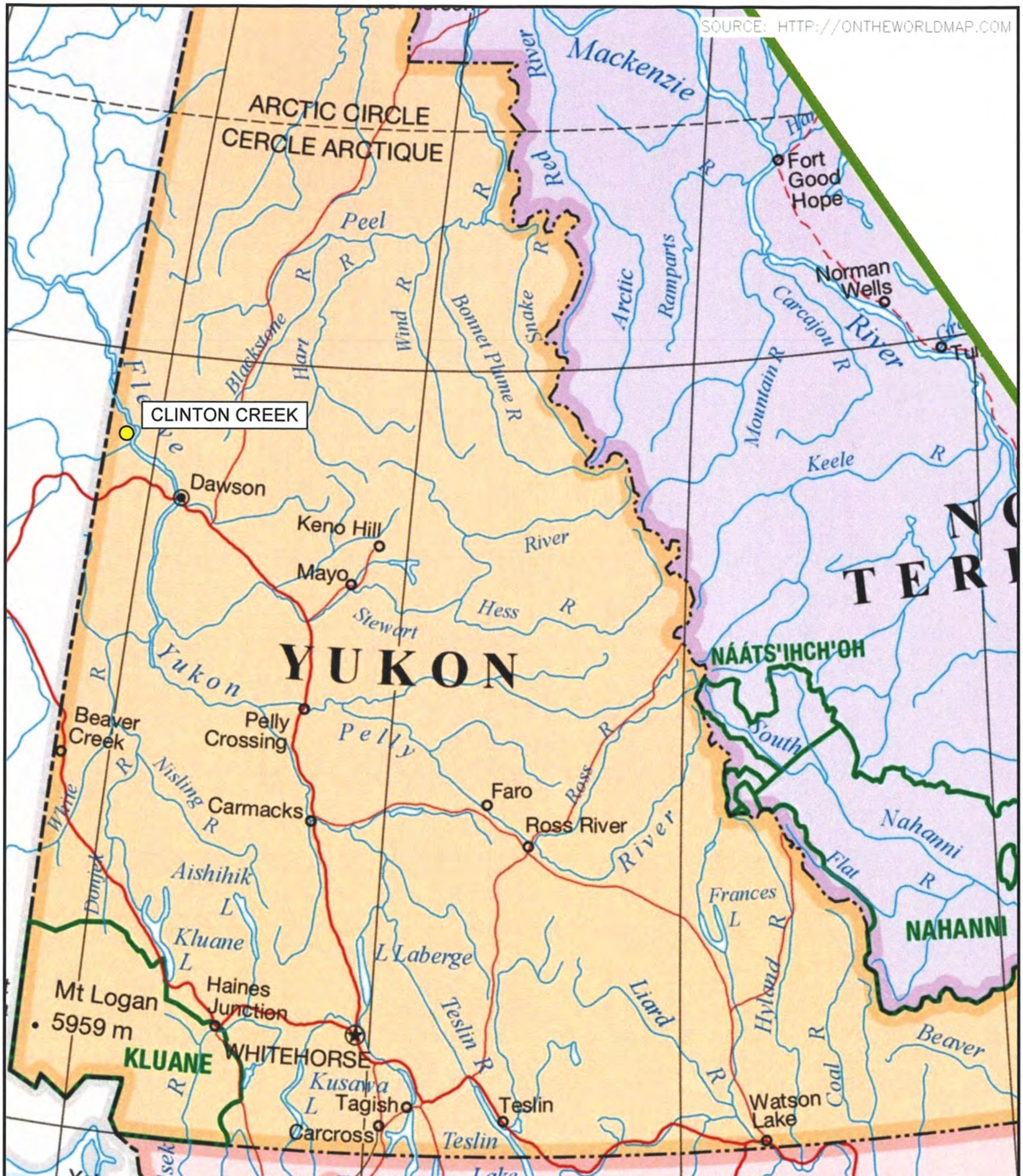
The Clinton Creek Mine Site (the Site) is a former asbestos mine that was operated between 1968 and 1978. The site is located approximately 100 km northwest of Dawson City, Yukon, near the confluence of Fortymile River and the Yukon River (Figure 1-1). The site is accessed from the Top of the World Highway (Yukon Highway 9), then the Clinton Creek Road. These roads are typically maintained between the months of June and September when the George Black River Ferry is running between East Dawson and West Dawson. During the fall and winter months the site is only accessible by helicopter or snowmobile.

Major elements of the site are shown on Figure 1-2. During mine operations, material was removed from three ore sources, the Porcupine Pit (the largest), Horseshoe Pit and the Creek Pit. Waste was placed in the following locations:

1. Clinton Creek Waste Dump, where waste was placed along the south valley wall of the Clinton Creek valley. It is estimated that 60 million tonnes of waste were placed in the Clinton Creek Waste Dump;
2. Porcupine Creek Waste Dump, where waste was placed into the Porcupine Creek valley (Porcupine Creek Waste Dump); and
3. Snowshoe Pit Waste Dump, where waste was placed on the north side of the Snowshoe Pit along the top of the south Clinton Creek valley wall.

During mining operations, ore was transported via an aerial tramway from the south side of the Clinton Creek valley to the Mill Site at the top of the west valley wall of Wolverine Creek. The ore, a serpentine rock containing chrysotile asbestos, was processed in the mill and the waste material, or tailings, were transported via conveyor to two piles along the steep west slope of Wolverine Creek, one pile located north of the other. Approximately 12 million tonnes of tailings were deposited in these two piles. It is understood from conversations with former mine workers that material was never dozed over the valley wall, and that the piles were gravity stacked. There were however some attempts to densify the tailings at the toe of the south lobe. In addition, a stabilization berm had begun on a portion of the north facing lower portion of the north lobe. There are no as-built records available for any of the tailings operations.

In 1974, waste material placed on the south slope of the Clinton Creek valley, the Clinton Creek Waste Dump, failed, apparently several times and possibly at different locations, which blocked the Clinton Creek flow path. It should be noted that Clinton Creek had been diverted north of the natural creek alignment, which originally flowed along the toe of the south slope of the Clinton Creek valley, prior to the failure of the Clinton Creek Waste Dump. The failure created a landslide dam, which impounded water upstream, producing what is now known as Hudgeon Lake. Additional information about the formation of Hudgeon Lake is provided in Amec Foster Wheeler (2018a). It is currently believed that only a portion of the Clinton Creek Waste Dump failed, and that efforts were made to stabilize the resulting landslide dam. Currently, water discharging from Hudgeon Lake travels southeast via Clinton Creek to Fortymile River, approximately 8 km downstream, through four gabion drop structures (DS1, DS2, DS3 and DS4), constructed between 2002 and 2004. DS4 was upgraded and repaired in 2015, following damage sustained in 2010. Damage to DS4 was noted in the field following the spring freshet in 2018, and additional damage was caused to the drop structure during a flood event in August 2018. Supplementary repairs to DS4 were then completed in the fall of 2018 (Tetra Tech 2018).



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CHK'D BY: GG			PROJECT NO: VE52705E
DATUM: NAD 83	TITLE: SITE LOCATION PLAN		REV. NO: A
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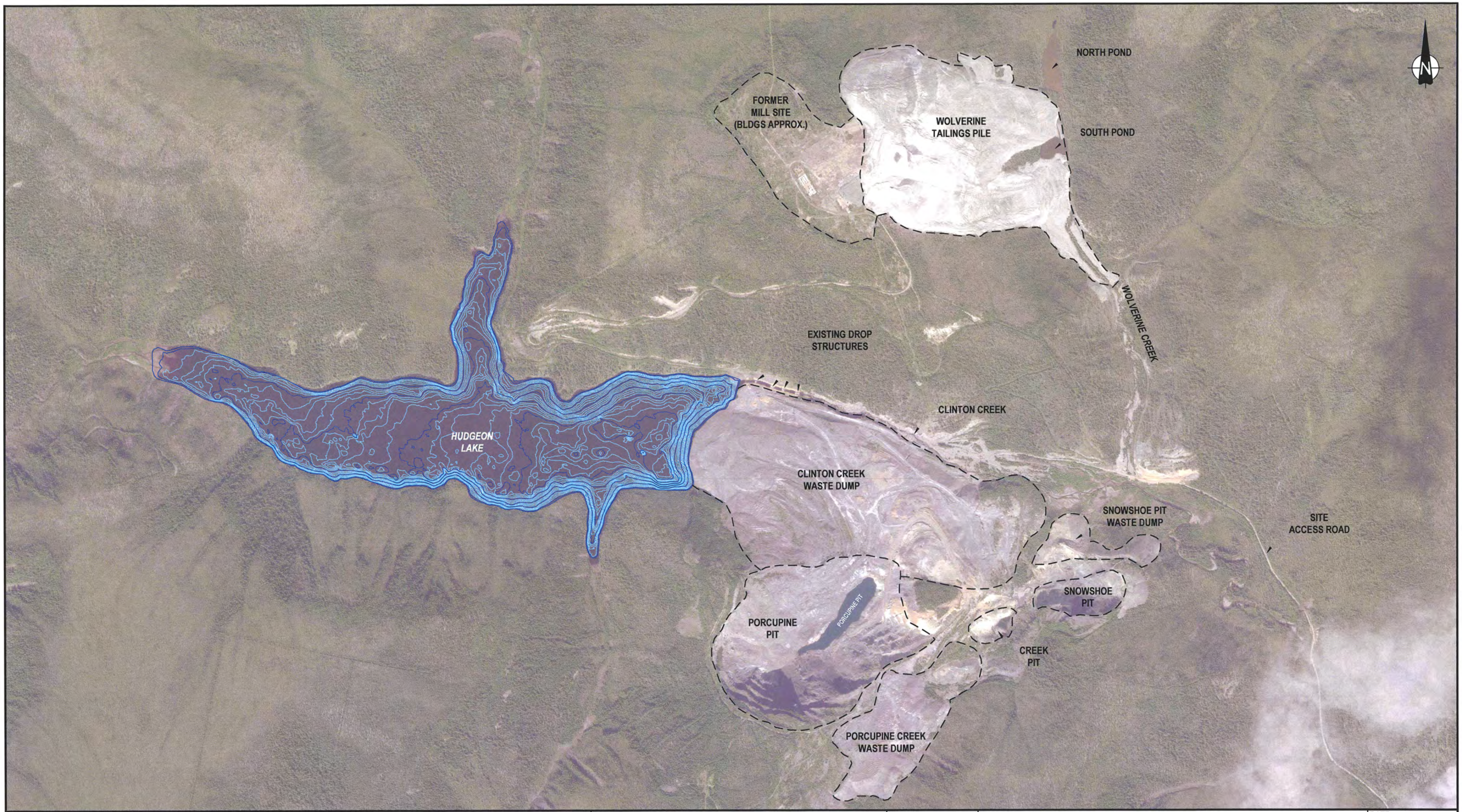

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DWN BY: TH	PROJECT: CLINTON CREEK MINE REMEDIATION PROJECT		DATE: NOV 2019
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The south tailings lobe also failed in 1974, blocking Wolverine Creek. It is understood that the initial failure of the tailings was relatively rapid, and there was considerable mobility of the initially steep tailings cone down the slope, blocking Wolverine Creek, and then down the Wolverine Creek valley following the breach of the temporary landslide dam. Per Amec Foster Wheeler (2018a), there is some evidence that suggests static liquefaction may have been a factor in the failure of the tailings pile. At some time post mine-closure, the north tailings pile also blocked Wolverine Creek. At present, there are two ponds which have formed along Wolverine Creek, one upstream of the north tailings lobe and one between the two tailings lobes, referred to as North and South Ponds, respectively. The North Pond discharges into the South Pond and flows from the South Pond is conveyed south via Wolverine Creek, finally discharging into Clinton Creek near the site gate.

There is little factual information on many aspects of site development, and reports by consultants following failures were at a reconnaissance level and necessarily subjective and qualitative reflecting the limited scopes. There are also no reliable pre-development site plans/contours which complicates interpretations of the borehole information and an understanding of failure mechanisms.

Additional locations of interest on the Site, referred to as the Common Elements, include the following locations and/or features:

- Former mill site;
- Air strip;
- Clinton Creek access road;
- Clinton Creek site roads;
- Clinton Creek ford crossings;
- Hudgeon Lake outlet abutments and log boom;
- Ore piles;
- Miscellaneous borrow areas; and
- Miscellaneous infrastructure, equipment and waste.

There are no buildings remaining at the Site; however, large, heavily reinforced concrete foundations are present at the former mill site, the crusher building, and the former Tram Tower #3. These structures were left in-place due to demolition constraints (reinforced steel), accessibility concerns, and low hazard classifications (UMA/AECOM 2006).

1.2 Project Background

1.2.1 Project Partners and the IPRP

The development of the CCRP has been guided by the following Project Partners:

- the Government of Yukon, Energy, Mines and Resources, Assessment and Abandoned Mines (Wood's client);
- Crown Indigenous Relations and Northern Affairs Canada (CIRNAC); and
- the Tr'ondëk Hwëch'in (TH) First Nation.

In addition, the Project Partners, through CIRNAC, maintain an Independent Peer Review Panel (IPRP) that provides independent technical oversight and advice at key junctures of project development.

1.2.2 Original Scope

In 2016, the Project Partners sought the development of a 10% design and cost estimate for closure concepts on the Clinton Creek, Wolverine Creek, and common components of the property. The intent of the 10% design development was to advance the design of the closure concepts to a level that would allow the Project Parties to select a single remedial option to advance for the site. As such, Wood Environment & Infrastructure Solutions (Wood; formerly Amec Foster Wheeler) was initially retained in the fall of 2016 by the Project Parties to:

- conduct a review of the available information;
- develop a data gap and a site investigation plan to collect the missing information (e.g., Human Health Ecological Risk Assessment [HHERA], geotechnical studies) to complete the remediation design to 10%, and to develop a cost estimate for each concept, as well as address the common elements;
- conduct site investigations, including gathering field data (e.g., geotechnical investigation on the waste dump and tailings piles, field data for HHERA) to ensure all information that was required was available to develop the design and cost estimate for each concept; and
- develop a 10% design and an AACE (American Association of Cost Engineers) Class 4 Life Cycle Costs Analysis (LCCA) for each concept and the common elements.

1.2.3 Updated Scope

Following review of Wood data collected during an initial 2016 field investigation and the associated design concepts, the Project Parties elected to pause development of the geotechnical aspects of the 10% remediation designs until an agreed upon conceptual site model was established. A workshop was held in May 2017 to summarize existing information and discuss a path forward. This resulted in a revision/ update to the scope of work that was detailed in Yukon (2017). In summary that revised scope of work included:

- updating the draft documents produced in 2016/17;
- a Data review and analysis;
- a Data gap assessment;
- planning and execution of a supplementary field investigation;
- development of 10% Designs and an AACE Class 4 LCCA for each concept and the common elements; and
- project management.

Wood's approach for the delivery of services addressing this updated scope was detailed in a proposal submitted to the Government of Yukon, Assessment & Abandoned Mines, in May of 2018 (Wood 2018c). The closure concept designs that are the subject of this report represent some of the key deliverables called for under this updated scope. A detailed description of the activities and components originally proposed for the development of this report were described In Wood's Task Authorization Request #14 to the Government of Yukon (Wood 2019).

1.2.4 Project Milestones – 2018/2019

There were a number of key milestones associated with Wood's updated scope, specifically:

- 2018 site investigation program planning - May to July 2018;
- 2018 site investigation program execution - August and September 2018;

- Workshop #1 - Site Investigation Field Debrief - November 2, 2018;
- Workshop #2 - Site Investigation/Characterization Report and Design Development Review - January 22, 2019; and
- Workshop #3 - IPRP Site Characterization and Design Development Review - May 7 and 8, 2019 (note; the Wood presentations that were integral inputs to Workshops #2 and #3 relied on ongoing data compilation and interpretation (i.e., they were point in time presentations); these presentations are included in the Meeting Notes that are referenced in Section 2)).

1.2.5 Key Scope Reviews

The second and third project workshops were particularly important milestones because they involved discussions with the Project Partners and the IPRP about the implications of site characterization outcomes for subsequent design development activity. These discussions provided critical input to the designs outlined in this document. The following particular outcomes of the workshops are worth noting.

In the January 2019 Workshop (Workshop #2), Wood presented the view that characterization outcomes indicated that extraordinary measures would be required to execute some of the candidate options, and/or that some options would involve the retention of significant post closure risks and liabilities. The idea of reducing the number of candidate options (a possibility that was acknowledged in the AAM work scope (Yukon 2017)) was discussed and later rationalized in a discussion paper submitted to the Project Partners (Wood 2019h). The Project Partners' review of the discussion paper concluded that it was premature to discount any of the options prior to the 10% design milestone and, accordingly, all of the candidate options were carried forward and considered in this design report.

Workshop #3 (May 2019) provided a more comprehensive presentation of site characterization outcomes (including March 2019 inclinometer data) and brought the IPRP into the discussion of the associated influences on closure option assessments. The IPRP's perspectives on characterization status and suggestions for closure alternations and/or supplements were captured in the Workshop notes (Wood 2019i). Wood's response to these suggestions (Wood 2019j) noted that while additional option assessments and variations in focus will inevitably feature in post 10% design development activity, the original 10% design development scope was still expected to provide sufficient support to the Project Partners' concept select deliberations.

At these meetings there were also discussions probing the objectives and quantitative deliverables of a closure plan vis-à-vis the subjective closure principles formulated by the Project Partners (see Table 5-1 in Section 5). It was discussed that in development of the Clinton Creek options, and two of the Wolverine Creek options, Wood's perspective has been to harden the design configurations as much as is practical so as to minimize the future risks of conditions whereby the site could revert to its present condition unless massive remedial measures were then instituted at some future date. However, this does not exclude the potential for some degree of on-going maintenance until a true "walk away" condition is achieved. Wood notes that the combination of the CC3 (Lake Removal) and WC3 (Tailings Relocation) options, removing most landslide dam wastes and all tailings wastes to Porcupine Creek, and re-establishing original creek gradients, most closely approximates a "walk away" closure state – if in fact that is the desired solution.

1.2.6 10% Design Phase Definition

When Wood's current scope was initiated in 2016 there was some ambiguity about the specific endpoint objectives for the 10% design development phase. Early attempts to define this phase more specifically evolved through various iterations and the issue was addressed again in the April 2018 Project Worksop with the IPRP. In their report on that session (IPRP 2018). The panel recommended the following guidance for establishing the current design phase objectives.

> *During the discussions it was evident that there were differing opinions on what constitutes a 10% design level for the waste pile closure plans. Instead of using this type of design definition, which is open to differing interpretations, the Panel recommends that the following level and description of design be considered. …….It is recommended that designs be developed to a pre-feasibility study (PFS) level2. This means there needs to be sufficient field data to prepare designs that meet the design bases and criteria with reasonable certainty and to reasonably assure there are no fatal flaws. The field data base can be supplemented by reasonable engineering assumptions based on experienced professional judgement, and it must be possible to deal with design uncertainties using reasonable worst-case assumptions and cost contingencies.*

Wood considered this recommendation in the broad definition of objectives that were outlined in the proposal for current design development activity (Wood 2018c). This definition proposed that the 10% design development stage would involve advancing concepts to the degree that a single base case concept could be selected with a low probability that fatal flaws in the selected concept would be encountered thereafter. It was noted that fatal flaws would include technical conditions or constraints that preclude application of the concept, insurmountable regulatory burdens and/or prescriptions, and/or "exotic" (i.e., economically implausible) costs. Wood also noted that there would likely be significant uncertainties related to the base case concept and the 10% design development activity would include identifying the major characterization and design assessment gaps required to mitigate those uncertainties. Further it was acknowledged that the application of Adaptive Management strategies could be applied as part of the strategy to mitigate characterisation and/or design uncertainties. The cost estimates prepared as part of the 10% design development effort were intended to provide a level of refinement sufficient to support the concept select objective of this phase.

1.2.7 Comment Logs

The comment Logs that are included with this document describe the disposition of Project Partner comments on the draft submission of this report. The context offered by these responses provides support to the review and interpretation of this document's content.

2.0 Site Properties and Characterizations

The general nature and setting of the Clinton property, and the available characterizations of site conditions, have determining influences on the assessment of any options contemplated for site closure. The current description of site properties and characterizations is a compilation of cursory investigative and assessment programs dating back to the latter stages of site operations, up to the more comprehensive recent investigative activities completed by Wood in 2018 and 2019. The outcomes of the project's investigative history and the associated characterizations of site conditions are captured in the following key documents. These documents are the central inputs to the assessment of alternatives described in this report and should be reviewed in conjunction with any consideration and/or interpretation of this document. The bolded Geotechnical Summary Report is a particularly important reference because it describes the design bases for the dump and tailings slopes and configurations that feature in the designs presented herein.

- Clinton Creek Mine Geotechnical Data Gaps. Prepared for Government of Yukon Energy, Mines and Resources Assessment and Abandoned Mines by Amec Foster Wheeler Environment & Infrastructure. March 2018.
- Clinton Creek Mine Geotechnical Design Gaps. Prepared for Government of Yukon Energy, Mines and Resources Assessment and Abandoned Mines by Amec Foster Wheeler Environment & Infrastructure. March 2018.
- Clinton Creek Remediation Project Status of Geotechnical Studies (DRAFT). Prepared for Government of Yukon, Department of Energy, Mines and Resources, Assessment and Abandoned Mines Branch by Wood Environment & Infrastructure Solutions. April 2019.
- Clinton Creek Remediation Project, Environmental Site Characterization Update. Prepared for Government of Yukon Energy, Mines and Resources Assessment and Abandoned Mines by Wood Environment & Infrastructure Services. June 2019.
- Clinton Creek Remediation Project, Site Investigation Report. Prepared for Government of Yukon Energy, Mines and Resources Assessment and Abandoned Mines by Wood Environment & Infrastructure Services. July 2019.
- Clinton Creek Remediation Project, Human Health and Ecological Risk Assessment Update. Prepared for Government of Yukon Energy, Mines and Resources Assessment and Abandoned Mines by Wood Environment & Infrastructure Services. July 2019.
- Clinton Creek Remediation Project, Geological and Geotechnical Site Characterization and Model. Prepared for Government of Yukon Energy, Mines and Resources Assessment and Abandoned Mines by Wood Environment & Infrastructure Services. August 2019.
- ***Clinton Creek Remediation Project, Geotechnical Summary Report. Prepared for Government of Yukon Energy, Mines and Resources Assessment and Abandoned Mines by Wood Environment & Infrastructure Services. August 2019.***
- Clinton Creek Remediation Project Meeting Notes, Workshop #2 - Site Investigation/Characterization Report and Design Development Review. Prepared for Government of Yukon, Department of Energy, Mines and Resources, Assessment and Abandoned Mines Branch by Wood Environment & Infrastructure Solutions. January 2019.

- Clinton Creek Remediation Project Meeting Notes, Workshop #3 - Site Characterization and Design Development Review. Prepared for Government of Yukon, Department of Energy, Mines and Resources, Assessment and Abandoned Mines Branch by Wood Environment & Infrastructure Solutions. May 2019.
- Memo re: *Wood Response to IPRP Comments, Suggestions and Recommendations During CCRP Workshop #3*. Prepared for Government of Yukon, Department of Energy, Mines and Resources, Assessment and Abandoned Mines Branch by Wood Environment & Infrastructure Solutions. 5 June 2019.

The flow channel location and configuration assumptions applied for the stability analyses and quantity estimates presented in the Geotechnical Summary Report described above (Wood 2019d) preceded the development of final channel designs that appear in the 10% design drawings referenced in Sections 5 and 6 and included in this document. Post 10% updates of stability assessments for these channel configurations may result in some adjustments to design slopes. The quantity estimates applied in the 10% design cost estimate (Wood 2019m) apply estimates based on the channel configurations shown in this design report drawings (i.e., they update the estimates described in Appendix G of Wood (2019d)).

3.0 Closure Option Descriptions

3.1 Original Scope Descriptions

The Project Partners' descriptions of the six candidate options specified in Yukon's original scope document (Yukon 2017) were as follows. Note that the references to LCCA (Life Cycle Cost Analyses) Options in these descriptions are taken from the option definitions applied in a 2014 estimating exercise completed for Yukon in 2014 (WorleyParsons 2014).

Clinton Creek Side Closure Concepts:

a. **Water Passage and Catastrophic Failure Mitigation (LCCA Options D3, I2) (CC1 in Wood reports)** - Conduct sufficient work on the waste rock pile to mitigate a catastrophic failure of the pile and construct a water conveyance channel to provide water passage from Hudgeon Lake to Clinton Creek. Now called CC1 in Wood reports.

b. **Water Passage, Catastrophic Failure Mitigation and Lowering Lake (LCCA Option E3) (CC2 in Wood reports)** - Conduct sufficient work on the waste rock pile to mitigate a catastrophic failure, construct a water conveyance channel to provide water passage from Hudgeon Lake to Clinton Creek and lower Hudgeon Lake as part of that concept.

c. **Water Passage with Reduction of the Lake Level, Eliminating the Dam, and Mitigating Catastrophic Failure (LCCA Option F) (CC3 in Wood reports)** - Conduct sufficient work on the waste rock pile to prevent it from acting as a Dam (i.e., as defined by the Canadian Dam Association) on Clinton Creek and to mitigate a catastrophic failure of the waste rock pile. Construct a water conveyance channel to provide water passage through the site.

Wolverine Creek Side Closure Concepts:

a. **Sediment Control Only (Not in the LCCA) (WC1 in Wood reports)** - Construct a sediment control structure downstream of the rock-lined channel in Wolverine Creek - no work on the tailings pile or the channel is required.

b. **Water Passage and Stability Improvement (LCCA Options B, C, D, D2 - note that Option B does not have a remediation measure for the tailings) (WC2 in Wood reports)** - Conduct sufficient work at the base of the tailings pile to minimize the tailings movement and provide a semi-stable surface to construct a water conveyance channel.

c. **Isolate the Asbestos (LCCA Options E, E2) (WC3 in Wood reports)** - Stabilize tailings pile to allow a cover to be placed or relocate the tailings pile.

3.2 Interpretations of Candidate Options

As part of the 10% design phase development activity, Wood has considered these candidate options in light of outcomes and findings of ongoing works, particularly those coming from the 2018 site investigation, and this has produced some evolution in the way these candidate options are interpreted and described. Wood's interpretations of the options were initially outlined in the draft Geotechnical Status Report (Wood 2019c) and subsequently discussed with the Project Partners and the IPRP (particularly during Workshops 2 (January 2019; Wood 2019e) and 3 (May 2019; Wood 2019i). The following summary interpretations of the candidate options reflect Wood's understanding of the consensus that emerged from these discussions (note that the following also reflect written CIRNAC comments received on the draft Geotechnical Status report). These interpretations end with Wood's summary understanding of where the Project Partners' intended the option to fall within the effort and risk ranges defined by the specified candidate options. In these descriptions, the term effort refers to the work required to affect the closure option, and risk refers to those risks remaining in, or for the post closure landscape following execution.

3.2.1 Clinton Creek 1 (CC1) - Retention of Hudgeon Lake

This option involves maintaining the current level of Hudgeon Lake and assumes that any variations in the vertical alignment of the spillway are constrained by the configuration of the embayment connecting the lake and the head of the spillway.

This was originally posited as a low effort bookend concept for Clinton Creek that roughly mimics the status quo. However, efforts since have demonstrated that various extraordinary works will likely be required to make this alternative viable over the long term (see Wood (2019d) and Section 5.1). Hence, this option can be viewed as a high effort/moderate risk concept for Clinton Creek (largely because of development and maintenance liabilities associated with the spillway, this is not viewed as a secure, low maintenance closure option).

3.2.2 Clinton Creek 2 (CC2) - Lower Hudgeon Lake with Regime Channel

This option involves:

- providing the specified reduction in lake level via a “regime channel” which mimics natural stream flow patterns and evolutions, thereby providing for a more sustainable, long term conveyance of creek flows;
- development of a flow channel that avoids the steeper and more challenging vertical alignment of the CC1 spillway; and
- lowering the lake to a level that reduces the technical and regulatory challenges of impounding water in the post closure landscape.

CC2 can be viewed as a moderate effort/low to moderate risk concept for Clinton Creek. This option could require some degree of maintenance, especially after a significant seismic event, or a major runoff event in a closure landscape.

3.2.3 Clinton Creek 3 (CC3) - Removal of Hudgeon Lake

This option involves lowering the lake to levels that would avoid any categorization of the remaining waste dump materials as a dam. A channel would be developed in the reconstructed Clinton Creek valley to provide for the sustainable conveyance of creek flows.

CC3 can be viewed as a high effort/low risk bookend for the Clinton Creek valley.

3.2.4 Wolverine Creek 1 (WC1) - No Tailings Disturbance; Sediment Control Only

This option involves, for the most part, retention of the status quo in the Wolverine Creek valley, specifically:

- no modification or disturbance of the tailings surfaces;
- natural processes are left to erode and destabilize the tailings in the post closure landscape; and
- a sediment control structure is constructed downstream of the current rock lined structure in Wolverine Creek to reduce sediment and asbestos releases.

WC1 can be viewed as a low effort/high risk bookend for closure on Wolverine Creek.

3.2.5 Wolverine Creek 2 (WC2) - In-Place Tails Stabilization and Surface Water Conveyance

This option involves stabilizing the tails in place, largely via the development of an in-valley buttress at the base of the pile. Any modifications to the tailings surface would be limited to local slope modifications (i.e., limited net 'out-of-valley' tails movements). The likely scale of the in-valley buttress will be such that a down valley shell structure (dam shell) will be required to safely retain the higher elevation lake, and control static and dynamic loadings to the south, down the Wolverine Creek valley. The dam shell will require internal erosion control and it is possible that a permanent spillway will also be necessary.

WC2 can be viewed as a high effort/moderate risk concept for the Wolverine Creek valley.

3.2.6 Wolverine Creek 3 (WC3) - Isolate Tailings

The in-place stabilization variant of WC3 originally envisaged:

- reducing the tailings slope, covering them and providing for conveyance of creek flows (e.g., via the 3.75H:1V cut/fill slope (with the slope toe defined along the centre-line of Wolverine Creek) contemplated in WorleyParsons (2014) LCCA Option E. The LCCA Option E did not consider liquefaction of tailings. Subsequently Wood in the Status of Geotechnical Studies Report (Wood 2019c) supplemented this variant with a drain-field to control pore pressures in the liquefiable tailings); or
- supporting the upper tailings with a mid slope shear key, relocating the lower tailings to the Porcupine Pit Storage Structure and re-establishing a flow channel in the creek valley.

The first of these approaches would be technically viable only if the tailings are not liquefiable or drained to less than 85% saturation. As the current data indicates the tailings are liquefiable and drainage is considered impractical, this option was removed from final consideration. Further, Wood has rejected the mid slope shear key concept because it introduces execution risks (i.e., upslope liquefaction failures) that would be challenging to mitigate. Developing a closure plan around this concept would generate uncertainties, costs and risks that are unlikely to be tolerable. These considerations led to a conclusion that the WC3 variant that involves relocation of the tails to the Porcupine Pit Storage Structure is the only viable isolation option meeting the intent of this closure option.

This tailings relocation is a conceptually straightforward approach and there is no variation between Wood's interpretation of the alternative and its description in AAM's scope, except that Wood has identified a disposition location that would apply to it (i.e., the Porcupine Pit Spoil Structure (PPSS)). Some tailings could be disposed of west of the valley in the geothermally disturbed plant site area.

WC3 as presented herein can be viewed as the high effort/low risk bookend for closure on Wolverine Creek.

4.0 Closure Option Designs – Common Hydrotechnical Elements

4.1 Hudgeon Lake Drawdowns

For all three Clinton Creek options, Hudgeon Lake must be drawn down to a level that permits safe construction and/or meets the design intent of an option. For each of the three options, a different drawdown level will be required depending on seepage analyses undertaken during detailed design. For the 10% design level, Wood has assumed the following:

- CC1 – Drawdown 10 m to El: 402 m (10 m below the spillway inlet level; note that this level reduction differs from those for the other Clinton options in that it is a temporary requirement to support construction of the permanent spillway; it is not an element of the final closure concept).
- CC2 – Drawdown 22 m to El: 390 m (10 m below the new lake outlet level of 400 m; again, this incremental 10 m drawdown is a temporary requirement to support construction of the channel); and
- CC3 – Complete removal of the lake.

The concept for the drawdown of Hudgeon Lake considers a yearly decrease of the lake levels starting after the freshet every year. Each year, after the target depth is reached, the existing drop structure would be partially breached to the target level, and a temporary channel will be built to route the freshet flows for the following year. Once the spring freshet has passed, the drawdown would resume until the next target depth is reached; this pattern would be repeated until the desired drawdown depth is reached. This approach aims to avoid instabilities in the submerged slopes due to a rapid drawdown and to address the extra flows from the freshet.

The design of the drawdown system depends on geotechnical requirements for the stability of surrounding slopes facing the lake, the storage elevation curve for the lake and the balance between the inflows (precipitation) and outflows from the system. The following sections describe the drawdown requirements, the water balance and the removal options considered.

4.1.1 Geotechnical Stability

The geotechnical Design Basis Memorandum (DBM) included a prediction of drawdown rates for the waste dump (Appendix C of Appendix A in Wood 2019d). The results indicated that the predicted drawdowns and hydraulic heads vary significantly with the assumed permeability of the materials in the waste dump and the basal drain (the thawed, potential high permeability alluvium and/or bedrock beneath). In other words, the time to be required for dewatering the waste dump highly depends on the permeability of the materials in the units.

The lake drawdown rate will need to be integrated with the project execution schedule in ways that provide for economically viable materials management plans. Optimizing this integration will require the more definitive understanding of dump permeabilities that will come out of the post 10% phase data gaps mitigation efforts outlined in Section 7. Any disconnects in the drawdown rates ultimately found necessary to address both geotechnical constraints and execution schedule viability could be mitigated via dump groundwater pumping, drawdowns scheduled well in advance of the execution of the civil works or some combination thereof. For the purposes of this 10% design phase, it has been assumed that these mitigations will not be necessary (except as noted in Section 5.3.1.4.2 for CC3), and that annual drawdowns in the range of 5 m could be accommodated geotechnically. Further, the 10% design phase materials management plans have been developed incorporating this annual drawdown assumption.

4.1.2 Water Balance Hydrology

One of the design criteria for the drawdown system is that the drawdown method selected must have a capacity greater than the inflows into the lake. As the lake level decreases the volume of water to be pumped to lower the lake a given amount also decreases due to the lake bathymetry. This relationship is based on a storage elevation curve for the lake (Figure 4-1) provided by YG.

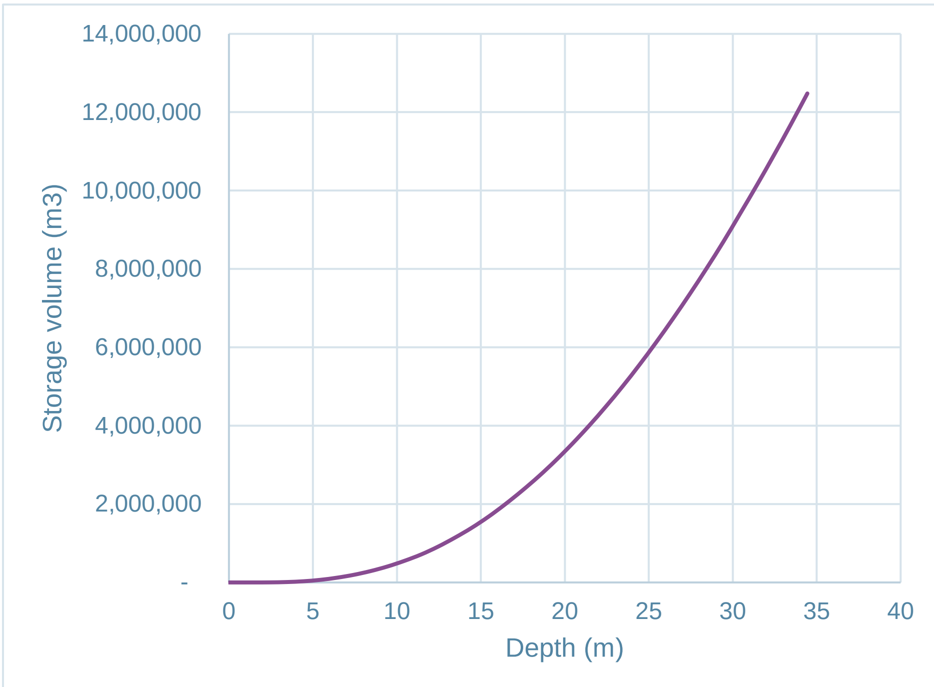


Figure 4-1: Storage Elevation Curve for Hudgeon Lake

4.1.2.1 Precipitation

Precipitation during the drawdown period should be considered as part of the input volumes into the reservoir; these volumes are based on the daily records from 1968 to 1972 from the Clinton Creek weather station managed by Environment Canada (Figure 4-2).

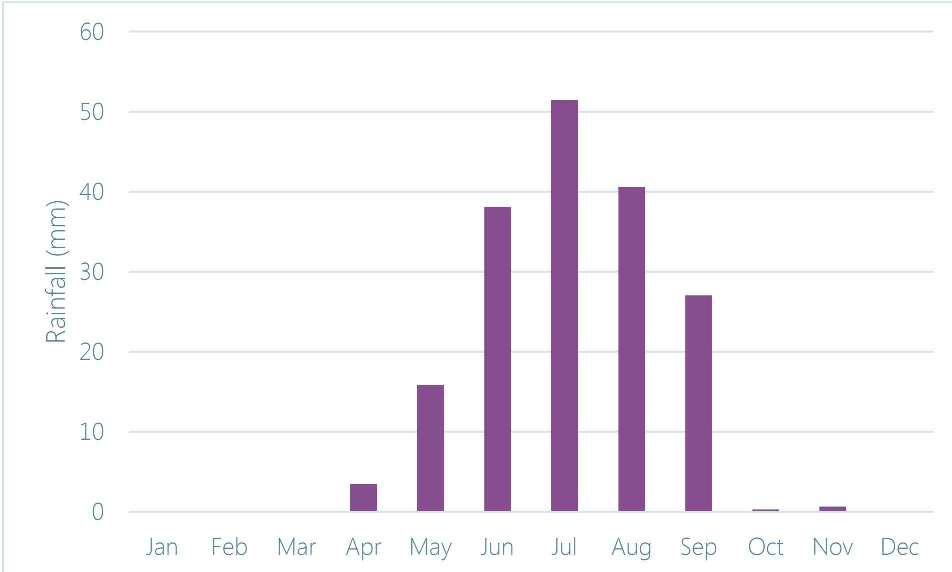


Figure 4-2: Monthly average precipitation. Clinton Creek 1968-1972

Additionally, the summer storms could potentially stretch the pumping capacity and affect the yearly drawdown targets. A 1 in 2-year and 1 in 5-year storm have been considered to represent the additional volume. These storms are based on the Intensity Duration Curve for the Dawson Airport precipitation records.

4.1.2.2 Runoff Coefficient and Catchment Area

For water balance analyses, a conservative catchment runoff coefficient 70% was selected. The catchment area is 115 km^2.

4.1.3 Options for the Drawdown of Hudgeon Lake

To avoid instabilities in the submerged slopes during the drawdown, a maximum drawdown depth per year of 5 m is planned. Taken over a period of up to 30 days, the average daily drawdown would be 0.16 m. Three different Options for lake water discharge were considered during the 10% design phase. These were:

- Gravity Drain;
- Siphon; and
- Pump Discharge.

4.1.3.1 Option 1 - Gravity Drain

The gravity drain option involves lowering the Lake water level using a 1.2 m diameter steel pipe at a predetermined invert that varies by closure option. The following system components would be required:

- intake screen complete with floating decant chamber or alternatively three different floating bell shape intake pipes with debris control (utilizing floating barriers);
- flow control provisions utilizing weir gates in the floating decant chamber;
- a 1.2 m diameter steel pipe to convey lake water to the downstream of fourth gabion structure on the creek; and

- a throttling valve at the discharge location to control discharge rates from the Lake.

The pipe would be tunneled through the soil deposits and require a wall thickness suitable for deep burial. A coffer dam structure would be required to facilitate the gravity drain pipe's installation into the Lake.

A major advantage of a gravity system is that, once installed, the system doesn't rely on diesel or electrical power to operate. Some of the challenges for a gravity system include:

- deep pipe installations would require some specialized tunneling machinery with the attendant risks, complexity and cost;
- the reliance on a gravity system reduces the opportunity for full control on the discharge rates; and
- in case of any blockages costly and time-consuming maintenance may be required.

Given the challenges associated with installing a tunneled or bored gravity drain pipe, this option was considered an unlikely drawdown alternative.

4.1.3.2 Option 2 - Siphon

The siphon Option involves a multiphase construction due to maximum siphon lift limitations. Following is the list of construction steps involved for this option.

- Two 800 mm diameter HDPE siphons would be installed at the lateral slopes of the existing channel. Different sized siphons could also be used to more effectively control discharge rates. The configuration of the siphon system setup would involve installing both siphons with top of crest passing over drop structure 1 at approximate elevation 411 m. The estimated average discharge rate would be approximately 5 m^3/s (for two 800 mm siphons).
- Existing drop structure 1 would be lowered and a new 1.5 m diameter culvert would be installed at inlet elevation of 407 m to maintain the lake water level at this lowered elevation. The new culvert would discharge into a convenient location on the current drop structures. It is estimated that the 1.5 m diameter culvert would be installed at 3 percent grade which would facilitate the discharge of approximately 8 m^3/s (assuming full flow). The culvert would prevent the water level from rising above the drawdown level previously achieved.
- The existing siphons would be lowered, and the water level drawn down another increment.
- The existing and siphons would be lowered again to the new position and the cycle repeated until the designed drawdown level is achieved.

The advantages of a siphon are:

- the system does not require burial, tunneling or boring through the waste dump;
- no coffer dam would be required for construction;
- the system requires only temporary power to prime the siphons;
- drawdown is possible for all options using a similar staged approach.

Disadvantages of siphons include:

- total head on the siphon is limited which requires a staged approach to drawdowns;
- siphons need to be primed each time the flow is interrupted;

- flow regulation is more difficult; though a system with different sized pipes can overcome this difficulty;
- multi phase construction will further complicate the implementation of this option; and
- the drop structures downstream of DS1 would be subject to substantial flows that would likely necessitate additional structure upgrades and/or maintenance.

4.1.3.3 Option 3 - Pump

This option involves installation of three parallel pumps and valve systems for the lake water discharge. Conceptually, the system would include:

- three floating diesel motor driven pumps;
- fuel storage and delivery equipment;
- a floating access bridge for maintenance and monitoring; and
- three HDPE 600 mm discharge pipes and valves to convey water from the lake to the last drop structure on the Clinton Creek.

Similar to the siphon option, the overall operation will be completed in stages to reduce the head the pump must overcome and to align with allowable drawdown rates. The concept is illustrated on Drawing number VE52705E.DRAWDOWNS.1.

The pump would be designed with a 42-inch impeller and pre-installed to fit in a 20 ft metal container. A 500 HP diesel engine would drive the pump and each of the three pump systems would incorporate flexible coupling and hoses to allow for axial and vertical movement. For each phase of pumping, there would be provisions for level drops and extensions of discharge piping utilizing heavy duty rubber hose. Pump system flotation would be provided via a fibreglass tank filled with low density polyurethane foam.

The pump option would provide a relatively high degree of control on lake drawdown rates but would require comparatively complex infrastructure and support.

4.1.4 Drawdown Method Summary

Each option to drawdown Hudgeon Lake requires substantial effort and some may not be effective and/or feasible for all of the candidate options. The purpose of this study was to undertake a conceptual level design to ensure that the end result can be achieved. The specific method for drawing down Hudgeon Lake will be the subject of additional assessment and optimization following concept selection and subsequent design development activity. Wood has selected pumping as the preferred drawdown option for the purposes of this 10% design phase because it offers flexibility in controlling drawdown rates and therefore relative certainty in outcomes.

4.1.4.1 Selection of Pump Capacity

Selection of pump capacity is driven by:

- the allowable drawdown rates considering geotechnical stability of the dump slopes;
- the water balance, considering monthly average precipitation and storm events; and
- balances between pump size, efficiency and cost.

For the 10% design, it was assumed that:

- the lake would be lowered by 5 m each construction season;

- the drawdown would be achievable in a 1-month period after freshet (June); and
- spare capacity is required to maintain the drawdown after rainfall and summer storms.

As the lake level lowers, the volume of water required to be pumped reduces for a given 5 m interval. In Year 1, a total volume of 3,8 Mm^3 must be pumped to lower the lake by 5 m. Therefore, in Year 1, over a 30-day period, an average 1.46 m^3/s must be pumped with zero inflows to the lake. Environment Canada data show an average June precipitation of 38.1 mm in Dawson (see also Section 4.1.3). Assuming a conservative runoff coefficient of 70% and a catchment area of 115 km^2, the potential additional volume to be pumped in June is approximately 3.1 Mm^3. The resultant pump rate to lower the lake by 5 m in June therefore must be at least 2.7 m^3/s if the pumps run 24 hrs/day over 30 days. Taking into consideration summer storms, pump downtime and other uncertainties, a system was selected that has a pumping rate of 3.6 m^3/s to a head of up to 8 m with an efficiency of 70% (see Figure 4-3 (from ETec (2019)).

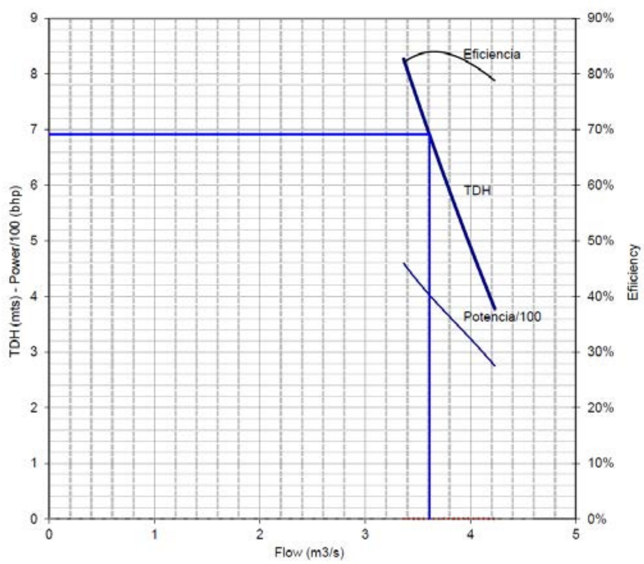


Figure 4-3: Operation Curve for a 42" Pumping Equipment Considered for the Drawdown Assessment

4.1.4.2 Results

Table 4-1 presents the phasing defined for Hudgeon Lake assuming a 5 m drawdown each year and a pumping capacity of 3.6 m^3/s with an efficiency of 70%. The first three years are expected to require around 20 days to reach the targeted depth, and in the final 3 years, the pumping duration will decline to about 10 days. Additional time has been considered to address the direct precipitation and runoff inputs into the lake during the drawdown period. Table 4-2 presents the input volumes of water estimated for the complete month of May, and what will be expected if the lake receives an extreme storm during the drawdown. The minimum days to reach the target depth demonstrates that the drawdown could be achieved with the pumping capacity available; subject always to the geotechnical constraints on drawdown rates.

This analysis concludes that the temporary drawdown for CC1 construction would take approximately 2 years, CC 2 drawdowns (permanent and temporary for construction) in about 4 years and complete drawdown of the lake in about 6 years. These drawdowns, or portions thereof, could be completed in advance of the materials management execution schedule (i.e., the drawdown and earthmoving execution schedules can be de-linked, to at least some degree) if this provides for a more efficient execution strategy.

Table 4-1: Volumes of Water to Drawdown from the Hudgeon Lake (Considering No Precipitation)

	Initial Depth (m)	Target Depth (m)	Target Volume Extracted (m^3)	Initial Volume (m^3)	Volume Remaining (m^3)	Minimum Days Required to Reach Target Depth
Phase 1	34.446	29.446	3,782,330	12,478,899	8,696,569	20
Phase 2	29.446	24.446	3,142,203	8,696,569	5,554,366	20
Phase 3	24.446	19.446	2,446,268	5,554,366	3,108,098	20
Phase 4	19.446	14.446	1,716,661	3,108,098	1,391,437	10
Phase 5	14.446	9.446	983,296	1,391,437	408,141	10
Phase 6	9.446	4.446	377,907	408,141	30,234	10

Table 4-2: Volumes of Water Expected During the Drawdown Due to Precipitation

	Catchment Area (km^2)	Runoff Coefficient	Monthly Precip Assumed (mm)	Extreme Storm Rainfall (mm/day)	Volume Expected Per Month	Volume Expected Per Day	Total Volume	Extra Days of Pumping Expected Due to Precipitation
Monthly (May)								
Runoff	115	0.7	15.86		1,276,730			
Direct Precipitation	0.8	1	15.86		12,688		1,289,418	6
1 in 2 years								
Runoff	115	0.7		19		1,529,500		
Direct Precipitation	0.8	1		19		15,200		
							1,544,700	7
1 in 5 years								
Rainfall Runoff	115	0.7		23.5		1,891,750		
Direct Precipitation	0.8	1		23.5		18,800		
							1,910,550	9

4.1.5 Drawdown Impacts on Stream Water Quality

4.1.5.1 Metals

Existing background upstream and down stream, and Hudgeon Lake water quality data were reviewed and compared with the CCME's protection of Aquatic Life guideline criteria. Figure 4-4 shows the water quality sampling locations that are used for the ongoing site monitoring program. Data for three upstream (R1, R2 and R3) and four down stream (E1, E4, E7 and E8) sampling locations were compared with data for three Hudgeon Lake locations (HL1, HL2, and HL3).

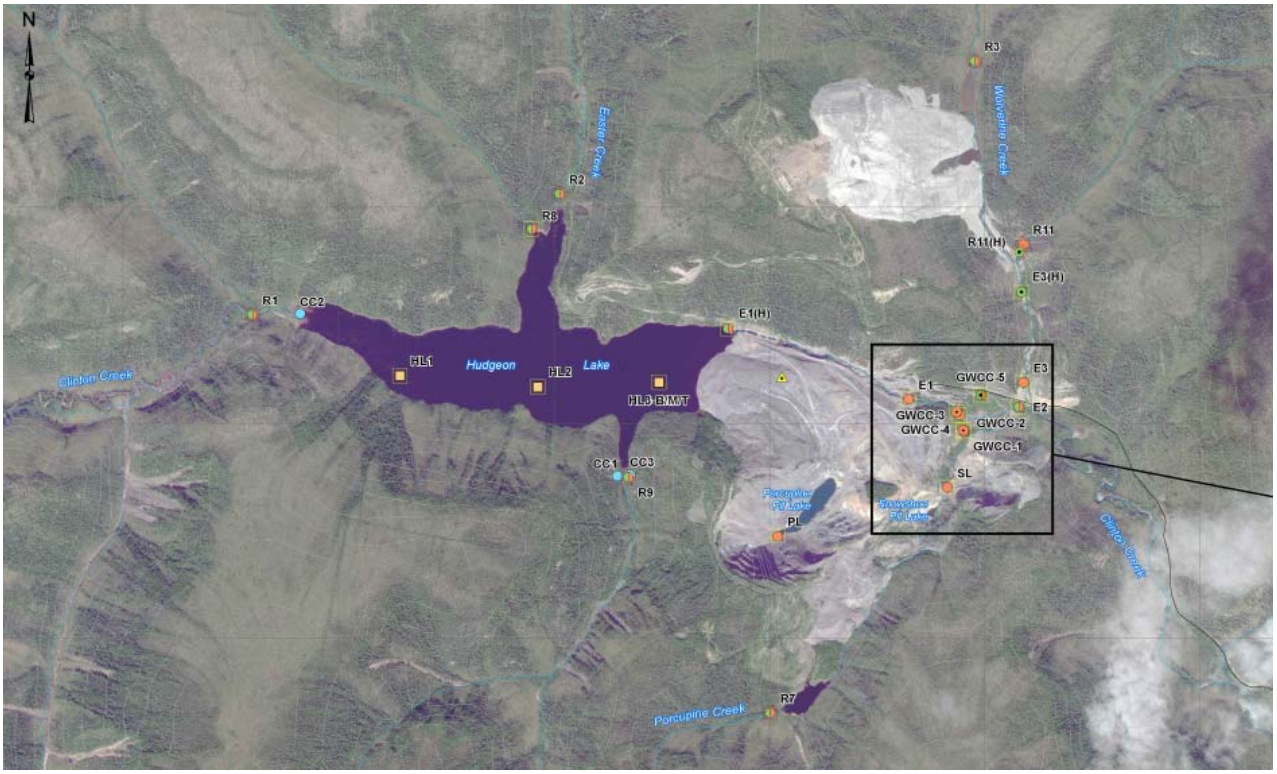
For the targeted sampling locations, it is apparent that arsenic and selenium are commonly exceeded parameters in the recent 2017/2018 period. Therefore, a further trend analysis was completed focusing on these parameters. A summary of this data analysis has been provided in Figure 4-5. The maximum total selenium concentration in the Hudgeon Lake is lower than that analyzed in the upstream water bodies but higher than that recorded for the downstream water bodies. However, for the dissolved selenium concentration, the Hudgeon Lake's level is slightly higher than that observed in the upstream and the downstream water bodies. For both total and dissolved selenium, the recorded concentrations are higher (except the upstream average concentration) than the CCME FAL guidelines.

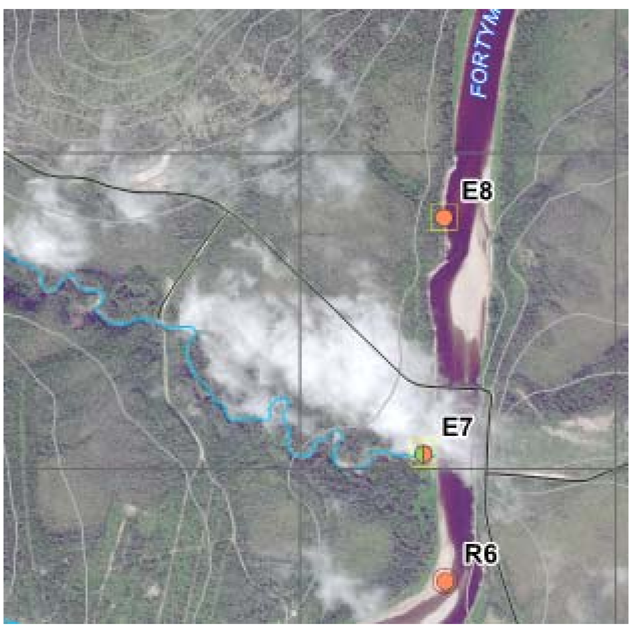
For total and dissolved arsenic, the average Hudgeon Lake's recorded concentrations levels are lower than the CCME FAL criteria but higher for the maximum recorded values. Both dissolved and total arsenic average and maximum levels are higher in the lake when compared with the upstream and the downstream recorded concentrations.

The exceedances for these analyzed parameters are not expected to be a major concern as long as the discharge rates are managed adequately. The downstream water bodies are already accustomed to elevated levels (relative to CCME FAL) of these parameters from Hudgeon Lake overflow and other nearby water bodies (e.g., the Porcupine Pit Lake). Ecological Logistics and Research (ELR 2014) Limited conducted some water quality analyses for both upstream and downstream of Hudgeon Lake and concluded that these parameters persist in all exposed sites above the CCME-FAL guideline levels that drain into Clinton Creek, downstream of the Hudgeon Lake. In addition, Hemmera (2016) described elevated parameter levels in various water bodies upstream and downstream of Hudgeon Lake. This supports the conclusion that the downstream water ecologies are accustomed to elevated levels of these parameters. In summary, the net impact of the Hudgeon Lake drawdowns contemplated for the Clinton Creek options on the downstream water bodies is not expected to represent a material deviation from the current condition. Accordingly, for the 10% design phase it has been assumed that there will be no treatment requirements and/or liabilities associated with these drawdowns. That said, it is acknowledged that available data relating to the stratification of Hudgeon Lake is limited and the need for additional data validating these 10% design assumptions should be reviewed as part of detailed drawdown planning.

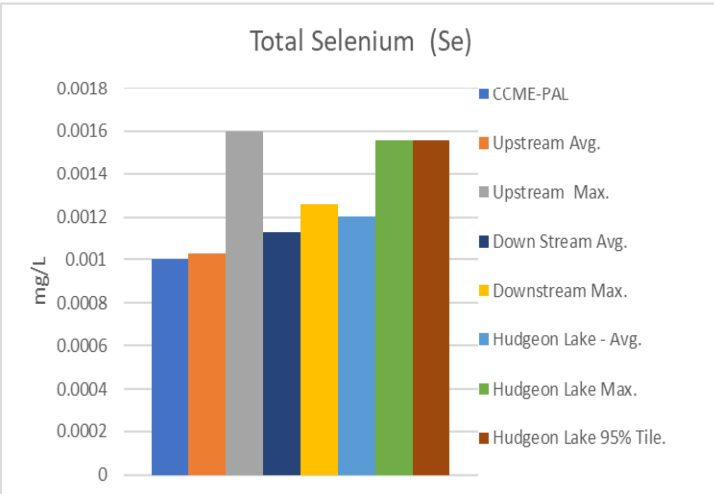
4.1.5.2 Sulphides and Oxygen

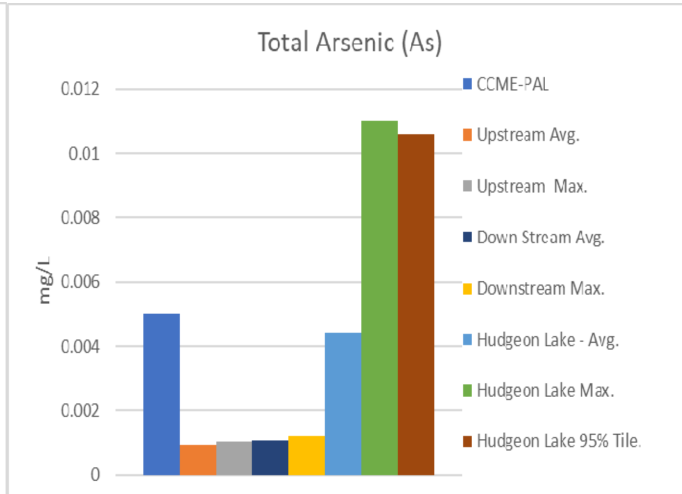
Hudgeon Lake is reported to be permanently anoxic (depleted of oxygen) in its bottom waters. Liebau (2010) describes anoxic conditions extending from the lake bed to within about 5 m of the surface. In anoxic conditions, the sulfates are reduced to sulfides. However previous reports have concluded that the sulfide levels in downstream areas are acceptably low and oxygen levels sufficiently high (DFO 2007). It is believed that some re-oxygenation is occurring immediately beyond the outlet of Hudgeon Lake to re-convert sulfides to off-gas. The four gabions drop structures likely contribute to the re-oxygenation of water leaving the Lake. It is possible that downstream oxygen levels will decline if removal of the drop structures precedes lake drawdowns. If a significant and sustained decline was observed during execution water quality monitoring, mitigation could likely be provided by adding temporary aeration (e.g., solar powered floating surface aerators) to the sediment ponds that will be an element of the execution plans for those Clinton options involving significant lake drawdowns (i.e., CC2 and 3). However, this is considered to be a possible execution contingency requirement, not a defined scope element for the 10% design concepts.

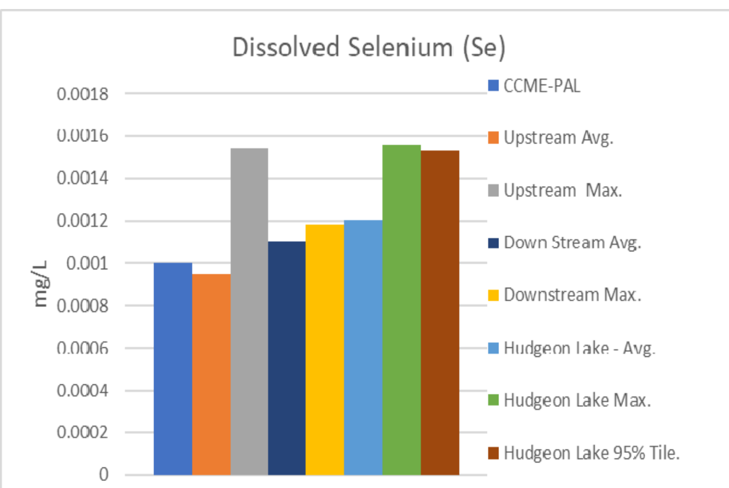


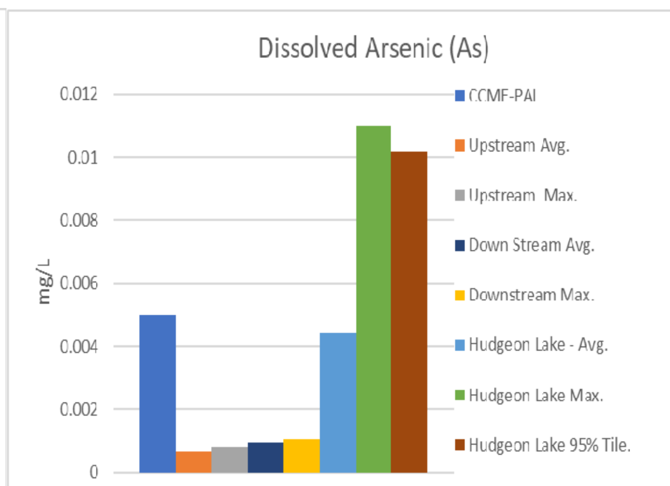


wood.	Clinton Creek Remediation Project			
Yukon Government Depart of Mines & Resources	Yukon	Surface Water Quality Sampling Locations (from EDI 2018)		
Drawn: RBG	Scale: NTS	Date: July 2019	Project No.: VE52705E.100.2	**Figure: 4-4**









wood.		**Clinton Creek Remediation Project**		
Yukon Government Depart of Mines & Resources	Yukon	**As and Se Levels, Hudgeon Lake and Downstream (from EDI 2018, Hemmera 2016)**		
Drawn: RBG	Scale: NTS	Date: July 2019	Project No.: VE52705E.100.2	**Figure: 4-5**

4.2 Disposition of Impounded Waters in the Wolverine Creek Valley

Options WC2 (In Place Stabilization) and WC3 (Tailings Isolation) involve disruption and/or relocation of tailings that will require removal of some or all of the Wolverine Creek water that is currently impounded by the north and south tailings lobes (i.e., the North and South Wolverine Creek Ponds). Plans for the management and/or disposition of this water will be influenced by the following factors:

- as described in Wood (2019l), there is no water quality data available for these water impoundments; however, the Wolverine and Clinton Creek water quality data suggest that downstream ecological impacts are limited and low;
- given the nature of the tailings, it is likely that these impounded waters exhibit metal and/or asbestos levels for at least some parameters (e.g., chromium and nickel) that exceed surface water aquatic life criteria;
- regardless of the quality of these impounded waters, execution plans for WC2 and 3 will require sediment control plans/structures that will likely be similar in form and performance to the sediment pond that is the central design element of WC1 (sediment control only) (see Section 6.1.1 and Drawings VE52705.E.WC1.1 to 3); and
- disposition of the Wolverine Creek waters would likely occur largely coincident with the Hudgeon Lake level reductions that are a feature of all of the Clinton Creek options, and it will therefore be possible to integrate schedules for the management of the Clinton and Wolverine Creek water inventories in ways that are beneficial.

Given these factors, it has been assumed for this 10% design phase that the disposition of the Wolverine Creek impoundments will not generate treatment and/or storage liabilities beyond those that can be addressed or provided for by those scope elements that are otherwise planned for the Clinton and/or Wolverine Creek options. This assumption derives from the following observations/issues:

- the lack of downstream ecological impacts of significance mitigates against potentials for encountering parameter excursions in the impounded waters capable of generating acute impacts during release;
- the pond that will be constructed in any case to control sediment discharges as part of execution plans for Wolverine Creek will provide at least some mitigation of elevated metal levels (via settling of the undissolved component), and a storage capacity that will allow for a degree of control over the scale and timing of impounded water releases;
- the timing of pond releases could be integrated with Hudgeon Lake drawdowns in ways that attenuate water quality excursions and the associated potentials for downstream impacts;
- any parameter excursions during releases will be limited temporally, which also reduces the potential for lasting downstream impacts of significance; and
- pond storage provides opportunities for the application of treatments (e.g., aeration, flocculation) if short term water quality excursions are more significant than anticipated.

5.0 Closure Option Designs – Clinton Creek

This section describes the 10% design development activity and outcomes for each of the candidate options for the Clinton Creek valley. The discussion addresses the following items or issues for each alternative:

- Scope Elements: a presentation (including drawings) of the key components required to address the closure scope associated with an option.
- Materials Management Concept: this discussion reflects the importance of earth movements for most of the options and provides an outline by option of how these movements will be executed.
- Anticipated Performance Outcomes: a discussion of Wood's judgements regarding the post closure outcomes that the options will deliver, with references to the Project Partners' anticipated outcomes when the options were selected.
- Constructability/Execution Issues: an outline of key constructability/execution issues that are particular features of an option (i.e., intended to highlight differentiating execution challenges; not as an exhaustive schedule of more routine execution requirements).
- Key Risks and Uncertainties: a discussion of the key risks and uncertainties that apply to the design concept at this 10% design stage (i.e., prior to execution), and for the closure landscape following execution of an option (i.e., the long-term liabilities that must be retained by the Project Partners).
- Associated Closure Criteria: description of the closure and reclamation criteria that have been assumed for the 10% design described, or are defined by the fundamental characteristics of the option. This section refers broadly to the general Project Partner objectives established for CCRP (Table 5-1) and also describes more specific criteria that, in Wood's view, will be associated with an option.

5.1 Clinton Creek 1 (CC1) – Retention of Lake

This option involves conducting sufficient work on the waste dump to mitigate the potential for catastrophic failure and to construct a spillway to provide water passage from Hudgeon Lake. Under this option, the level of Hudgeon Lake will remain similar to the existing level (approximately 411.5 m) and a new spillway will be constructed with an alignment moved slightly to the south.

5.1.1 Scope Elements

The closure scope for this option will involve construction of a spillway channel and drop structures, modifying the slopes and configuration of the waste dump to accommodate the channel and to ensure its stability, and completing the subgrade improvements needed to limit long term dump movements to levels compatible with the long-term sustenance of the spillway.

5.1.1.1 Spillway

5.1.1.1.1 Design

5.1.1.1.1.1Dam Breach Assessment

A dam breach assessment (DBA) was undertaken in support of this 10% design phase. The assessment was undertaken in advance of the 10% design to enable the design criteria to be established for the spillway. A report documenting the methodology and results assessment is provided under separate cover (Wood 2019k).

Table 5-1: Clinton Creek Remediation Project Objectives

1.	Protect human health and safety	• Reduce or eliminate risks to worker health and safety. • Prevent, minimize or mitigate any adverse effects on the health and safety of people accessing the site. • Animals, plants and berries around the mine site are safe for humans to harvest.
2.	Protect the environment, including land, air, water, fish, and wildlife	• Prevent, minimize or mitigate adverse effects on the aquatic environment including fish and fish habitat. • Prevent, minimize or mitigate adverse effects on the terrestrial environment. • Protect, and to the extent possible, restore aquatic and terrestrial habitats using methods conductive to natural regeneration.
3.	Return and/or retain the site to a state that supports community and traditional land uses	• Maximize access for public use. • Reclaim disturbed areas to support community and traditional land use. • Water flowing from the mine site will be safe for recreational use.
4.	Maximize local, First Nation and Yukon socio-economic benefits from the Clinton Creek Project	• Maximize project-related benefits through training, employment and business opportunities for Tr'ondëk Hwëch'in citizens. • Maximize project-related benefits through training, employment and business opportunities for local residents and Yukoners, in a manner that is consistent with the Devolution Transfer Agreement. • Maximize opportunities for capacity building for locals, Tr'ondëk Hwëch'in and Yukoners.
5.	Minimize project related liability, risk and costs	• Minimize implementation and post-closure risks associated with the project. • Minimize post-closure residual liabilities. • Minimize project implementation costs. • Minimize post-closure operations and maintenance costs.

Notes:
Restore - it is understood that the 'measure' as to whether the environment is restored is not necessarily to pre-mining conditions, but rather will be to a stable, improved or self-sustaining state.

For Clinton Creek, the assessment considered the consequences of failure of the drop structures through headcutting erosion. Due to uncertainties in estimating breach parameters, a sensitivity analysis was undertaken for breach elevation (maximum depth), width and time of formation. In summary, the DBA found that:

- the severity of flood resulting from a breach of the drop structures depends more on the breach formation time than the width or depth of breach;
- the resultant flood hydrograph is attenuated from approximately 1,131 m^3/s immediately downstream of the dam to 560 m^3/s at the Yukon River;
- water levels rise in the incised reaches immediately downstream of the mine by up to 5 m; the impact in Forty Mile River is an incremental rise in water levels of approximately 1.4 m, which is still well within bank levels; and
- it is not expected that the resultant flood hydrograph will significantly affect infrastructure downstream of the mine including the old Clinton Creek townsite, the road crossing of Forty Mile River or any infrastructure along the Yukon River.

The rise in floodwater and anticipated downstream damage are such that it was concluded the previously assumed classification (Tetra Tech EBA 2016) for the dam under CDA guidelines as "Significant" remains valid.

5.1.1.1.1.2Design Criteria

The spillway design takes into consideration the requirements for dam safety in the Canadian Dam Association (CDA) Guidelines. For mining dams that cannot be decommissioned and have to be maintained as a functional dam for a very long time, the CDA Technical Bulletin: Application of Dam Safety Guidelines to Mining Dams applies (CDA 2014). For Closure – Passive Care Phase, there may not be regular monitoring or an opportunity to effectively respond to warning signs or emergencies. The bulletin therefore recommends taking into consideration an extended design interval when developing design criteria for dam safety. The recommended design flood for a Significant classification dam is 1/3 between the 1/1000 event and the PMF (Probable Maximum Flood). The estimated discharge for this event is 363 m^3/s (Amec Foster Wheeler 2017).

Other criteria considered in the design were:

- erosion protection on side slopes of the dam;
- accuracy of flood estimates based on short periods of record in relation to the design events;
- effects of climate change on extreme events and natural changes to conditions of the site;
- changes that could affect seepage within the dam; and
- potential for future changes to land use at and downstream of the site.

5.1.1.1.2 Components

The spillway will consist of a broad rock lined channel with 12 drop structures, each with a vertical drop of approximately 3 m spaced generally 60 m apart with the drops constructed from vertical sheet piles. Each drop structure will have a plunge pool to prevent scour and to dissipate energy, designed following guidance in (Smith 1995). With some additional design considerations during construction (e.g., incorporating a v-notch in one of the drops), vertical sheet pile drops will be suitable for accurate flow monitoring. The spillway channel features a trapezoidal low flow channel 5.0 m wide and 0.6 m deep with a broad flood channel to convey flood flows up to the IDF (Inflow Design Flood) (363 m^3/s).

The low flow channel will be lined with Coletanche ES3 bituminous geomembrane to keep low flows from infiltrating into the spillway foundation and to reduce drainage requirements from behind each sheet pile drop. Since the broader flood conveyance section will only occasionally carry flows, the rock armouring in this section will overlay a non-woven geotextile.

The spillway will discharge to the natural channel upstream of the confluence with Wolverine Creek.

A rock armoured dyke will be constructed on the both banks on the upstream end of the spillway to protect the structure from outflanking in the event of a seiche flood caused by a landslide into Hudgeon Lake. Potential seiche heights will require additional assessment during detailed design development. For the purposes of this 10% design phase and estimate, it was assumed the seiche dyke will be 5 m high.

5.1.1.1.3 Alignment Profile and Details

The proposed spillway is shown on Drawings VE52705E.CC1.1 and to VE52705E.CC1.4. Key features and components of the spillway are as follows:

- the west (lake) end inlet elevation is 412 m, which will increase the current lake elevation by approximately 0.4 m;
- the conveyance channel has a constant slope of 0.5%, in between vertical drops of 3 m;
- the spillway alignment is offset from the north slope by cutting south into the waste dump to mitigate potential impacts on the stability of the north slope and to allow for any rebuilding/buttressing of that slope that may be required;
- the base flow channel has been designed to pass up to 5 m^3/s; and
- the entire flow channel has been designed to pass the IDF year storm per CDA guidelines.

5.1.1.2 Waste Dump Modifications

The Geotechnical Studies Summary Report (Wood 2019d) describes the development, conduct and outcomes of the stability assessments that were used to define the waste dump configuration and slopes required to accommodate CC1 (see Appendix G of Wood (2019d)). In summary, the key outcomes were as follows:

- final cut slopes of 6.0H:1V for the waste dump slopes facing Hudgeon Lake; and
- final cut slopes of 6.5H:1V for the waste dump slopes facing Clinton Creek.

These slopes are governed by requirements to mitigate seismic liquefaction and are generally indicative of those likely required. Slopes may vary somewhat, or may be supplemented by additional measures (e.g., water table controls), as post 10% design development is undertaken. These waste dump cut slopes are reflected in the CC1 alignments, profiles and details presented in Drawings VE52705E.CC1.1 through 4.

5.1.1.3 Subgrade Improvements

The ice rich colluvium that has been identified in the waste dump subgrade would, if left un-remediated, produce large and unpredictable dump movements that would undermine the long tern physical integrity of any spillway constructed over the dump. Thawing and densifying the ice rich materials under the spillway is therefore a pre-requisite for the development of the spillway contemplated for CC1.

5.1.1.3.1 Extent of Ice Rich Colluvium

The data on the extent of the ice rich colluvium is limited, and this data gap has been identified as one of the key issues for the post 10% design development effort (see Section 7.1.2.2). For the purposes of this phase, judgments have been made about the boundaries of the ice rich area that could underlie the proposed CC1 spillway alignment and configuration. The limits of the area assumed cover some 6 ha (an area of roughly 200 m by 300 m) and are shown on Figure 5-1. Further, it has been assumed that this area of high ice content permafrost starts at elevation 387 and extends for an average depth of 4 m below that elevation.

5.1.1.3.2 Ground Thawing

A geothermal analysis was undertaken to determine the amount of energy required for thawing ice rich relict permafrost under the CC1 spillway alignment. These results were input to the identification of appropriate heat application processes and hardware (see following section). The geothermal analysis is fully described in Appendix A; the following sections summarize key outputs.

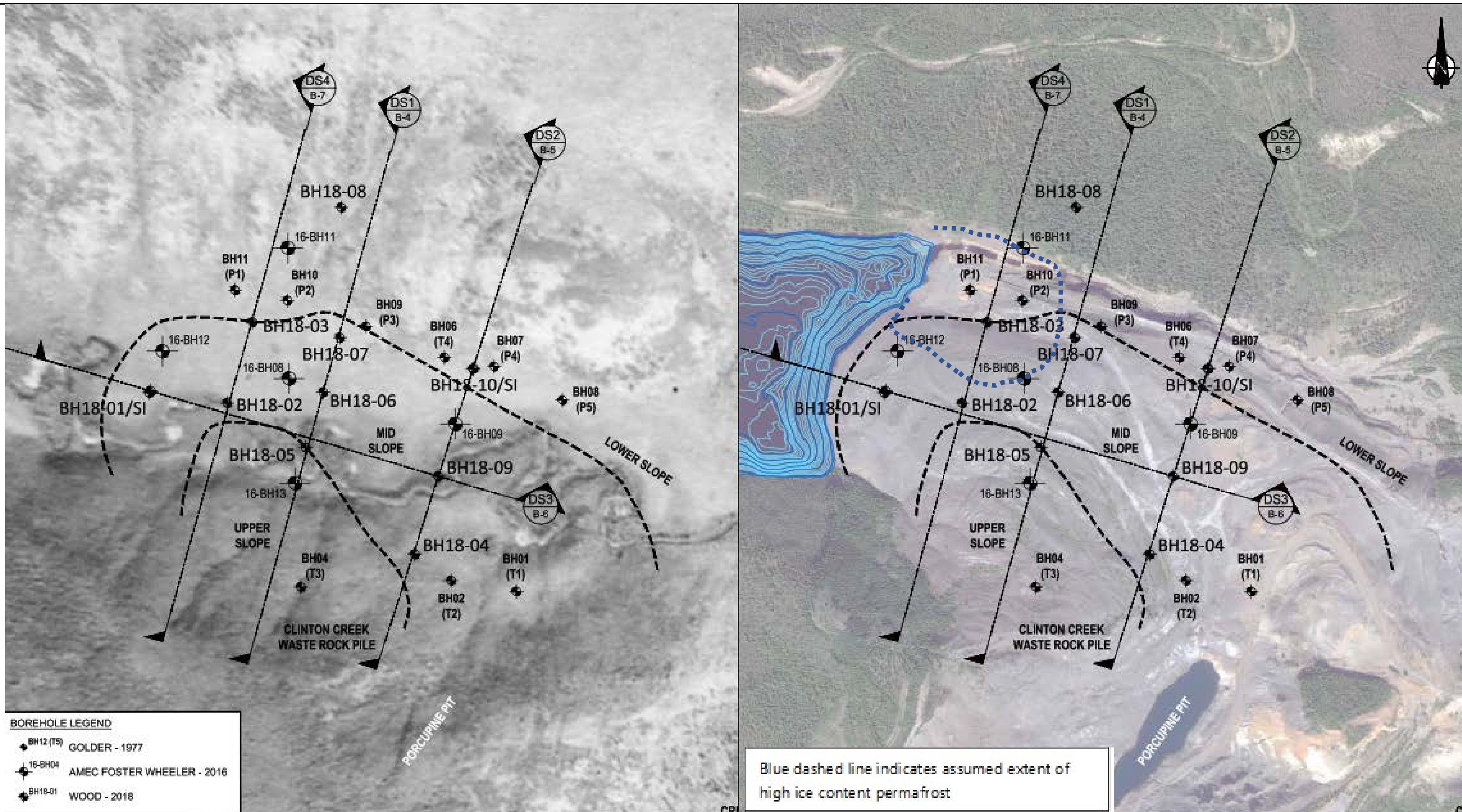
A two-dimensional version of SIMTEMP software (developed in-house by Wood) was used to analyze the temperature regime of the thawing permafrost under the spillway. The program uses the finite element method to compute a numerical solution for the heat transfer problem. Physical/mathematical algorithms used in the SIMTEMP model have been published and the simulation process has been verified against well-known analytical solutions and with numerical solutions produced by other commercial/ non-commercial geothermal modelling software.

The results of the modelling undertaken are shown in Table 5-2. The table identifies the amount of energy (MJ/m^3) required to thaw 1 m^3 of frozen soil and the energy (MJ/m^2) that will be lost warming up 1 m^2 unfrozen soil around the permafrost layer.

Table 5-2: Energy Amounts Required for Permafrost Thawing

Thawing Time, Month	Hole Grid, mxm/ftxft	Required Temperature of Heater, °C/°F	Energy, MJ/m^3 (BTU/ft^3)	Temperature Warming Beyond Permafrost Layer at, °C/°F	Loss Energy into Surrounding Unfrozen Soil, MJ/m^2 (BTU/ft^2)
24	6x6/19.68x19.68	74/165	297.549(7985.98)	1.05/1.89	2.902(77.887)
24	5x5/16.4x16.4	47/117	282.299(7576.68)	0.85/1.53	2.349(63.045)
24	4x4/13.12x13.12	27.5/82	270.664(7264.41)	0.64/1.15	1.769(47.478)
18	6x6/19.68x19.68	103.5/218	312.943(8399.14)	1.28/2.30	3.537(94.930)
18	5x5/16.4x16.4	65/149	293.361(7873.57)	1.00/1.80	2.763(74.157)
18	4x4/13.12x13.12	37.5/100	277.144(7438.32)	0.74/1.33	2.045(54.886)
12	6x6/19.68x19.68	171/340	346.593(9302.28)	1.66/2.99	4.587(123.111)
12	5x5/16.4x16.4	104.5/220	315.556(8469.27)	1.26/2.27	3.482(93.454)
12	4x4/13.12x13.12	59/138	291.463(7822.63)	0.92/1.66	2.542(68.225)

As expected, the amount of energy required to thaw frozen soil depends on the heater grid and time of thawing. Table 5-2 shows a maximum energy requirement for a 6x6 m heater grid over 12 months and a minimum requirement for a 4x4 m grid over 24 months. The table also shows that the loss of energy to warm up unfrozen soil around permafrost is insignificant. For instance, the maximum and minimum energies required for thawing 1 m^3 of frozen soil are approximately 346 and 270 MJ, respectively, while amount of energy for warming surrounding unfrozen soil is approximately 4.6 and 1.8 MJ.



wood.		Clinton Creek Remediation Project		
Yukon Government Depart of Mines & Resources	Yukon	Extent of High Ice Content Permafrost		
Drawn: KH	Scale: NTS	Date: August 2019	Project No.: VE52705E.100.2	**Figure: 5-1**

5.1.1.3.3 Heat Applications

The following options were considered for the delivery of the heat inputs needed to affect the required ground thawing:

- Hydronic OPEN loop method: HEATED WATER – lake water would be heated to accelerate the thawing process and protect lines from freezing;
- Hydronic CLOSED loop method: HEATED WATER – this would be a closed loop arrangement with a primary circuit comprised of 30% propylene glycol, and the secondary circuit, lake water; and
- Electrical Heating: This option employs finned radiant heaters.

An overview of the potential application of these alternatives to the Clinton property is provided in Appendix B.

For the purposes of this 10% design phase, it was assumed that the electric heating option would be applied to the thawing scope for the following reasons:

- the use of hydraulic technologies introduces uncertainties with respect to the associated influences on local piezometric regimes, seepage outcomes and thermal dynamics;
- electric systems are comparatively common in these applications and offer fewer uncertainties with respect to operating logistics and outcomes; and
- electric systems can be more readily and reliably adapted to winter operations.

The assumed electric heating system would be comprised of (see the schematic for Option 3 in Appendix B):

- a series of finned heater tubes arranged arealy and vertically to encompass the frozen zone;
- local (at the fin) and central control panels; and
- a local power source.

The power source would be the predominant cost element for this system. Power requirements would be in the range of 5 kw per fin assembly, which translates into a generating capacity requirement in the range of 8 MW for a 6 m x 6 m fin grid over 6 ha. This power could be delivered via a series of diesel generators or a mobile gas turbine generator.

The heating delivery assumptions applied for this design phase are early concepts that would require a dedicated validation study if a decision was taken to pursue CC1. This more detailed assessment would likely produce significant variations from the assumed concepts; however, the broader conclusion that delivering the required heat inputs will add significant complexity and cost to closure activity would likely still apply.

5.1.1.3.4 Ground Densification

Structural improvements to the spillway subgrade will be required to mitigate the impacts of post liquefaction settlements in the event of a design earthquake. The anticipated scale of settlement and the associated mitigations are detailed in the Liquefaction Assessment that is provided in Appendix C. The following excerpts summarize the assessment outcomes.

The proposed spillway structures for CC1 are subject to seismically induced settlements of about 1.2 m at the west end (Station 0+000 to 0+ 200) with settlements reducing to 0.5 m (Station 0+200 to 0+ 450) and 0.3 m (Station 0+450 to 0+ 600). Settlements east of Station 0+600 are expected to be 0.2 m or less and therefore will not require ground improvement.

Ground improvement will be comprised of stone columns installed in the following manner:

- A densified zone all around the sheet piles installed in a rectangular pattern and at a distance of about 2.5 m from the sheet piles. The width of the zone of stone columns around the sheet piles will be about 5 m with the columns extending from the ground surface to the top of bedrock;
- A densified zone immediately below the sheet piles between the outer densified area. This will be a 5 m wide zone extending from the bottom of the sheet pile to the top of bedrock; and
- A non-densified zone with loose stone immediately around the sheet pile and between the outer densified zone. This will be a 5 m wide zone extending from the bottom of the sheet pile to the ground surface.

Figure 5-2 shows a typical sketch of the stone column layout as described above.

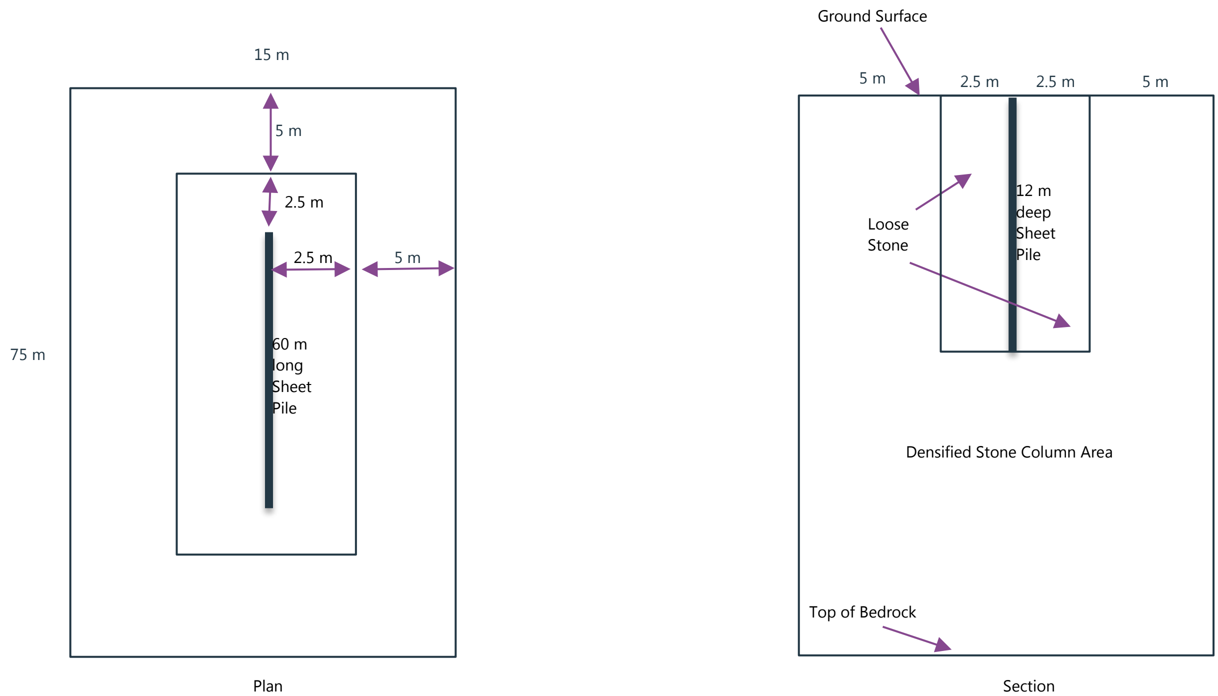


Figure 5-2: Stone Column Arrangement

Stone columns are not required in the spillway channel between sheet piles since the potential effects of seismically induced settlements here are not expected to cause major adverse effects on the functionality of the channel. The volume of treated ground has been estimated based on the depth to bedrock from the ground surface in the subject area, which ranges from about 40 m in the west portion of the spillway and gradually reduces to about 15 m in the east end. This translates into an estimated volume of ground improvement of 240,000 m^3, and that the works would require importing about 115,00 m^3 of select granular material (i.e., the substance of the stone columns).

The columns would be constructed as follows:

- columns would be installed with a crane equipped with a vibrator at the end. Stone would be introduced by a bucket or loader into an annulus that the vibrator pushes down and advances vertically;

- this would be done at select locations around and below the selected sheet piles;
- no excavation or cut and cover would be required, and no spoil excavation generated.

5.1.1.4 Lake Drawdowns

It has been assumed that CC1 will require a reduction in the current lake level of some 10 m (i.e., from el. 412 to 402) to facilitate construction of the permanent spillway. This level reduction differs from those for the other Clinton options in that it is a temporary requirement to support execution; it is not an element of the final closure concept. The drawdown assumed is a judgement applied for the purposes of this phase and reflects the need for a significant reduction in level to accommodate the substantial civil works and depths that will be associated with spillway construction. This level reduction is also intended to provide the reservoir storage needed to accommodate storm events during project execution.

5.1.1.4.1 Drawdown Methods

The pumping system described in Section 4.1.3.3 has been assumed to provide the drawdowns required for CC1.

5.1.1.4.2 Drawdown Rates

For this 10% design development effort Wood has assumed that over the course of two years piezometer levels would have declined sufficiently to maintain dump stability. This drawdown rate is consistent with the annual reductions of 5 m described and rationalized in Section 4.1.

5.1.2 Materials Management Concept

Although this concept essentially maintains the status-quo in terms of lake level, there are considerable earthworks required both to construct the spillway and to stabilise the slopes adjacent to it. CC1 involves the following key materials movements:

- removal of 4.4 Mm^3 of waste dump materials; these materials would be directed to the Porcupine Pit Spoil Structure (PPSS) or used to address any fill requirements for the selected Wolverine Creek closure option; and
- importing some 19,000 m^3 of riprap (D_{50}=500 mm) and 33,000 m^3 of riprap (D_{50}=300 mm).

The assumed materials management concept for these movements is as follows:

- a truck and shovel operation comprised of a fleet of two CAT 385 excavators and seven CAT 745 haul trucks and associated ancillary/support equipment;
- all waste dump materials excavated are assumed to be directed to the PPSS;
- the waste dump materials will be hauled to the PPSS via a two-way haul road constructed on the waste dump; and
- the waste dump materials would be moved in a continuous full season operation over a period of about 18 to 24 months, with the detailed execution schedule integrated with the lake drawdown plan.

5.1.3 Anticipated Performance Outcomes

The lake retention option (CC1) is described in Section 3.2 as representing a high effort/ moderate risk concept for Clinton Creek. Wood's design development outcomes validate this representation because the option features and/or provides for the following:

- a reduction in the risks associated with physical failures of the remaining waste dump;

- mitigating the impacts of dump movements via a ground thawing and densification effort and a spillway design capable of accommodating some movement;
- maintenance of the long-term physical integrity of valley slopes, both upstream and downstream of the dump, while reducing the probability of incurring a significant, ongoing liability; and
- unrestricted access to the Clinton Creek valley with few restrictions on the future utility of the lands.

The spillway design is much more robust than the current series of drop structures. The spillway has been designed to convey the IDF following CDA guidelines for mining dams in active care phase; but taking into account the limited site access and intervals between inspections. That said, it should be recognized that a spillway of the type described for CC1 does not represent a walkaway solution. By constructing the spillway, the owner will be responsible for inspection, maintenance and overall dam safety in perpetuity. In the opinion of Wood, the scheme does not permit Closure Passive Care under CDA guidelines. Depending on the materials used during construction, the spillway will also have a finite design life and, as such, would eventually require replacement, upgrading or large-scale repairs.

5.1.4 Constructability/Execution Issues

Execution issues and/or risks that will require particular consideration and mitigation for the lake retention option are as follows:

- Lake Drawdowns: monitoring of dump piezometric levels during lake drawdowns will be necessary to ensure dump stability is maintained while minimizing impacts on the broader execution schedule.
- Ground Thawing: injecting heat into the dump subsurface is a comparatively unusual scope element. There may be challenges in procuring and supporting the specialized expertise and equipment needed to execute this scope.
- Sediment Control: it has been assumed that sediment discharges during execution will be controlled using a downstream settling pond similar to that described for Option WC1 (Section 6.1.1.1). The limitations of controlling sediments with or without a pond will require additional, more quantitative assessment if a decision is taken to pursue CC1.

5.1.5 Key Risks and Uncertainties

5.1.5.1 Pre- Execution

Current assessments of the Lake Retention (CC1) option will potentially be influenced by the outcomes of the following post 10% design phase investigative outcomes (see Data Gaps discussion in Section 7):

- zonation of waste dump liquefaction potentials;
- delineation of ice rich permafrost;
- seismic induced settlement potential assessments; and
- supplementary waste dump hydrogeological characterizations.

The nature and number of design development data gaps that these investigative activities are intended to address suggest that the current assessments and conclusion’s relating to CC1 are highly sensitive (relative to the other candidate options) to the outcomes of future investigative activity.

5.1.5.2 Post Execution

The risks and/or uncertainties that would be particular to CC1 are as follows:

- the maintenance of the lake means that this option retains the breach consequences that could be associated with unexpectedly high seepage, piping and erosion;
- limitations in the definition of ice rich colluvium boundaries could result in degradation of the spillway and/or dump integrity over the long term (i.e., if impacted areas were overlooked);
- there remains some potential for failures on the north valley slope that could partially block the flow channel; and
- instabilities in the valley slopes upstream of the remaining waste dump could create seiches beyond the spillway's capacity, potentially resulting in an avulsion of the spillway channel out of the design channel with subsequent knock-on erosion and risk of a breach.

5.1.6 Associated Closure Criteria

Key closure criteria associated with CC1 are as follows:

- reduces the human safety risks generated by the waste inventory in the Clinton Creek valley by improving the physical integrity and stability of the waste dump;
- maintains the lake in a state that supports community uses;
- avoids the need for public access restrictions to the Clinton Creek valley;
- provides for the long-term passage of creek flows up to the IDF;
- retains in perpetuity the risks and liabilities associated with maintenance of a dam and spillway (i.e., option is not compatible with CDA Passive Closure Care status); and
- does not provide a prescribed specification for vegetative cover of the dump, but rather relies on those cover outcomes that develop spontaneously over the long term.

Additional assessment and comment on the relation of this option to the Project Partners' objectives is provided in Section 8.

5.2 Clinton Creek 2 (CC2) - Lower Hudgeon Lake with Regime Channel

This option involves lowering Hudgeon Lake by some 12 m (to elevation 400 m) and conveying flows via a regime channel that mimics natural stream flows and patterns of aggregation and degradation.

5.2.1 Scope Elements

The closure scope for this option will involve construction of the regime channel; modifying the slopes and configuration of the waste dump to accommodate the channel and to ensure its stability; affecting the water removals needed to lower Hudgeon Lake and restoration or management of exposed valley slopes upstream of the waste dump.

Due to the highly erodible nature of the underlying waste dump, the channel will be armoured to reduce the potential for failure during severe floods. Over a lengthy period of time the channel will begin to resemble a natural regime as sediment is transported from upstream and movement of the bed material is experienced during floods.

5.2.1.1 Regime Channel

5.2.1.1.1 Design

The design philosophy for the regime channel is that the gradient of the channel will be reduced to a point that retains a lake but returns the channel to a stable slope that will erode, degrade, aggrade and change through natural processes. Rock will be needed to line the channel to prevent rapid erosion of the underlying dump material, however the normal practice of using geotextile as an underlay to prevent erosion beneath the armouring will be avoided. Instead larger rock will overlay a filter layer of smaller rock to permit natural processes in the channel bed.

Under this scheme the channel morphology will forever be altered from the pre-mine state because of the retention of upstream sediment load in Hudgeon Lake. However, with sufficient time, the channel will evolve to a more natural state resembling the downstream morphology.

The design flow selection has taken into consideration the potential that the regime channel could still be considered a spillway and the impoundment considered a dam. As such, Wood has used the CDA guidelines to design the channel. CDA guidelines define closure as *"the process of establishing a configuration for the dam with the objective of achieving long term physical, chemical, ecological and social stability and a sustainable, environmentally appropriate after use."*

The dam classification for the current drop structure configuration has been considered "Significant" because:

- there is no permanent population at risk;
- the habitat at risk is marginal and could be restored; and
- only recreational facilities, seasonal workplaces and infrequently used transportation routes are at risk.

Wood considers the regime channel to carry a lessor likelihood and consequence than applies to the current drop structure configuration and therefore, if the regime channel is considered to be a structure qualifying as a dam impoundment, the classification should be "Low" (see also Section 5.2.5.3 and Section 7, and the Comments Log of the Dam Breach Report (Wood 2019k)).

For Closure – Passive Care, the system must be in a passive state that does not require operating personnel on site or regular surveillance. For Closure – Passive Care, the CDA recommends a design flood of 0.1% AEP or 1 in 1000 year. Wood has designed the regime channel to withstand the 0.1% AEP design flood (89.8 m^3/s) using tractive force calculations to size the riprap armouring. The in-bank depth is approximately 2.0 m. An additional 1.0 m freeboard has been added to the erosion protection for uncertainties in hydrology estimates and channel hydraulic calculations. Since the depths of flooding are low in the freeboard area, turf reinforced mats are used instead of riprap.

5.2.1.1.2 Alignment Profile and Details

The proposed regime channel that is a central element on CC2 is shown on Drawings VE52705E.CC2.1 to VE52705.CC2.3. Key features and components of the channel are as follows:

- the west (lake) end inlet elevation is 400 m, which will reduce the present lake level by approximately 12 m (i.e., from the current elevation of 412 m);
- the channel has an approach section approximately 8 m wide (low flow) and 50 m wide (total width) with a transition in gradient from 0.5% to 1% to an eventual regime channel constant slope of 2.45% from the lake outlet to its convergence with the existing Clinton Creek channel to the east;

- the channel alignment is offset from the north slope by cutting south into the waste dump to mitigate potential impacts on the stability of the north slope end to allow for any rebuilding/buttressing of that slope that may be required;
- the proposed base, or low flow trapezoidal channel, is 1 m deep, has a top width of 10 m and is lined with riprap overlying a granular filter layer;
- the base flow channel has been designed to pass the 50% AEP (1 in 2-year) storm event; and
- the entire flow channel has been designed to pass the 0.1% AEP (1 in 1,000-year) storm event.

The rationales for selecting the storm events referenced above and the associated flow determinations are described in Section 5.2.5.3.

5.2.1.2 Waste Dump Modifications

The Geotechnical Summary Report (Wood 2019d) describes the development, conduct and outcomes of the stability assessments that were used to define the waste dump configuration and slopes required to accommodate CC2 (see Appendix G of Wood 2019d). In summary, the key outcomes were as follows:

- final cut slopes of 6.0H:1V for the waste dump slopes facing Hudgeon Lake; and
- final cut slopes of 6.5H:1V for the waste dump slopes facing Clinton Creek.

These slopes are governed by requirements to mitigate seismic liquefaction and are generally indicative of those likely required. Slopes may vary somewhat, or may be supplemented by additional measures (e.g., water table controls), as post 10% design development is undertaken. These waste dump cut slopes are reflected in the CC2 alignments, profiles and details presented in Drawings VE52705E.CC2.1 to 3.

5.2.1.3 Valley Slopes Management/Restoration

The lowered level of Hudgeon Lake will expose an area of the Clinton Creek valley of the waste dump totaling some 31 ha. Exposing these slopes creates a variety of potential closure issues:

- the presence of woody and organic debris (i.e., the vegetative inventory inundated when the lake was formed) may create an undesirable aesthetic, and/or may interfere physically with any active surface restoration effort; and
- the change in the thermal and pore pressure regimes in the valley slopes produced by lake drawdowns introduce the potential for slope instabilities.

Any active surface restoration/stabilization efforts directed to these slopes (i.e., debris removal, soil profile restoration, slope stabilization) would be complicated by the following:

- there is no road access to most of the impacted perimeter; mobilizing equipment of any scale would be challenging and costly;
- reliably predicting where slope instabilities may occur, and their associated scales would require large investigative efforts that would again be challenging given the physical and logistical constraints involved; and
- stabilizing slopes and/or restoring soil profiles would likely require large scale importation of materials via a materials management effort that would be difficult and costly.

Further, it is not clear that an active surface restoration/stabilization effort would provide a better outcome over the long term. Allowing the area to equilibrate and revegetate passively and spontaneously may be feasible because:

- the organic debris may act to mitigate erosion, stabilize slopes and facilitate spontaneous revegetation (by providing sheltered organic islands);
- the local slope failures that may occur may fall below significance thresholds that would generate concerns about the impacts of seiches on the remaining waste dump and regime channel; and
- it is possible that the level of disruption associated with an active surface restoration/stabilization effort would be counterproductive (i.e., the effort itself may create more erosion and instability than it mitigates).

At the least, it would likely be more effective and efficient to define any active surface restoration/ stabilization scope based on observed outcomes following closure, rather than a predictively driven effort at closure. The limited negative consequences potentially associated with a passive slope management/ restoration effort add support to the idea of deferring any active efforts on this scope element. Given the above, Wood has assumed for this 10% design phase concept, that no active surface restoration/ stabilization activity will be directed towards slopes exposed by lake water drawdowns under CC2.

5.2.1.4 Lake Drawdowns

The CC2 concept involves a permanent 12 m drop in the lake elevation (i.e., from el. 412 to 400). CC2 also requires an additional temporary level reduction of 10 m (i.e., from el. 400 to 390) to facilitate construction. As for CC1, this additional drawdown has been assumed as a requirement to support the civil works and depths that will be associated with regime channel construction. This level reduction is also intended to provide the reservoir storage needed to accommodate storm events during project execution.

5.2.1.4.1 Drawdown Methods

The pumping system described in Section 4.1.3.3 has been assumed to provide the drawdowns required for CC2.

5.2.1.4.2 Drawdown Rates

Wood has assumed that over the course of four years piezometer levels would have declined sufficiently to maintain dump stability. This drawdown rate is generally consistent with the annual reductions of 5 m described and rationalized in Section 4.1.

5.2.2 Materials Management Concept

CC2 involves the following key materials movements:

- removal of 7.1 Mm^3 of waste dump materials; these materials would be used to address any fill requirements for the selected Wolverine Creek closure option, or directed to the Porcupine Pit Spoil Structure (PPSS);
- importing some 37,000 m^3 of large riprap (D_{50}=500 mm), 10,000 m3 of mid sized riprap (D_{50}=300 mm) and 5,000 m^3 of smaller riprap (D_{50}=175 mm) and granular engineered fills from an off-site quarry; and
- bringing to site approximately 26,000 m^2 turf reinforced mat (TRM) for erosion protection above the riprap and in the freeboard zone.

The assumed materials management concept for these movements is as follows:

- a truck and shovel operation comprised of a fleet of two CAT 385 excavators, and seven CAT 745 haul trucks and associated ancillary/support equipment;

- all waste dump materials excavated are assumed to be directed to the PPSS (note: if portions of the inventory are used as fill in a Wolverine Creek option, the incremental effort and cost of redirecting these materials (i.e., upgraded Wolverine Creek haul road, longer haul) will be included in the scope and estimate for the associated Wolverine Creek option);
- the waste dump materials will be hauled to the PPSS via a two-way haul road constructed on the waste dump;
- the waste dump materials would be moved in a continuous full season operation over a period of 30 to 48 months, with the detailed execution schedule integrated with the lake drawdown plan.

5.2.3 Anticipated Performance Outcomes

The lake reduction/regime channel option (CC2) is described in Section 3.2 as the Project Partners' representation of a moderate effort/low to moderate risk closure concept for Clinton Creek. Wood's design development outcomes validate this representation because the option provides the following:

- reduces the risks associated with physical failures of the remaining waste dump;
- reduces the downstream flooding consequences associated with any low probability dump failures;
- mitigates the impacts of dump thawing and settling via a flow channel configuration that adjusts passively to changes (via patterns of degradation and aggregation that mimic natural processes);
- provides for the long-term physical integrity of valley slopes, both upstream and downstream of the dump, with a low probability of incurring a significant, ongoing maintenance liability; and
- provides for unrestricted access to the Clinton Creek valley with few restrictions on the future utility of the lands.

5.2.4 Constructability/Execution Issues

Execution issues and/or risks that will require particular consideration and mitigation for the lake reduction/regime channel option are as follows:

- Lake Drawdowns: monitoring of dump piezometric levels during lake drawdowns will be necessary to ensure dump stability is maintained while minimizing impacts on the broader execution schedule. In addition, Options CC2, and CC3 will require a detailed hydrogeological study to investigate whether or not rapid drawdown of the lake is an issue. Note that some 40 years has elapsed since water was impounded, but there is no data on how long it took to develop the phreatic surface in the landslide dam. It might have only been a few years, it which case dewatering will be relatively rapid.
- Sediment Control: the comparatively high materials movements associated with CC2, and the exposure of potentially sediment laden valley slopes upstream of the dump, will potentially generate significant sediment loads in Clinton Creek during execution. For the purposes of this 10% design phase, it has been assumed that a control structure similar to the WC1 sediment pond (see Section 6.1.1) will be required to mitigate the impacts of these sediment discharges during execution. Additional assessment of sediment control options will be required if CC2 is pursued, and the specific approach taken may vary in form and/or detail from the WC1 sediment pond. However, assuming development of the pond as a CC2 execution requirement ensures that adequate provision for sediment control is included in the 10% design phase estimate.

- Dump Removal Staging: dump removal could begin before or concurrent with dewatering in those cut areas above about 415 masl, which will have a beneficial effect on reducing the driving stresses that could cause instability of the cut slopes. This could reduce but not eliminate drawdown rate restrictions and will be a matter for the next design phase to investigate and optimize.

5.2.5 Key Risks and Uncertainties

5.2.5.1 Pre- Execution

Current assessments of the Lowered Lake/Regime Channel (CC2) option will be influenced by the outcomes of the following post 10% design phase investigative outcomes (se Data Gaps discussion in Section 7):

- zonation of waste dump liquefaction potentials;
- delineation of ice rich permafrost;
- supplementary waste dump hydrogeological characterizations.

The nature and number of design development data gaps that these investigative activities are intended to address suggest that the current assessments and conclusion's relating to CC2 are moderately sensitive (relative to the other candidate option's) to the outcomes of future investigative activity.

5.2.5.2 Post Execution

The risks and/or uncertainties particular to the CC2 option would be as follows:

- the possibility that the extents of ice rich colluvium below and around the regime channel are great enough to generate movements over the long term that significantly compromise the performance of the channel and/or create a requirement for significant rehabilitation/maintenance;
- the potential for failures on the north valley slope that could partially block the regime channel; and
- instabilities in the exposed valley slopes upstream of the remaining waste dump that create seiches beyond the regime channel's capacity, and/or that create the need for extensive post closure valley slope stabilization/restoration.
- the potential for a debris management problem at the regime channel inlet during until the new regime is established.

5.2.5.3 Channel Breach

Since the regime channel will still result in an impoundment, an assessment was made of the consequences of severe erosion in the channel and to check the validity of the underlying assumption that the consequences of failure of the structure is low. The robustness of the design was tested using sediment transport modules within US Army Corps of Engineers hydraulic modelling package HEC-RAS v. 5.0.6. Two sediment transport model runs were undertaken as follows:

- channel with design dimensions but no armouring. Erosion was simulated cutting down through the waste dump material that underlies the armoured channel (i.e., total failure of all riprap) for a 1% AEP (1 in 100 year), 0.1% AEP (1 in 1000 year) and the IDF (1/3 between 1000 year and PMF);
- armoured channel with design riprap gradation and 1000-year design flow; and
- armoured channel with IDF.

The model runs demonstrated that under the unlikely scenario where there is complete loss of armouring in the channel, the channel will downcut through the waste dump by approximately 2.6 m, 3.3 m and 7.1 m for the 1%, 0.1% and IDF, respectively. The material will be transported and deposited downstream along the profile shown on Drawing #VE52705E.CC2.1. Under the "armoured channel with IDF" scenario, the model showed no erosion of the channel; suggesting that the rock size might be optimized during the next design stage.

The modelling shows that complete downcutting to the original channel bed is unlikely to occur even with complete failure of the riprap armouring. With the volume of rock lining the channel, it is also extremely unlikely that a headcutting failure would occur. It was concluded that the regime channel design is robust and the failure consequences assumption valid.

5.2.6 Associated Closure Criteria

Key closure criteria associated with CC2 are as follows:

- reduces the human safety risks generated by the waste inventory in the Clinton Creek valley;
- eliminates the need for public access restrictions to the Clinton Creek valley (provided that the debris field upstream of the dump that is exposed as the lake is lowered does not introduce extra-ordinary physical hazards into the post closure landscape);
- improves the water quality and fish bearing capabilities of Hudgeon Lake;
- provides for the long-term passage of creek flows and fish;
- does not provide a prescribed specification for vegetative cover, but rather relies on those cover outcomes that develop spontaneously over the long term; and
- reduces the long-term monitoring and/or maintenance liability associated with the Clinton Creek valley.

Additional assessment and comment on the relation of this option to the Project Partners' objectives is provided in Section 8.

5.3 Clinton Creek 3 (CC3) - Removal of Hudgeon Lake

This option involves lowering the lake to levels that would avoid any categorization of the remaining waste dump materials as a dam. A new channel would be developed in the reconstructed Clinton Creek valley to provide for the sustainable conveyance of creek flows.

5.3.1 Scope Elements

The closure scope for this option will involve removing the lake and restoring the channel to the pre-mine configuration as far as practical. The complete removal of Hudgeon Lake will require significant earthworks to remove sufficient waste dump material to stabilise the embankments and to manage elevated total suspended solids in the runoff until vegetation is naturally re-established on the freshly exposed slopes.

The scope elements for CC3 are:

- drawdown of Hudgeon Lake from the current elevation of 412 m to 385 m;
- removal of the dump material to create room for the new channel;

- excavation of a new meandering channel in the footprint of the former waste dump; and
- construction of a temporary sediment pond upstream of Wolverine Creek.

The bed of Hudgeon Lake has likely accumulated silt deposits since the lake was formed which introduces the potential for excessive sediment loads in downstream discharges following lake removal. This potential could be partially mitigated by constructing a base flow trench through the former lake area upstream of the waste dump footprint. However, this would be difficult, costly and potentially disruptive given the lack of access and the irregular ground and debris conditions that are likely to be encountered. For the purposes of this 10% design phase, it has been assumed the final lake drawdown can be set at an elevation within the upper levels of the reservoir debris field in a way that retains some sediment retention capability in the former reservoir area, while maintaining the general 'lake removal' tenet of the CC3 design concept. The final setting of this elevation will require additional assessment during post 10% design development and may result in some variation from the drawdown elevation assumed for the 10% concept.

The current concept assumes that this refinement of the drawdown elevation will be combined with a dedicated sediment trap/pond just upstream of Wolverine Creek, to provide the degree of sediment control that will be required for CC3. There will initially be higher sediment loads in the stream because of the gradual erosion of silt currently deposited in the lake bed. The proposed sediment trap/pond will require annual maintenance until the sediment loads drop to an acceptable level.

5.3.1.1 Channel Design

Under this scheme, a new channel for the area below the waste dump footprint has been designed that mimics as far as practical the original meandering form of the pre-mine channel. The original channel was digitised from air photos from 1949 obtained from the National Air Photo Library (Plates A12061_021, A12061_022, A12061_023).

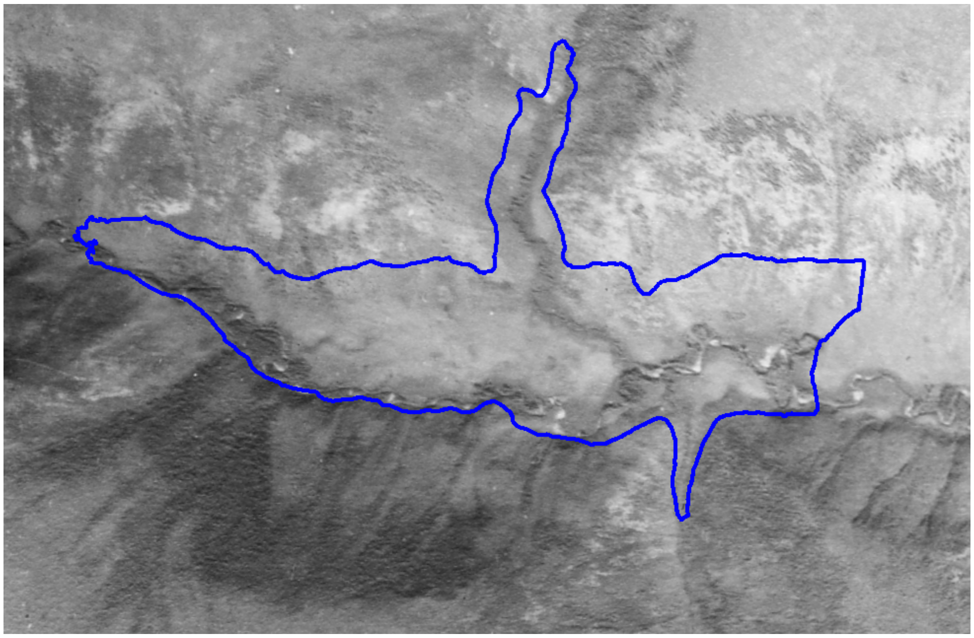
5.3.1.1.1 Alignment Profile and Details

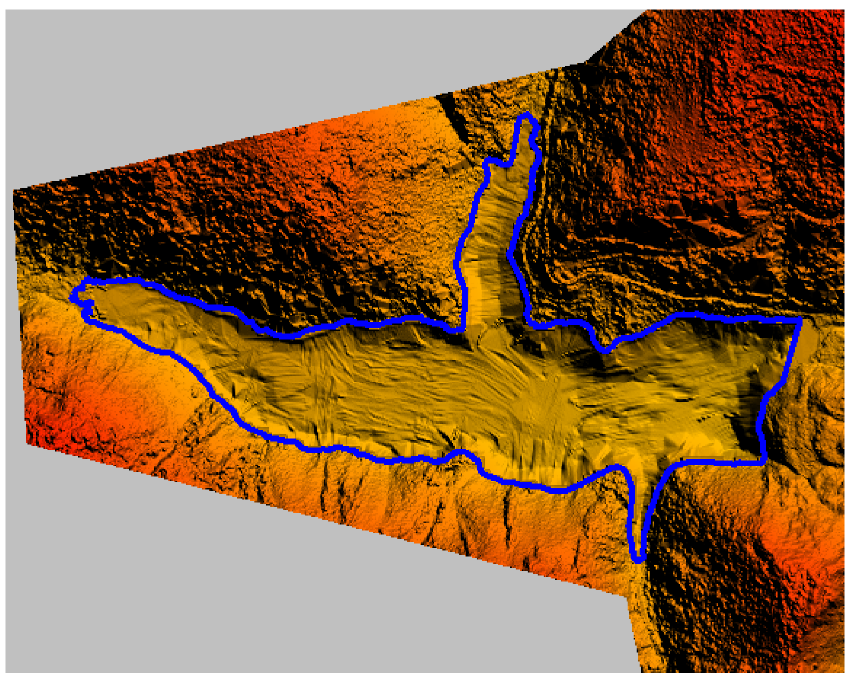
The proposed new channel and the associated waste dump slope and configuration modifications are shown on Drawings VE52705E.CC3.1 through 5. Key features and components of the channel are as follows:

- approximately 9.8 Mm^3 water will be drained from the lake;
- the lake bathymetry shows a level of 385 m near the current outlet; and
- the removal of the lake will expose approximately 72 ha of former lake bed containing silt, decomposing organics and debris; valley wall failures will no doubt contribute to the total amount of this debris.

Historical air photographs (Figure 5-3) show that the original channel alignment through the area now flooded by Hudgeon Lake followed the south hillside. Current bathymetry (Figure 5-3) shows a fairly flat lake bottom. Part of the concept is to re-establish a new conveyance channel through the former dump footprint in a location that will ultimately find regime. The optimal alignment for the new conveyance channel will depend on the bed material and form exposed once the lake has been drained and the dump removed. Conceptually, the channel will be excavated at a steady profile from the lake reservoir outlet (approximately 385 m contour) down to where Clinton Creek returns to its natural bed downstream of the waste dump (just upstream of Wolverine Creek). The gradient will be approximately 1.35%.

Hudgeon Lake Area in 1949:





Hudgeon Lake – Current bathymetry

wood.		**Clinton Creek Remediation Project**		
Yukon Government Depart of Mines & Resources	Yukon	**Hudgeon Lake Pre-Development and Current Bathymetry**		
Drawn: GG	Scale: NTS	Date: July 2019	Project No.: VE52705E.100.2	**Figure: 5-3**

5.3.1.1.2 Design Flow Criteria and Calculations

For 10% design purposes, a 50% AEP (1 in 2-year return period) channel was assumed for the channel. No riprap armouring or other erosion protection measures will be used. Rather, the channel will be allowed to morph into a regime channel over time; with sediment control being used to minimise the impact on the downstream environment until total suspended solids in the runoff reaches an acceptable level.

At a constant gradient of 1.3%, the 50% AEP design flood velocity will be approximately 2.1 m/s at a depth of 1.1 m. The design flood will cause the channel to erode material between 0.002 mm to about 20 mm grain size and will transport fines; ultimately to the downstream sediment pond until a self-armoured regime is established. Once the channel is in regime, only larger flood events will cause significant change.

5.3.1.2 Waste Dump Modifications

The Geotechnical Studies Summary Report (Wood 2019d) describes the development, conduct and outcomes of the stability assessments that were used to define the waste dump configuration and slopes required to accommodate CC3 (see Appendix G of Wood 2019d). In summary, the key outcomes were as follows:

- final cut slopes of 6.0H:1V for the waste dump slopes facing Hudgeon Lake; and
- final cut slopes of 6.5H:1V for the waste dump slopes facing Clinton Creek.

These slopes are governed by requirements to mitigate seismic liquefaction and are generally indicative of those likely required. These slopes may vary somewhat, or may be supplemented by additional measures (e.g., water table controls), as post 10% design development is undertaken. These waste dump cut slopes are reflected in the CC3 alignments, profiles and details presented in Drawings VE52705E.CC3.1 through 5.

The cut slopes required for the CC3 option channel may daylight ice rich colluvium in the general area of the present spillway. Special measures may be required to stabilize such slopes.

5.3.1.3 Valley Slopes Management/Restoration

The lowered level of Hudgeon Lake will expose an area of the Clinton Creek valley totalling some 72 ha. The issues related to the management and/or potential restoration of these lands are similar to those described for CC2 (the lowered lake option) in Section 5.2.1.3, specifically that it is not clear that the considerable effort and cost associated with an active surface restoration would produce an outcome materially superior over the long term than passive monitoring/management. Accordingly, and consistent with the approach taken for CC2, Wood has assumed that for this 10% design phase concept, no active surface restoration/stabilization activity will be directed toward lands exposed by lake water drawdowns under CC3.

5.3.1.4 Lake Drawdowns

Option CC3 calls for a reduction in the current lake level of some 27 m (i.e., from el. 412 to 385 m at the current outlet).

5.3.1.4.1 Drawdown Methods

The pumping system described in Section 4.1.3.3 has been assumed to provide the drawdowns required for CC3.

5.3.1.4.2 Drawdown Rates

As discussed in Section 4.1.4.2, for the purposes of this 10% design phase it has been assumed that the 27 m lake drawdown for CC3 will require a program of pumping that will operated over a period of six years. It has also been assumed that this pumping period will be initiated two years in advance of the project materials management effort (Section 5.3.2). This drawdown rate is generally consistent with the annual reductions of 5 m described and rationalized in Section 4.1.

5.3.1.4.3 Drawdown Staging

Like the other Clinton Creek options, the complete removal of the lake will require the drawdown to be undertaken in stages with the reconstruction of temporary spillways to facilitate the passage of the yearly freshet. Wood's vision of the staging is as follows:

- Summer Year 0 – install piezometers across waste dump and take initial readings (two or three readings).
- Spring Year 1 – construction of pumping infrastructure including: any road upgrades, pump system, electrical facilities, pipes, outlet embayment, and piezometers in waste dump (if necessary).
- Summer Year 1 – trial drawdown of lake (to level prescribed by geotechnical engineers).
- Fall Year 1 – breach Drop Structure 1 and reconstruct outlet at lowered lake level.

Following observation of slope stability and piezometer levels in the waste rock pile:

- Spring Year 2 – observe performance of temporary spillway during freshet;
- Summer Year 2 - lower lake by amount deemed safe by geotechnical engineers and environmental engineers (taking into consideration downstream water quality); and
- Fall Year 2 – breach temporary spillway and reconstruct outlet at lowered lake level.

This process would be repeated as required to achieve the desired drawdown (i.e., essentially complete lake removal for CC3). As the lake is drawn down. the lower portion of the waste dump could be removed, and the sediment pond constructed, probably around Year 5.

Given the amount of drawdown required, trafficability for haul trucks operating on uncompacted saturated granular will influence productivities and the overall construction schedule. Considering the shape of the drawdown curve with lake drawdown drainage ditching may be required well back from the crest of excavated slopes to maintain trafficability.

Over an extended construction period (in the range of say 10 years for the entire CC3 closure effort), there is a 9.5% chance that a 1% AEP (1 in 100 year) flood would occur. Assuming a 25-year requirement for the sediment pond, there is a 22% chance the 1% AEP flood would occur. The risk over the whole construction period and design life should be taken into consideration in the detailed design and planning for the project.

5.3.1.5 Sediment Pond

The exposure of lake sediments under CC3 will increase the potential for elevated downstream sediment loads during storm events. For these reasons this 10% design phase concept assumes that a dedicated sediment pond will be a required element of the CC3 concept. The pond is shown on Drawing VE52705E.CC3.3 and has been sized on the basis British Columbia Ministry of Environment's guidelines (BCMoE 2015). These guidelines recommend a design to capture a minimum 10-micron soil particle. The required retention time for x mm particle settling with a settling velocity of V m/s and depth "d" meter can be calculated as follows:

Required Retention Time: Tr = d/(3600*V)

Assuming that approximately 10-micron (and coarser) particles need to be settled out in the pond, and that the settling velocity is approximately 5.92 x 10^{-5} m/s (assumed). The sediment pond area ("A" in m^2) can be calculated as follows:

Area= (Flow (Q, m^3/s) / Velocity (V, m/s)) m^2

Using above MoE guideline equations, Table 5-3 represents the calculated preliminary pond area design.

Table 5-3: Estimated Pond Area Based on the MoE Guidelines

Avg. Flow	Average Pond Depth	MoE Method Criteria	Settling Velocity	Required Area	Retention Time (hr)
3.0	2.2	10 µm (Fine Silt) with 20% F.O.S.	5.92E-05	60,900	12

An area of some 60,000 m^2 will require a significant footprint in Clinton Creek upstream of Wolverine Creek. To reduce the environmental impact due to a large area development (for the estimated pond size), a somewhat smaller pond (approximately 45,000 m^2 footprint) with an underdrain system has been assumed for the solids' retention (i.e., the proposed system will affect solids removal with a smaller footprint requirement for gravity settling).

5.3.2 Materials Management Concept

CC3 involves the removal of about 14M m^3 of waste dump materials; these materials might be used to address any fill requirements for the selected Wolverine Creek closure option (however they cannot be used for the WC2 Buttress fill Dam), or directed to the Porcupine Pit Spoil Structure (PPSS). The assumed materials management concept for these movements is as follows:

- a truck and shovel operation comprised of a fleet of two CAT 385 excavators and seven CAT 745 haul trucks and associated ancillary/support equipment;
- all waste dump materials excavated are assumed to be directed to the PPSS (note: if portions of the inventory are used as fill in a Wolverine Creek option, the incremental effort and cost of redirecting these materials (i.e., upgraded Wolverine Creek haul road, longer haul) will be included in the scope and estimate for the associated Wolverine Creek option);
- the waste dump materials will be hauled to the PPSS via a two-way haul road constructed on the waste dump; and
- the waste dump materials would be moved in a continuous full season operation over a period of some 50 to 72 months, with the detailed execution schedule integrated with the lake drawdown plan.

5.3.3 Anticipated Performance Outcomes

The lake reduction/regime channel option (CC3) is described in Section 3.2 as the Project Partners' representation of a moderate effort/low to moderate risk closure concept for Clinton Creek. Wood's design development outcomes validate this representation because the option provides the following:

- largely eliminates the risks associated with physical failures of the remaining waste dump;
- eliminates the downstream flooding consequences associated with any low probability dump failures;
- mitigates the impacts of dump thawing and settling via a flow channel configuration that adjusts passively to changes (via patterns of degradation and aggregation that mimic natural processes);

- provides for the long-term physical integrity of valley slopes, both upstream and downstream of the dump, with a low probability of incurring a significant, ongoing maintenance liability; and
- provides for unrestricted access to the Clinton Creek valley with few restrictions on the future utility of the lands.

5.3.4 Constructability/Execution Issues

Execution issues and/or risks that will require particular consideration and mitigation for the lake reduction/regime channel option are as follows:

5.3.4.1 Lake Drawdowns

The riskiest time for any on-stream construction project is during construction itself when care of water for environmental and safety purposes is paramount. The drawdown for the lake removal option will be a considerable challenge because of the length of time required to achieve stability in the surrounding slopes and the probability of floods occurring during this period. The proposed drawdown system has been designed to rapidly drawdown the flood rise quickly after an event. However, rapidly fluctuating water levels in the lake will bring instabilities that are not quantifiable with any degree of certainty.

As for CC2, execution of CC3 will require monitoring of dump piezometric levels during lake drawdowns to ensure dump stability is maintained while minimizing impacts on the broader execution schedule. In addition, both CC2 and CC3 will require a detailed hydrogeological study to investigate whether or not rapid drawdown of the lake is an issue (see Section 7.1.2). Note that some 40 years has elapsed since water was impounded, but there is no data on how long it took to develop the phreatic surface in the landslide dam. It might have only been a few years, it which case dewatering will be relatively rapid.

5.3.4.2 Sediment Control

The concept assumed for CC3 includes a dedicated sediment control structure because the scale of dump materials movements, and the exposure of previously submerged valley slopes are expected to generate significant sediment loads during execution. Monitoring and managing sediments will likely be a significant issue during execution of CC3 that may also require the application of observationally driven, supplementary mitigative measures (e.g., targeted removal of select, exposed lake sediment accumulations seen to be contributing disproportionately to sediment discharges).

5.3.5 Key Risks and Uncertainties

5.3.5.1 Pre- Execution

Current assessments of the Lake Removal (CC3) option will be influenced by the outcomes of the following post 10% design phase investigative outcomes (see Data Gaps discussion in Section 7):

- zonation of waste dump liquefaction potentials;
- delineation of ice rich permafrost;
- detailed waste dump hydrogeological characterizations;
- validation of the passive and/or spontaneous equilibration/re-vegetation closure assumption for exposed valley slopes.

The nature and number of design development data gaps that these investigative activities are intended to address suggest that the current assessments and conclusion's relating to CC3 are moderately sensitive (relative to the other candidate option's) to the outcomes of future investigative activity.

5.3.5.2 Post Execution

The risks and/or uncertainties that would be particular to CC3 would be as follows:

- the possibility that the extents of ice rich colluvium below and around the channel are great enough to generate movements over the long term that significantly compromise the performance of the channel and/or create a requirement for significant rehabilitation/maintenance;
- the potential for failures on the bedrock north valley slope that could partially block the channel; and
- instabilities in the exposed valley slopes upstream of the remaining waste dump that create seiches beyond the channel's capacity, and/or that create the need for extensive post closure valley slope stabilization/restoration.
- the potential for storm related sediment discharges from the exposed lake reservoir bottom and slopes to overwhelm the proposed sediment pond/trap with the associated impacts to downstream fish habitat, particularly during the period immediately after closure, and prior to the spontaneous re-establishment of a regime channel and vegetation in the former reservoir area.
- ongoing thaw flows along both the north and south slopes of the exposed Clinton Creek valley following lake drawdown may exacerbate downstream sediment loading.

5.3.6 Associated Closure Criteria

Key closure criteria associated with CC3 are as follows:

- minimizes the human safety risks generated by the waste inventory in the Clinton Creek valley;
- eliminates the need for public access restrictions to the Clinton Creek valley (provided that the debris field upstream of the former dump that is exposed as the lake is removed does not introduce extraordinary physical hazards into the post closure landscape);
- provides for the long-term passage of creek flows and fish;
- does not provide a prescribed specification for vegetative cover, but rather relies on those cover outcomes that develop spontaneously over the long term; and
- reduces the long-term monitoring and/or maintenance liability associated with the Clinton Creek valley.

Additional assessment and comment on the relation of this option to the Project Partners' objectives is provided in Section 8.

5.4 Design Decision Log – Clinton Creek

A log of the key design decisions taken for the Clinton Creek options is provided in Appendix D. This log lists decisions taken by candidate option, and identifies the technical alternatives considered for each key design element, the decision taken and the rationale(s) for that decision.

6.0 Closure Option Designs – Wolverine Creek

This section describes the 10% design development activity and outcomes for each of the candidate options for the Wolverine Creek valley. The presentation of these design outcomes follows the same format outlined in Section 5 for the Clinton Creek side of the property.

6.1 Wolverine Creek 1 (WC1) - No Tailings Disturbance; Sediment Control Only

Option Wolverine Creek 1 (WC1) involves leaving the Wolverine Creek tailings inventory as it currently stands, and reducing the associated downstream sediment loads via the development of a sediment control structure.

6.1.1 Scope Elements

The closure scope for this option is limited to the development of a sediment pond downstream of the tailings inventory.

6.1.1.1 Pond Design Criteria

Discussions with the project Partners during Workshops 2 and 3 in January and May of 2019, respectively, identified the following general design philosophy for the sediment control structure:

- it should provide for the reduction of sediment and asbestos releases for base flows in Wolverine Creek;
- there are no particular storm events and/or quantitative sediment capture criteria that the structure must satisfy; and
- the scale of sediment control structures should not attract costs so high as to be inconsistent with the "low effort/high risk" nature of the Wolverine Creek 1 concept.

It was agreed that control structures should, in effect, reflect a method, rather than performance, specification. The concept will incorporate the largest structure than can readily be developed given the applicable physical constraints, and the closure concept will be structured around whatever performance that pond delivers (in terms of storm event capacity and sediment capture).

6.1.1.2 Pond Design

The baseline criteria from BCMoE's guidelines has been applied for the pond design. BCMoE recommends a design to capture a minimum 10 micron soil particle. However, due to potentially finer particle's presence in the flow stream, 5 micron size has been adopted as a design basis. The required retention time for x mm particle settling with a settling velocity of V m/s and depth "d" meter can be calculated as follows:

*Required Retention Time: Tr = d/(3600*V)*

Assuming that approximately 5 micron (and coarser) particles need to be settled out in the pond, and that the settling velocity is approximately 1.48 x 10^{-5} m/s (assumed). The sediment pond area ("A" in m^2) can be calculated as follows:

$$Area=(Flow\ (Q,\ m^3/s)\ /\ Velocity\ (V,\ m/s))\ m^2$$

Using above MoE guideline equations, Table 6-1 presents the calculated preliminary pond design.

Table 6-1: Estimated Pond Area Based on MoE Guidelines

Avg. Flow	Average Pond Depth	Settling Velocity	Required Area (m^2)	Approximate Retention Time (d)	Available Area (m^2)	Approximate Retention Time (d) @Avg Flow
0.1	2.2	1.48E-05	15,000	2.5	36,000	9

The required area of approximately 15,000 m^2 can be developed at the confluence of Wolverine Creek and Clinton Creek area. The required area significantly increases for the estimated peak flows of 5 m^3/s. It will not be feasible to accommodate the peak flow, with a conventional settling pond design, in the available land footprint. Similar to the Clinton Creek pond design for CC3, a pond with an underdrain system is being proposed to augment the conventional settling process. The proposed system will also be an effective physical barrier for solids removal.

The 10% design phase pond location, layout, profile and details are shown on Drawings VE52705E.WC1.1 through 4. Context and comment relating to the development and nature of this pond concept follow:

- the berms are constructed of local materials;
- Clinton Creek is diverted to a channel immediately south of the pond;
- the pond has been configured with a primary and secondary cell to facilitate efficient sediment removal operations;
- Wolverine Creek flows can be directed to either, or both of the pond cells;
- the pond would be equipped with sub-drainage system to provide a physical separation barrier for higher flow conditions;
- a two-cell structure allows for easy solids removal during operation (i.e., flow can be diverted to alternate cell for solids removal); and
- a fish passage channel has been incorporated in the design on west side of the settling pond.

6.1.2 Materials Management Concept

The materials management requirement for this option is limited to the local earthmoving cut and fill operation required to construct the sediment control pond. The engineered granular materials identified on the drawings would be imported from the off-site sources identified in the project Estimate Basis Memorandum (EBM) (Wood 2019g).

6.1.3 Anticipated Performance Outcomes

WC1 provides no direct mitigation of the central risks on the Wolverine Creek side of the property, specifically, the risks associated with physical failures of the tailings slopes and the human health risks associated with asbestos and metals in uncovered tailings surfaces. The only available mitigative approach for these key risks under this option would be to restrict access to the lands in question.

With respect to sediment pond performance, Wood has undertaken first order assessments of the capabilities of the proposed pond concept, as follows:

- Storm Event: The proposed pond design allows the hydraulic capacity to pass a large storm event (30 mm in a 24-hr storm event (1 in 10)) without significantly impacting the settled solids inventory. The estimated Hydraulic Retention time of 2 hrs is estimated for this event.

- Sediment Capture: The installation of the proposed pond is expected to attenuate the storm event's effect on the downstream system therefore reduce the sediment loading in the down stream water bodies.
- Asbestos Capture: By adopting a smaller particle size (5 micron) as the design basis, it would be reasonable to assume that asbestos captures would be some subset of the sediment capture. During base flows, it could be assumed that the pond would provide a mitigative benefit for asbestos that would be comparable to the reductions predicted for sediments (i.e., there will be asbestos released, but significantly less than is currently the case).

6.1.4 Constructability/Execution Issues

There would be no challenges of significance related to the construction of the proposed sediment pond. The sequence of pond cell construction would need to be integrated with other closure elements (e.g., construction of haul roads that might be needed for other material movements); however, this would fall into the category of regular construction scheduling and would not represent a significant constraint particular to the closure option.

Investigation of foundation permafrost conditions will be required.

6.1.5 Key Risks and Uncertainties

6.1.5.1 Pre- Execution

The sediment control only option for Wolverine Creek (WC1) involves retention of the status quo for the tailings structures themselves. As noted in the Data Gaps discussion in Section 7, the main design considerations for Wolverine Creek options are (1) the steepness of the in-situ valley wall slopes, and (2) the liquefaction susceptibility of the tailings. While the tailings are largely unsaturated to a level that effectively precludes liquefaction being triggered, it is problematic to rule out a thin skin of liquefiable tailings along the tailings / in-situ contact. Large shearing strains induced by in-situ slope movements, or seismic loading would then readily lead to failure. Therefore, it is unlikely that additional detailed investigation would lead to substantive changes in design perspectives. Given this, it is reasonable to characterize the current assessments and conclusions relating to WC1 as insensitive (relative to the other candidate options) to the outcomes of future investigative activity.

6.1.5.2 Post Execution

The defining characteristics of Option WC1 is that it involves accepting most of the risks associated with the status quo and all of the predominant ones, particularly the risks of large-scale failures and/or movements of the tailings piles and the health and ecological risks generated by asbestos and metals in exposed tailings surfaces.

6.1.5.2.1 Failure Risks

The geotechnical characterization and summary reports (Wood 2019f, 2019d) detail what is currently understood about the likely stability of tailings piles and particularly their susceptibility to liquefaction failures (both static and seismic). These characterizations suggest that applying WC1 should only be contemplated with the understanding amongst the Project Partners that significant physical failures will occur at some point, and that reliable predictions of the nature and scale of the associated consequences are not available. These consequences would include:

- the physical hazards to any site occupants during failure events;

- the potential release of impounded waters during failure events and the associated physical and ecological impacts;
- the health and ecological risks generated by the suspension and dispersion of asbestos and metals during and after failure events;
- the potential that failures could further restrict Wolverine Creek flows and increase volumes of impounded water; and
- a changed post closure land characteristic that may be less compatible with future land use expectations/requirements than the current tailings configuration.

Given the remote setting and limited utility of the Clinton Creek property, a decision to accept these consequences might be contemplated if applying WC1 was accompanied with the following mitigative actions/approaches:

- permanently preventing public access from a conservatively bounded failure zone of influence;
- developing and applying protocols for managing the activities of any approved site visitors (for monitoring or for any other activity deemed necessary by the Project Partners);
- developing and applying a failure event monitoring and response plan, to identify measures that might be useful for predicting events and to outline protocols for assessing impacts and response requirements following failure events; and
- conducting a breach assessment for current water volumes impounded on Wolverine Creek to confirm that a short-term release of these volumes is tolerable (i.e., the above discussion is predicated on the assumption that a tailings breach is tolerable; an updated validation of this assumption has not been completed).

Retaining the failure risks associated with WC1 would generate liabilities for the Project Partners of a nature and scale that Wood has not attempted to fully characterize or quantity. Any further consideration of this option should include soliciting appropriate advice on the implications of retaining these liabilities and any non technical measures that may be appropriate to mitigate them.

6.1.5.2.2 HHERA Risks

Up until any large-scale tailings movements and/or failures occur, the health risks associated with asbestos and metals described in the HHERA update (Wood 2019b) would apply for the exposed tailings surfaces. In Wood's view, the only practical mitigative approach would be to permanently prevent public access to the tailings piles. The methods applied to restrict access could range from signage to boundary fencing depending on the required/desired certainty of access restriction compliance. In any case, ongoing monitoring would be required to assess the effectiveness of whatever controls are applied and to confirm their condition and effectiveness.

6.1.5.2.3 Sediment Pond Performance

A lesser concern for WC1 would relate to the long-term integrity and performance of the sediment pond. As noted in Section 6.1.1.1, of necessity, it will not be feasible to size this structure for extreme storm events. Further, there is a high probability that impounded water releases during tailings failure events would compromise the physical integrity of the pond. Both of these factors indicate a high probability that the pond will require reconstruction at some point, and the need for multiple reconstructions cannot be discounted. There is a correspondingly high probability that the benefits provided by the pond will be interrupted by extreme storm/failure events, and that short-term fugitive releases of pond contents could occur during these events.

6.1.6 Associated Closure Criteria

Key closure criteria associated with WC1 are as follows:

- retains the current safety risks (i.e., high probability of large-scale tailings movements and/or slope failures) generated by the tailings inventory in the valley;
- retains the current human health risks (i.e., asbestos and metal levels incompatible with post closure land uses) and ecological impacts generated by the tailings inventory;
- mitigation of retained risks will require permanent land access and use restrictions over the tailings area of influence;
- requires the development and maintenance of a technical and economic response plan to address the consequences associated with large scale tailings movements and/or slope failures that are likely to occur in the future; and
- does not provide for any vegetative cover on tailings surfaces in the valley, beyond those limited covers that may develop spontaneously over the long term.

Additional assessment and comment on the relation of this option to the Project Partners' objectives is provided in Section 8.

6.2 Wolverine Creek 2 - In-Place Tails Stabilization and Surface Water Conveyance

Wolverine creek 2 (WC2) involves stabilizing the tailings in place so that the bulk of the tailings inventory can be retained in the creek valley.

6.2.1 Scope Elements

6.2.1.1 Design Overview

The main tailings slopes down the main or west valley wall facing east, that is the North and South Lobes, must be made stable under static and seismic loading. These slopes will require that a buttress fill be placed against the east slope, as discussed in Appendix H of Wood (2019d). The following key concept components must also be addressed, again as described in Wood (2019d):

1. In order to contain the buttress fills to the south down the Wolverine Creek valley, a Buttress Fill Dam must be placed across Wolverine Creek.
2. The stability of the remaining perimeter tailings slopes to the west, south and north must also be left in a stable condition.
3. There must be a long-term stable outlet for Wolverine Creek along the buttress fills, and a spillway down the Buttress Fill Dam (see following section).

6.2.1.2 Stabilization Components

The configuration of the WC2 stabilization concept is shown on Drawings VE52705E.WC2.1 through 7. This stabilization concept incorporates the following key elements:

- <u>buttress fill</u>: constructed at the base of the tailings within the Wolverine Creek valley and comprised of compacted Clinton Creek waste dump materials and compacted tailings relocated from locally modified slopes;
- <u>buttress fill dam</u>: constructed within the Wolverine Creek valley to contain the buttress fill and comprised of imported, select and compacted granular materials;

- dam drains: basal and chimney drains (with transverse pipe collectors and outtakes) comprised of imported, select and compacted granular materials;
- toe berm: a perimeter toe berm providing support to the north tailings and buttress fill slopes comprised of imported, select and compacted granular materials;
- slope reductions: removing tails from the west and south slopes to provide the requisite factors of safety; slopes would be reduced to 7H:1V;
- flow conveyance: the spillway and channel required to pass the design flows (see discussion in Section 6.2.1.3); and
- tailings cover: a one metre cover of waste dump spoil placed over tailings surfaces to provide ballast mitigating shallow, local slope failures in combination with local slope flattening of otherwise remediated slope segments. This cover provides a substantial secondary benefit of limiting potentials for human exposures to asbestos and metals in the tailings, and for the erosion and downstream migration of asbestos/metal rich tails.

The geotechnical design bases and the stability assessments applied to develop these components and their configurations are detailed in Appendix H of Wood (2019d).

6.2.1.3 Water Conveyance Channel and Spillway

6.2.1.3.1 Design Criteria

CDA considers any structure impounding liquefiable tailings to be a dam and therefore, the design requirements for water conveyance across the new tailings buttress and buttress dam fall under the CDA guidelines. As such, consideration of the IDF must be made in the design. For 10% design phase purposes, it was assumed that the new dam would be classified as “Significant” since, following previous logic applied by Tetra Tech (2016):

- **Population at risk**; only temporary populations would be at risk;
- **Environmental and Cultural Values**;
  - no significant loss or deterioration of fish or wildlife habitat;
  - loss of marginal habitat only; and
  - restoration or compensation in kind is highly possible.
- **Infrastructure and Economics**; losses to recreational facilities, seasonal workplaces and infrequently used transportation routes.

Under CDA guidelines, for Closure – Passive Care, the IDF for a “Significant” classification dam is 1/3 between a 1/1000 event and the PMF. For Wolverine Creek, this equates to a flood discharge of 109 m^3/s. However, since the buttress and dam are new structures, an assumption was made that the design criteria for Active Care phase should be adopted since it is unlikely that such a structure could ever meet the criteria for Passive Closure. Therefore, a design discharge of 28 m^3/s was adopted for the new channel and spillway based on a flood frequency analysis of data from nine regional hydrometric stations in Yukon (Water Survey of Canada, undated) and Alaska (United States Geological Survey, undated).

6.2.1.3.2 Spillway and Conveyance Channel Components

Conveyance of Wolverine Creek across the new tailings buttress and to the buttress dam will be via an open channel and spillway. The main components of the conceptual conveyance channel are (Drawings VE52705E.WC2.2, 3 & 4):

- rectangular box inlet spillway;
- open channel with trapezoidal section 15 m wide at 1% slope;
- riprap chute with trapezoidal section 15 m wide at 16% slope;
- stilling basin at the toe of the riprap chute; expanding to a 32 m wide outlet;
- open channel with trapezoidal section 32 m wide at a 1% slope;
- stone chute designed to convey flow interstitially down a 44% slope; and
- riprap apron at the toe of the stone chute.

The rectangular box inlet spillway is an efficient and simple means of controlling flow into the open channel. It has been designed following guidelines in (Smith 1985). Under a 0.1% AEP (1 in 1,000 year) flood, the inlet head will be approximately 0.63 m.

The open channel sections will convey flows to the steep spillway down the face of the buttress dam. This section has a gradient of approximately 44%. Due to the difficulties in stabilising rock armouring on steep slopes, the conceptual design followed Mishra and Ruff (1998). Under this design, flow down this section will be entirely interstitial during all events, up to the IDF. The design methodology does not allow for flow above the riprap. Depth of flow down the channel would be 1.06 m. In the event that a flood comes during the winter, when the interstitial space might be frozen or full of snow, the spillway will be trapezoidal in shape with a depth of 1.0 m. In this case, open channel flow would govern with supercritical flow, low depth and high velocities down the 44% sections. The assumption is that the rock would be frozen in place and therefore stable.

At the outlet, USBR (1998) has shown that the toe of the slope can be protected with an apron which has been designed with a nominal length of 10 m to allow space for the hydraulic jump to occur if necessary.

6.2.2 Materials Management Concept

The primary materials requirements and movements associated with WC2 are summarized in Table 6-2. The assumed materials management concept is as follows:

- a truck and shovel operation comprised of a fleet of CAT 385 excavators and CAT 745 haul trucks and associated ancillary/support equipment would be used to affect the movement of tails and the transfer of Clinton waste dump spoil to the buttress fill (note that this dump material relocation reduces the dump spoil liability associated with any of the Clinton Creek closure options;
- tails would be moved from upslope to loading areas via a continuous, dozer push operation (assumed to require the full-time presence of a CAT D10 dozer);
- the two-way haul road via the Wolverine Creek valley concept described for the tailings relocation option (WC3; see Section 6.4.2.1) is applied as well for WC2. In practice, some of the haul road details would vary, but a common application was judged a reasonable assumption for this design phase;
- the imported, select granular fills would be transported via a long-haul operation from the remote sources identified in the Estimate Basis Memorandum (Wood 2019g); and
- the tailings relocations, dump material transfers and imported granular fill supply are assumed to be completed in a continuous all-season operation extending over a period of some three years.

Table 6-2: WC2 Material Volumes and Disposition

	Components	Length (m)	Surface Area (m^2)	Volume (m^3)	Fill Sources & Spoil Dispositions	Fill Volumes (m3)		
						Tails	Dump Spoil	Imported
TAILINGS DUMP	Overall Tailings Volume	-	448,000	7,688,000				
	Main Buttress Fill Volume (4.5H:1V)	-	190,000	3,954,000	From excavated tails/Clinton Waste Dump spoil	2,370,000	1,584,000	
	Excavated tailing (7H:1V)	-	168,000	2,370,000	To buttress fill			
	Sub-Excavation Volume Perimeter Berm (2H:1V)	-	24,000	121,000	Spoil to PCSS			
	Compacted Granular Fill (Berm)	-	50,000	550,000	Imported, select material			550,000
	1 m Capping over all tailings	-	358,000	358,000	From Clinton Waste Dump spoil		358,000	
BUTTRESS FILL DAM	Excavated Tailings and Ice Rich Colluvium Volume	-	29,000	169,000	Spoil to PCSS			
	Select Rockfill Shell and Backfill Volume	-	53,000	738,000	Imported, select material			738,000
	Chimney and Basal Drain Volume	-	52,000	192,000	Imported, select material			192,000
	8 inch Perforated pipes	400	-	-				
	8 inch Solid pipe length	300	-	-				
SPILLWAY & CHANNEL	Riprap d50=200 mm			2,085	Imported, select material			2,085
	Riprap d50=300 mm			2,270	Imported, select material			2,270
	Riprap d50=450 mm			2,470	Imported, select material			2,470
	Riprap d50=800 mm			11,640	Imported, select material			11,640
	Riprap d50=1,000 mm			5,290	Imported, select material			5,290
	Bedding Gravel			1,135	Imported, select material			1,135
					Totals	**2,370,000**	**1,942,000**	**1,504,890**

6.2.3 Anticipated Performance Outcomes

The in-place stabilization option for the Wolverine Creek Valley (WC2) is described in Section 3.2 as a "high effort/moderate risk" closure option. It can be characterized this way because it provides the following outcomes:

- reduces the risks associated with tailings failures in the valley;
- reduces the post closure health and/or ecological risks associated with the asbestos and metals in the tailings (via the ballast cover applied to exposed tailings surfaces);
- provides for the reliable and sustainable passage of creek flows with a requirement for ongoing maintenance limited to that needed to sustain the integrity and operation of the buttress fill dam;
- provides for the long-term physical integrity of valley slopes without a significant, ongoing maintenance liability;
- limits the need for access restrictions to the Wolverine Creek valley to those needed to ensure the safe operation of the buttress fill dam; and
- requires the perpetual devotion of impacted valley lands to the maintenance of a dam structure (i.e., precludes any alternate future land uses).

6.2.4 Constructability/Execution Issues

Execution issues and/or risks that will require particular consideration and mitigation for the in-place tails stabilization option are as follows:

- Air Quality: this alternative involves significant disruption of tails and creates associated concerns relating to asbestos and metal concentrations in air during execution. The need to haul materials over significant distances also increases the potential footprint of asbestos and metal impacts resulting from fugitive emissions during execution. Mitigations of these concerns will require robust contaminant controls, worker health and safety protocols, and monitoring regimes tailored to the particular characteristics of the materials movement methods ultimately adopted for relocation.
- Tailings Slope Failures: the specific materials relocation method and sequences will need to consider and mitigate the risks to downslope workers created by potential upslope failures of tailings surfaces.

6.2.5 Key Risks/Uncertainties

6.2.5.1 Pre- Execution

The interactions with 3-D effects have not been considered for the 10% Design and would need consideration if the Project Partners were to select this option. Considerations are:

1. **Perimeter Cut** Adopting the perimeter cuts as presented herein will also reduce the driving stress in the west downslope and therefore could reduce the current buttress fill requirements. This might also have a knock-on effect on reducing the height of Buttress Fill Dam.
2. **Stability Interactions** The stability interaction between a west sloping buttress fill and a right-angle transition to the north to south Buttress Fill Dam has not been analyzed. This would require a 3-D assessment utilizing a code such as FLAC.
3. **Buttress Fill Dam** Optimization of this dam with a 3-D model as complemented by appropriate site data may reduce the currently recommended measures taken for overall stability.

In addition to these considerations of 3-D effects, current assessments of the in-place stabilization option (WC2) will be influenced by the outcomes of the following post 10% design phase investigative outcomes (see Data Gaps discussion in Section 7):

- delineation of ice rich permafrost;
- supplementary buttress dam subsurface characterizations; and
- supplementary subsurface investigations and stability assessments for west, east and south tailings slopes.

The nature and number of design development data gaps that these investigative activities are intended to address suggest that the current assessments and conclusion's relating to WC2 are highly sensitive (relative to the other candidate option's) to the outcomes of future investigative activity.

6.2.5.2 Post Execution

Properly designed and executed, the in-place stabilization option (WC2) for Wolverine Creek would substantially mitigate post execution liabilities. The comparatively modest residual risks and/or uncertainties would be as follows:

- the impoundment of water behind the buttress fill structure and dam means that this option retains the breach consequences that would be associated with any drainage and/or structural failures;
- limitations in the definition of ice rich colluvium boundaries could result in degradation of the buttress fill and dam over the long term (i.e., if impacted areas were overlooked);
- there remains some potential for failures on the upstream valley slopes that could partially block the flow channel;
- instabilities in the valley slopes upstream of the remaining waste dump could create seiches beyond the spillway's accommodate capacities; and
- there is the potential that overtopping of the spillway channel (e.g., via freshet logjams, beaver dams or extreme storm events), or undermining of the channel (via internal erosion at the rockfill/natural ground contact on the east buttress fills or the east buttress dam abutment) could generate an avulsion out of the channel. This risk could be mitigated via regular maintenance and/or the placement of a wedge of supplementary fill on the side of the channel to deflect flows and/or settle into any erosion. Better definition of this risk and potential mitigative measures will be a post 10% design development requirement.

6.2.6 Associated Closure Criteria

Key closure criteria associated with WC2 are as follows:

- substantially reduces the human safety risks generated by the tailings inventory in the valley;
- substantially reduces the human health and ecological risks generated by the tailings inventory;
- substantially reduces the need for public access restrictions to the Wolverine Creek valley;
- improves the post closure aesthetic of the Wolverine Creek valley;
- provides for the long-term passage of creek flows;
- does not provide a prescribed specification for vegetative cover, but rather relies on those cover outcomes that develop spontaneously over the long term;

- requires the perpetual utilization of valley lands for the maintenance of a dam; and
- does not provide for upstream fish migration.

Additional assessment and comment on the relation of this option to the Project Partners' objectives is provided in Section 8.

6.3 Wolverine Creek 3 (WC3) - Isolate Tailings via Relocation

Wolverine Creek 3 (WC3) involves removing all of the tailings from the Wolverine Creek valley and consolidating them in the Porcupine Pit Storage Structure (PPSS).

6.3.1 Scope Elements

6.3.1.1 Tailings Removal

The 10% design phase concept assumes that the tails will be relocated using a truck and shovel operation to relocate materials via a dedicated, upgraded haul road. The specific materials management concept assumed is detailed in the following Section 3.2.6.1.2.

The total volume of tails requiring relocation has been calculated as outlined in Appendix G of the Geotechnical Summary Report (Wood 2019d). This volume is uncertain given the limitations of pre-development contour plans. For the purposes of this design phase, it has been assumed that the excavation limits associated with this volume will provide clean lines (i.e., will provide for the removal of all Contaminants of Concern (CoC) above prescribed remediation standards) in the restored valley. Additional assessment would be required during future design development to validate this assumption and to define the specific measures required to confirm that clean lines have been provided (e.g., additional pre-execution contaminant delineation, over-excavation provisions and/or extraordinary confirmatory testing during execution).

6.3.1.2 Porcupine Pit Spoil Structure Development

The tailings materials would be directed to the former Porcupine Pit area for disposal. The configuration and development of the PPSS, is described in Appendix G of (Wood 2019d). The final configuration of the structure would depend on the closure option selected for the Clinton Creek side and the associated volumes of waste spoil generated. Drawing VE52705E.PPSS.1 presents the spoil structure configuration for Wolverine Creek WC3 that brackets the upper bound waste volumes that could be co-disposed with the tailings (i.e., Drawing VE52705E.PPSS.1 is a configuration that assumes CC3 is combined with Wolverine Creek WC3). The drawing includes a storage elevation curve that describes how the top elevation of the PPSS would vary with the volume directed to the structure.

6.3.1.3 Channel Restoration

Following removal of the tailings, the Wolverine Creek channel would be restored to slopes generally consistent with the natural valley slope progression, in a meandering channel engineered to mimic natural creek bed evolution characteristics, and thereby to minimize the potential for attracting any long-term maintenance liability. The 1949 air photo of the area was georeferenced and overlaid on the current topography to determine pre-mine landform and channel characteristics. Interestingly, both north and south lobes appeared to fail on ground featuring natural draws or drainage paths in the slope. With the removal of the tailings, the two small ponds will disappear, and the channel will be restored. Specific stream bed reconstruction activities would be comprised of:

- controlled draining of the ponds either through small controlled breaches, pumping or siphoning;

- removal of the impounding tailings;
- excavation of a small meandering channel suitable for passing the 50% AEP flood in bank to connect the upstream natural channel with the downstream; and
- the channel would then be left to find regime over time (i.e., no armouring would be used in the channel).

The channel concepts, profiles and section details assumed for the reconstructed Wolverine Creek channel following tailings removal are shown on Drawing VE52705E.WC3B.1.

6.3.1.4 Surface Restoration

Following the removal of the tails, the emphasis for surface reclamation efforts will be to mitigate erosion of Wolverine Creek valley slopes in ways that do not attract an ongoing and significant maintenance liability, and that avoid any significant potentials for blocking the post closure drainage channel. It has been assumed active efforts to re-establish a vegetative cover will not be attempted. Surface reclamation has therefore been assumed to comprise the following:

- relocation of debris and unsuitable fills to the PPSS (note: the associated volumes have been assumed to be included in the tailings quantity described in Section 6.3.1.1);
- management of surface water flows in ways that sustain the long-term physical integrity of valley slopes via the construction of an integrated combination of ditches, swales, landforms and/or check structures; and
- incorporation of landforms into the surface management scheme that facilitates, as much as practical, the spontaneous establishment of indigenous vegetation (i.e., without the importation of organic soil materials and/or active planting efforts).

6.3.2 Materials Management Concept

6.3.2.1 10% Design Case

The assumed materials management concept for WC3 is comprised of the following key elements:

- tails removed from upslope to down the Wolverine Creek valley in a continuous all-season operation extending over a period of years (the specific durations are outlined in the project estimate under separate cover) (note: continuous operations were assumed because of the inefficiencies and timelines associated with summer only operations).
- a truck and shovel operation comprised of a fleet of CAT 385 excavators and CAT 745 haul trucks and associated ancillary/support equipment;
- an all-season, two-way haul road, running from the base of the tailings lobes to the PPSS via an alignment located adjacent to Wolverine Creek (see haul road plan, sections and details in Drawing VE52705E.WC3B.2; note: it has been assumed that excess cut materials generated via haul road construction would be added to the waste/tails inventory directed to the PPSS);
- tails are moved from upslope areas to a loading area at the toe via a continuous dozer push operation (assumed to require fulltime presence of a CAT D10 dozer);
- a ditch is constructed adjacent the haul road in the creek valley (note that the assumed ditch cross section (Drawing VE52705E.WC3.2) will not be sufficient to pass extreme storm events; it has been assumed operations would cease during these events, and that any associated damage to the haul road and/or ditch would be minor); and

- the haul road will utilize a temporary construction bridge structure through the transition to the Clinton Creek valley.

Note that the waste dump-cut volumes required to construct the haul road vary significantly depending on the closure option selected for the Clinton Creek valley. The approximate range in haul road dump cut volumes is as follows:

- CC1 - 300,000 m^3;
- CC2 - 45,000 m^3; and
- CC3 - 10,000 m^3

6.3.2.2 Alternatives

The assumed materials management concept is obviously the critical element of this particular closure option and it is important to note that additional assessment of movement options would be a required feature of future design development if a decision is taken to pursue this option. For the current phase, the following judgements have been applied to alternate materials movement concepts:

- <u>Conveyors</u>: considered likely to attract implausible capital costs for a single materials movement requirement like this, and similarly implausible operating costs to sustain operations over the winter.
- <u>Hydrotransport</u>: again, capital expenses were judged likely to be implausibly high, and the considerable complexities, risks and costs of the associated water management liabilities, unresolved.

There are also alternate truck, shovel and haul road concepts that would warrant consideration during any subsequent design phase. Upgrading the existing mill site access road to a two-way haul road specification was considered, but rejected for the following reasons:

- the longer haul distance significantly increases haul costs; and
- the road upgrades would require significant cuts and fills that would likely introduce significant geotechnical challenges/constraints (e.g., the stability of any ice rich soils potentially located under road fills).

Finally, it is possible that specialized excavation equipment could be used to selectively push or pull tails downslope to a loading operation. For example, a Sauerman scraper could be used to drag tails off the slope. A Sauerman scraper is a cable mounted bucket/dragline system that runs an excavator on a cable between fixed masts. The system, and other comparable cable dredging/dragline equipment, facilitate remote removals over wet or unstable areas.

Final selection of a materials management concept under this option would likely be best left to prospective contractors during the tendering phase. The option assumed for this 10% design phase was selected and assessed to validate that the required relocation could be executed, and to generate a cost estimate that conservatively reflects the likely range of associated costs.

6.3.3 Anticipated Performance Outcomes

The tailings relocation option (WC3) is described in Section 3.2 as the “high effort/low risk” closure option for the Wolverine Creek side of the property. It can be characterized this way because it provides the following outcomes:

- eliminates the risks associated with tailings failures in the valley;
- eliminates the post closure health and/or ecological risks associated with the asbestos in the tailings and substantially reduces risks associated with metals in the tailings;

- provides for the reliable and sustainable passage of creek flows with little or no requirement for ongoing maintenance;
- provides for the long-term physical integrity of valley slopes without a significant, ongoing maintenance liability; and
- provides for unrestricted access to the Wolverine Creek valley with no, or few restrictions on the future utility of the lands.

6.3.4 Constructability/Execution Issues

Execution issues and/or risks that will require particular consideration and mitigation for the tails relocation option are as follows:

- Air Quality: this alternative maximizes the disruption of tails and the associated concerns relating to asbestos and metal concentrations in air during execution. The need to haul materials over significant distances also increases the potential footprint of asbestos and metal impact resulting from fugitive emissions during execution. Mitigations of these concerns will require robust contaminant controls, worker health and safety protocols, and monitoring regimes tailored to the particular characteristics of the materials movement methods ultimately adopted for relocation.
- Tailings Slope Failures: the specific materials relocation method and sequences will need to consider and mitigate the risks to downslope workers created by potential upslope failures of tailings surfaces.

6.3.5 Key Risks/Uncertainties

6.3.5.1 Pre- Execution

The isolation via relocation option for Wolverine Creek (WC3) involves removing all tailings from the valley. It is unlikely then that additional investigative activity would lead to substantive changes in design perspectives for the relocation operation itself. The current design assumption for valley slopes exposed by this relocation is that these areas can be left to equilibrate and revegetate passively and/or spontaneously. If additional study of this concept in support of permitting efforts (see discussion in Section 7) fails to validate this approach, the efforts and costs of more direct methods of slope restoration could be substantial. Given this, it is reasonable to characterize the current assessments and conclusions relating to WC3 as moderately sensitive (relative to the other candidate options) to the outcomes of any future investigative activity.

There is a potential that tailings in the PPSS may result in contamination of groundwater (it is currently assumed that there is a hydraulic connection between the Porcupine Pit water and the seepage locations monitored by EDI in the Clinton Creek and Porcupine Creek valleys). This concern is mitigated by the limited impacts of tailings runoff on Wolverine Creek water quality that has been observed to date. Nevertheless, it would likely be an issue requiring additional consideration in post 10% design development activity and /or permitting.

6.3.5.2 Post Execution

One of the central benefits of the tails relocation option is the extent to which it mitigates the key closure risks and uncertainties (i.e., stability of tailings piles and health/ecological issues associated with exposed tails). The comparatively modest post closure risks and uncertainties that would be associated with this option include:

- the susceptibility of exposed valley slopes to local failures;

- the long-term stability and effectiveness of the surface water management/erosion control scheme developed for the valley slopes;
- the long-term nature and cover of a spontaneously reconstituted vegetative cover; and
- the influences of higher than anticipated valley slope erosion, and/or local valley slope failures, on the long-term performance of the reconstituted Wolverine Creek flow channel.

6.3.6 Associated Closure Criteria

Key closure criteria associated with WC3 are as follows:

- minimizes the human safety risks generated by the tailings inventory in the valley;
- minimizes the human health and ecological risks generated by the tailings inventory;
- eliminates the need for public access restrictions to the Wolverine Creek valley;
- improves the post closure aesthetic and utility of the Wolverine Creek valley;
- provides for the long-term passage of creek flows and fish; and
- does not provide a prescribed specification for vegetative cover, but rather relies on those cover outcomes that develop spontaneously over the long term.

Additional assessment and comment on the relation of this option to the Project Partners' objectives is provided in Section 8.

6.4 Design Decision Log – Wolverine Creek

A log of the key design decisions taken for the Wolverine Creek options is provided in Appendix E. This log lists decisions taken by candidate option, and identifies the technical alternatives considered for each key design element, the decision taken and the rationale(s) for that decision.

7.0 Data Gaps

This section outlines key gaps in the current understanding of conditions on the Clinton Creek property that are, or may be, relevant to post 10% closure planning. These gaps might have varying, and at this point largely unquantified, influences on the candidate options. In most circumstances they will be important considerations for design development, optimization, and/or permitting following selection of a preferred concept (i.e., concept selection will likely be driven by relatively broad considerations that will be less sensitive to the supplementary resolution in site characterization provided these gaps are addressed). That said, there is some potential that future investigative efforts could change perspectives on the relative appeal of options, and judgements about these influences should be made as candidate options are assessed by the Project Partners. Wood's judgements about circumstances and/or option evaluations that may be particularly sensitive to currently unanticipated investigative outcomes are offered in the "Key Risks and Uncertainty" discussion for each candidate option in Sections 5 and 6.

When considering the information that will ultimately be required to support the application of a closure plan for the Clinton property, it is useful to distinguish between:

- characterization data gaps; information relating to the character and condition of the property that will be needed to develop an executable closure design;
- design issues; questions about the specific configuration, details and performance of a closure plan that will be addressed during normal design development activity (i.e., development activity not dependant on supplemental data); and
- permitting requirements; data that may not be needed to complete, or execute, a closure plan design, but might be required to satisfy the permitting and/or consultation requirements of applicable regulatory processes (e.g., the Yukon Environmental and Socio-economic Assessment Board (YESAB) requirements).

Most of the geotechnical gaps in the following discussion can be described as characterization data gaps required to support design development activity. The bulk of the Environmental/HHERA discussion relates to the likely requirements for permitting processes. The Hydrotechnical discussion focusses primarily on characterization data gaps.

7.1 Geotechnical Gaps

7.1.1 Remote Sensing/Permafrost Distribution

While it is considered that a reasonable model of permafrost distribution has been assembled based on current drilling data and interpretation it is recommended that trials of ground based ERT (Electrical Resistivity Tomography) be executed for both the Clinton Creek and Wolverine Creek dumps and calibrated to existing boreholes. If a reasonable ground-truthed model is obtained, this would be invaluable in optimizing future borehole locations. Therefore, this work should be undertaken before any additional drilling is undertaken.

7.1.2 Clinton Creek Options

7.1.2.1 Dump and Foundation Characterization

A major design driver for all Clinton Creek Options is the conclusion that the waste dumps encompassing the landslide dam are liquefiable. This conclusion is based on 4 SPT boreholes in the waste fills comprising the main landslide dam. In addition, liquefiable signatures were encountered in Clinton Creek valley foundation deposits. This interpretation led to the 10% Design conclusion that slopes required flattening to 6-6.5H:1V as governed by the design earthquake. In consequence of this decision other foundation failure modes (such as interactions with permafrost and/or thawing permafrost, contractant foundation silt clays) were considered to be somewhat less critical. It can be argued that a quantum increase in dump and foundation boreholes and resulting data could potentially zone liquefiable vs non-liquefiable zones. By significantly increasing site characterization this could lead to capital cost reductions from the following perspectives:

1. It may be possible to zone dumps into segments where liquefaction is not a design issue, allowing steeper slopes, and less volume of spoil to be re-located.
2. It may then be viable to control liquefaction by blast-densification (using controlled explosives) allowing steeper slopes (i.e., not flattening slopes to 6-6.5H:1V).
3. However, blast densification would then result in other foundation modes becoming the potential slope control, necessitating an improved foundation zonation and characterization to support steeper slope assessments.

It is considered for costing purposes that 50 Boreholes with a range of testing, sampling, and some instrumentation be allowed for. The use of a Becker Hammer rig, as well as a mud rotary rig with energy measurements for SPT should be allowed for. Alternatively, the costs for this program could be saved by adopting the current 10% design basis and proceeding. It should also be noted that more detailed investigation and cost analysis may conclude the current design basis is valid. A cost-benefit analysis could be undertaken to consider the risk/reward.

7.1.2.2 Ice Rich Permafrost

Depending on the Option selected, a varying degree of investigation of the zonation of ice rich permafrost in the vicinity of BH18-03 is required to better define the scope of impacts on the Clinton Creek options (note that the ERT and/or additional drilling may define other high ice content zones). For CC1, it will be necessary to define the extent of ice rich material such that foundations requiring thaw and densification/ground improvement under the spillway can be defined. For CC2, it will be necessary to estimate the amount of settlement along the spillway. For CC3, the relative locations of ice rich ground and the north (or left bank) waste dump cuts require detailed assessment. For estimating purposes, 25 core holes and index testing can be assumed.

7.1.2.3 CC1 Spillway Settlement

The CC1 spillway considers a total of 12 sheetpile drop structures along the proposed alignment. Each sheetpile "wall" is a total of 60 m wide and up to 12 m deep. In order to provide the ability to reasonably survive differential settlement consequent upon a seismic event, the foundations down to bedrock require densification. In order to undertake the next design phase, depth to bedrock data will be required. Planning should account for 2 holes at the 1/3-point on the 12 walls and 6 holes in the intake area, for a total of 30.

7.1.2.4 Landslide Dam Hydrogeology

While the current hydrogeological regime in the western half of main landslide dam is reasonably well defined, the eastern half is not well understood. Additional nested piezometers in both dumps and foundations are required.

As discussed in the Geotechnical Summary report (Wood 2019d), the rate of Hudgeon Lake drawdown may be restricted depending on the in-situ hydraulic conductivity of the dump infills. Conducting a reasonably long duration in-situ pumping test may provide some guidance on allowable drawdown rates. A practical difficulty in conducting a pumping test is selecting a representative location from which to generalize and assess the impact of Hudgeon Lake recharge if the test area is close to the lake. It would be expected that detailed logging of the additional 50 boreholes (per above) would give a gross zonation and assist in selecting the focal point for a pumping test. Interpretation of test results with a 3-D Code including transient effects will be necessary.

7.1.2.5 Lake Drawdown Planning

Characterizing the landslide dam hydrogeology will provide key input to the post 10% design development work that will be needed to optimize plans for lake drawdowns. Detailed drawdown planning will need to consider:

- geotechnically driven drawdown rate constraints:
- the costs of a pumping system that could be used to lower dump water tables and thereby expedite lake drawdowns;
- in the absence of pumping, the costs of extending the broader construction execution plan to accommodate extended drawdown durations;
- the feasibility and costs of executing drawdowns in advance of mobilizing the broader construction execution effort;
- the nature and timelines of a construction execution schedule that is not constrained by drawdown durations; and
- the environmental impacts of drawdowns and the costs of associated mitigative measures (i.e., any measures required to maintain adequate oxygen levels in lake releases; mitigation of the fisheries impacts related to construction activities).

A quantitative understanding of these variables and their potential integration will be required to optimize closure execution plans and schedules. Some progression of this optimization will be a required element of post 10% design development activity. However, final optimization will be influenced by the particular materials management and pumping expertise and equipment applied and may therefore be best left for potential contractors to consider during the contract procurement and tendering phase.

7.1.2.6 Other Dumps

It is noted that the other dumps along the south valley Clinton Creek valley wall downstream of the main landslide dam, and the Porcupine Creek dumps have not been investigated. As the 10% Design is premised on leaving the Porcupine Creek valley "as-is" then no further action is required. However, if this decision is not formally adopted by the Project Partners then it is likely that additional investigations may be appropriate.

If the sedimentation pond for WC1 is placed in the Clinton Creek valley, with Clinton Creek located between the Snowshoe dump and the East Lobe then these dumps should either be investigated or removed. However, given the morphology of these dumps, they would be difficult to investigate, and the pragmatic decision may be to plan remove these two dumps. Post 10% planning should consider the utility of dump characterization vs removal in light of the closure option selected.

7.1.2.7 North Clinton Creek Valley Slope & Bedrock Considerations

There have been no detailed rock mechanics investigations of the bedrock along the north Clinton Creek valley wall, or within the Porcupine Pit. If there were any rock mechanics studies in support of the original pit, they are not available. Based on observations along the cut slope eroded by the present spillway channel and available bedrock studies, the bedrocks are highly disturbed, faulted and folded, making any useful generalizations difficult.

As the CC3 and WC3 options significantly rely on the use of Porcupine Creek for storage, a significant gap at this juncture is the development of a safe work plan, based on a detailed assessment of the pit by a rock mechanics specialist. If a safe work plan is not forthcoming then the development of an alternative waste disposal plan, in some way utilizing Hudgeon Lake, would appear necessary. This would in turn introduce further data gaps at a later date.

7.1.2.8 Seepage out of Porcupine Pit as Storage Structure

There are, albeit subjective, indications that the water level in this pit is more or less stable with time. A lack of access to the pit floor, due to safety concerns has prevented elevation measurements. It is possible that some of the observed seeps near the toe of the valley wall/dumps are due to bedrock and fault control which provides a conduit. The design of the pit infills has assumed that the phreatic surface will remain stable with time at a low level. This needs further resolution and water level monitoring, perhaps using a drone in some manner. The water may be staying approximately the same level if evaporation co-incidentally matches inputs.

The impact of a rising water level to the bedrock east pit crest has not been considered.

In addition, the potential impact of leachate due to percolation of precipitation downwards to bedrock structures and out to Clinton Creek valley has not been considered.

7.1.3 Wolverine Creek

The main drivers for the Wolverine Creek options are (1) the steepness of the in-situ valley wall slopes, and (2) the liquefaction susceptibility of the tailings. While the tailings are largely unsaturated to a level that effectively precludes liquefaction being triggered, it is problematic to rule out a thin skin of liquefiable tailings along the tailings/in-situ contact. Large shearing strains induced by in-situ slope movements, or seismic loading would then readily lead to failure. In addition, factor of safety calculations supported by slope indicator movements indicate the slopes are moving with a factor of safety approaching unity. Therefore, it is unlikely that additional detailed investigation would lead to a substantive change in design perspectives.

7.1.3.1 WC1

WC1 is essentially a do-nothing option, with a sediment pond. If this option is pursued it will likely be necessary to develop more quantitative predictions of the zone of influence associated with large scale tailings slope movements or failures as input to risk monitoring/management plans, and characterizing the scale of the post failure remedial efforts that will be required.

7.1.3.2 WC2

For WC2 the design response is to (1) buttress the slopes facing south, (2) design in a buttress fill dam located to the east down the Wolverine Creek valley, and (3) consider flattening all slopes not managed by the buttress fills. While the buttress fill dam is considered to require select rock fill, the buttress fill behind the dam can be constructed out of compacted tailings. There is also the potential (4) of placing tailings upstream of the currently planned buttress fills.

The significant design issue is the potential for ice rich permafrost as encountered in BGH18-16 on the west valley wall located in what would be the right or south abutment of the WC2 buttress fill dam. Cost allowance for 20 boreholes within both abutments and the valley bottom and permafrost testing would be appropriate.

The currently proposed buttress fill down the valley slope does not address the side slopes of the tailings to the west, south and east. Evident distress is visible in the west and east side slopes. The slopes to the north or towards the plant site appear stable. This may be due to a combination of better drainage, better foundation conditions on the upland, and defensive measures of densification of tailings to support steep slopes towards the plant site during operations. A budget allowance of 20 boring and CPT testing should be allocated to refine currently estimated slopes.

7.1.4 Instrumentation

Allowances for additional piezometers, thermistors, and slope indicators are recommended.

7.1.5 Borrow

The current 10% design effort has not considered borrow sources for a range of select materials. This will need to be addressed in the next phase of design by building on the conclusions of the current Chilcot report (CGE 2015). It would be appropriate to provide rock mechanics assessments for select rockfill requirements. Argillite bedrocks are entirely unsuitable as select fill. However selective mining of quartzitic (tan coloured) or serpentine rich bedrocks appear to have been used in recent spillway reconstruction. Previous work by Chilcot has suggested that larger sized rip-rap might be obtained by selectively mining in the Clinton Creek sediments, this should be explored further as such cobble/boulder sized rocks have passed a natural durability test. Determining the rock types of common boulders in Clinton Creek may assist in borrow identification.

7.1.6 Volume Estimates

Due to the lack of reliable pre-mining topographical data volume estimates are uncertain. If the additional drilling programs recommended herein are executed, this information along with recommended ERT can be used to upgrade the volume estimate data base.

7.1.7 Laboratory Testing

Wood has not undertaken any further specialized testing other than drained tests to determine effective stress parameters. At this time and given the materials identified, there appears to be no pressing reason to do additional testing. However, depending the findings of any future investigations, additional testing may be of value.

7.2 Environmental/HHERA

The following discussion outlines environmental and/or risk issues that may require more definition to address characterization data gaps and/or permitting requirements.

7.2.1 Characterization Data Gaps

In Wood’s review, the limited number of environmental/risk gaps requiring consideration to support closure design and/or execution activity would include the following:

- Waste Dump; sampling and analysis of surficial materials on final dump surfaces (i.e., after slope modifications/reductions) to confirm metal levels are consistent with assumptions applied in the project HHERA.
- Mill Site; closure on the elevated hydrocarbon at depth issue identified during the 2018 investigative program. If this cannot be discounted as an issue based on additional surface water monitoring activity, it may be necessary to undertake delineation drilling, likely as an adjunct to the supplementary geotechnical drilling described in Section 7.1.
- Hudgeon Lake; options involving reductions in the lake level will exposure sediments potentially contaminated with metals and/or asbestos. A surficial sampling effort, similar to that required for the re-configured waste dump, will be needed to confirm levels are consistent with HHERA assumptions and, if not, to define areas that require remediation (likely via removal to the PPSS).

  Detailed planning for the drawdowns that are associated with all of the Clinton Creek options may require additional data relating to lake parameter stratification to validate the 10% design assumptions that drawdowns can be completed without intolerable impacts to downstream ecologies.
- Impounded Waters: the property includes a number of other, comparatively small impounded water inventories for which there is little or no water quality data available (a reflection, generally, of the difficulty of accessing these areas). For many of the candidate options, there will be a need to release or relocate these waters during project execution. Water quality data will be needed to develop detailed plans for disposition, validate the current assumption that treatment liabilities will not be significant, and, very likely, to support permitting efforts. This would apply to any significant water impoundments on-site, but most specifically the Wolverine Creek tailings impoundments and waters in the Porcupine and Snowshoe pits.

7.2.2 Permitting Requirements

Environmental/risk information that may not be required to complete closure designs, but may be needed to support regulatory processes include the following.

- Hudgeon Lake Fishery; for those options that involve leaving all or part of the lake in the post closure landscape, more specific definition of the impacts of closure plans on local fish populations may be needed.
- Valley Restoration; for those options involving exposing valley slopes that are currently submerged or buried, the current assumption is that slopes can be left to equilibrate and revegetate passively and/or spontaneously. Additional definition of the rates at which these processes will occur, and the eventual outcomes they will provide, will likely be required to support regulatory applications.
- Sediment Control; execution of any closure concept will require plans for controlling sediment discharges to the local water shed, and for mitigating any associated impacts. In addition, Options CC3 and WC1 include a sediment central pond as a central element of the closure concept. Permitting processes will likely require more specific definition and quantitation of the performance that these plans and/or structures will deliver (e.g., YESAB processes may require characterization of sediment pond efficacy for the reduction of asbestos levels in water, and the impacts of any residual asbestos levels discharged from these ponds).

7.3 Hydrotechnical

While the installation of an accurate flow monitoring station would be beneficial in the long term for hydrology estimates, a lengthy period of time would need to pass before sufficient data is recorded for meaningful flood frequency analysis. The hydrology assessment used for the 10% design phase was based on regional data and therefore carries more uncertainty in the design flows. Without a local flow monitoring station, the optimisation of the hydrotechnical design becomes more difficult and the engineer is forced to be more conservative in the designs. However, optimising the designs could pay significant dividends in terms of cost reduction.

For future design development, Wood recommends that LiDAR based digital terrain modelling data be compiled for the whole of the Clinton and Wolverine Creek valleys to the confluence with the Yukon River. Finally, it is also recommended that an updated PMF study and breach analyses be undertaken on the selected closure concept.

8.0 Closure Options Comparative Assessment

The central purpose of this report is to describe designs for those candidate options that have been identified by the Project Partners. The Project Partners will be considering these designs, and the associated cost estimates (Wood 2019m), in light of the project objectives (Table 5-1), closure criteria supplementing these objectives (the criteria described by option in Sections 5 and 6) and various other considerations particular to each Partner's requirements and constraints. These considerations will lead to the selection of a preferred concept that will then be developed further in subsequent design activity. Wood recognizes and fully understands that this concept select process is driven by issues that are the Project Partners' alone to consider; issues that are not driven solely by the technical considerations that are the focus of this document. However, during the conduct of this phase of design development, Wood has formed opinions about the nature and utility of the options that may be useful input to the Project Partners' deliberations. This section is intended to capture and present those opinions.

8.1 Process/Format

Wood's interpretations of the options are presented in a tabular, comparative assessment relative to a common set of objectives and criteria. The objectives/criteria were developed from the Project Partners' general objectives (Table 5-1) supplemented by more specific criteria derived from Wood's understanding of project requirements and constraints, and the outcomes of discussions with the Project Partners and the IPRP during the various project workshops undertaken in 2018 and 2019 (Sections 1.2.4 and 1.2.5). The resulting comparative assessment is presented in Table 8-1.

It is worth noting that the ratings applied in this table are intentionally coarse (i.e., there are typically only three levels of differentiation considered under each criterion (e.g., low, medium, high)). It would not be appropriate to attempt more refined distinctions in a high-level comparative assessment like this, and the number of ratings applied were therefore limited.

8.2 Criteria Descriptions

The following sections describe each of the individual criteria considered in Table 8-1.

8.2.1 Protection of Human Health and Safety

These criteria refer to an option's ability to mitigate health and safety risks in the post closure landscape. Specific criteria descriptions are as follows:

- <u>Catastrophic Slope Failure Risk</u>: characterizes the extent to which an option mitigates the potential for large scale slope movements or failures that are likely to generate significant down valley consequences in the post closure landscape.
- <u>Asbestos Risks</u>: characterizes the post closure risks to site visitors posed by asbestos in air.
- <u>Other Contaminant Risks</u>: characterizes the post closure risks to site visitors posed by other contaminants (principally metals) in site wastes, soils and/or rocks.
- <u>Utility of Harvested Natural Produce and Wildlife</u>: characterizes the post closure risks associated with harvesting natural produce (e.g., plants, berries) and/or wildlife from the Clinton property.

Table 8-1
Clinton Creek Remediation Project
Comparative Assessment of Candidate Closure Options

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Option	Criterion	Protect Human Health & Safety (Post Closure): Catastrophic Slope Failure Risk	Protect Human Health & Safety (Post Closure): Asbestos Risks	Protect Human Health & Safety (Post Closure): Other Contaminant Risks	Protect Human Health & Safety (Post Closure): Utility of Harvested Natural Produce & Wildlife	Protect the Environment (Post Closure): Impacts on Fish Habitat	Protect the Environment (Post Closure): Impacts on Terrestrial Environment	Protect the Environment (Post Closure): Impacts on Surface Water Quality	Uncertainties – Pre Execution (Design Development and/or Permitting): Sensitivity of Current Option Assessments to Changes in Site Characterizations	Uncertainties – Post Execution: Relating to Slope Failure Potentials	Uncertainties – Post Execution: Relating to Environmental Outcomes	Uncertainties – Post Execution: Relating to Human Health & Safety Outcomes	Post Closure Land Utility: Access	Post Closure Land Utility: Compatibility With Pre-development Land Uses	Post Closure Land Utility: Recreational use of surface water bodies	Execution Challenges/Difficulty	Post Execution OPEX Liabilities (excl catastrophic failure remediation)	Permitting Challenges/Complexity	Compatibility with Maximization of First Nation & Yukon Socio-Economic Benefits	Costs (LCCA)
	Ratings	Low, Medium, High	Low, Medium, High	Low, Medium, High	Low, Neutral, High	Negative, Neutral, Positive	Negative, Neutral, Positive	Negative, Neutral, Positive	Low, Medium, High	Low, Medium, High	Low, Medium, High	Low, Medium, High	Restricted, Neutral, Unrestricted	Low, Medium, High	Restricted, Neutral, Unrestricted	Low, Medium, High	Low, Medium, High	Low, Medium, High	Low, Medium, High	as reported in Wood (2019m)
Clinton Creek																				
CC1 - Retention of Hudgeon Lake		Medium	Low	Low	Neutral	Neutral	Neutral	Neutral	High	Medium	Low	Medium	Unrestricted	Low	Unrestricted	High	Medium	High	Low	**$310,000,000**
CC2 - Lower Hudgeon Lake with Regime Channel		Medium	Low	Low	Neutral	Positive	Positive	Neutral	Medium	Low	Medium	Low	Unrestricted	Medium	Unrestricted	Medium	Low	Medium	High	**$197,000,000**
CC3 - Removal of Hudgeon Lake		Low	Low	Low	Neutral	Positive	Positive	Negative	Medium	Low	Medium	Low	Unrestricted	High	Unrestricted	Medium	Low	Low	High	**$290,000,000**
Wolverine Creek																				
WC1 - No Tailings Disturbance; Sediment Control Only		High	High	High	Low	Neutral	Negative	Neutral	Low	High	High	High	Restricted	Low	Restricted	Low	High	High	Low	**$50,000,000**
WC2 - In-Place Tails Stabilization and Surface Water Conveyance		Low	Low	Low	Neutral	Positive	Neutral	Positive	High	Medium	Low	Low	Unrestricted	Low	Unrestricted	Medium	Medium	High	High	**$310,000,000**
WC3 - Isolation via Relocation		Low	Low	Low	High	Positive	Positive	Positive	Medium	Low	Low	Low	Unrestricted	High	Unrestricted	Medium	Low	Low	High	**$260,000,000**

Color Legend

(green)	**Best**
(yellow)	**Mid**
(red)	**Worst**

8.2.2 Protection of the Environment

These criteria refer to an option's ability to mitigate the impacts of environmental degradation in the post closure landscape. Specific criteria descriptions are as follows:

- Impacts on Fish Habitat: describes whether the option is likely to have a positive or negative impact on the character and status of the property's fish habitat prior to closure (i.e., the status quo).
- Impacts on Terrestrial Environment: describes whether an option is likely to have a beneficial impact on the existing capability and/or aesthetic of land ecosystems in the post closure environment.
- Impacts on Surface Water Quality: characterizes an option's likely impact on post closure surface water quality, and indirectly then, on the health of local aquatic ecosystems.

8.2.3 Uncertainties

8.2.3.1 Pre-Execution

Section 7 noted that there is some potential that future investigative activity undertaken as part of post 10% design development efforts, could change perspectives on the relative appeal of the candidate options. This criterion qualitatively describes the sensitivity of the Table 8-1 representations of an option's characteristics and performance outcomes to future investigative outcomes that might fall outside of the range current assumptions. The Table 8-1 ratings reflect the outcomes of the discussion on this point that is provided in the "Pre-Execution, Key Risks & Uncertainties" discussions in Sections 5 and 6.

8.2.3.2 Post Execution

These criteria characterize the reliability of predictions for the health, safety and environmental outcomes potentially offered by an option. Specific criteria descriptions are as follows:

- Slope Failure Potentials: characterizes uncertainties in predictions of stability, recognizing the practical limits to the geotechnical dataset that could be assembled for an option (i.e., that while the current datasets may be supplemented during detailed design, the inevitable limits to data compilation will produce uncertainties that must be accommodated in a closure plan).
- Health, Safety and Environmental Outcomes: similarly, the practical limits to site characterization datasets and risk analyses will produce residual uncertainties requiring consideration in any closure plan.

8.2.4 Post Closure Land Utility

These criteria characterize the degree of public access that an option will provide post closure and the compatibility of potential future land uses relative to similar undeveloped lands. Specific criteria descriptions are as follows:

- Access: characterizes the limits to public access that may be required under an option to mitigate post closure risks.
- Compatibility with Pre-development Land Uses: characterizes the ability of an option to provide for land uses consistent with those offered by undeveloped lands in the area. This criterion is applied with a long-term perspective (e.g., considering the capabilities of the property after spontaneous revegetation has occurred).
- Recreational Use of Surface Water Bodies: characterizes any limits to the public's access to local water bodies that may be required to mitigate post closure risks.

8.2.5 Other Criteria

Table 8-1 includes various other criteria focusing on the difficulty of executing options, the scale of post closure liabilities that may be associated with them, how difficult and/or complex the regulatory approvals process may be and the potential for options to deliver local socio-economic benefits. Specific criteria descriptions are as follows:

- Execution Challenges/Difficulties: characterizes any distinguishing procurement, construction and/or operating challenges that might be associated with executing an option in this remote northern setting.
- Post Execution Liabilities: characterizes the general scale of ongoing operating, monitoring and maintenance requirements that would be associated with an option. Note that this does not include the response and/or remediation liabilities generated by any large-scale slope movements and/or failures that might occur post closure (the probabilities, consequences and influences on option selection of these potential failures are captured under the "Protection of Human Health & Safety" criteria).
- Permitting Challenges/Complexity: a broad and general characterization of any distinguishing consultation, permitting and approvals liabilities associated with an option.
- Compatibility with Maximization of First Nation and Yukon Socio-Economic Benefits: a characterization of any challenges and/or obstacles that an option might pose to utilizing local resources (e.g., extensive requirements for highly specialized equipment and/or expertise).

8.2.6 Costs

This column presents the total costs by option detailed in the 10% design phase cost estimate report (Wood 2019m).

9.0 Summary Comments and Observations

Wood offers the following summary comments and observations relating to the status of the various candidate options at the conclusion of this 10% design development phase. Again, Wood recognizes that the selection of a preferred closure concept involves the consideration by the Project Partners of a variety of issues and trade-offs that go beyond Wood's remit. The following comments and observations are offered simply to provide support to the Project Partners' deliberations as the candidate options are reviewed.

9.1 Clinton Creek

All of the candidate options for the Clinton Creek side of the property involve substantial civil works and costs, some more than others. The closure efforts demanded on the Clinton side are rooted in subsurface conditions that require substantial ground improvements and/or dump slope reductions to support the development of a sustainable flow channel. The selection of a preferred option will be heavily influenced by Project Partner perspectives on the desirability of retaining a lake of some description within the valley. Maintenance of the current lake would involve substantial costs and the retention of relatively high post closure performance uncertainties and operational/maintenance liabilities. The associated efforts/costs, risks and liabilities drop significantly with a lowered lake concept that can be integrated with a largely self-sustaining regime channel concept. Complete removal of the lake would clearly involve substantial civil works/costs, but offers relative certainty in outcomes and a reduced post closure uncertainty/liability profile.

The Clinton Creek options did not include something comparable to the largely status quo alternative that is represented on Wolverine Creek by WC1. If such an approach were contemplated on the Clinton side, the basic trade-offs would be similar to those outlined below for Wolverine Creek. Limiting effort/cost in this way would require the assumption of high risks and post closure liabilities that include negative outcomes (e.g., dump breaches) that generate substantial (although not definitively intolerable) downstream consequences.

9.2 Wolverine Creek

The Wolverine Creek options highlight a general conclusion that is similar to that described for the Clinton side, specifically that mitigating the considerable risks generated by subsurface conditions will involve substantial civil works and costs. In Wood's view, the Wolverine candidate options effectively bookend the basic choices that are available to the Project Partners. Option WC1 (sediment control only) represents a comparatively low effort/cost approach to closure but involves the retention of very significant risks and limitations to post closure land utility. The likelihood of a major failure with substantial (but not definitively intolerable) consequences approaches unity over the extended time horizons consistent with closure. The two Wolverine options that mitigate these risks by stabilizing and isolating the tails either in-place or ex-situ (i.e., WC2 and WC3) both involve substantial efforts and costs and, in the case of in-place stabilization, significant ongoing monitoring and maintenance liabilities. The tailings relocation option (WC3) involves substantial civil works but offers relative certainty in performance outcomes and a largely unconstrained availability and utility of the post closure landscape.

9.3 An Indicative Study

Wood's overall task was to refine six Candidate Options as developed by the Project Partners with a view towards providing a basis for selecting their go-forward decision. We believe that potential fatal flaws have been identified and that indicative designs and estimates have been prepared. We would expect that once Options for Clinton Creek and Wolverine Creek have been selected there will be scope for optimizations and design specific gaps that may need to be addressed – depending on the Options selected. We note that the final reports presented do not contain all the observations and interpretations that have been made as this project evolved – and such information is found in earlier reports and presentations made to the IPRP and the Project Partners.

10.0 Closure

This report has been prepared for the exclusive use of Government of Yukon 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. Wood 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, expressed or implied, is made.

With appreciation,

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Comment Logs

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COMMENT LOG

Document Title: Clinton Creek Remediation Project - 10% Design Phase Report

Document Date: 29 August 2019 **File No.** VE52705E.100.2

Comments By: J. Pigage (CIRNAC), A. Machica (AAM), J. Esterhuizen (Jacobs)

Responses By: B. Geddes, G. Graham, E. McRoberts

Response Dates: 15 November 2019

Note 1 – Page numbers per commented document.

	Comment ID[1]	Comment	Response
1.	**j. pigage** **Section 3.2.6, Page 12** **10/04/2019**	It was my understanding that the tailings are currently unsaturated? What assumption changes their condition in the future? Won't the addition of a cover further reduce the likelihood of saturation?	The geotechnical position is that much of the upper portion of existing tailings is unsaturated to a sufficient level to be considered non-liquefiable. But the possibility of a relatively thin saturated zone at the tailings / original ground level cannot be discounted. In addition as stated in design report predicting future hydrogeology of the tailings is not realistic, in view of climate change factors. Impact of cover type is problematic. It appears that raw tailings exposed to weathering develops a "skin" that may shed water. Placing a more permeable cover for long term erosion resistance may actually increase infiltration.

	Comment ID[1]	Comment	Response
2.	**a. machica** **Section 4.1, Page 13, 2nd bullet** **10/07/2019**	This bullet could benefit from adding or clarifying if/that this additional 10 m drawdown is a temporary requirement to support construction of the regime channel. I understand that this is later on clarified in it's own section but mentioning it upfront I think would be helpful.	The text has been modified to distinguish between the permanent and temporary drawdowns.
3.	**j. esterhuizen** **Section 4.1.3.2, Page 16, 1st and 2nd bullets** **10/07/2019**	For the siphon option, the discharge rate to downstream of the DS1 is relatively high (5 m/s to 8 m/s), roughly similar or higher than typical freshet flows. Suggest note that the lower 3 drop structures must accommodate these relatively high flows over long periods of time, likely requiring more maintenance and with DS4 possibly requiring a more extensive rehabilitation initially.	A note to this effect has been added to the text.
4.	**a. machica** **Section 4.1.5.1, Page 20, 4th para, 3rd sentence** **10/07/2019**	ELR 2014.	Corrected.
5.	**a. machica** **Section 4.1.5.1, Page 20, 4th para, last sentence** **10/07/2019**	This reviewer thinks there is not enough study done yet to characterize the stratification (of lack thereof) of Hudgeon lake to safely say that the impact of lake drawdown is not expected to represent material deviation from current conditions. I think it is a gap that must be filled before conclusion can be made.	A note qualifying the conclusions about drawdown impacts has been added to this section, and a reference to the potential need for additional characterization/stratification data on Hudgeon Lake added to Data Gaps section (Section 7.2.1).

	Comment ID[1]	Comment	Response
6.	**j. pigage** **Section 5.1.1, Page 24** **10/04/2019**	The alternative approach being planned future maintenance of the spillway in response to anticipated movements. As CC1 results in a dam in perpetuity, some level of site presence for operation, inspection, and maintenance of the structure will be required. The intent of an LCCA is to weigh upfront capital costs and the risks they address against longer term risks and the associated maintenance costs (CAPEX vs. OPEX). This thinking is largely absent from the submitted design and cost estimate reports - the focus is on the design and capital cost of solutions which are assumed to not require substantive maintenance in the future.	The design report acknowledges (Section 5.1.3) that CC1 will involve the assumption of monitoring and maintenance liabilities in perpetuity. Further, the Post Closure Care and Maintenance Costs described in the estimating workbook, and the Life Cycle Cost Analysis (LCCA) outlined in Section 8 of the estimate document (Wood 2019m), capture the post closure costs related to CC1 that can be considered in an assessment of all costs (both during execution and thereafter) and risks (as outlined in the Design Report) for CC1 relative to the other candidate options.
7.	**j. esterhuizen** **Section 5.1.1.1.2, Page 26** **10/07/2019**	Any concerns with cobbles or boulders in the subsurface? Suggest noting the feasibility of driving sheet piles. Overall, the spillway concept seems appropriate.	Large boulders and/or cobbles have not been encountered in drilling activities to date, and would not be expected given that the waste dump is comprised largely of processed materials. The current characterizations of dump materials have not identified conditions clearly incompatible with sheet pile installations
8.	**j. esterhuizen** **Section 5.1.1.3.3, Page 30** **10/07/2019**	Section 5.1.1.3.3. A major design concept component for the CC1 option is to provide means for thawing the subgrade beneath the spillway channel. The cost associated with the thawing component is extremely high. It is unclear why this option is considered only for the CC1 option and not for the CC2 option. The drops in the CC1 option is 2.5 m thick and seems to be able to accommodate significant movement before impairing its function. The	The premise behind CC1 is that the maintenance of a permanent dam (carrying a “significant” failure consequence classification) requires a hard spillway founded on a firm substrate. The regime channel (CC2) is assumed to attract a lower performance standard (i.e., a “low” consequence structure) that can accommodate relatively high subgrade movements along a lower channel slope that is allowed to evolve over time to something

	Comment ID[1]	Comment	Response
		regime channel protection in CC2, on the other hand, has a thickness of 1.3 m and seems to be more vulnerable to movement, associated loss of protection, and disruption of the channel characteristics to accommodate relatively high velocities.	mimicking a natural stream profile. Settlements due to permafrost thawing may end up forming small ponds which will enhance the natural appearance of the stream. Any repairs deemed necessary can easily be executed. In short, CC1 mitigates the impacts of ground movements by preventing them, while CC2 mitigates the impacts of those conditions by accommodating them.
9.	**a. machica** **Section 5.1.1.3.4, Page 30** **10/07/2019**	It seems that the ground densification effort is only a means to maintain the sheet piles stable, not the full spillway nor the waste rock pile. As such, it would be interesting to understand the decision behind choosing ground densification over say concrete or metal piles (with the sheet piles on top) which I think would achieve a higher degree of success, as it would be sitting directly above or on the bedrock. Also the means of verifying whether the right densification has been achieved could be challenging.	Densification through the spillway alignment is combined with slope reductions elsewhere to provide the general stability that CC1 requires. It is true that densification is not the only option for providing the requisite stability in the CC1 spillway structure. Densification was judged as likely to provide a reasonable representation of the level of execution effort required to provide the necessary stability. Should the Partners elect to pursue CC1, there would be a need to examine the "densification" scope in more detail to identify any optimizations that might be available. Wood's objective was to provide sufficient definition to the densification scope to provide confidence that "concept select" was undertaken with a reasonable representation of relative levels of effort and cost amongst the Candidate options.

	Comment ID[1]	Comment	Response
10.	**j. esterhuizen** **Section 5.2.1.1.1, Page 34** **10/07/2019**	The reviewer agrees with the general notion that the hazard associated with the regime channel is lower than for the spillway (CC1). The breach parameters will be different and the reservoir storage is less. It would have been preferable to use breach analyses to confirm that a lower hazard classification indeed applies.	Acknowledged. See updates to, and Comments Log for, the final Dam Breach Assessment (Wood 2019k).
11.	**j. pigage** **Section 5.2.1.1.1, Page 35** **10/04/2019**	CIRNAC is not convinced this reduction in dam classification is sufficiently supported. Refer to comments in Dam Breach Assessment report for more detail.	Acknowledged. See updates to, and Comments Log for, the final Dam Breach Assessment (Wood 2019k).
12.	**a. machica** **Section 5.2.1.1.1, Page 35, 4th para (continuation of regime channel design)** **10/07/2019**	This reviewer believes that justification for reducing dam consequence classification from "Significant" to "Low" has not been laid out sufficiently by Wood. Assuming the regime channel performs more robustly than the current drop structure, the downstream consequences are still the same. There is no clear argument that the 10 m permanent drawdown of lake level would result in: • no population at risk and no possibility of life loss other than unforeseeable misadventure • minimal short-term loss to environmental and cultural values • minimal economic losses I also did not see clear argument(s) from the Dam Breach Assessment Report. There was no DBA for CC2 from which the reviewer could check the inundation zone for the 'Low' consequence classification.	Acknowledged. See updates to, and Comments Log for, the final Dam Breach Assessment (Wood 2019k).

	Comment ID[1]	Comment	Response
13.	**a. machica** **Section 5.2.1.2, Page 36** **10/07/2019**	The reviewer finds it interesting that there are no subgrade improvements done for the regime channel considering that the it is located close to where the CC1 spillway would have been and under the same material.	See response to Comment 8.
14.	**j. pigage** **Section 5.2.3, Page 38** **10/04/2019**	The rip-rap armoured spillway (regime channel) in CC2 can accommodate anticipated settlements (both seismic and thaw induced) but the rip-rap armoured spillway (drop structures or equivalent) in CC1 cannot? Both are constructed spillways built on the same foundation conditions yet only CC1 carries the pre-requisite of costly ground thawing and mechanical densification? CIRNAC is concerned this is a continuation of Wood's trend of presenting their preferred candidate closure option (CC2) in a more favourable light than the others. This makes objectively comparing the merits of each option during an options evaluation process very challenging.	See response to Comment 8. Wood is not attempting to preferentially present the candidate options, but rather to describe the basic differentiating attributes of them. As noted in the response to Comment 8, and elsewhere in the 10% design documents, the presentation of CC1 and CC2 is an attempt to contrast the requirements, performance, risks and costs of solutions that mitigate foundation movements versus those that accommodate or adapt to them. In the end, the presentation may be imperfect given the complexities and uncertainties associated with the effort, but any limitations are not grounded in any effort on Wood's part to bias the interpretation.
15.	**j. esterhuizen** **Section 5.3.1.1.2, Page 43** **10/07/2019**	Is there an estimate of the volume of eroded material to be captured in the downstream sediment pond?	There are provisions for CC3 sediment pond cleanout reflected in the cost estimate (total of about 180,000 m^3 over 10 years; thereafter, the estimating assumption was that valley restoration mitigates the need for pond cleanouts); however, these are judgment-based provisions, not predictions. Generating reliable predictions of sediment generation rates for CC3 would be challenging given the unknowns relating to the character of the exposed

	Comment ID[1]	Comment	Response
			upstream valley following drawdowns. The Design Report notes (Section 5.3.1) that it will likely be beneficial to set the final lake drawdown elevation so as to retain a degree of sediment retention in the former upstream reservoir area. The report also notes (Section 5.3.4.2) that monitoring and managing sediment generation/control for CC3 will likely require the application of observationally driven, supplementary mitigation measures.
16.	**j. esterhuizen** **Section 5.3.1.4.3, Page 44** **10/07/2019**	Drawdown stability should be largely a concern at the portions of the waste rock slope directly against the lake where the lake water provides a direct stabilizing effect. For the portions of the north facing waste rock slope that do not have the lake directly against it, the drawdown should have a positive effect on stability.	Current lake levels impact the water table of most slopes. If the drawdown of the water table is slow, then high water tables behind slopes will impact slope stability.
17.	**a. machica** **Section 6.2, Page 52** **10/07/2019**	The reviewer believes that there is some need to conduct subsurface work or rock anchoring to stabilize the buttress. Was this considered by Wood or was the buttress design deemed sufficient to counteract overturning moments?	Wood had provided concept designs for gravity fill structures, and do not see the need for the mitigation suggested for WC2.

	Comment ID[1]	Comment	Response
18.	**a. machica** **Section 6.2.1.3.2, Page 54** **10/07/2019**	The reviewer has some concerns over the spillway and conveyance channel design for WC2 as on paper it seems very similar to the failed ACB mat spillway constructed for DS4. I understand that design could still change later on but was the performance of the ACB mats considered in the design of the spillway and channel?	The design is very different to the drop structures on Clinton Creek. Due to the difficulties in stabilising rock armouring on steep slopes, the design follows guidance from USBR for protecting overtopped embankments. The flow down the steep chute section is entirely interstitial. Energy is dissipated down the length of the chute; not just at the outlet. At the outlet, USBR has shown that the toe of the slope can be protected with an apron. The design is explained and references given in Section 6.2.1.3.2.
19.	**a. machica** **Section 7.0, Page 62** **10/07/2019**	The reviewer is interested to know if there was any negative effects between lake level and available solar heating, that as the lake level is drawn lower, the availability of solar heating becomes lesser and the thawing and heating process takes longer. The reviewer is interested in knowing if permafrost formation at lower lake level (CC2 and CC3) could be more prevalent and problematic.	Wood has not considered these factors at this time.
20.	**a. machica** **Section 7.0, Page 62** **10/07/2019**	Part of the scope for the 10% Design report was work on the common elements. There are no mention of that in this report. Is that covered somewhere else?	The Common Elements were not addressed explicitly in the Design Report or Cost Estimate largely because the associated closure scopes and costs are unlikely to be differentiating issues in the Partners' concept select deliberations. The Environmental Site Characterization Update (Wood 2019l) grouped these Common Elements into three categories, namely the Air Strip, Roads/Crossings and Piles/Debris/Redundant Infrastructure. The place of the first two categories in the closure landscape is unclear (i.e., there may be a

	Comment ID[1]	Comment	Response
			need/desire to retain some of them), Further they may be subsumed by the materials movements that will be integral to the closure effort. In any case, the residual closure requirements are likely to be incidental, scope and cost wise. Similarly, the last debris/infrastructure category will likely be addressed in the normal course of other closure activity at incremental costs that will not be material to concept select deliberations.
21.	**j. esterhuizen** **VE52705E.CC1.2** **10/07/2019**	It is assumed that the purpose of the bituminous geomembrane is to serve as a seepage barrier to reduce hydraulic gradients at the drops. There are some potential negatives associated with the use of the geomembrane (1) reduce the capacity of spillway channel to provide drainage for the waste rock slopes above the channel, and (2) if flows in the channel drops rapidly, high excess (uplift) pore pressures can be trapped below the geomembrane. Since sheet pile will be partial seepage barrier (typically soil-tight but not water tight) as well, consider deleting the geomembrane and depend on a good drainage geotextile (or filter sand/gravel layer) to provide filtering downstream of the drop.	The geomembrane is only beneath the low flow channel. The width including the slope is approximately 7 m across a spillway that is 47 m wide (including side slopes). We included it to reduce seepage from the low flow channel. Since the geomembrane is only a fraction of the overall channel, we don't consider uplift pressures to be a concern; however, alternatives to the geomembrane can be considered in the next design stage.

	Comment ID[1]	Comment	Response
22.	**j. esterhuizen** **VE52705E.WC1.4** **10/07/2019**	Seems there are a few callouts that need to be fixed. For example, in Cell Typ Section 1, there are callouts to Details 1 and 4 that are missing. With pipe running in trench supposedly backfilled with drain gravel it is not clear why a PVC socked drain pipe is called out. Those tend to clog, and typically not desirable for heavy civil/dam applications. Section 7 shows riprap armored slopes on inboard side only. The thickness and size of the riprap armoring is not shown; assume it is more than the 150 mm at the bottom. Note that in the cost estimate, it is noted that both the inboard and outboard slopes are armored, which is not consistent with this detail.	Wood has used this design at other sites. Diminishing performance on socked drain pipe is a known problem. The system would be flushed through the cleanout by closing off the outlet and pressurizing and flushing the system with water. Details on the riprap armoring is now included on the drawing. The armoring is there to prevent erosion of the berm by floods in Clinton Creek not for protection from overtopping from the sediment pond. The spillway near the outlet chamber is designed to prevent overtopping of the berm. Cost estimate has been corrected to remove any armouring of the internal side of the berm.
23.	**j. esterhuizen** **VE52705E.WC2.3** **10/07/2019**	Suggest adding dimensions to this drawing. The scale does not appear to be correct; is the vertical and horizontal scales equal?	Drawing has been edited.
24.	**j. esterhuizen** **VE52705E.PPSS.1** **10/07/2019**	Will the compacted material (blue layer) have a much lower permeability than the waste material (yellow)? Are there any concerns with building a phreatic surface in the waste rock slope? It is assumed that slope stability did not consider groundwater in the slope? If no issue, consider adding text to explain.	The "blue" zone is select material intended to act as a drain element as well as providing a stabilizing effect. The specifications of this material are not provided for 10% design.

Tr’ondëk Hwëch’in Comments on Draft Clinton Creek 10% Design Report

Note: Wood responses to these comments are noted in italicized, blue indented text below

Thank you for an opportunity for TH staff to review the Draft Clinton Creek 10 per cent Design Report by Wood PLC. The following brief comments and questions about the report also benefitted from the contributions of David Chambers of the Center for Science in Public Participation and from Al von Finster of AvF Research and Development.

Included below are general comments about the design options and the report’s supporting material, as well as comments about specific Clinton and Wolverine Creek design options:

Closure Option Designs - Clinton Creek

Volumes of Material requiring removal:

There appears to be some discrepancy in the volume of waste dump materials listed in the report compared to the Geotechnical Summary, and as a consequence, requirements for removal: The report says that CC1 will require the removal of 3.9 M m3 of material but the Geotechnical Summary says 4.8 M m3; For CC2, the report says 6.57 M m3 to be removed but the summary indicates 7.7 M m3. Please correct our understanding and/or clarify.

1. ***There were some superseded volume estimates in the Materials Management sections of the Design Report that have been corrected in the final. The volumes reported now align with those used in the Cost Estimate (Wood 2019m). That said, there are some minor differences between these volumes and those reported in the Geotechnical Summary. The reasons for this difference are noted in Section 2.0 of the Design Report, as follows:***

   “The flow channel location and configuration assumptions applied for the stability analyses and quantity estimates presented in the Geotechnical Summary Report described above (Wood 2019d) preceded the development of final channel designs that appear in the 10% design drawings referenced in Sections 5 and 6 and included in this document. Post 10% updates of stability assessments for these channel configurations may result in some adjustments to design slopes. The quantity estimates applied in the 10% design cost estimate (presented under separate cover) apply estimates based on the channel configurations shown in this design report drawings (i.e., they update the estimates described in Appendix G of Wood (2019d)).”

Armouring, and downcut modelling:

Modelling of CC2 showed the channel will downcut through the waste dump by approximately 2.6 m, 3.3 m, and 7.1 m for the 1 in 2, 1 in 1000, and IDF respectively (assuming the armouring is destroyed). Under the “armoured channel with IDF” scenario, the model showed no erosion of the channel.

Are storm events used to model downcutting conservative enough? A "regime channel" would theoretically need to face a PMF (Probable Maximum Flood) event at some point in time, so shouldn't the potential impacts of that event be assessed?

2. ***The design floods were defined on the basis of criteria outlined in the Canadian Dam Association guidelines. These guidelines establish design floods as a function of the consequences of failure for any given structure. The process by which Wood interpreted these guidelines and established design flows for this phase of design is outlined in the Dam Breach Assessment (Wood 2019k) and referenced in the individual option descriptions in Section 5 of the design report. The CDA guidelines do not recommend that all structures be designed for the PMF regardless of consequence classification***

Are there pros and cons of putting in a grout curtain to minimize infiltration from the remaining portion of the lake?

3. ***Yes. Issues apply to CC1,CC2. A grout curtain would need to key into low permeability bedrock, and penetrate all residual permafrost, on both valley walls and valley bottom. A grout curtain would need to robustly maintain integrity under design loadings, including seismic action. A grout curtain would largely eliminate design concerns with internal erosion. A grout curtain would assist in controlling liquefaction, however it could not be assumed to eliminate a deep water table. Grout curtain designs would need to consider the potential implications of global cooling on the integrity of the grout. Cost would expected to be a major concern, and whether use of a grout curtain reduces overall cost has not been considered. Future studies could consider net benefits.***

Finally, the CC3 option does not include any armouring. Is there potential for rapid erosion of the waste dump, as modelling of CC2 showed? Should armouring of this channel be considered for this option

4. ***CC3 mitigates potentials for large scale dump failures by eliminating the dam and the consequences that would be associated with dam failures. The channel section and alignment are intended to mimic a natural stream alignment. There is some potential for local slope failures during extreme events, as there would be in a natural stream setting. However, these local failures are assumed to equilibrate passively via processes of erosion and deposition. The final dump slopes have been reduced to levels that are intended to mitigate the risks of large slope failures that would re-establish a lake.***

The Design Report acknowledges that sediment generation and management will be a significant issue for CC3 and notes (Section 5.3) that it will likely be beneficial to set the final lake drawdown elevation so as to retain a degree of sediment retention in the former upstream reservoir. This nominal upstream storage will also serve to attenuate the impacts of extreme storm events on the CC3 channel. The Design Report also notes (Section 5.3.4.2) that monitoring and managing sediment generation/control for CC3 will likely require the application of observationally driven, supplementary mitigation measures.

The alternative design option is to budget for a complete restoration of the Hudgeon Lake bottom, including likely failures of valley wall segments.

Clinton Creek Options And Fish and Fish Habitat:

For context, all fish are presently denied access to Upper Clinton Creek (Upper Clinton Creek includes the creek upstream of the lowermost gabion structure aka Drop Structure 4). Fish in the mine-site include Arctic Grayling, that migrate up Clinton Creek in the spring. The timing of upstream migration has not been documented, but they are present at the mine site in late May. Spawning occurs at the mine site and has been observed immediately below the gabion structures. Almost all Arctic Grayling leave Clinton Creek in the autumn. Juvenile Chinook Salmon from populations upstream of the Fortymile River begin to move up Clinton Creek in July. Upstream migration to the mine site may be rapid if the migratory path is clear. The juveniles feed, overwinter and then leave the Creek by about June 1. Slimy Sculpin are resident at the mine site. They are expected to make small movements in the creek during spring and summer and then return to sites where they may overwinter. Much smaller numbers of Long Nosed Sucker and Lake Chub have been captured but are not considered to be a population.

Retention of Lake (CC1)

CC1 will result in a reduction of fish habitat, as the new channel is proposed to return to the Creek channel approximately 700 meters down the valley from the area that Drop Structure 4 is now. CC1 will of course also not allow fish to utilize any of the Upper Clinton Creek channel in the foreseeable future.

5. ***Acknowledged.***

Lowering of Hudgeon Lake with Regime Channel (CC2)

This option allows fish passage to Upper Clinton Creek, and mitigates the potential for long term sediment releases from channel infill and/or the post closure valley wall deposits by allowing for settling within the residual lake. It also returns Clinton Creek to a more natural hydrological regime and reduces the potential for obstructions to upstream migrating Arctic Grayling and Chinook Salmon.

6. ***Acknowledged.***

Removal of Hudgeon Lake (CC3)

This option allows for fish passage to Upper Clinton Creek and returns Clinton Creek to a natural hydrological regime, as well as reduces the potential for obstructions to upstream migrating Arctic Grayling and Chinook Salmon.

However, there is potential for long term degradation of fish habitat within the area of Hudgeon Lake and in downstream waters. With Hudgeon Lake dewatered, the re-exposed lake bottom could be exposed to gullying and other forms of land slips/mass wasting, and once started this is very difficult if not impossible to control. If this *potential* effect occurred, sediments would be eroded and transported to the lower creek, where it would degrade the fish habitat. One question is how well we know the under-water environment of the lake; to date we understand it has not been very well characterized. CC3 may require long term maintenance of the Sediment Pond as it fills with sediments from upstream channel development and landscape processes.

7. ***Acknowledged; see also Response #4 above.***

Do plans for the removal of the lake include plans to construct sediment control ponds that allow the upstream passage of fish? From the report it appears that the entire creek flow will be routed through the sediment ponds during construction and after it. Please confirm.

8. ***That is correct; all of the flow is routed through the pond. The current concept assumes that this pond will be used until passive restoration of the former lake reservoir reduces sediment generation rates. Thereafter, the pond would be decommissioned. At this early stage of design, there was no consideration given to incorporating fish passage into the pond design. Incorporating this capability during future design development (should CC3 be selected) could likely be done without materially influencing the attributes, outcomes and costs of CC3.***

The lake removal option poses substantial short- and mid-term risks to fish habitat during construction. Feed to the ponds (one pond for bed-load material and one for suspended sediment) during construction will be implicitly controlled during summer storms through variations in the rate of pumping. One risk is that all water and sediment during spring freshet will be carried away as construction takes place.

The pond was designed using BC government guidelines. The Guidelines are found in *Technical Guidance 7, Environmental Management Act: Assessing the Design, Size, and Operation of Sediment Ponds Used in Mining, Version 1.0*. Are these guidelines more applicable to off-stream applications and land surface drainage, rather than to settling the entire flow of unregulated streams? Clinton Creek is given to short duration/high energy floods during which high volumes of sediment are carried. These can rapidly fill a pond. As a normal sediment retention time is related to its available volume, a pond of reduced volume is unlikely to meet the desired criteria.

9. ***As noted in Response 4, the CC3 concept assumes that this pond acts in concert with a nominal storage capability in the area upstream of the waste dump (i.e., by setting the final lake drawdown to eliminate the designation of the dump as a dam, but high enough to provide for some storage). The details of how these two storage capabilities (i.e., the residual upstream pond and the constructed sediment pond) are sized and operated would require assessment in future stages of design. The sediment pond in the current concept is intended to be generally representative of the pond size likely to come out of this assessment.***

Common elements related to fish and fish habitat for all CC options

Pumping

Of concern is point 4.1.6.2. Recognizing that this is early in the design process, the issue of anoxic water and the proposed mitigation requires consideration of both the upstream (i.e. at pump/pipe/siphon inlet) and downstream (pump/pipe/siphon outlet) ends of the structure(s). Upstream mitigations could include inlet designs to reduce the potential to draw anoxic water up to the pump. Outlet designs could include discharging the water into the air at the outlet to encourage the oxygenation of the flow.

10. ***Acknowledged. Detailed drawdown planning will need to consider the impacts of anoxic discharges, and the potential mitigative measures, in more detail. For the 10% design phase, Wood took the view that it is reasonable to assume that anoxic lake conditions will not be a determining issue in concept select, or have a major influence on execution costs.***

Residual flows

It is unclear whether a residual flow will be left in Clinton Creek for the resident fish – in this case limited to Slimy Sculpin – or for the migratory Arctic Grayling and juvenile Chinook Salmon. When DIAND drew down the lake to place the gabion structures in 2003, we understand they cut off the residual flow to the lower creek. They used electrofishers and other methods to attempt salvage of the fish in the Canyon. The work was conducted under license and in a professional manner. At the time, the canyon was considered to be safe to work in. They captured in excess of a thousand fish. However, the coarse rock in the stream bottom in the canyon provided cover for many more fish. These fish remained in the creek and died when the flow was cut off. In 2004, DIAND provided residual flows and no dead fish were observed. The message here is that fish cannot be successfully salvaged in the canyon, and that any works that call for the fish to be salvaged there should not proceed.

One suggestion that TH has received from our consultant is that there needs to be an obstruction to the upstream migration installed below the canyon prior to starting any construction. The obstruction should be multi-year and be placed in the autumn. Fish will pass over it on their downstream migration but will not be able to ascend past it the following spring. Slimy Sculpin are vulnerable to minnow trapping with salmon roe bait. Any remaining above the obstruction could be trapped in the spring and released below it. As a final point, potentially anoxic lake water discharged above the obstruction would have a better chance to re-oxygenate in the channel above the obstruction.

11. ***Acknowledged. This 10% design phase has not considered measures required to mitigate impacts to local fisheries during execution. This would be among the many issues that will need to be considered during future design development (post concept select) and detailed execution planning.***

Drawdowns

All options require the drawdown of the Lake at some point. Section 4.1.4.1 goes into this in some detail, particularly in describing how the lake will shrink in volume as the multi-year drawdown occurs. However, the potential for environmental constraints (anoxic water, sediment entrainment) to the rate of drawdown is not addressed. This is of some concern as the plan seems to have the Lake drawn down early in the season when the annual de-gassing of the water may not have been completed.

12. ***Acknowledged. The report acknowledges (Section 7.1.2.5) that more detailed drawdown planning will need to consider a variety of geotechnical and economic issues, and that the outcomes of this planning will have significant influences on execution plans, schedules and costs. The comments in Section 7.1.2.5 have been expanded to note that drawdown planning will also need to consider a variety of environmental issues/constraints (more detailed review of downstream water quality impacts; mitigation of fisheries impacts during execution).***

Beavers

The damming of the channel inlet at the lake is a potential issue for the Retention- and Lowering of the Lake options. Beaver can swiftly build a dam and have done so at lake outlets. When lake outlet dams break, catastrophic releases of water may occur. In 2000 McKenna et.al. stated:

"The program confirmed that beaver activity, especially dam building, has a profound effect on the natural landscape. Beaver dams block streams and lake outlets, attenuate flows, divert streams, flood large areas, trap sediment, create beaver meadows, trigger landslides, and significantly alter the boreal forest ecology. Beaver dams can reach three to four metres high and be over a kilometre long - no stream is too small to dam and few rivers are too large. Large dams can be constructed in just a few days and can be repaired overnight. Beaver colonies can consume up to a hectare of deciduous forest per year and a beaver pond can affect tens of hectares of forest. Outburst flooding of abandoned beaver dams has caused numerous cases of damage to infrastructure."

McKenna is still active in mine reclamation, and may be able to provide input. His website is: https://gordmckenna.com/pdf/McKenna_MGI_CV_Resume_2019.pdf

13. ***Acknowledged. Identification and mitigation of beaver dam impacts will need to be included in the scope of future design development activity and detailed execution planning. Alternatively increased beaver habitat could be viewed as a positive by local stakeholders.***

Closure Option Designs - Wolverine Creek

WC2 - Failure During Seismic Event

According to the Geotechnical Summary (Aug 19) the WC2 buttress, as proposed, would fail under the design seismic event, even if the tailings remained unsaturated. If the tailings were to partially saturate, the seismic vulnerability would be even greater. This could probably be addressed by the construction of a larger buttress, but that would also increase the cost. All things considered, we question the viability of the WC2 design.

In the Geotechnical Summary another variant of the WC2 is discussed, called LCAA Option E, which involves regrading the tailings to a constant 3.75:1 slope. LCAA Option E has slightly better seismic stability than the buttress option, but is still vulnerable to seismic failure from the design seismic event, which is not the largest earthquake that could happen in the long- term (the Maximum Credible Earthquake, the theoretical 1 in 10,000 year seismic event). The design earthquake used for geotechnical analysis is the 1 in 2,475 year event.

14. ***The geotechnical position is that much of the upper portion of existing tailings is unsaturated to a sufficient level to be considered non-liquefiable. But the possibility of a relatively thin saturated zone at the tailings / original ground level cannot be discounted. In addition, as stated in design report predicting future hydrogeology of the tailings is not realistic.***

Porcupine Pit

The top of Porcupine Pit Storage Structure should be sloped to minimize storm water infiltration. This is essentially an upstream dam, and potential static and seismic failure need to be carefully investigated. Much of the waste material is known to decompose, so this poses another long-term stability risk that should be considered by the designers.

> ***15.** Future design development for the Porcupine Pit Storage Structure (PPSS) will need to consider measures for managing local surface waters (i.e., perimeter drainage, drainage/erosion controls on the structure, landform designs for PPSS slopes), and the associated influences on the physical integrity and stability of the final facility. Wood is not of the view that degradation rates of the placed and compacted material will be sufficient to compromise long term stability, but the issue will be considered during detailed design development. Nevertheless, Wood is not suggesting that natural earth materials will last "forever". If tailings and wastes must be removed to execute the Option selected by the Project Partners then the PPSS is the logical place for disposal versus any of the other options.*

Design Decision Logs

Both the Clinton Creek and Wolverine Creek Design Decision Logs appears to have Remarks and Rationale boxes with truncated texts. More space has been suggested so that the entire text can be viewed.

> ***16.** Spacing has been expanded in the final document.*

Comparative Assessment of Candidate Closure Options Table

There appear to be some issues with the "Comparative Assessment of Candidate Closure Options" table contained in Section 8 of the report. While it is appreciated that Wood has provided some input in this regard, which is helpful, it important to note that certain table headings and distillation of the objectives has not occurred between the project partners, and it is potentially misleading how certain objectives have been summarized.

> ***17.** Acknowledged. Section 8 was envisaged partly as a vehicle for summarizing the design assessments detailed in previous sections, and partly as a platform to outline Wood's perspectives on the relative attributes, outcomes and risks of the options. In the introduction to Section 8, we attempted to qualify this presentation by noting that it represents Wood's opinions, offered as input to the Partners' deliberations and recognizing that the Partners will be considering factors and criteria that go beyond the largely technical and economic considerations that are reflected in Section 8. Further, Section 8.1 notes that the comparative criteria used were a combination of the Partners' project objectives modified and informed on a subjective basis by Wood's understanding of the evolution of the project over the last couple of years. Again, these criteria were not intended to supersede the prescribed Partner objectives, but rather as a vehicle for presenting Wood's conclusions relating to the candidate options.*

Working from left to right, questions/comments from TH about this table include:

1) "Utility of Harvested Natural Produce and Wildlife" is read to imply that Wood has characterized the value of this harvest to harvesters… in that regard, it could be high or low depending on the harvester, so perhaps it would be best to say "neutral" in this regard, as we understood the HHERA has indicated that harvest is safe from this area?

   18. The term medium has been replaced by neutral in the table.

2) Impacted to "Current" Fish Habitat – If the word "current' is removed from this objective results are different. The word "current" is NOT in the closure objectives so we are unclear why it is added here.

   19. The term current has been deleted from this portion of the table.

Drawings

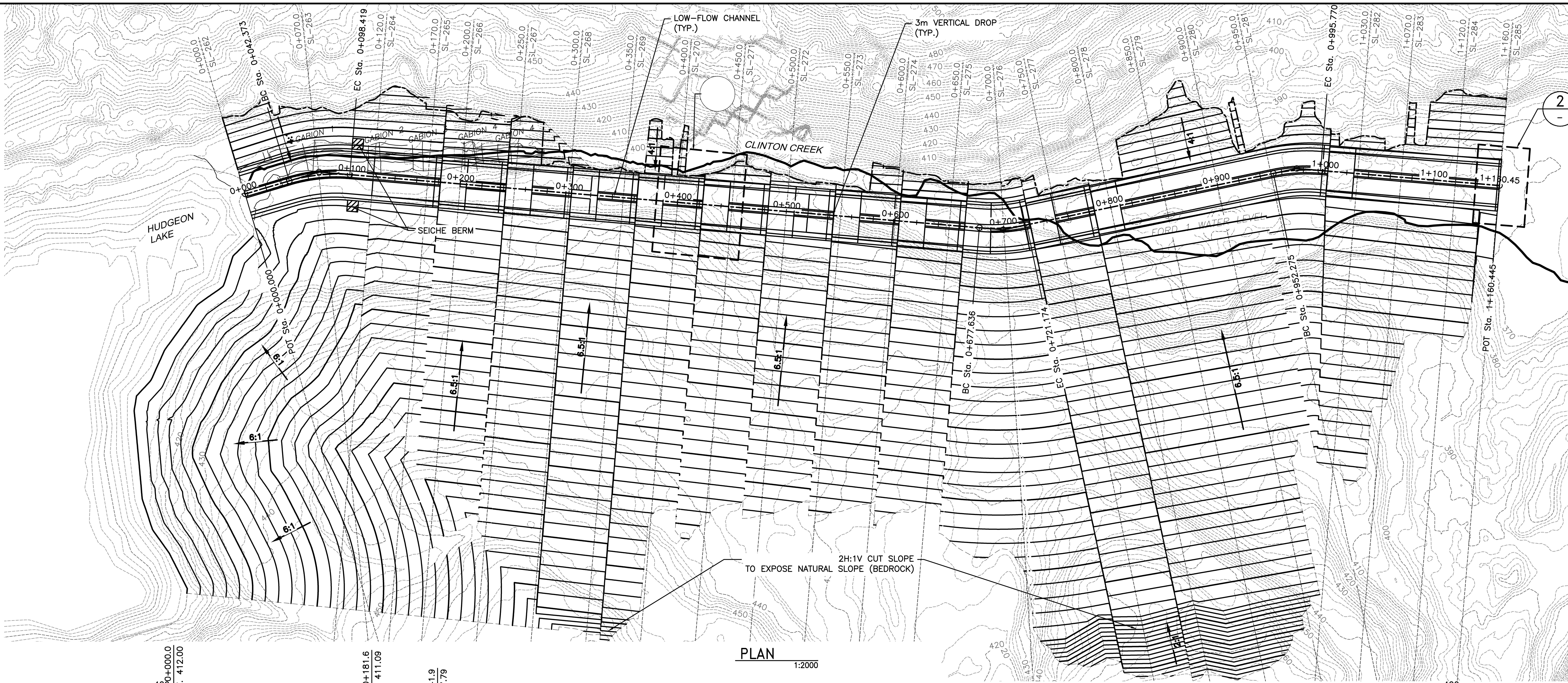
CC2 drawings – although this is only the 10 % Design Phase, detailed drawings are provided in the package, drawings that appear to have taken considerable time and resources to produce. CC2 partial drawdown is a closure solution that will enable fish passage and as such requires a low water channel flow, yet the drawings DO NOT incorporate a V configuration at the bottom of the spillway as per what we understood were accepted suggestions from Fisheries Habitat biologist Al von Finster… this omission should be corrected on CC2 drawings going forward.

20. The CC2 regime channel has a bottom width of 4 m so it would be difficult to create a low flow channel with rock armouring in such a narrow channel. The design has not taken into consideration some of the finer details of designing for fish passage. Detailed design could incorporate a thalweg and resting pools for fish. The final design could also incorporate a gravel bed and other features to aid in fish passage and habitat. The design of these details require input from fish biologists and is beyond what Wood considers the scope for 10% design.

If you have any questions about the above comments please contact TH Natural Resources' Special Project Coordinator, Bill Kendrick, at bill.kendrick@trondek.ca.

Drawings

CC1 (Lake Retention)



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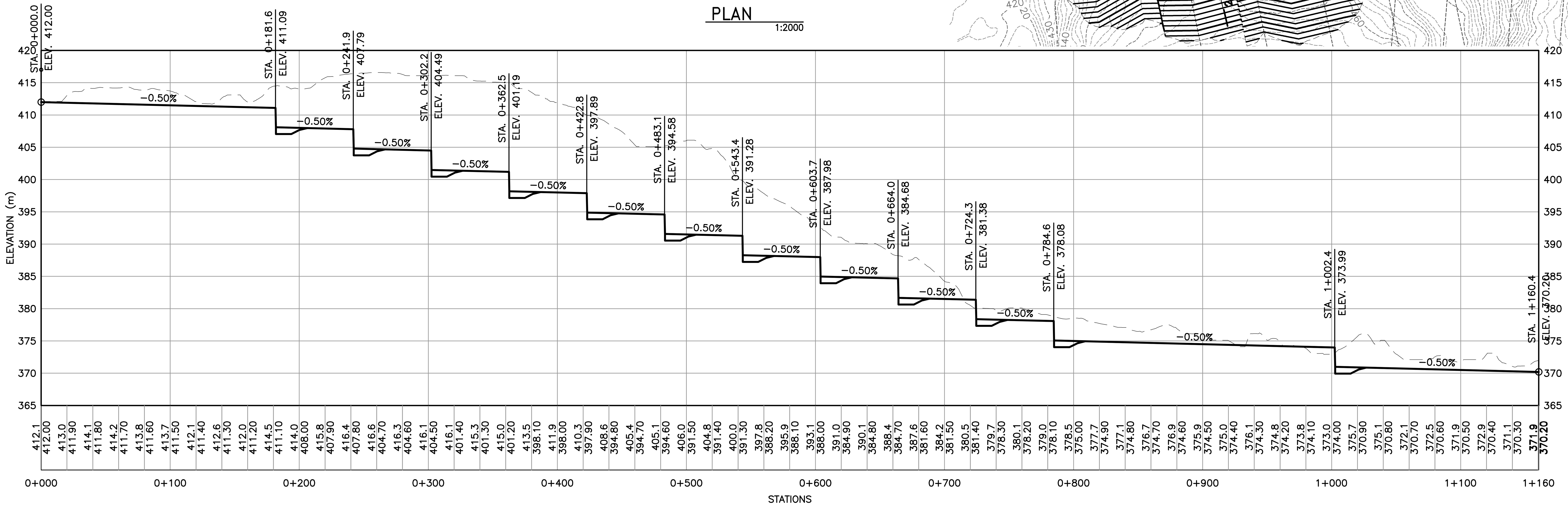

PROFILE VIEW
HORZ 1:2000/ VERT 1:400

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3	VE52705E.CC1.4	CROSS SECTIONS - SHEET 2 OF 2
2	VE52705E.CC1.3	CROSS SECTIONS - SHEET 1 OF 2
1	VE52705E.CC1.2	SECTIONS / DETAILS

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	20JUN2019	ISSUED FOR REVIEW	LB	MH				

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PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS SHOWN

	BY	DDMMMYY
DES	KB	24JUN2019
DRN	LB	24JUN2019
CHK	MH	24JUN2019
APP		

Yukon

wood.

SUBJECT: CLINTON CREEK REMEDIATION PROJECT OPTION CC1 (LAKE RETENTION) PLAN AND PROFILE

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.CC1.1

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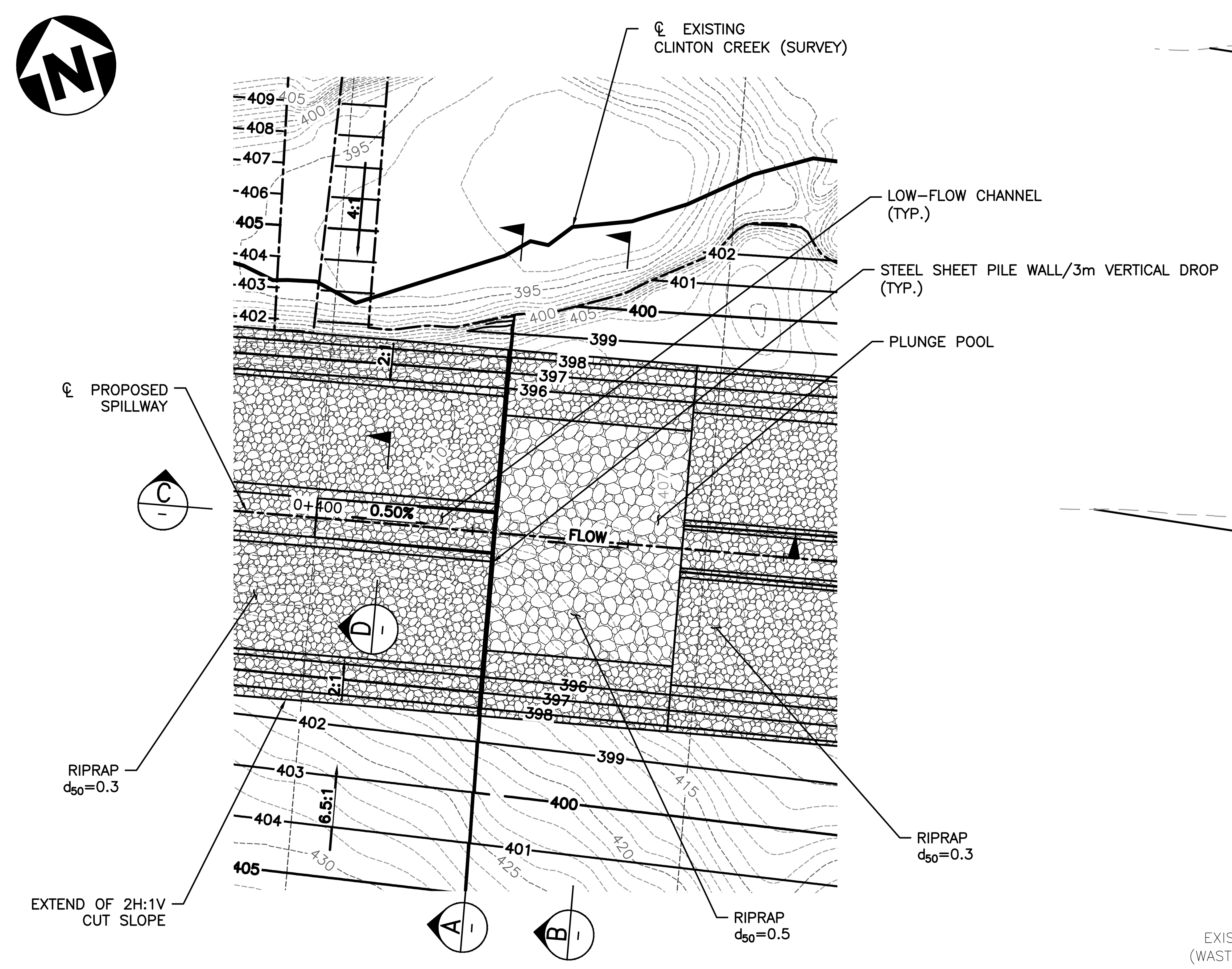
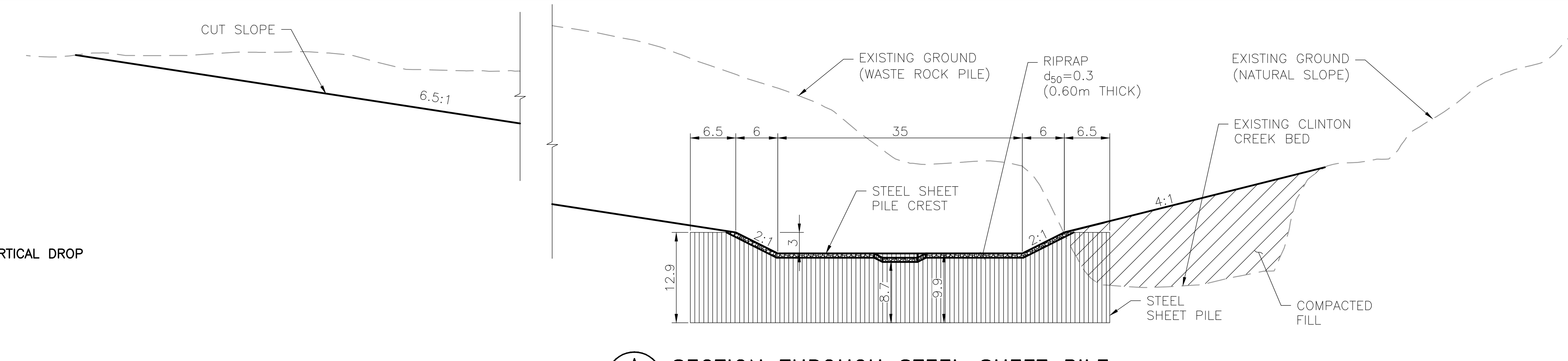
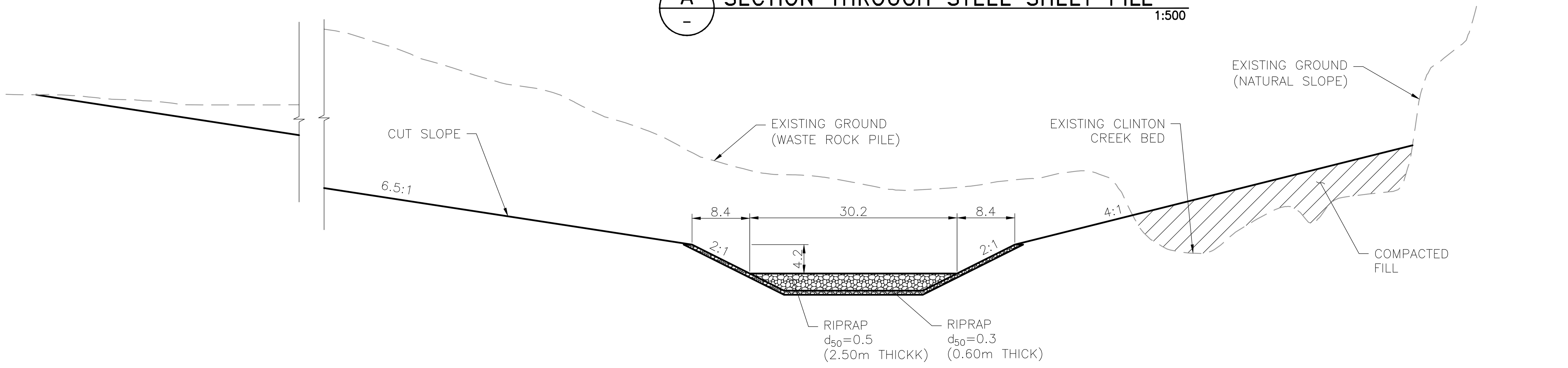


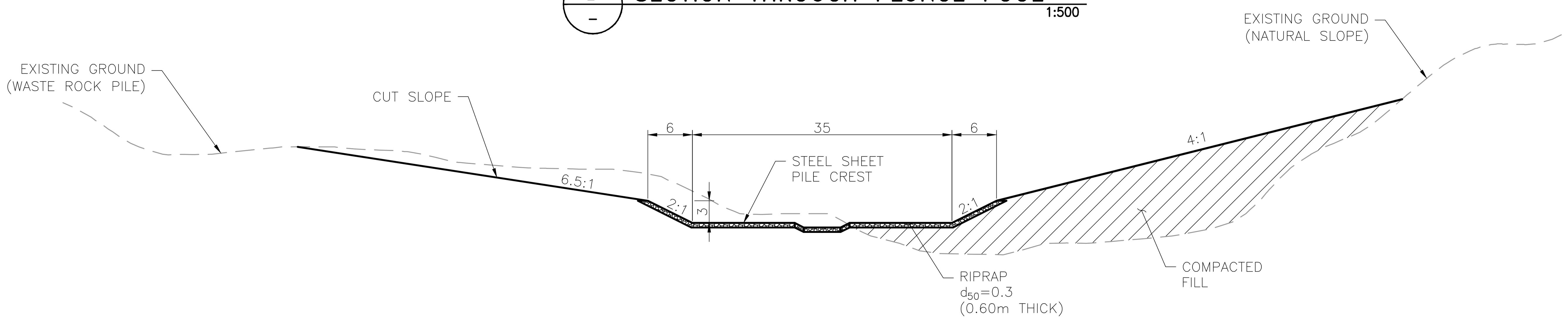
1 DETAIL – TYPICAL STEEL SHEET PILE DROP STRUCTURE 1:500



A SECTION THROUGH STEEL SHEET PILE 1:500



B SECTION THROUGH PLUNGE POOL 1:500



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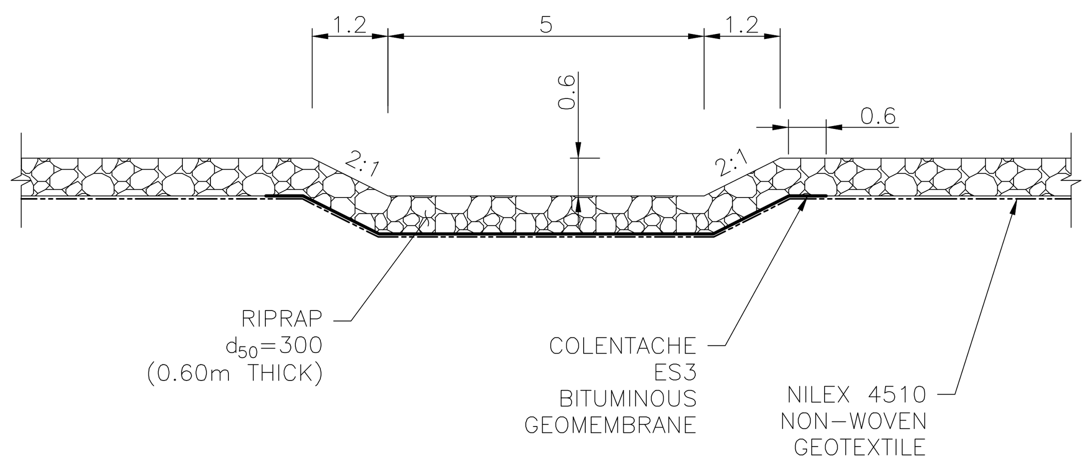

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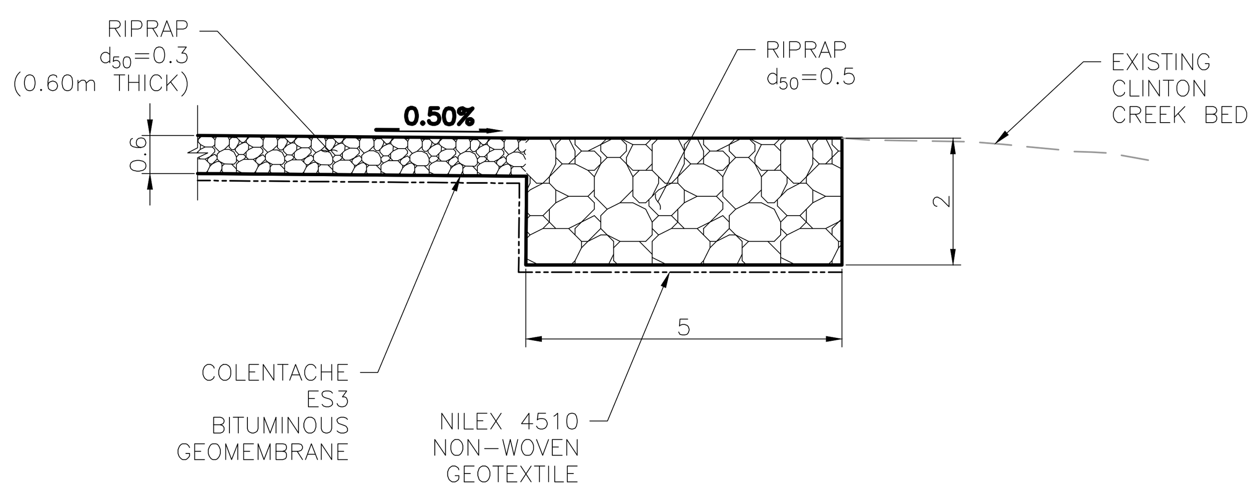
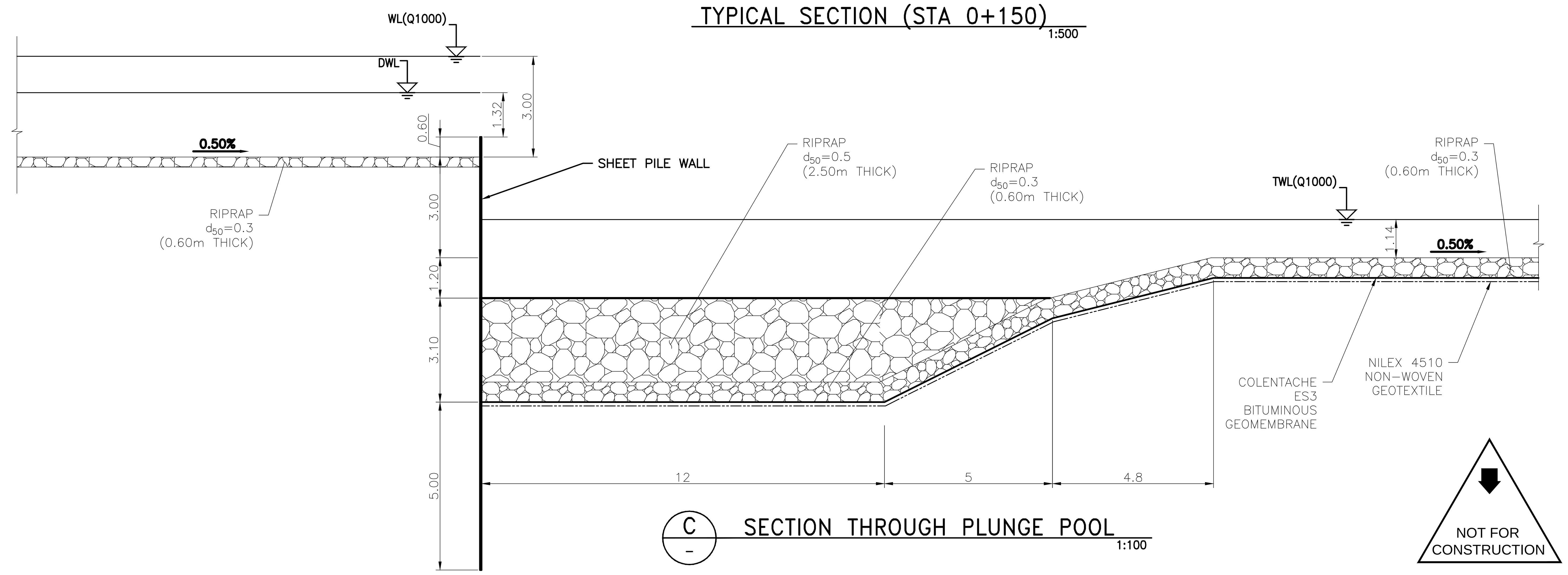


2 PROFILE THROUGH SPILLWAY TOE KEY IN TO BED 1:100



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A	20JUN2019	ISSUED FOR REVIEW	LB	HM				

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2	VE52705E.CC1.3	CROSS SECTIONS - SHEET 1 OF 2
1	VE52705E.CC1.1	PLAN AND PROFILE

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VE52705.100.2	DES	KB	24JUN2019
	DRN	LB	24JUN2019
SCALE: AS SHOWN	CHK	HM	24JUN2019
	APP		

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SUBJECT: CLINTON CREEK REMEDIATION PROJECT OPTION CC1 (LAKE RETENTION) SECTIONS & DETAILS

wood.

AREA

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DRAWING NO. VE52705E.CC1.2 REV A

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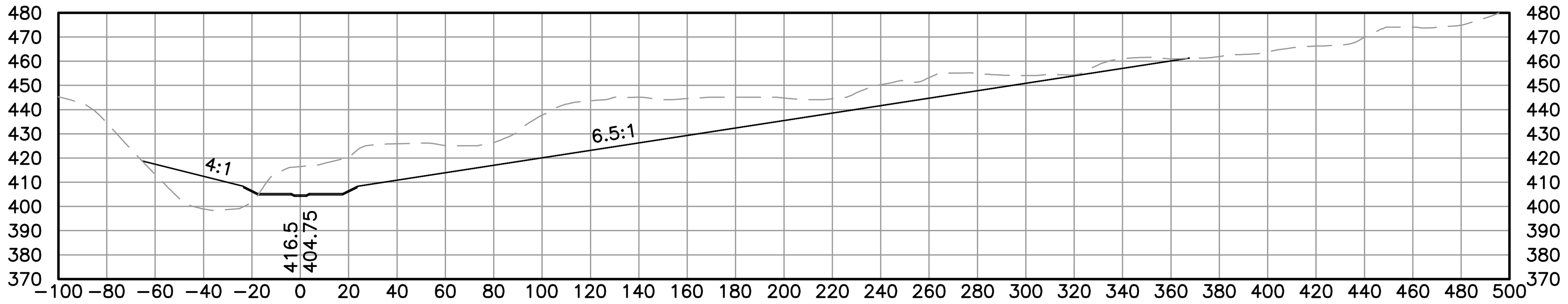

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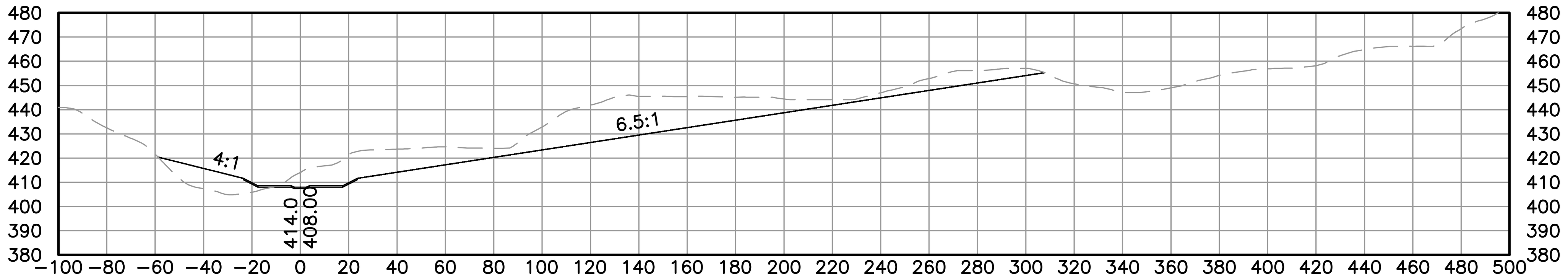

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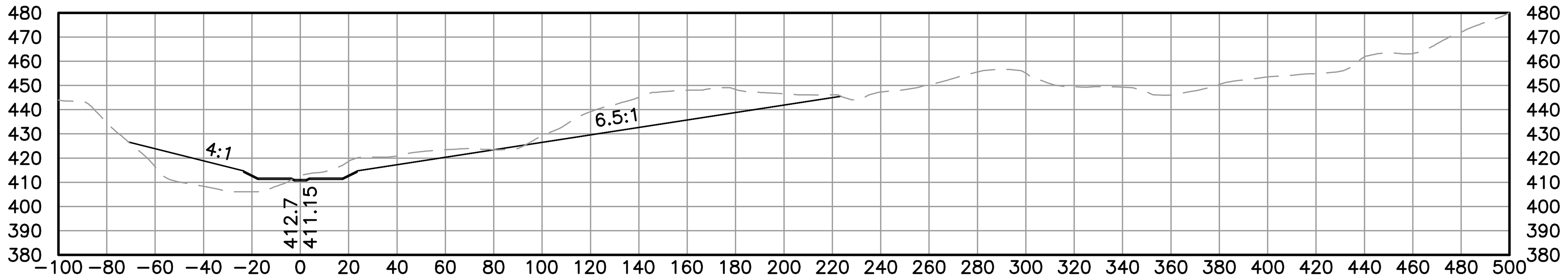

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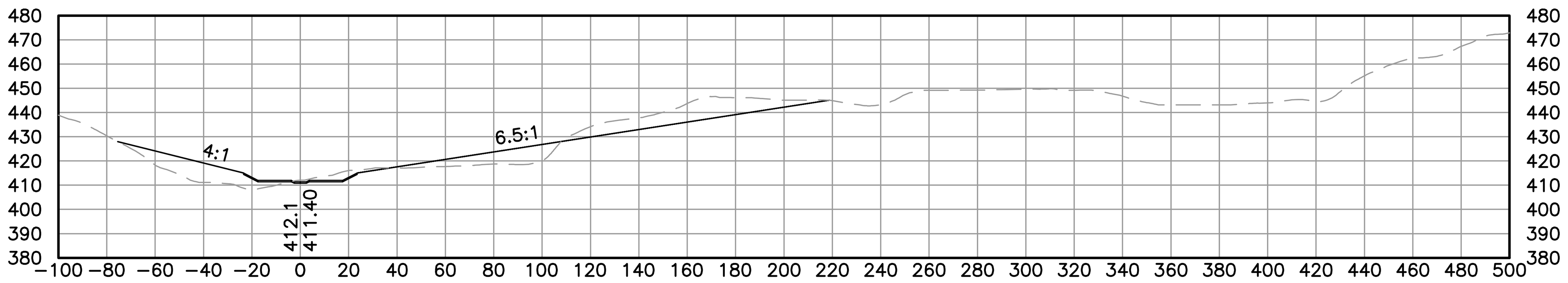

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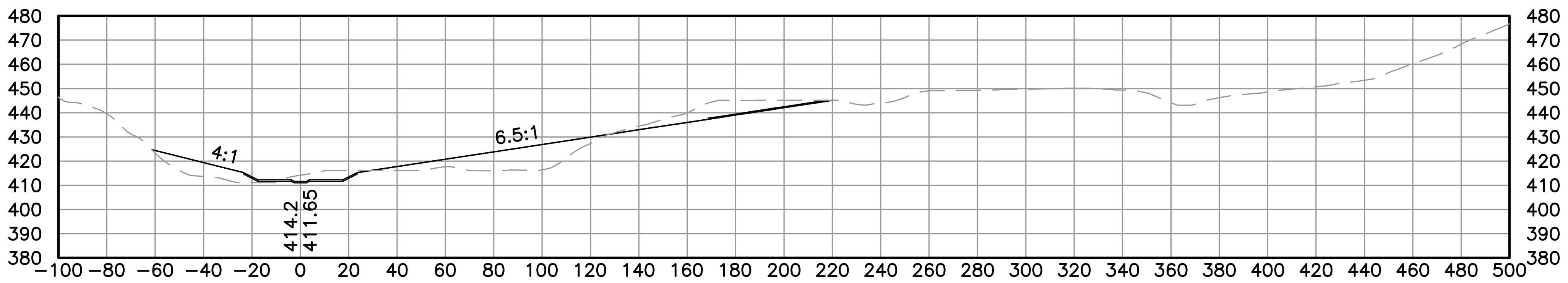

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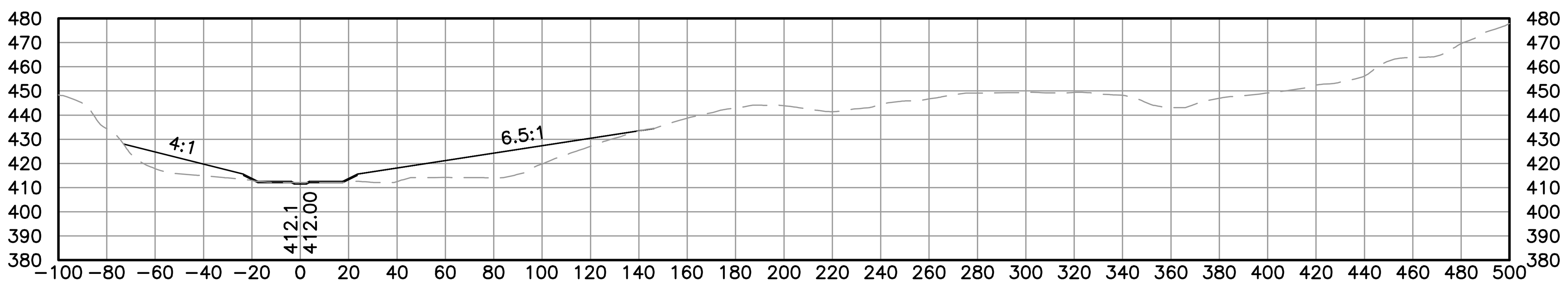

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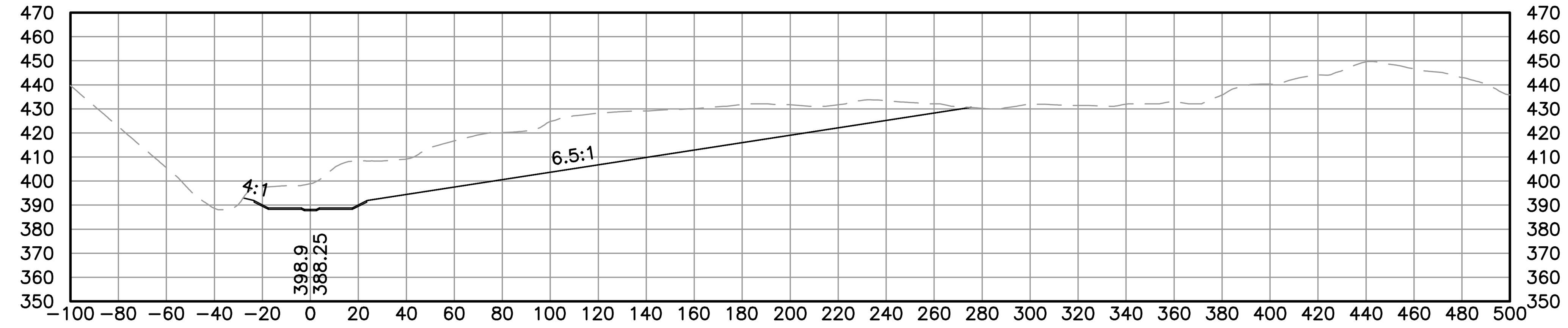

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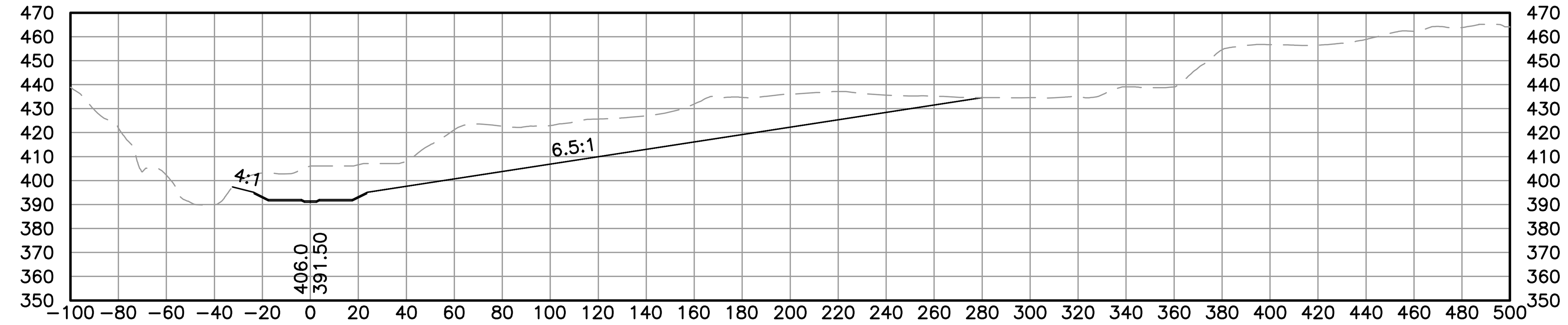

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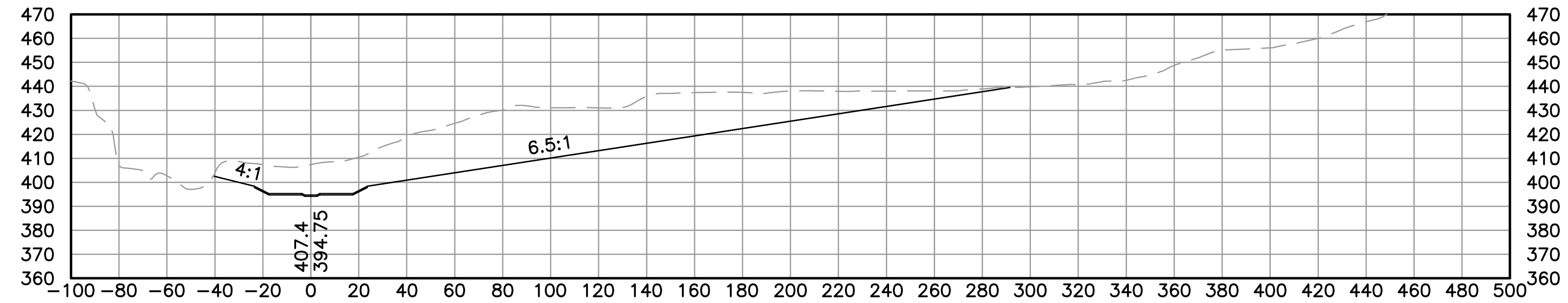

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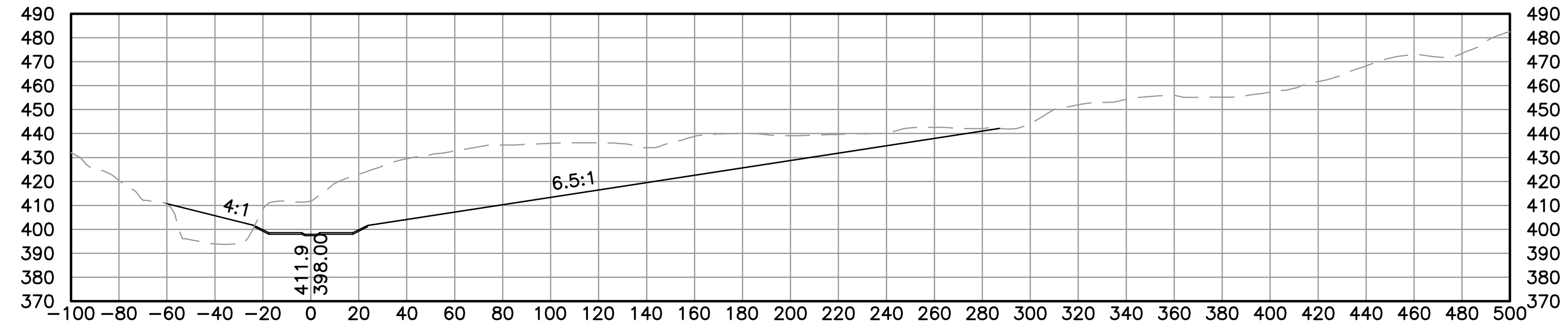

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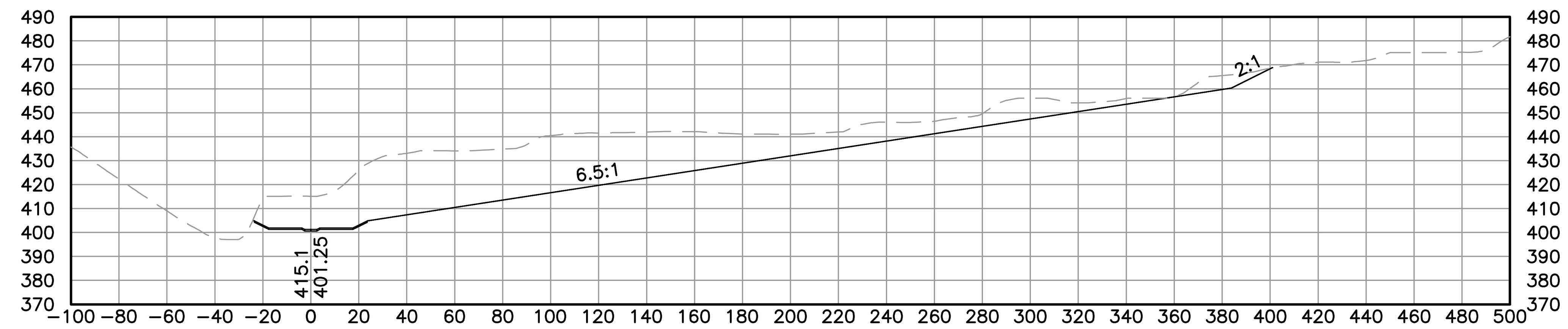

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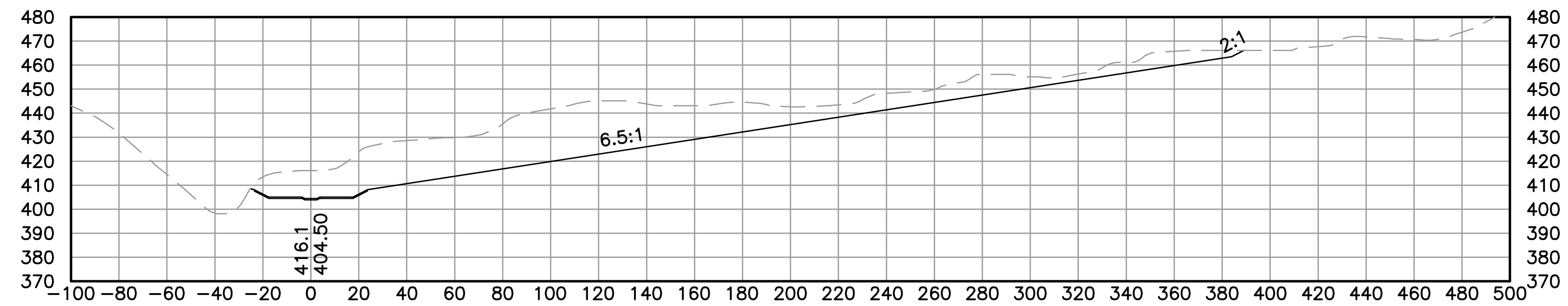

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2	VE52705E.CC1.2	SECTIONS / DETAILS
1	VE52705E.CC1.1	PLAN AND PROFILE

REFERENCES

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PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: 1:2000

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DES	KB	24JUN2019
DRN	LB	24JUN2019
CHK	MH	24JUN2019
APP	MH	

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION CC1 (LAKE RETENTION)
CROSS SECTIONS - SHEET 1 OF 2

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.CC1.3

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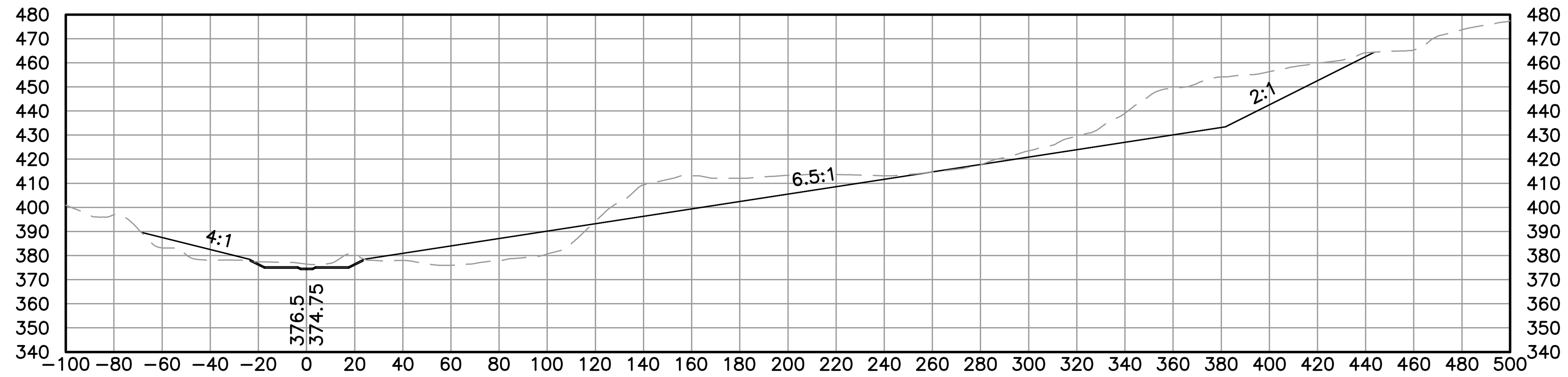

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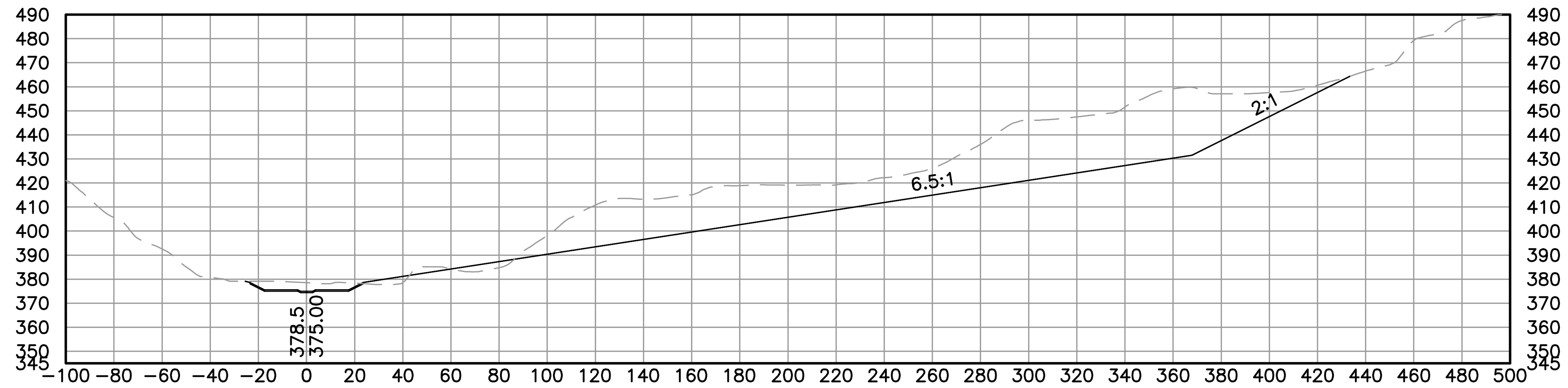

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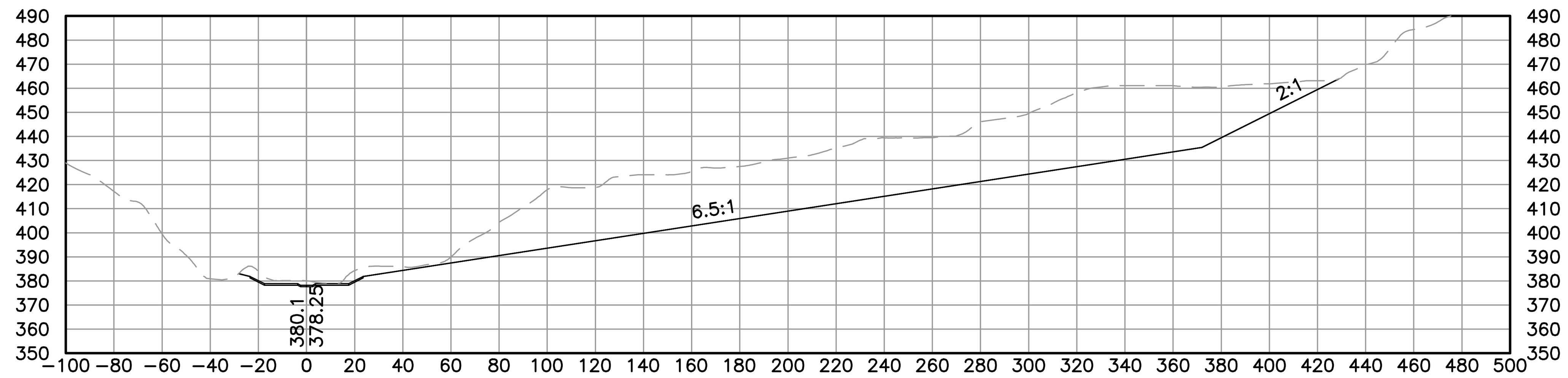

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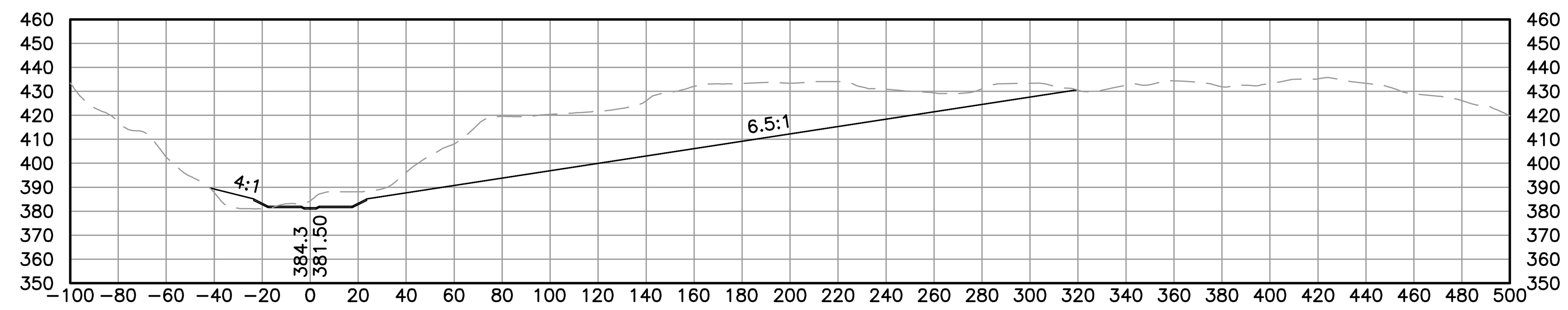

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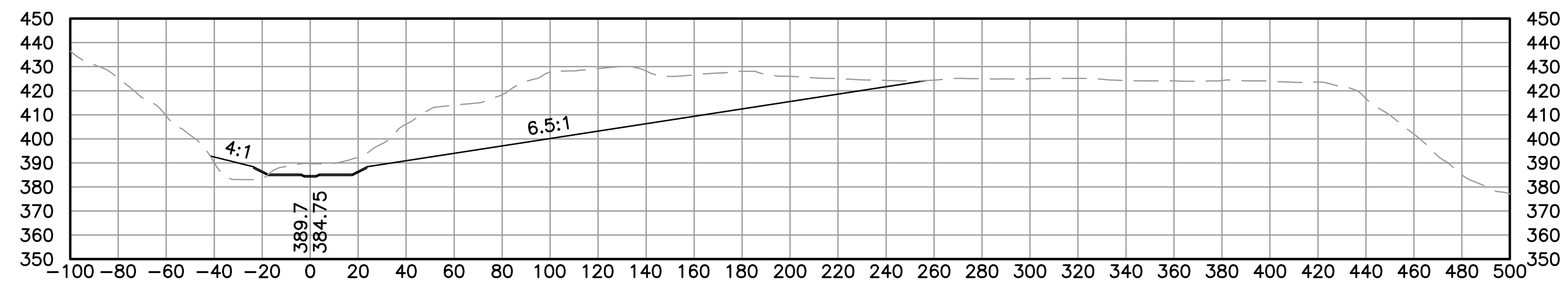

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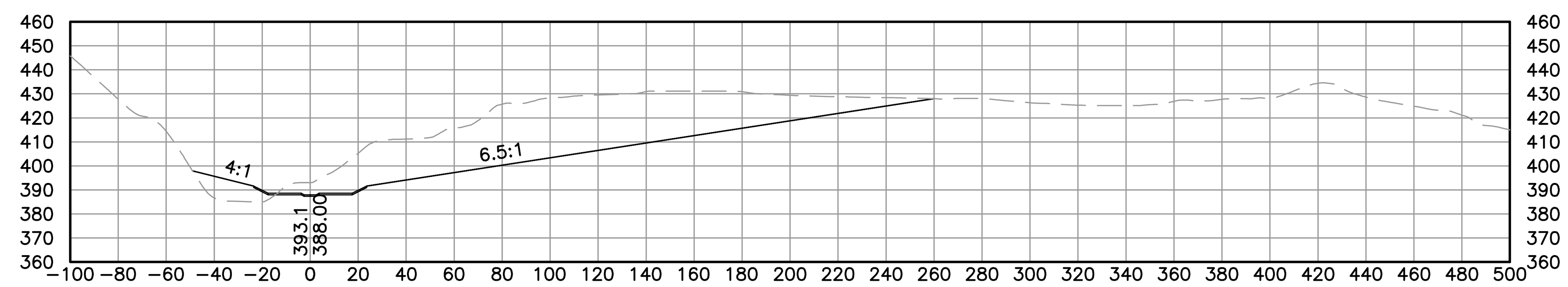

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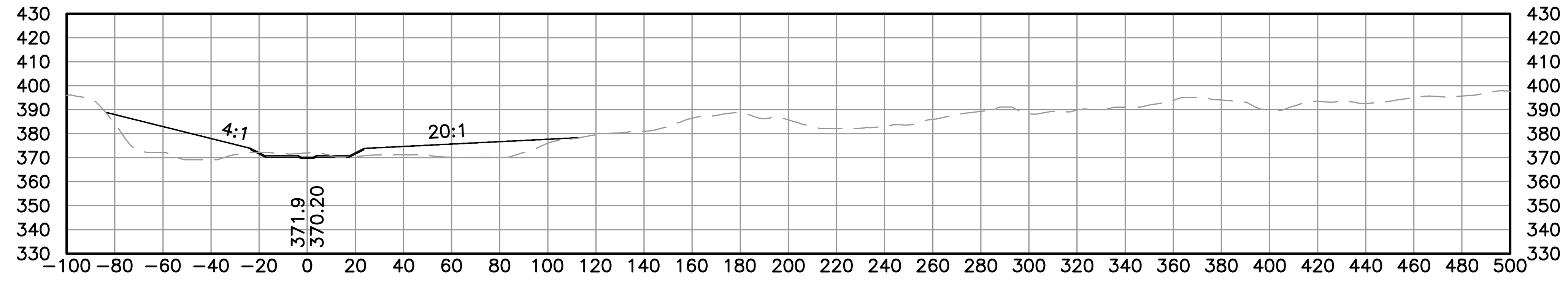

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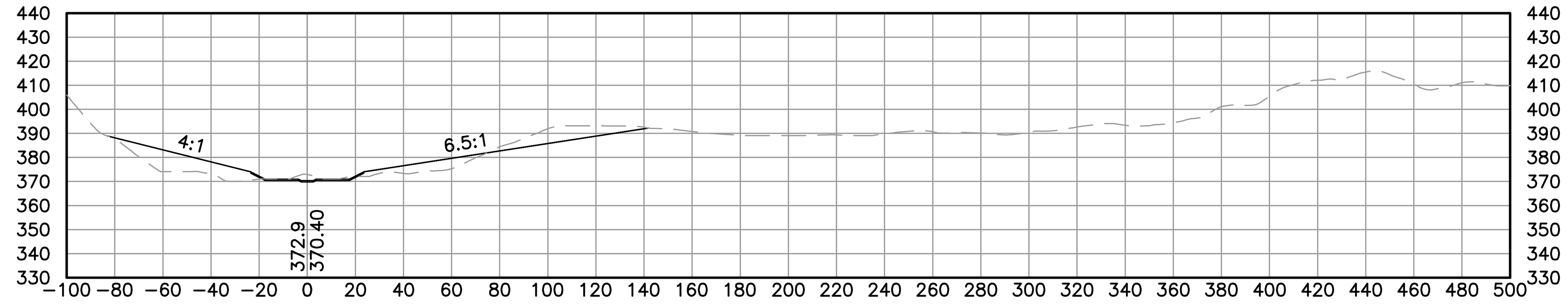

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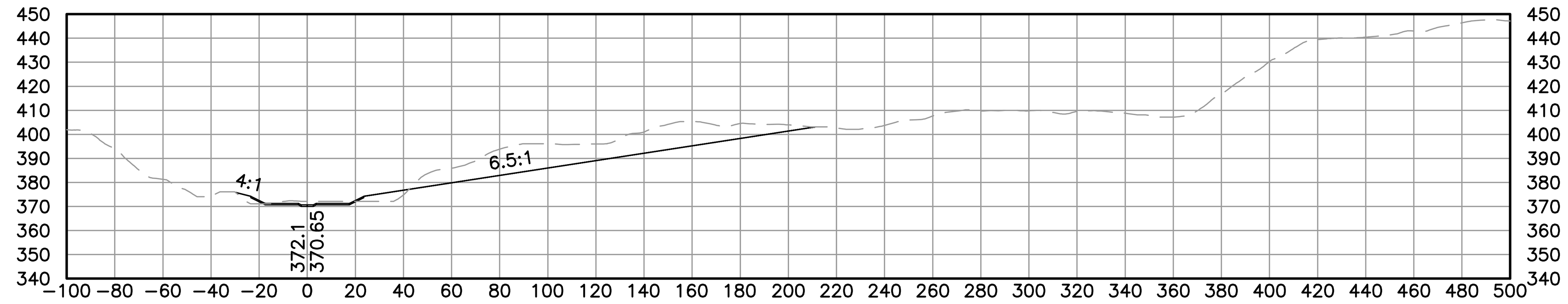

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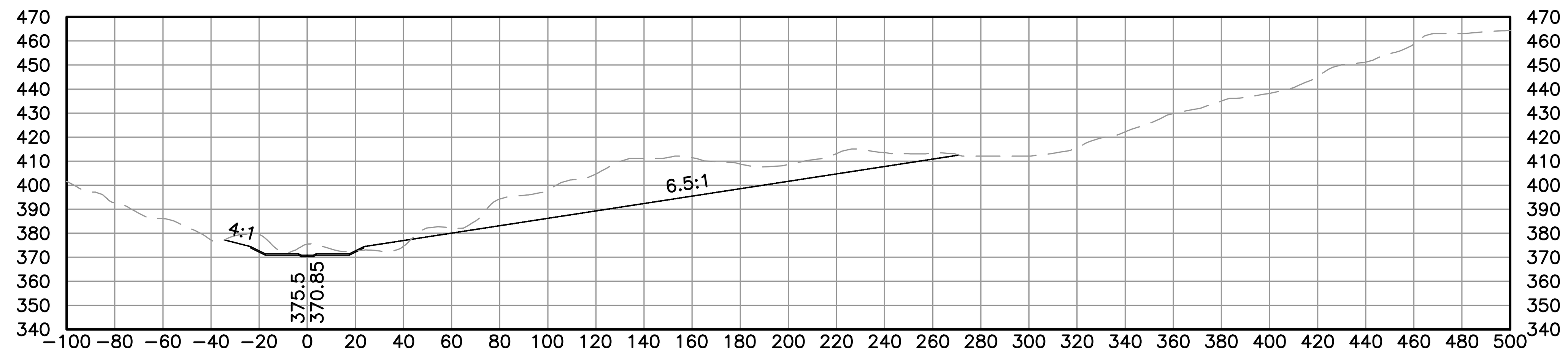

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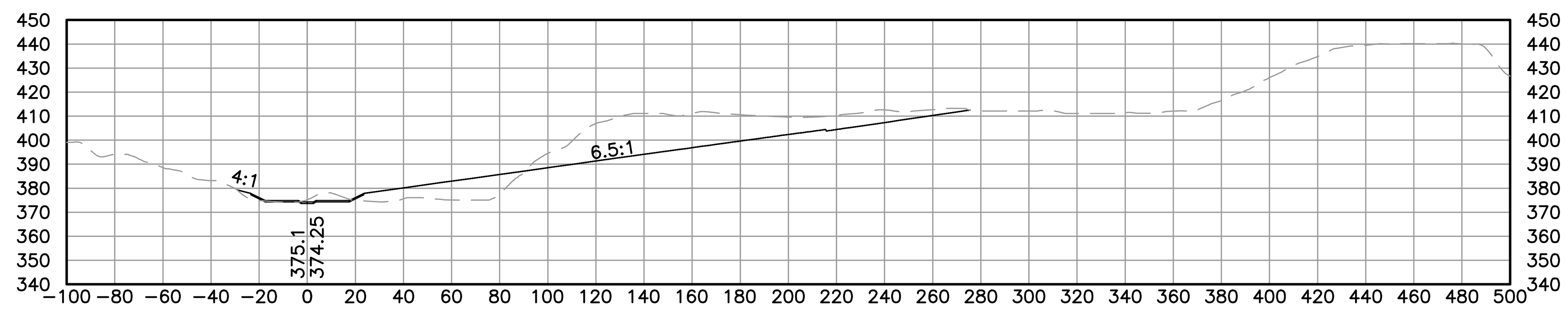

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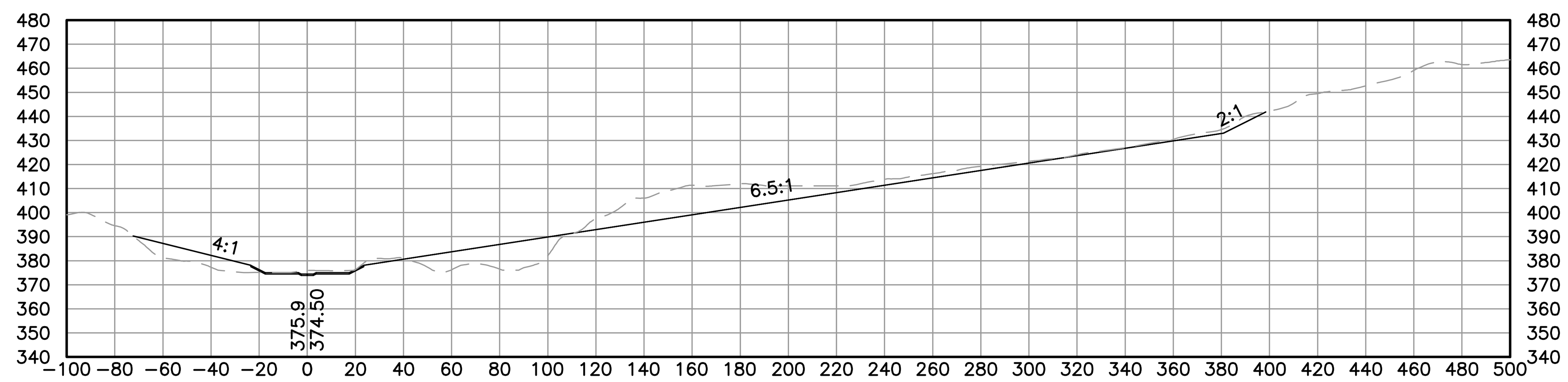

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REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	24JUN2019	ISSUED FOR REVIEW	LB	MH				

REF	NUMBER	TITLE
3	VE52705E.CC1.3	CROSS SECTIONS - SHEET 1 OF 2
2	VE52705E.CC1.2	SECTIONS : DETAILS
1	VE52705E.CC1.1	PLAN AND PROFILE

REFERENCES

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PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: 1:2000

	BY	DDMMMYY
DES	KB	24JUN2019
DRN	LB	24JUN2019
CHK	MH	24JUN2019
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SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION CC1 (LAKE RETENTION)
CROSS SECTIONS - SHEET 2 OF 2

wood.

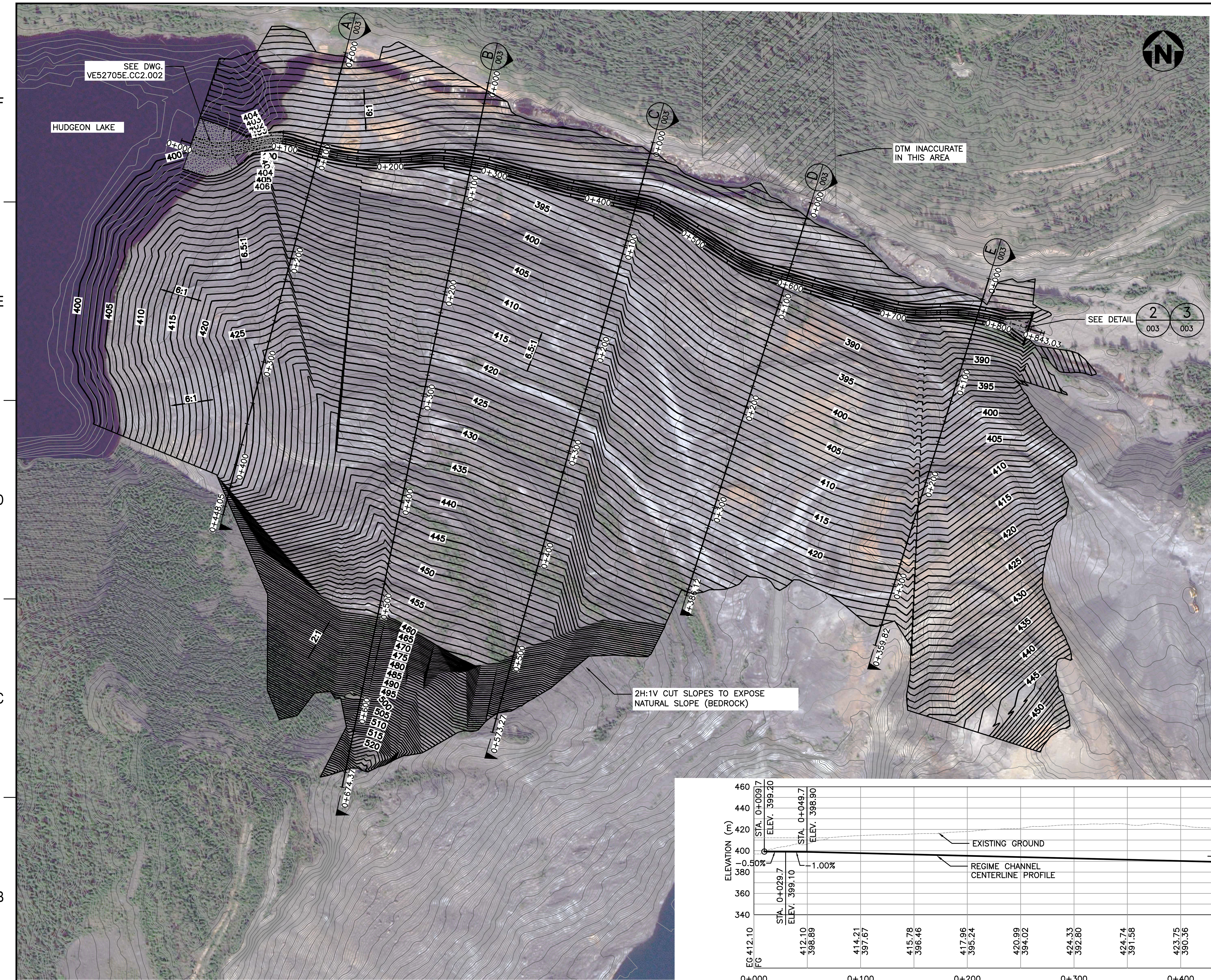
AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.CC1.4

REV: A

CC2 (Lower Lake with Regime Channel)



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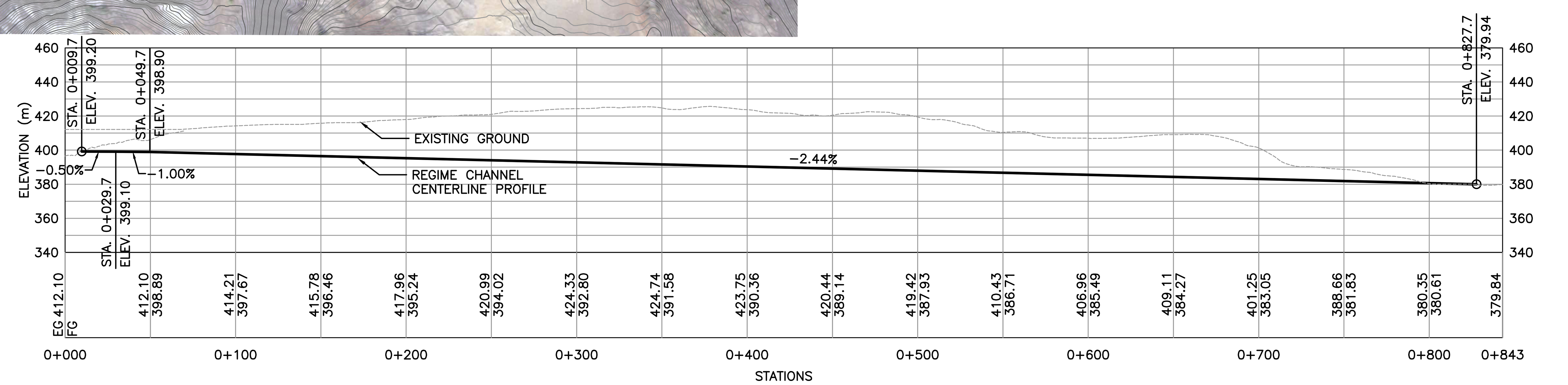

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REFERENCES

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PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: 1:2000

	BY	DDMMMYY
DES	GG	10JUL19
DRN	JM	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT
CLINTON CREEK REMEDIATION PROJECT
OPTION CC2
(LOWER LAKE WITH REGIME CHANNEL)
PLAN AND PROFILE

wood.

AREA

CLIENT DWG NO.

DRAWING NO. VE52705E.CC2.1 REV

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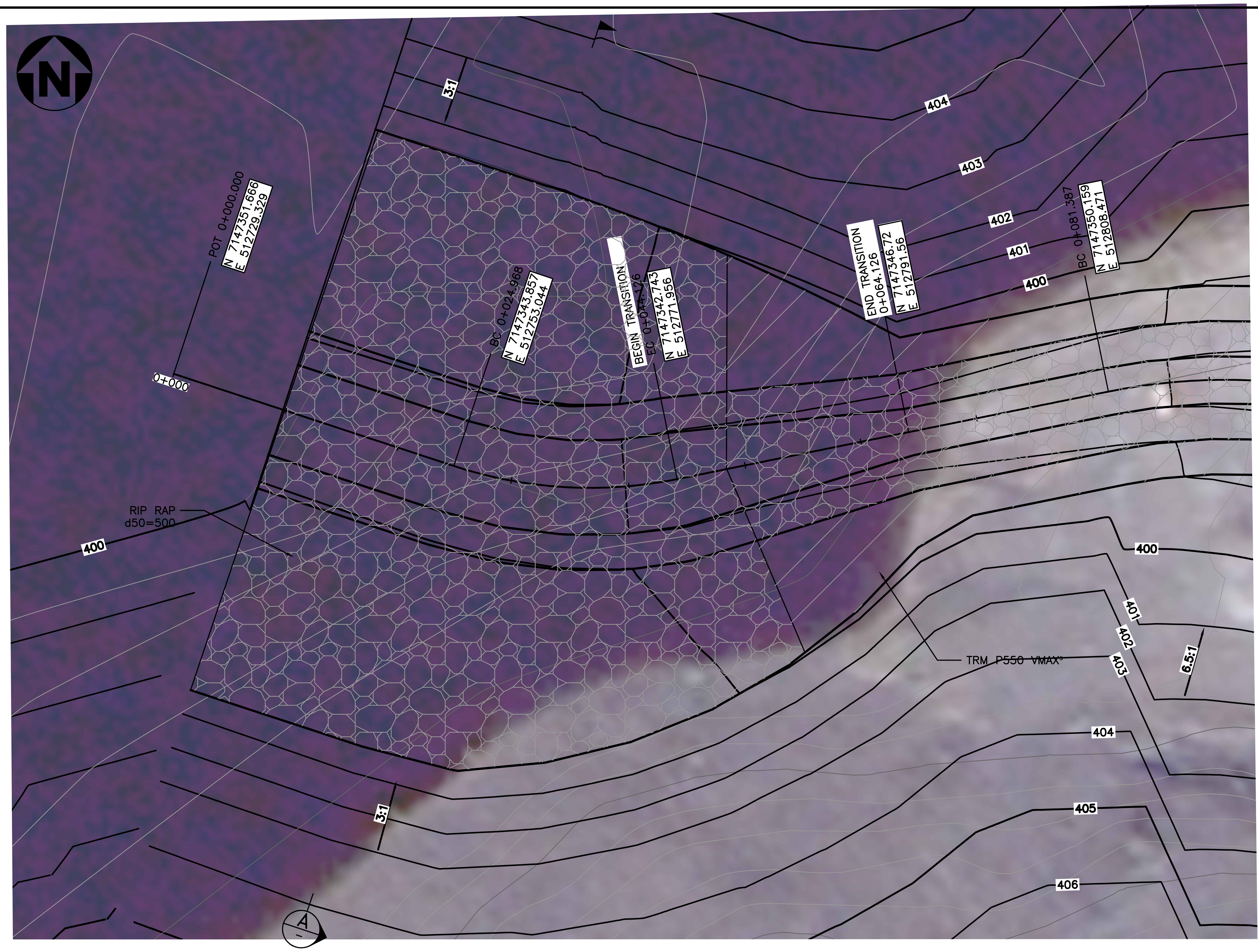

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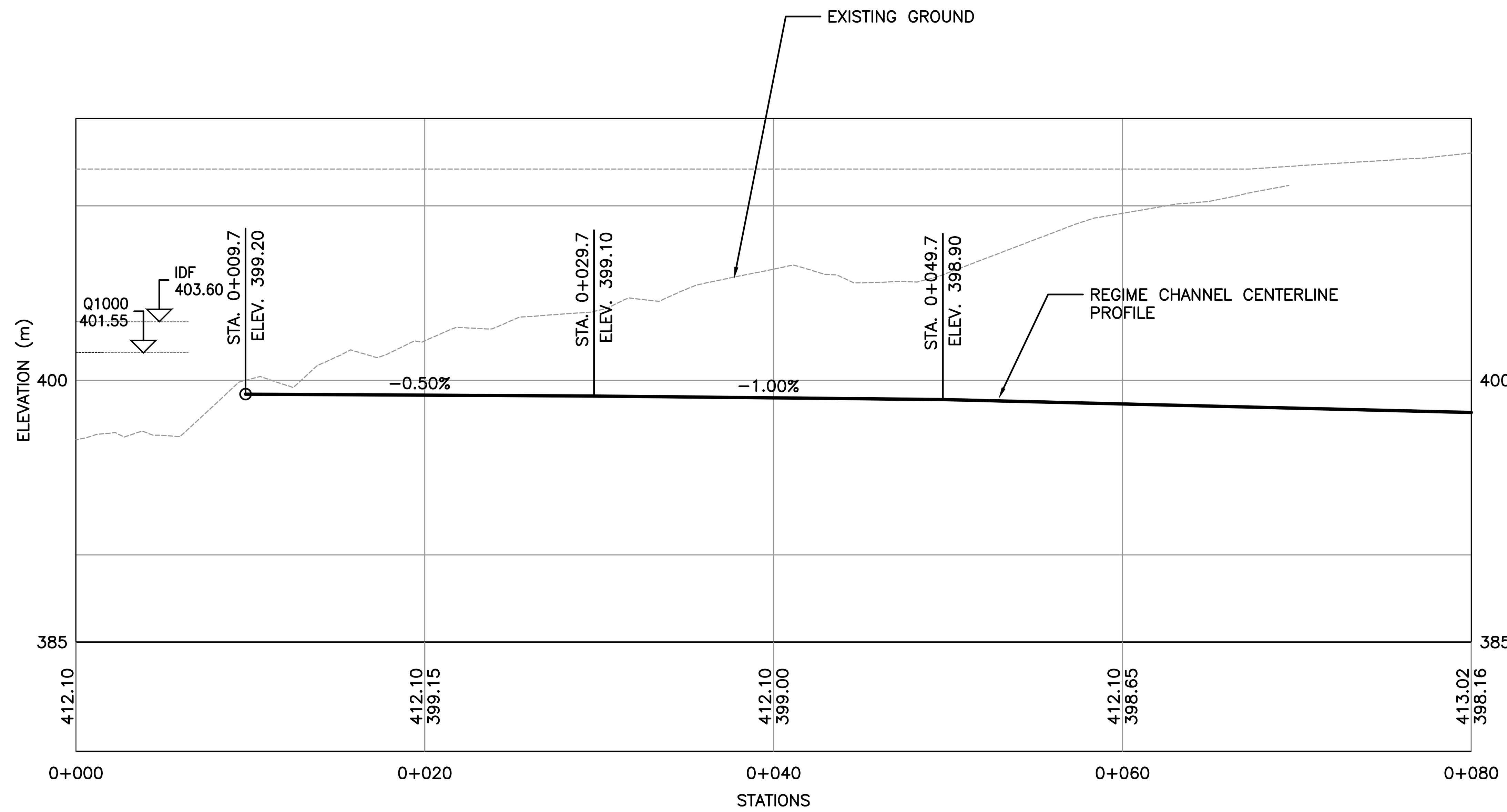

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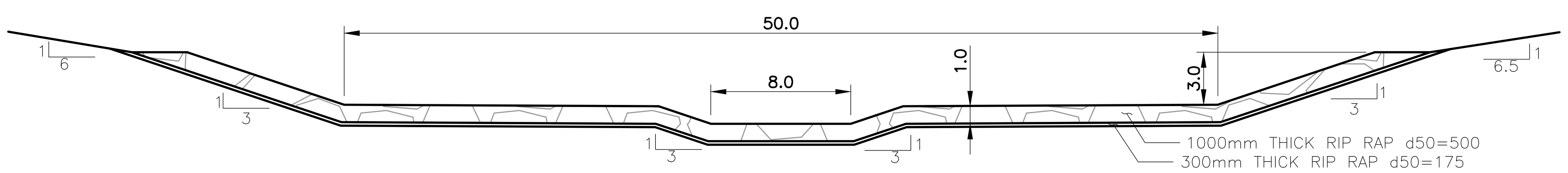

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REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	GG	10JUL19
DRN	JM	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT
CLINTON CREEK REMEDIATION PROJECT
OPTION CC2
(LOWER LAKE WITH REGIME CHANNEL)
REGIME CHANNEL INTAKE

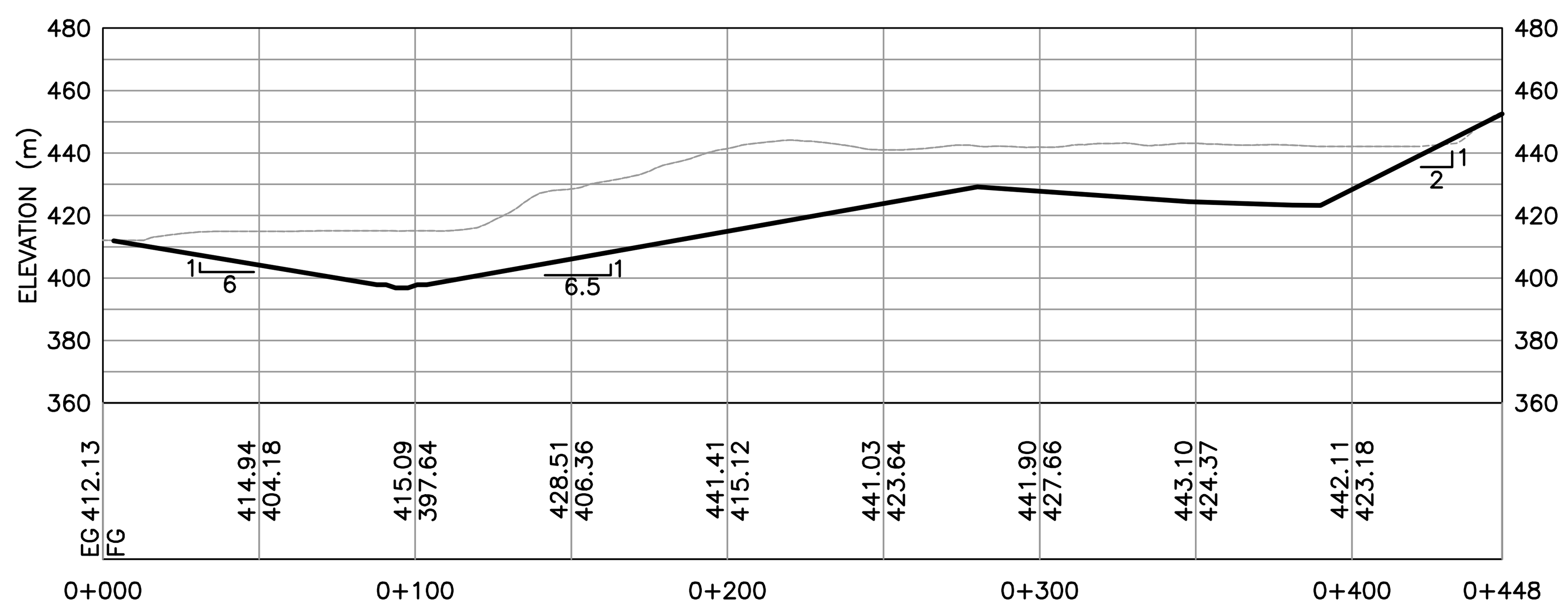
wood.

AREA

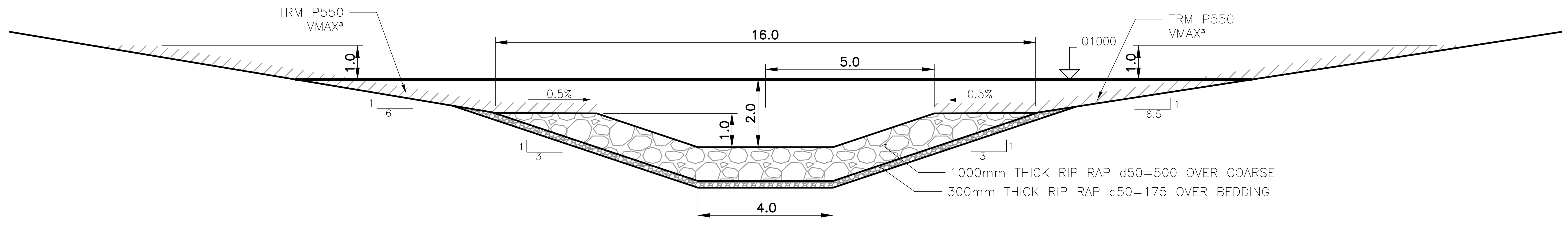
CLIENT DWG NO.

DRAWING NO. VE52705E.CC2.2

REV

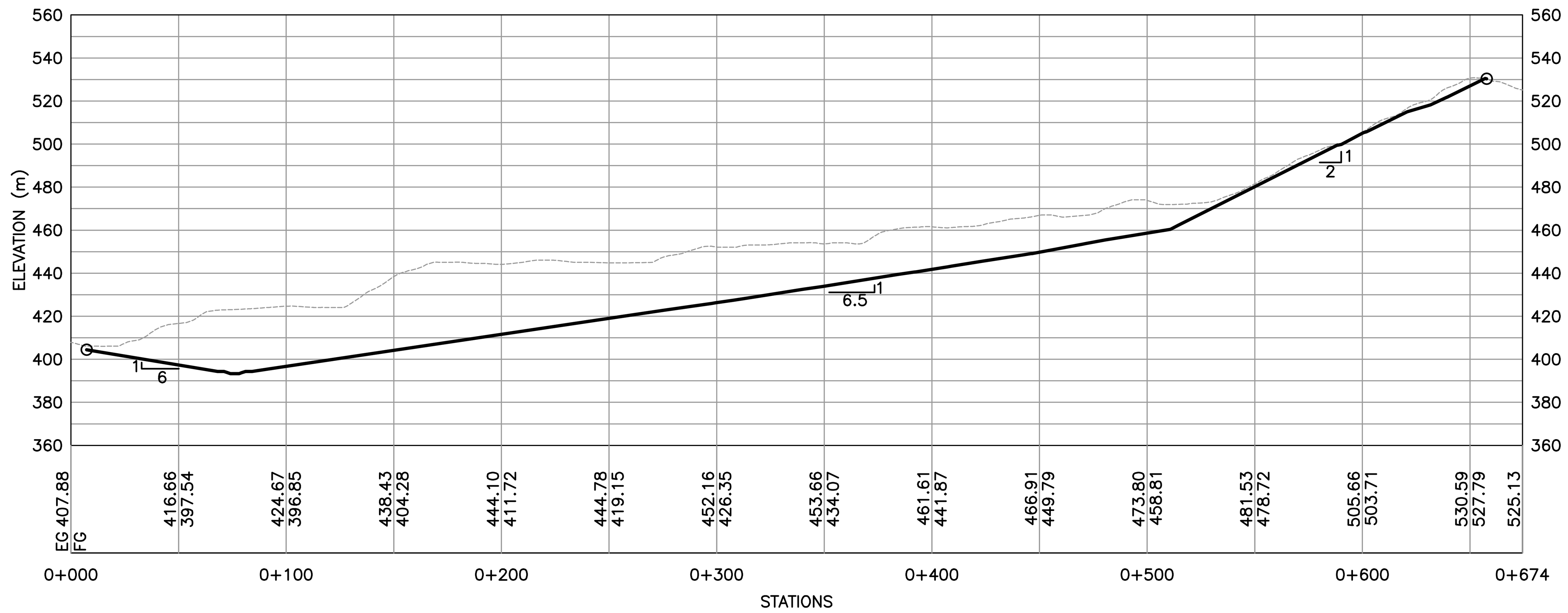


SECTION A 001
1:2000H 1:2000V

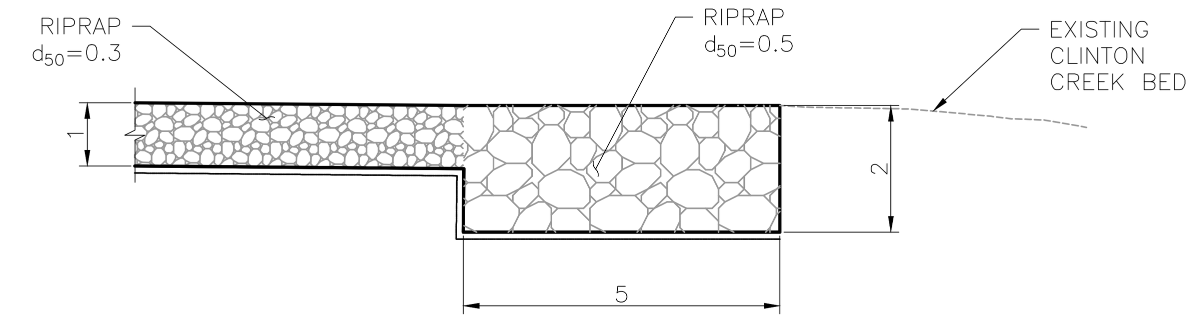


TYPICAL SECTION

DETAIL 1 –
1:100

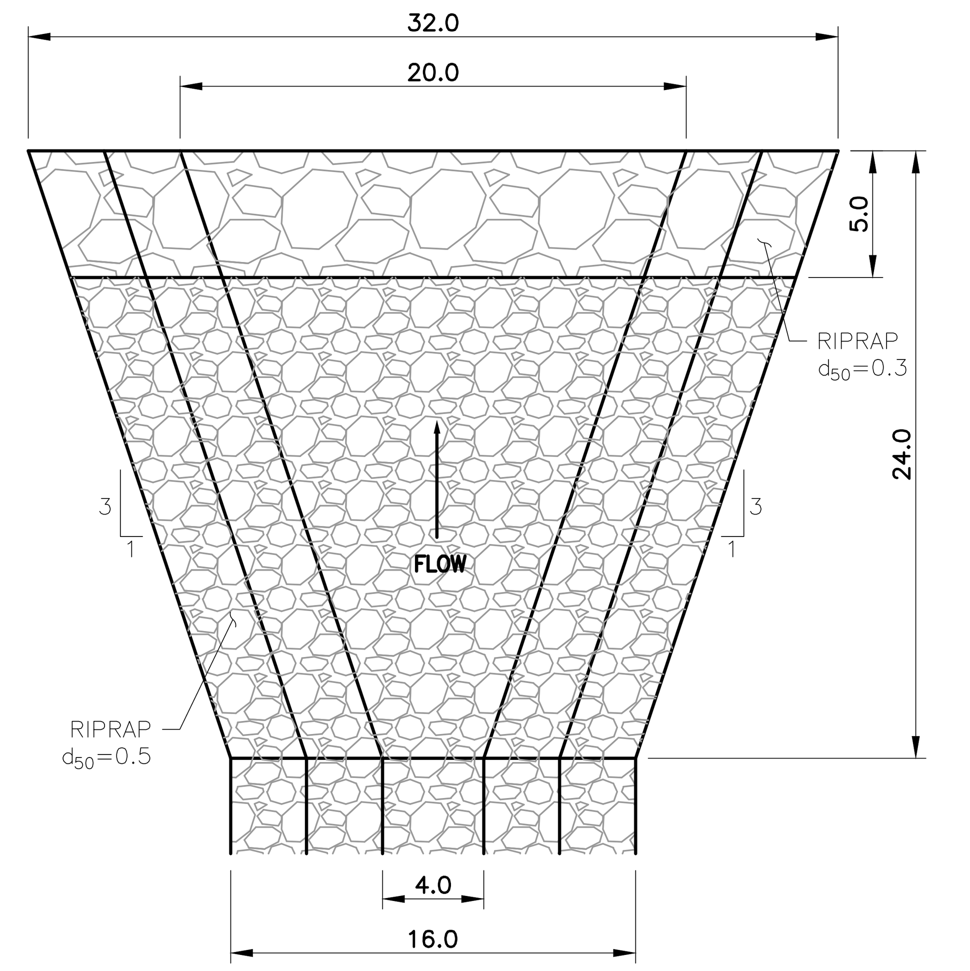


SECTION B 001
1:2000H 1:2000V



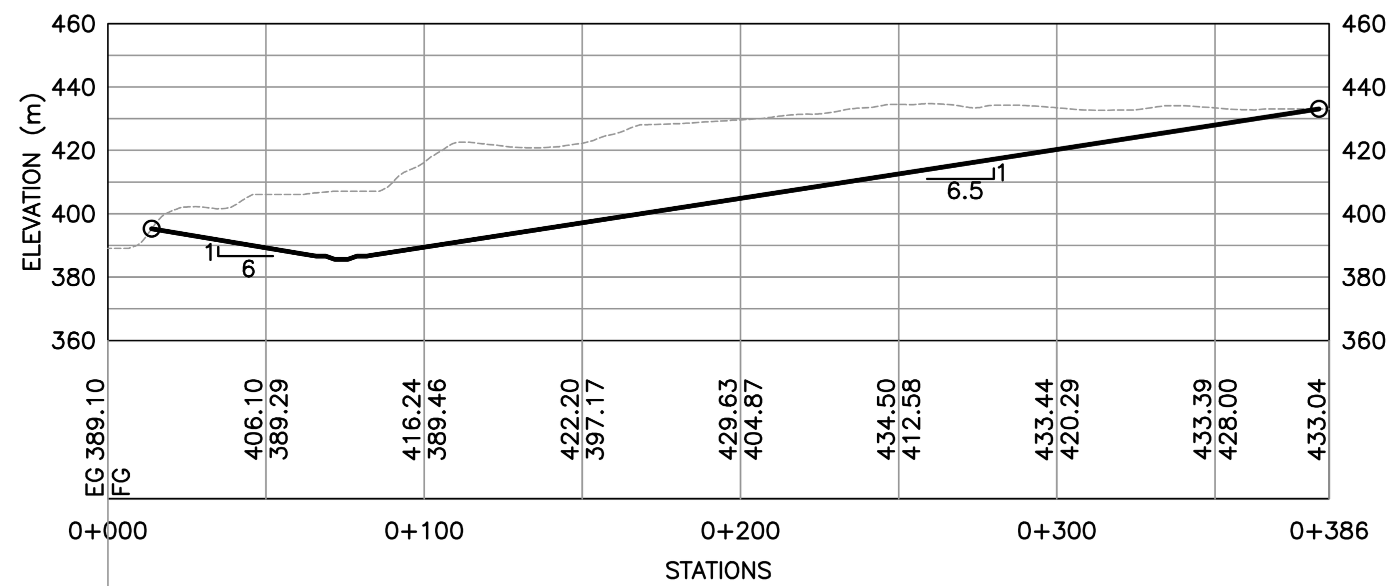
PROFILE THROUGH REGIME CHANNEL TOE

DETAIL 2 –
1:100

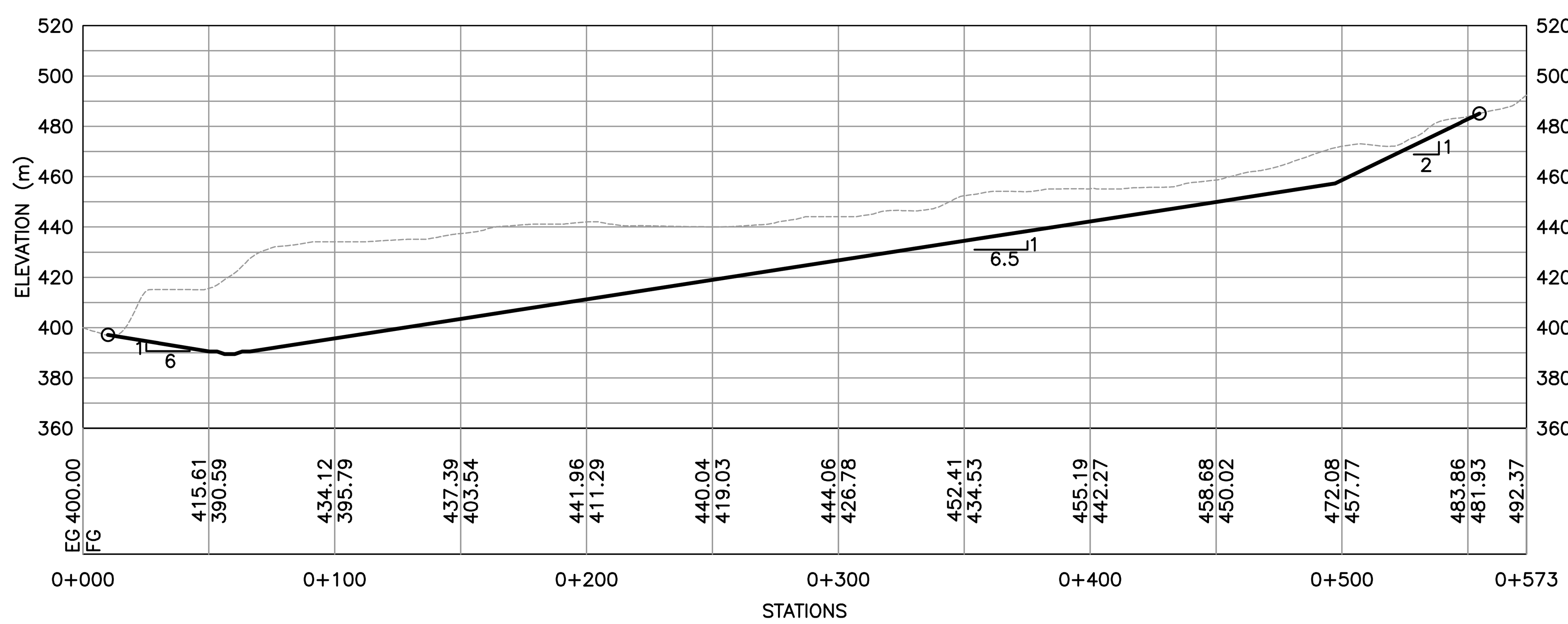


PLAN VIEW OF REGIME CHANNEL TOE APRON

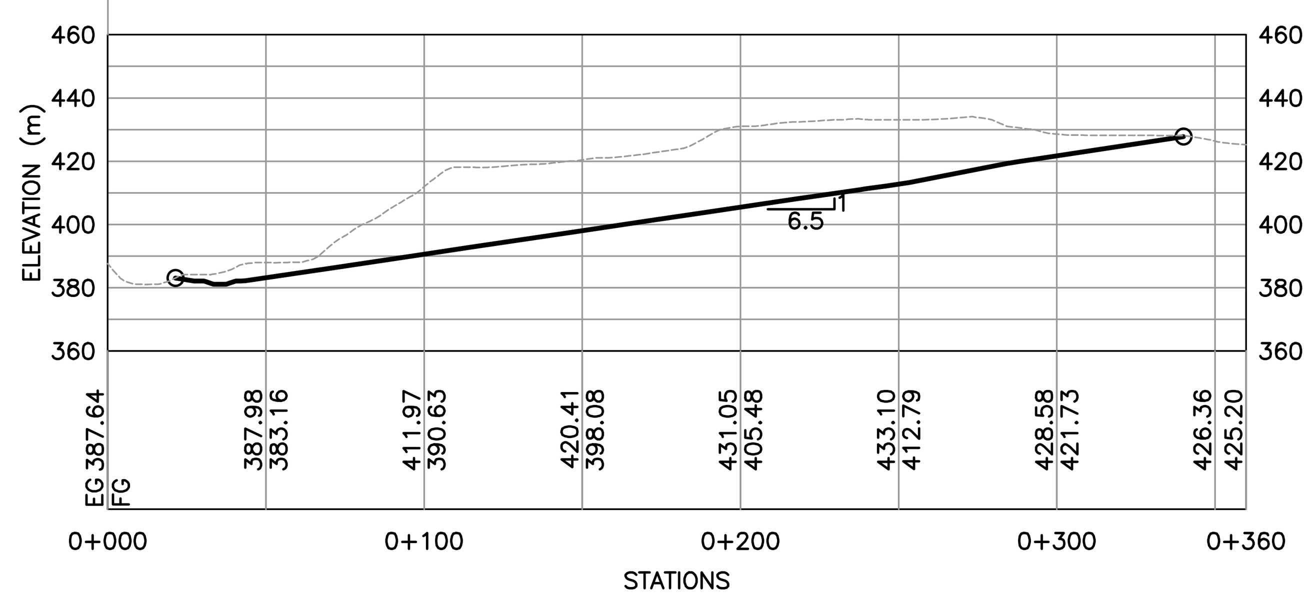
DETAIL 3 –
1:100



SECTION D 001
1:2000H 1:2000V



SECTION C 001
1:2000H 1:2000V



SECTION E 001
1:2000H 1:2000V

NOT FOR CONSTRUCTION

0m 20 40 60 80 100
1:2000

0m 1 2 3 4 5
1:100

REF	NUMBER	TITLE
2	VE52705E.CC2.2	REGIME CHANNEL INTAKE
1	VE52705E.CC2.1	PLAN AND PROFILE

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

APPROVED FOR __________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	GG	10JUL19
DRN	JM	10JUL19
CHK	GG	10JUL19
APP		

SUBJECT
CLINTON CREEK REMEDIATION PROJECT
OPTION CC2
(LOWER LAKE WITH REGIME CHANNEL)
SECTIONS & DETAILS

Yukon

wood.

AREA

CLIENT DWG NO.

DRAWING NO. VE52705E.CC2.3

REV

CC3 (Removal of Lake)

PLAN
1:2500

REF	NUMBER	TITLE
4	VE52705E.CC3.5	SEDIMENT POND SECTIONS DETAILS
3	VE52705E.CC3.4	SEDIMENT POND PROFILE
2	VE52705E.CC3.3	SEDIMENT POND PLAN
1	VE52705E.CC3.2	RESTORED CHANNEL PLAN AND PROFILE

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

APPROVED FOR __________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS NOTED

	BY	DDMMMYY
DES	GG	10JUL19
DRN	JM	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION CC3 (REMOVAL OF LAKE)
PLAN

wood.

AREA

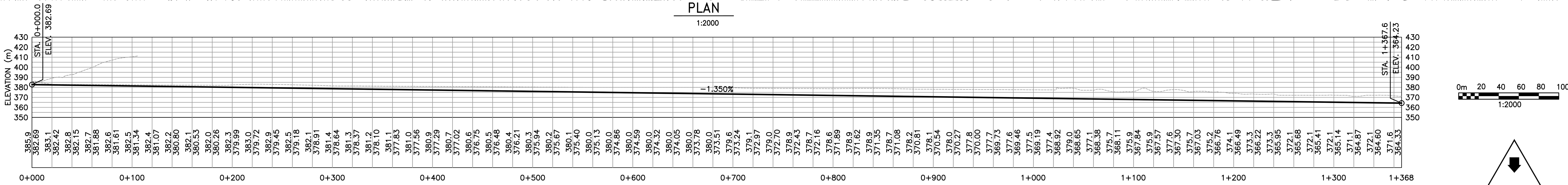
CLIENT DWG NO.

DRAWING NO.: VE52705E.CC3.1

REV

PLAN

1:2000



PROFILE

1:2000

NOT FOR CONSTRUCTION

REF	NUMBER	TITLE
4	VE52705E.CC3.5	SEDIMENT POND SECTIONS & DETAILS
3	VE52705E.CC3.4	SEDIMENT POND PROFILE
2	VE52705E.CC3.3	SEDIMENT POND PLAN
1	VE52705E.CC3.1	PLAN

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS NOTED

	BY	DDMMMYY
DES	GG	10JUL19
DRN	JM	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION CC3 (REMOVAL OF LAKE)
RESTORED CHANNEL PLAN AND PROFILE

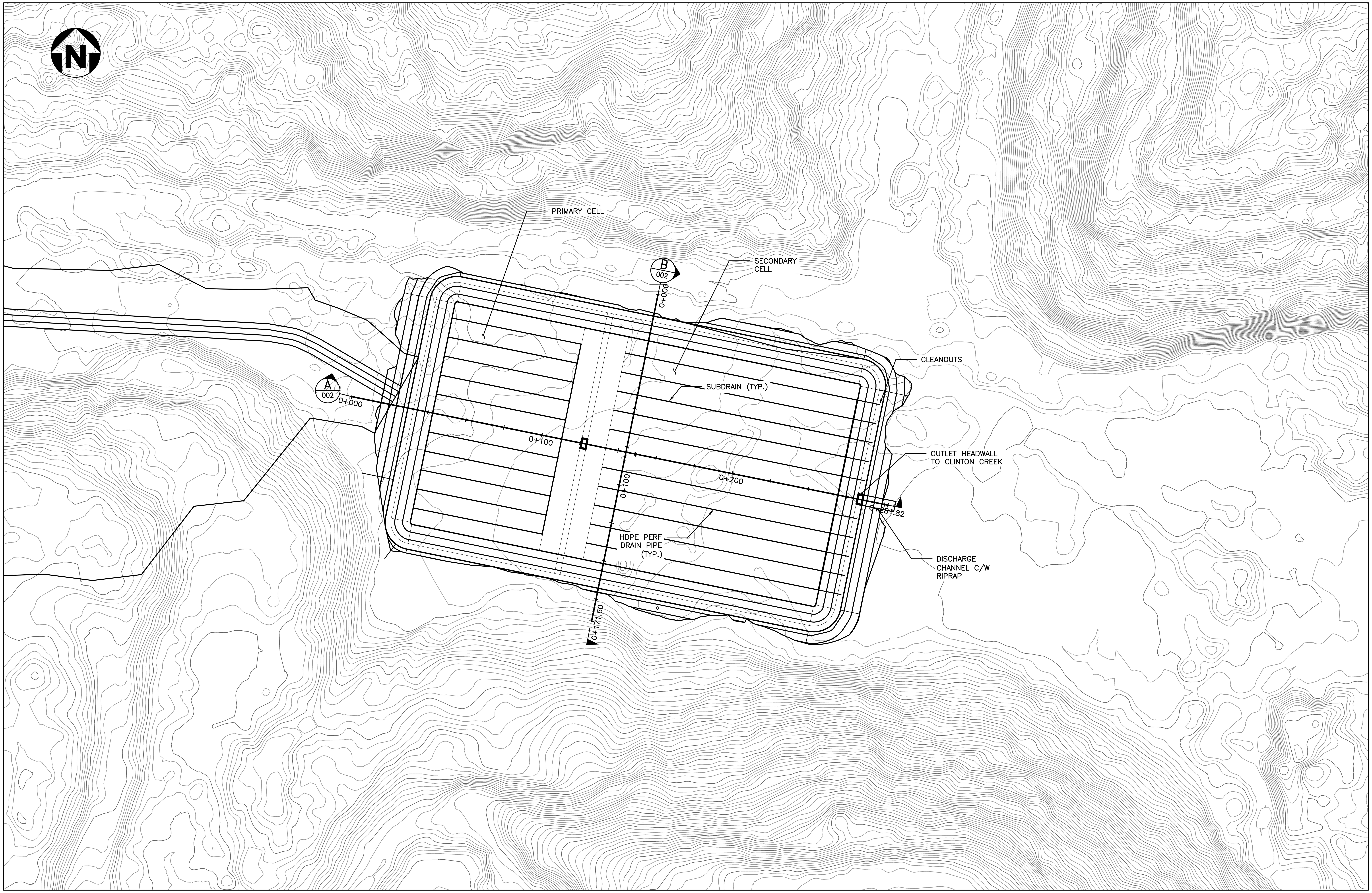
wood.

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.CC3.2

REV



NOT FOR CONSTRUCTION

PLAN
1:1000

0m 10 20 30 40 50
1:1000

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	05/JUN/19	ISSUED FOR REVIEW						

REF	NUMBER	TITLE
4	VE52705E.CC3.5	SEDIMENT POND SECTIONS DETAILS
3	VE52705E.CC3.4	SEDIMENT POND PROFILE
2	VE52705E.CC3.2	RESTORED CHANNEL PLAN AND PROFILE
1	VE52705E.CC3.1	PLAN

REFERENCES

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.		BY	DDMMMYY
VE52705E.100.2	DES	SM	10JULY19
	DRN	JM	10JULY19
SCALE: 1:1000	CHK	SN	10JULY19
	APP		

Yukon

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION CC3 (REMOVAL OF LAKE)
SEDIMENT POND PLAN

wood.

AREA

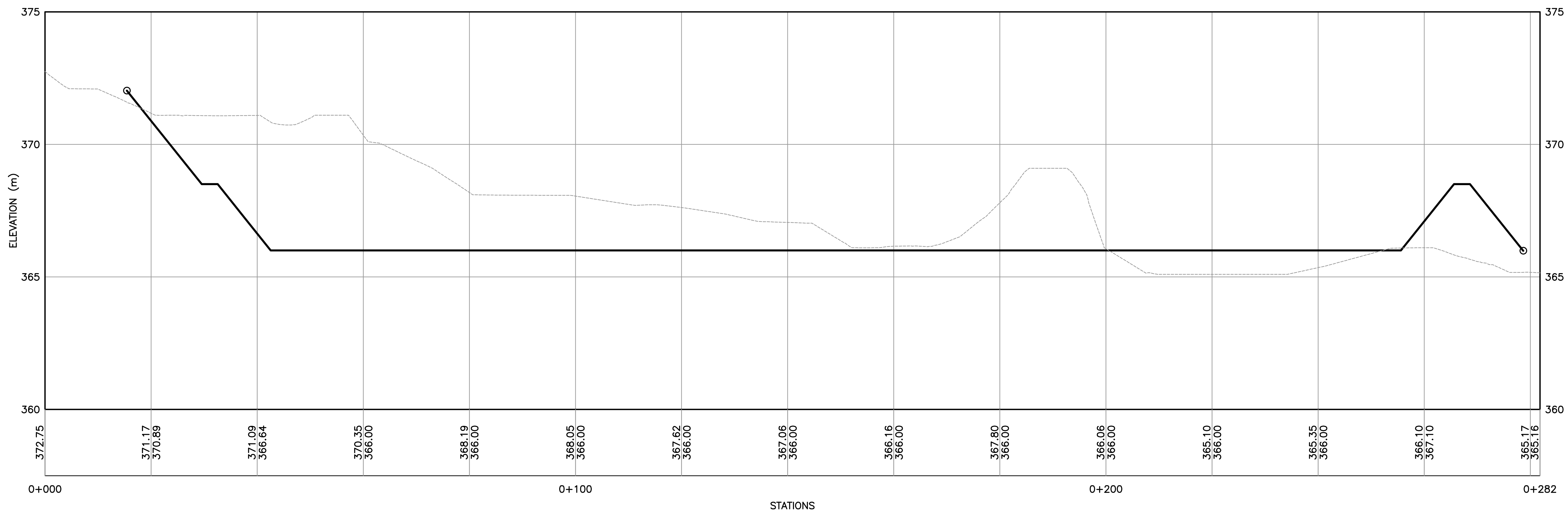
CLIENT DWG NO.

DRAWING NO. VE52705E.CC3.3

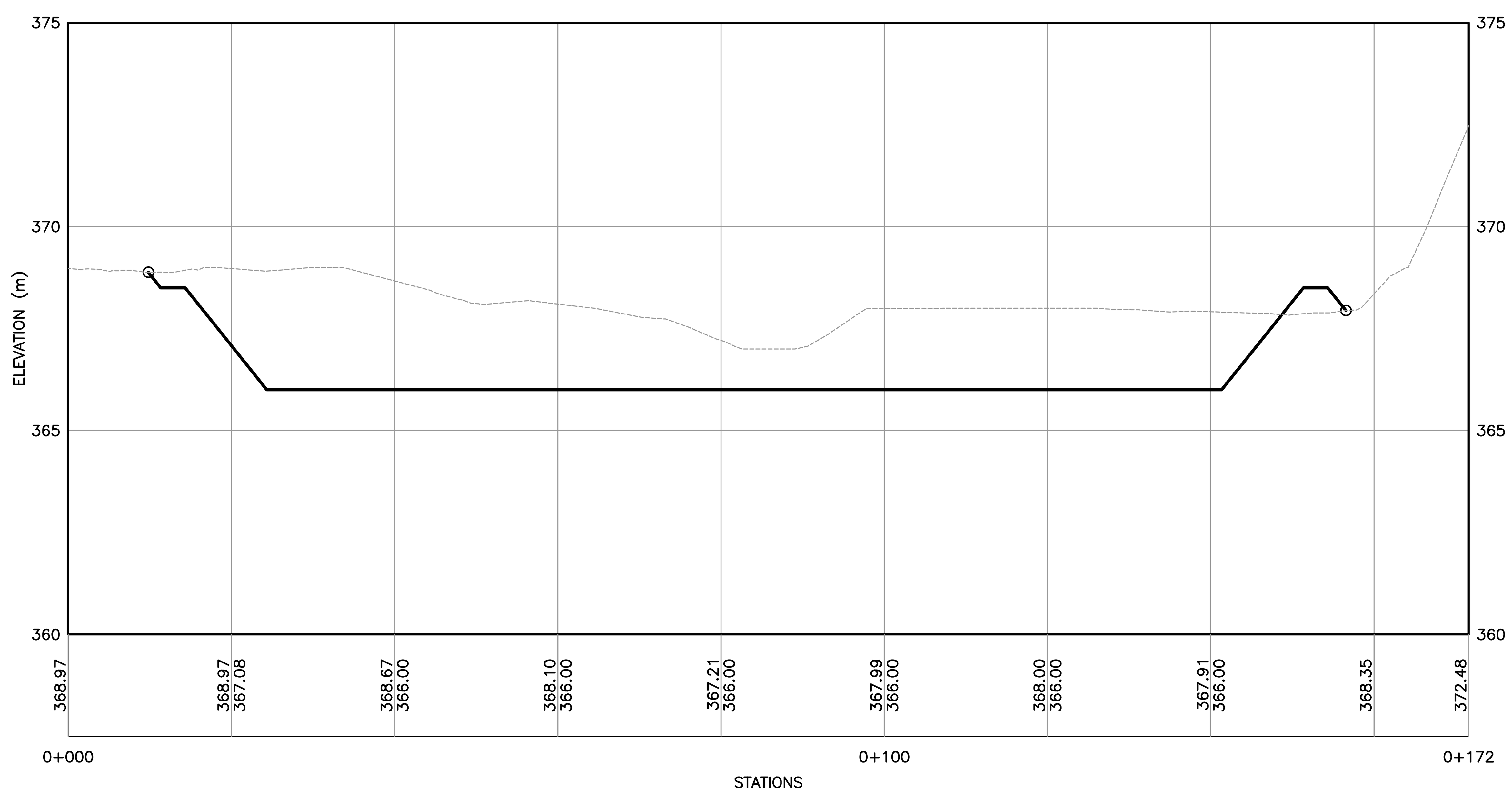
REV

SAVED: 21-Aug-19 2:53 PM PLOTTED: 15-N -19 1:10 PM USER: LIN, KEVIN

CAD FILE: P:\CAD\CIVCC3-RESTORATION CHANNEL-NO LAKE\SEDIMENT POND\HUDGEON LAKE SEDIMENT POND CC3.DWG



SECTION A
1:500H 1:100V



SECTION B
1:500H 1:100V

NOT FOR CONSTRUCTION

0m 5 10 15 20 25
1:500

0m 1 2 3 4 5
1:100

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	05/JUN/19	ISSUED FOR REVIEW						

REF	NUMBER	TITLE
4	VE52705E.CC3.5	SEDIMENT POND SECTIONS DETAILS
3	VE52705E.CC3.3	SEDIMENT POND PLAN
2	VE52705E.CC3.2	RESTORED CHANNEL PLAN AND PROFILE
1	VE52705E.CC3.1	PLAN

REFERENCES

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS NOTED

	BY	DDMMMYY
DES	SM	10JULY19
DRN	JM	10JULY19
CHK	SM	10JULY19
APP		

Yukon

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION CC3 (REMOVAL OF LAKE)
SEDIMENT POND PROFILE

wood.

AREA

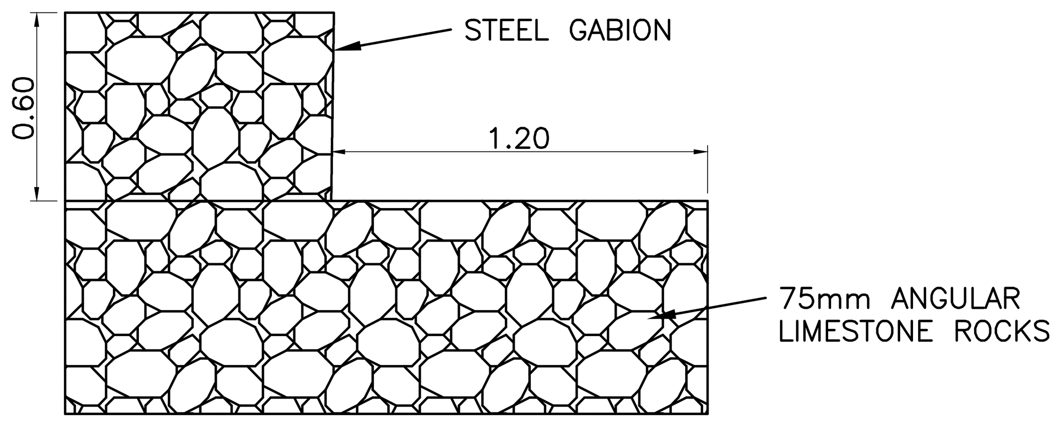
CLIENT DWG NO.

DRAWING NO.: VE52705E.CC3.4

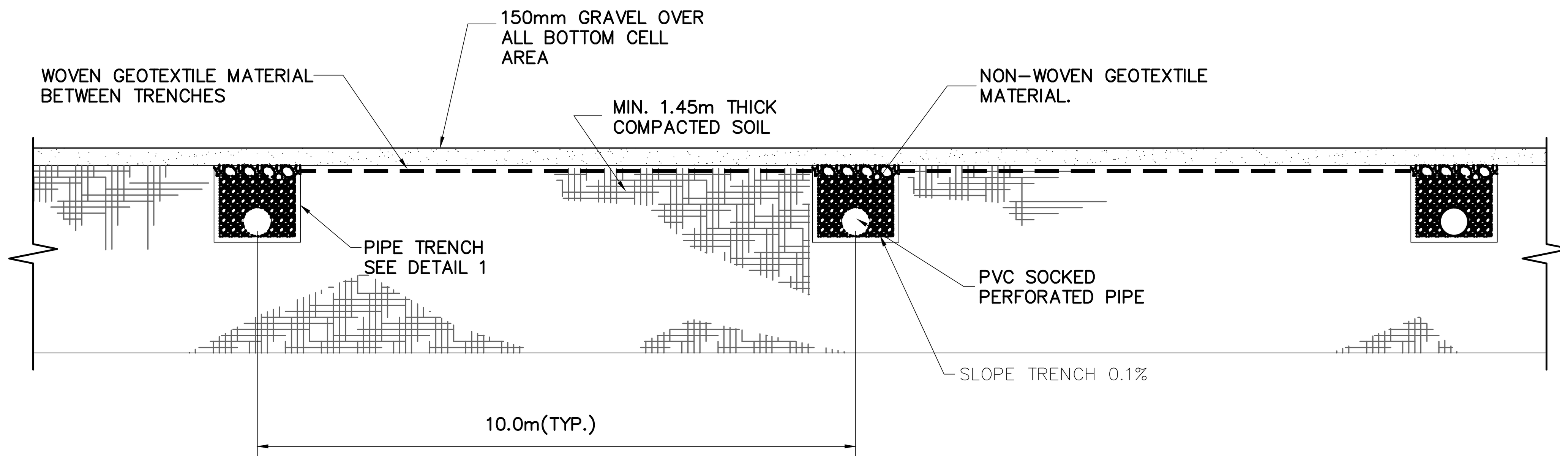
REV

CAD FILE: P:\CAD\CIV\CC3-RESTORATION CHANNEL-NO LAKE\SEDIMENT POND\HUDGEON LAKE SEDIMENT POND CC3.DWG

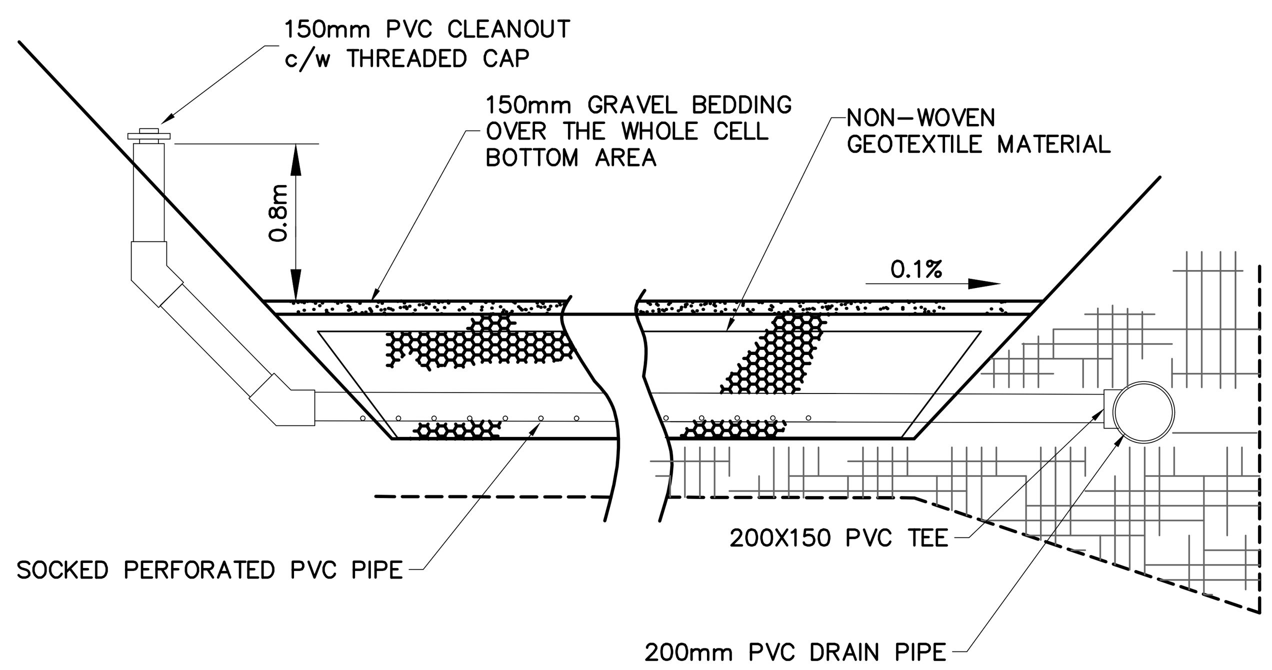
SAVED: 21-Aug-19 2:53 PM PLOTTED: 15-N -19 1:14 PM USER: LIN, KEVIN



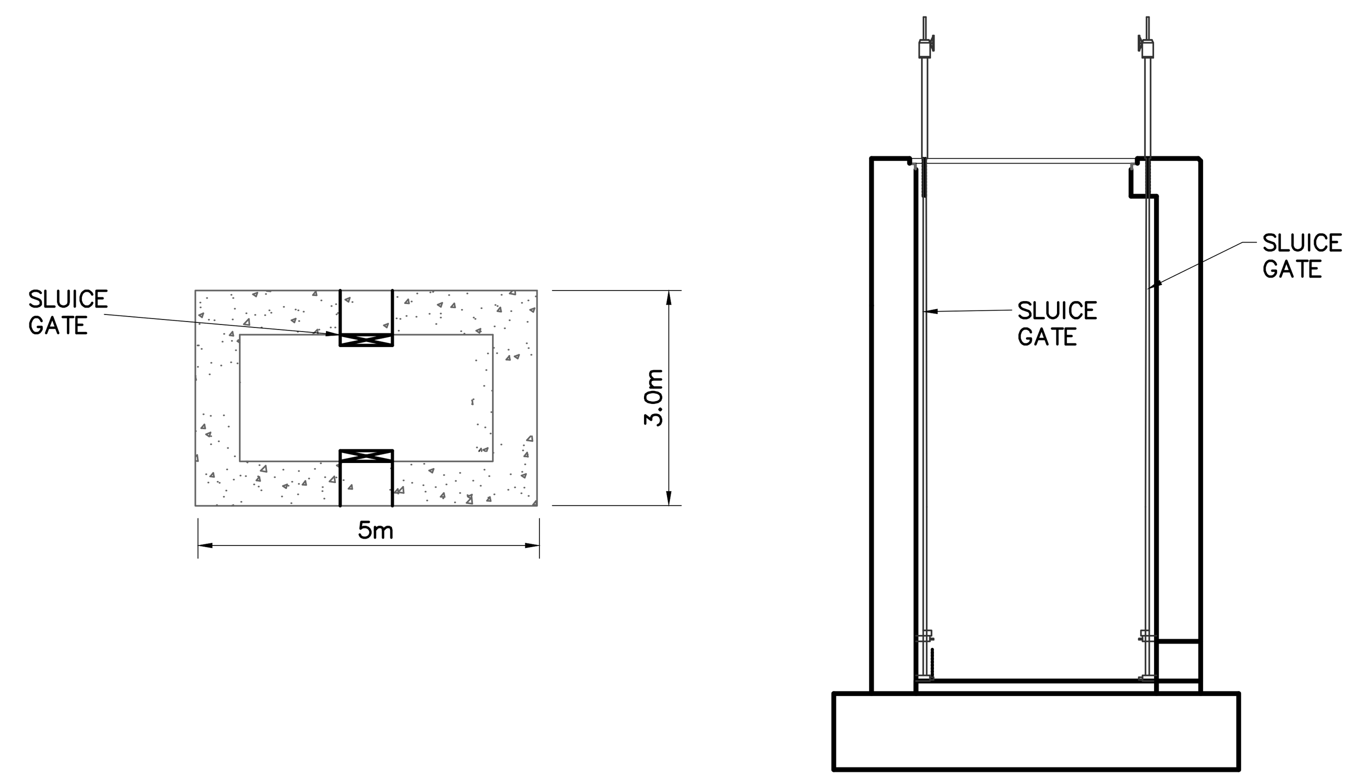
1 TYPICAL CASCADE AERATION DROP



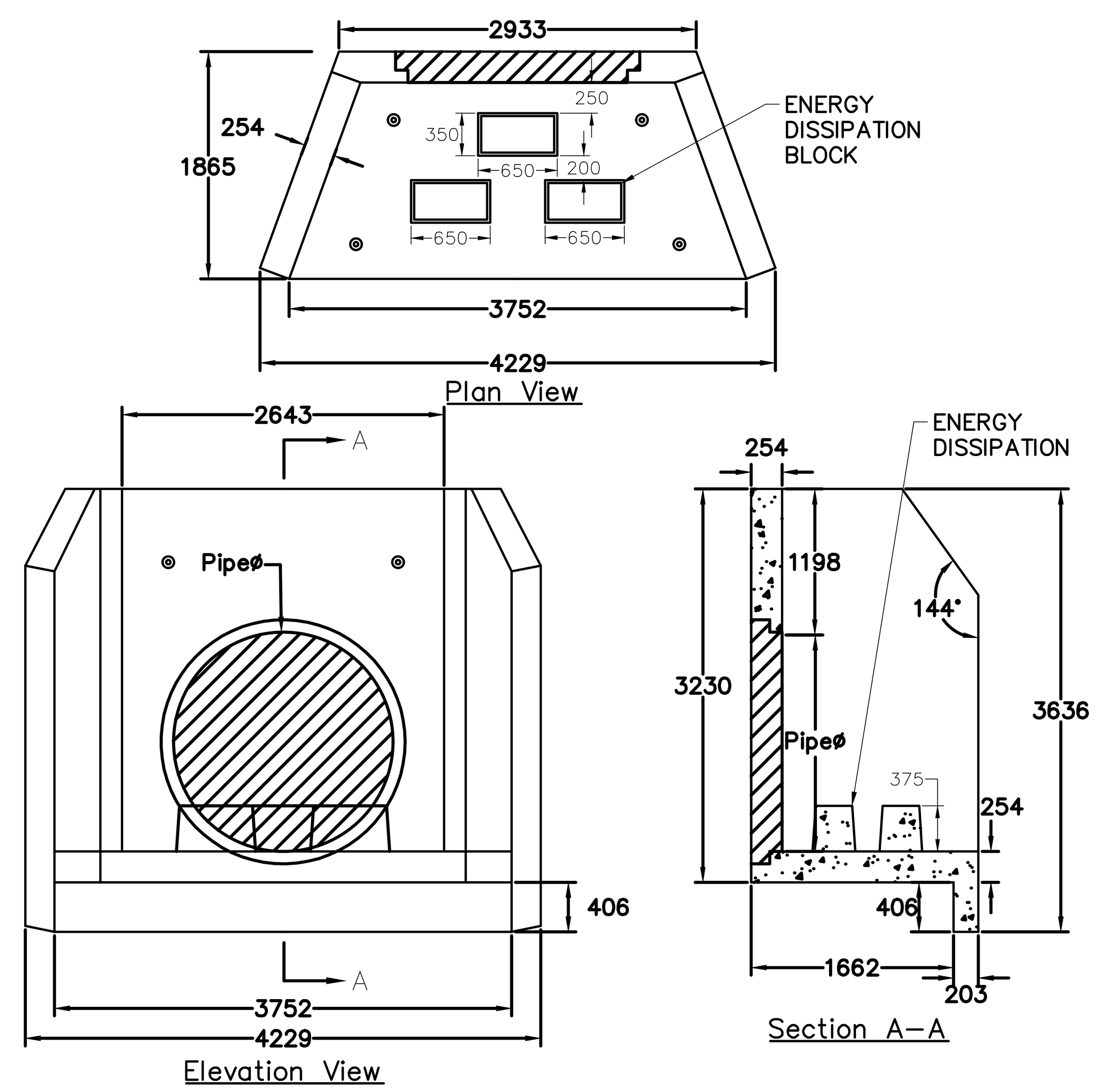
5 CELL SECTION (TYP)



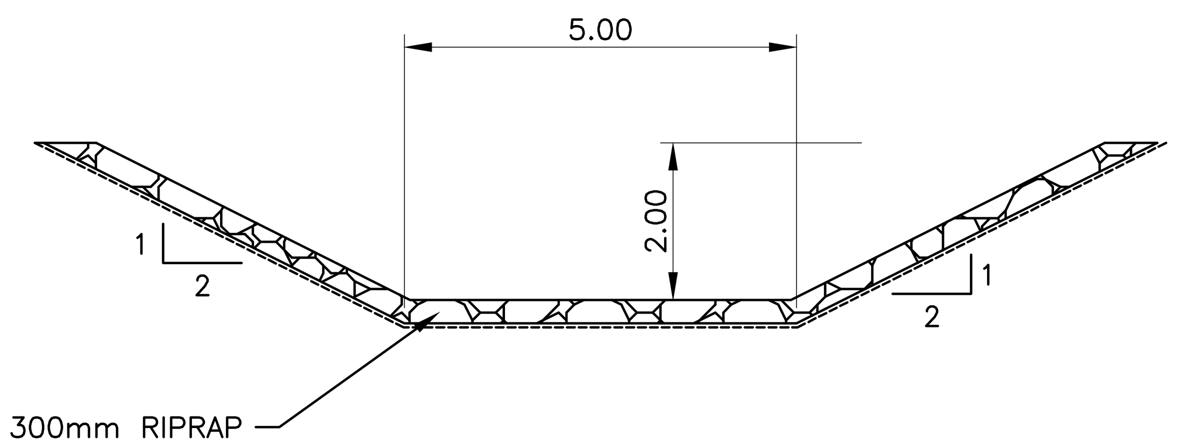
2 SUBDRAIN CLEANOUT



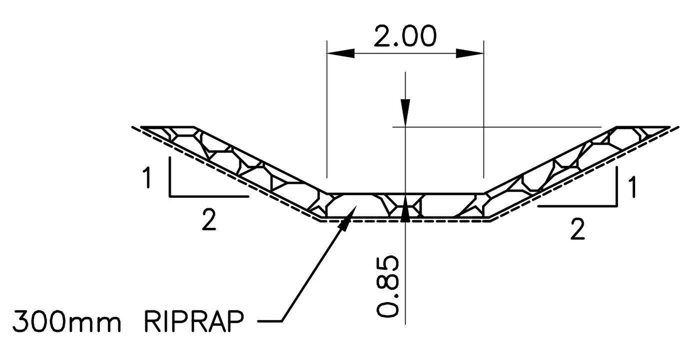
6 TYPICAL CHAMBER PLAN AND SECTION



7 OUTLET HEADWALL (TYP.)



3 TYPICAL CHANNEL SECTION (TYP.)



4 SECTION (TYP.)

NOT FOR CONSTRUCTION

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	05JUN19	ISSUED FOR REVIEW						

REF	NUMBER	TITLE
4	VE52705E.CC3.4	SEDIMENT POND PROFILE
3	VE52705E.CC3.3	SEDIMENT POND PLAN
2	VE52705E.CC3.2	RESTORED CHANNEL PLAN AND PROFILE
1	VE52705E.CC3.1	PLAN

REFERENCES

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	SM	10JULY19
DRN	JM	10JULY19
CHK	SM	10JULY19
APP		

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION CC3 (REMOVAL OF LAKE)
SEDIMENT POND SECTIONS & DETAILS

AREA

CLIENT DWG NO.

DRAWING NO.: VE52075E.CC3.5

REV

WC1 (Sediment Control Only)

PLAN
1:2500

0m 25 50 75 100 125
1:2500

NOT FOR CONSTRUCTION

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	05/JUN/19	ISSUED FOR REVIEW						

REF	NUMBER	TITLE
3	VE52705E.WC1.4	SEDIMENT POND SECTIONS DETAILS
2	VE52705E.WC1.3	SEDIMENT POND PROFILES
1	VE52705E.WC1.2	SEDIMENT POND PLAN

REFERENCES

APPROVED FOR __________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: 1:2500

	BY	DDMMMYY
DES	SM	10JULY19
DRN	JM	10JULY19
CHK	SM	10JULY19
APP		

Yukon

wood.

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION WC1 (SEDIMENT CONTROL ONLY)
SEDIMENT POND GENERAL ARRANGEMENT

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.WC1.1

REV

CAD FILE: P:\CAD\CIV\WC1\WC1-001-GENERAL ARRANGEMENT.DWG

SAVED: 15-Aug-19 2:38 PM PLOTTED: 15-N -19 1:28 PM USER: LIN, KEVIN

PLAN
1:750

0m 10 20 30 40
1:750

NOT FOR CONSTRUCTION

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	05/JUN/19	ISSUED FOR REVIEW						

REFERENCES

REF	NUMBER	TITLE
3	VE52705E.WC1.4	SEDIMENT POND SECTIONS DETAILS
2	VE52705E.WC1.3	SEDIMENT POND PROFILES
1	VE52705E.WC1.1	SEDIMENT POND GENERAL ARRANGEMENT

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: 1:750

	BY	DDMMMYY
DES	SM	10JUL19
DRN	JM	10JUL19
CHK	SM	10JUL19
APP		

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION WC1 (SEDIMENT CONTROL ONLY)
SEDIMENT POND PLAN

AREA

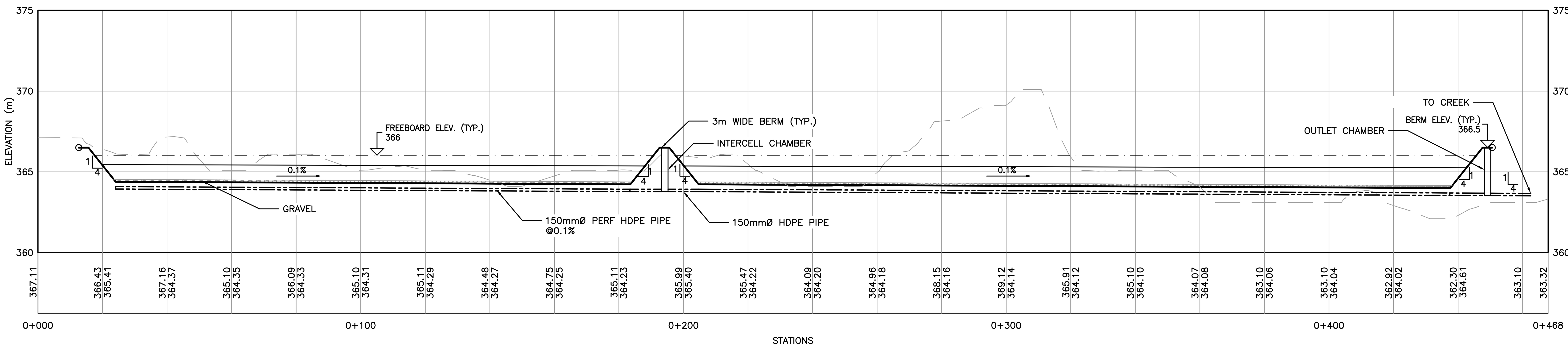
CLIENT DWG NO.

DRAWING NO. VE52705E.WC1.2

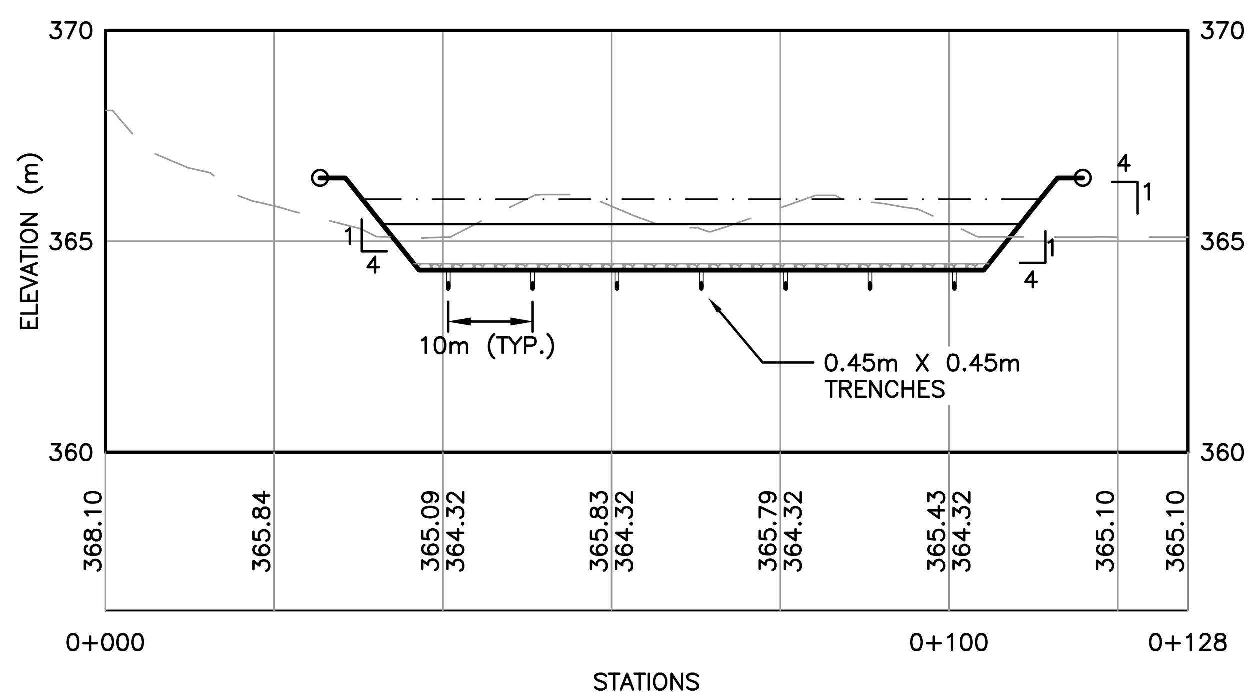
REV

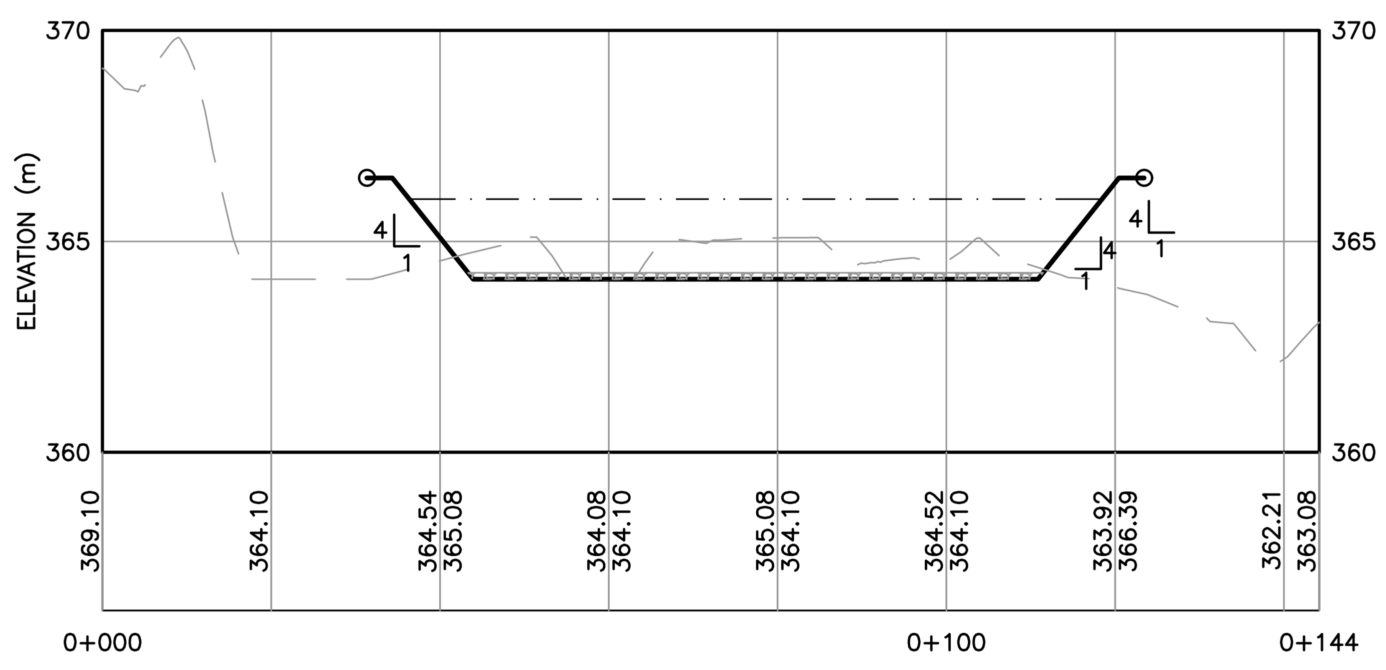
CAD FILE: P:\CAD\CIVIL\WC1\WC1-002-OVERALL SEDIMENT POND.DWG

ISO A1-594x841



SECTION A
1:750H 1:150V





SECTION B
1:750H 1:150V

0m 10 20 30 40
1:750

0m 1.5 3 4.5 6 7.5
1:150

NOT FOR CONSTRUCTION

REF	NUMBER	TITLE
3	VE52705E.WC1.4	SEDIMENT POND SECTIONS DETAILS
2	VE52705E.WC1.2	SEDIMENT POND PLAN
1	VE52705E.WC1.1	SEDIMENT POND GENERAL LAYOUT

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	05/JUN/19	ISSUED FOR REVIEW						

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS NOTED

	BY	DDMMMYY
DES	SM	10JUL19
DRN	JM	10JUL19
CHK	SM	10JUL19
APP		

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION WC1 (SEDIMENT CONTROL ONLY)
SEDIMENT POND PROFILES

Yukon

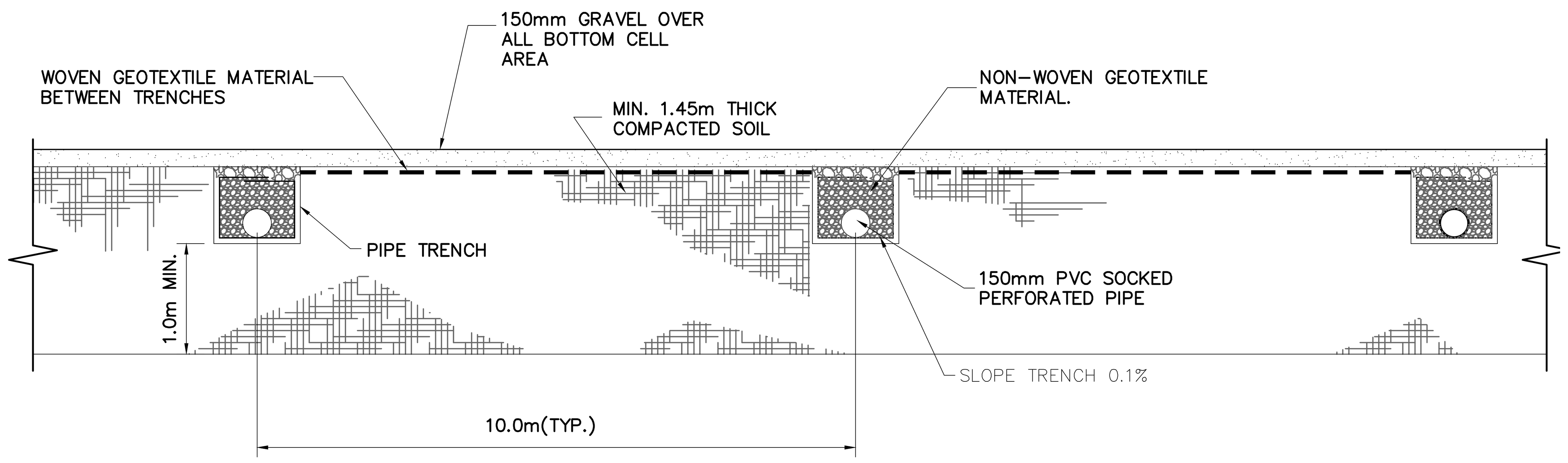
wood.

AREA

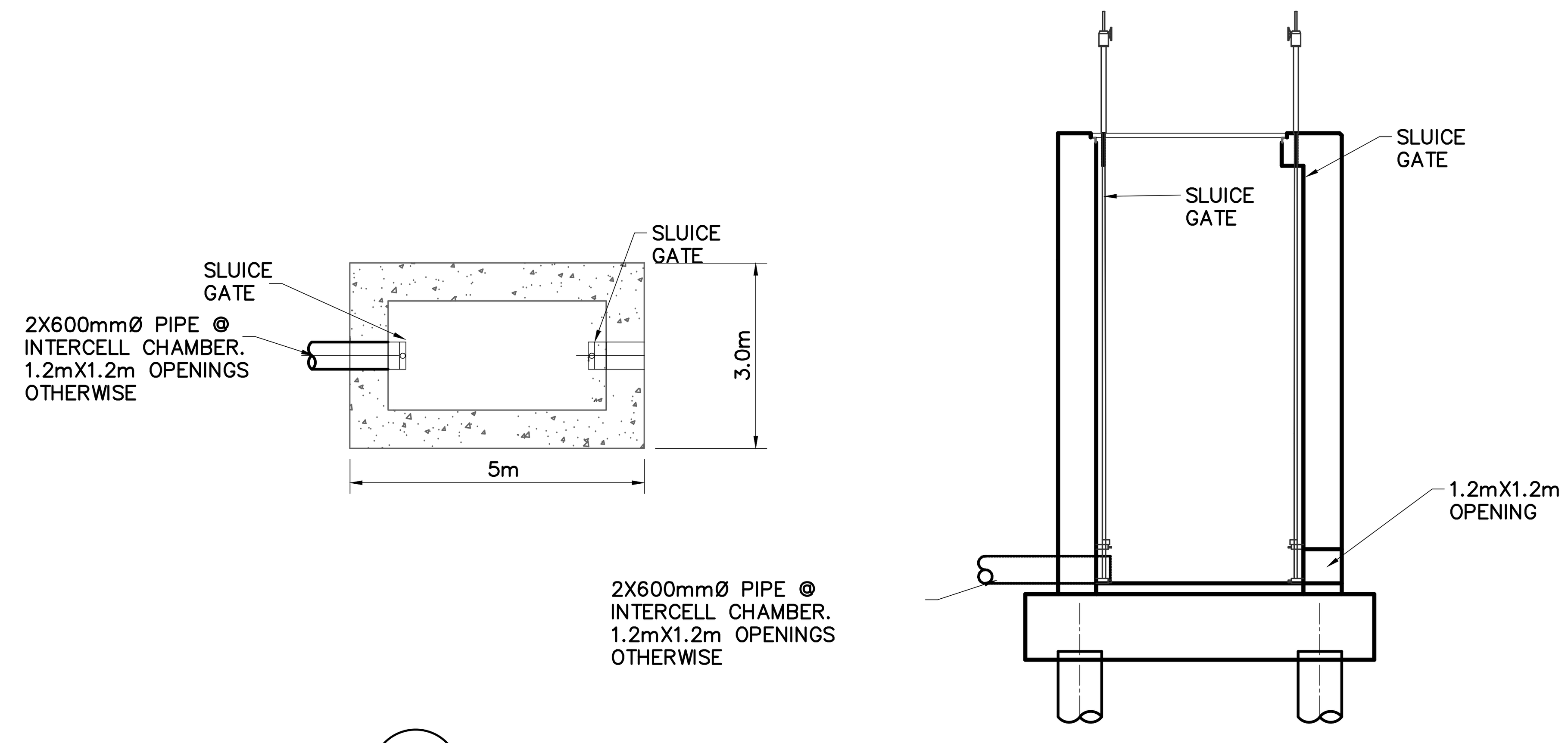
CLIENT DWG NO.

DRAWING NO.: VE52705E.WC1.3

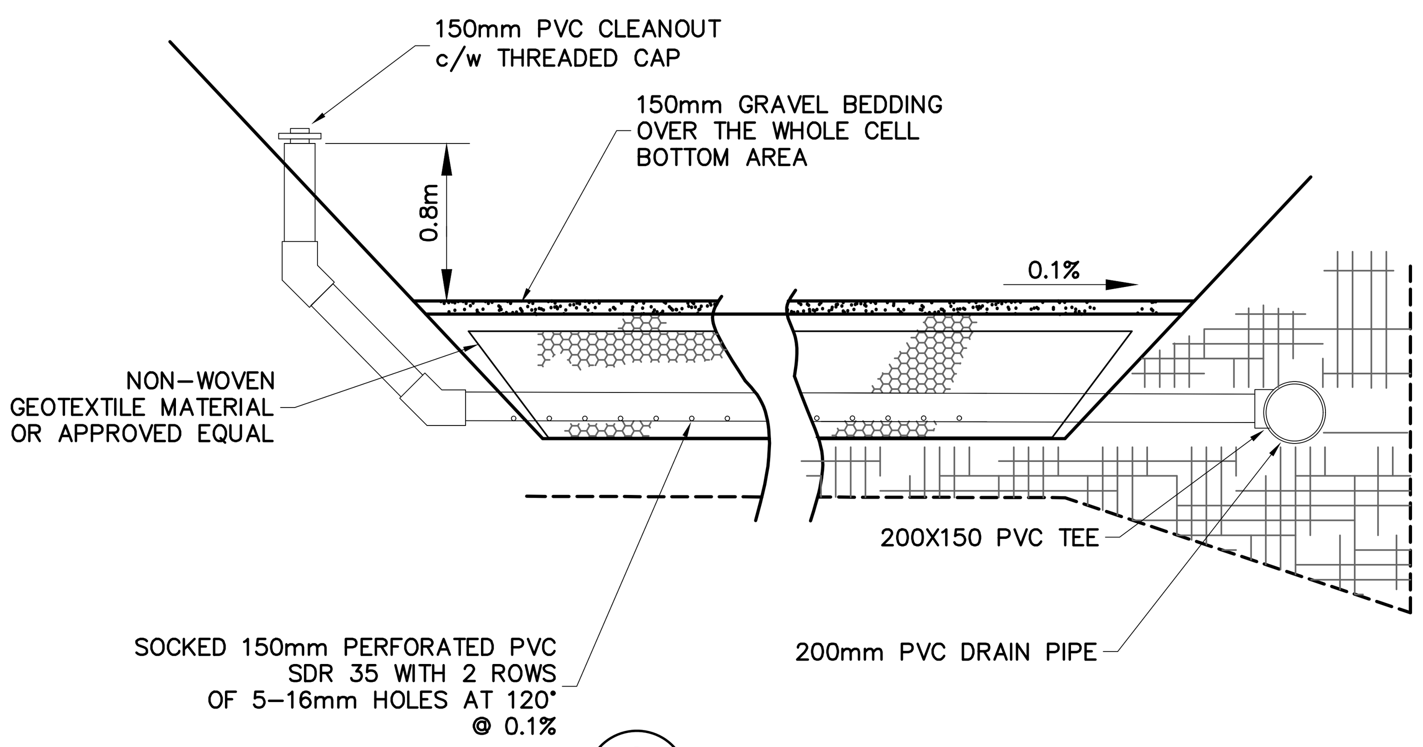
REV



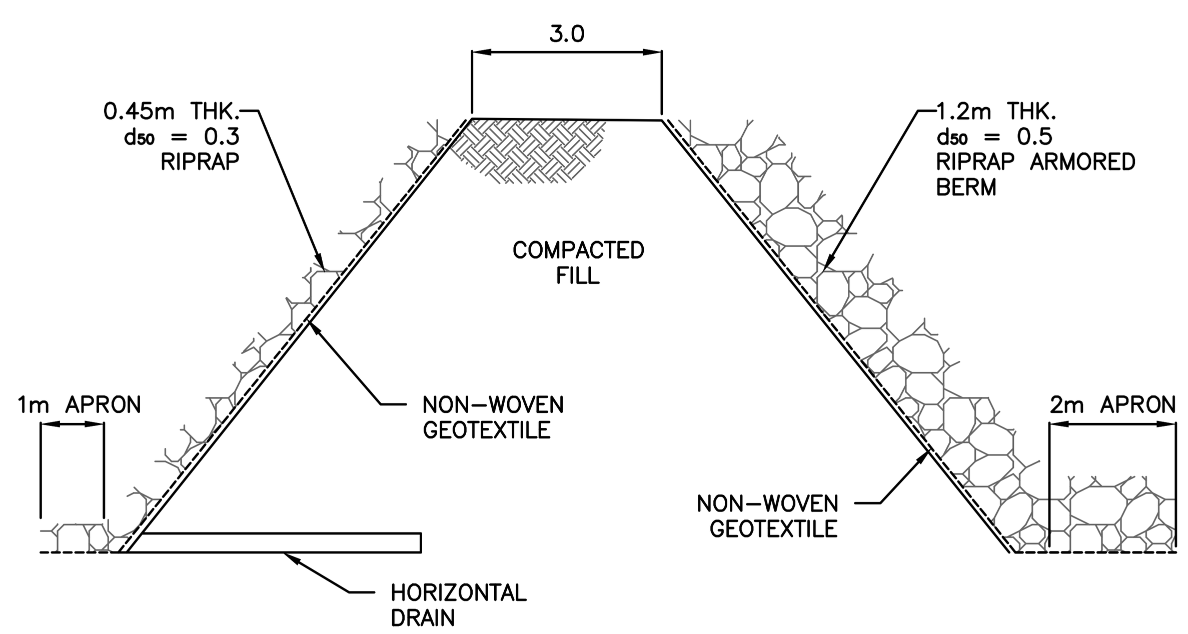
1 – CELL SECTION (TYP)



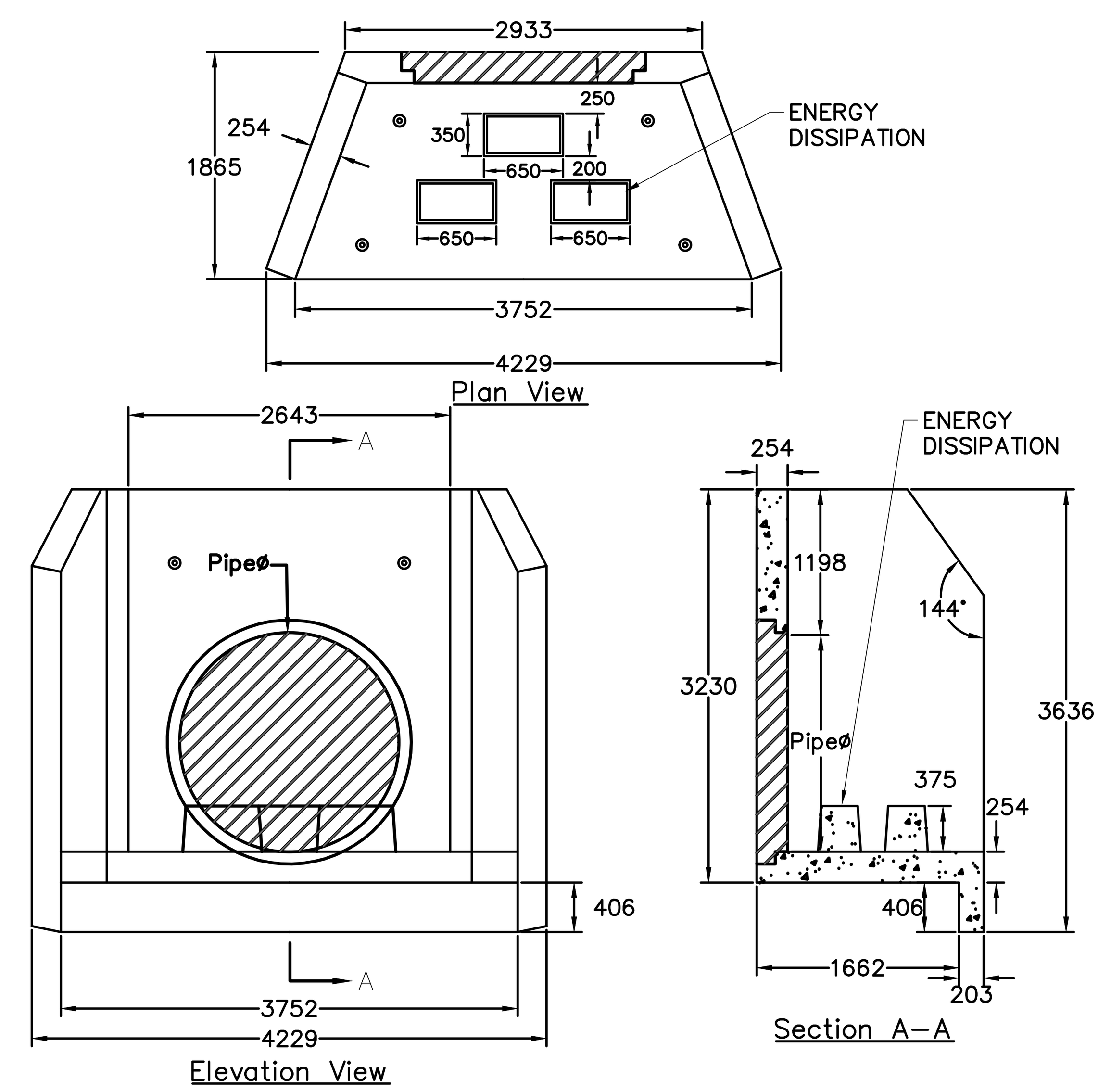
5 – TYPICAL CHAMBER PLAN AND SECTION



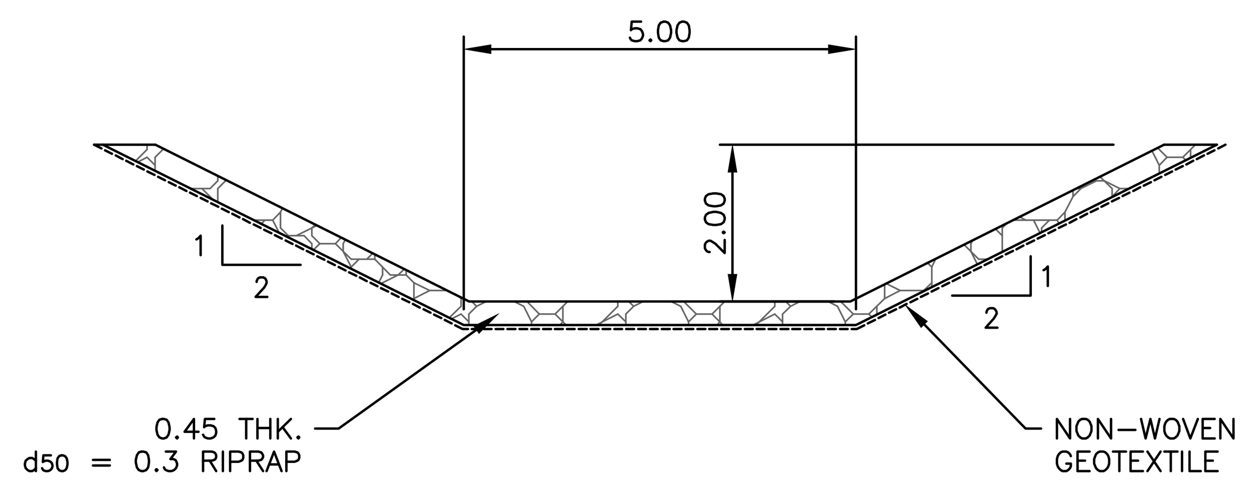
2 – SUBDRAIN CLEANOUT



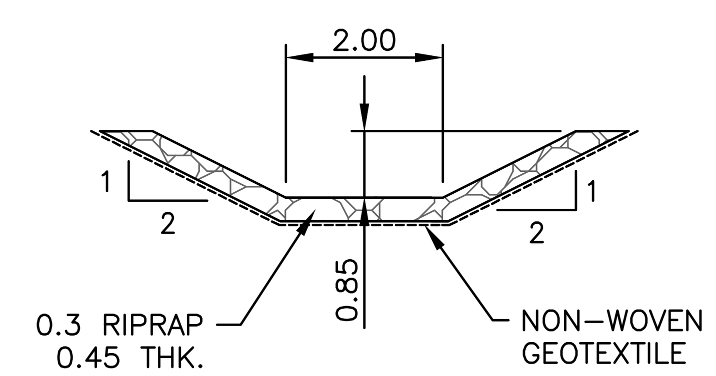
7 – ARMORED BERM



6 – HEADWALL (TYP.)



3 – CLINTON CREEK DIVERSION SECTION (TYP.)



4 – WOLVERINE CREEK DIVERSION SECTION (TYP.)

NOT FOR CONSTRUCTION

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP
A	05JUN19	ISSUED FOR REVIEW						

REF	NUMBER	TITLE
3	VE52705E.WC1.3	SEDIMENT POND PROFILES
2	VE52705E.WC1.2	SEDIMENT POND PLAN
1	VE52705E.WC1.1	SEDIMENT POND GENERAL LAYOUT

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	SM	10JUL19
DRN	JM	10JUL19
CHK	SM	10JUL19
APP		

Yukon

SUBJECT: CLINTON CREEK REMEDIATION PROJECT OPTION WC1 (SEDIMENT CONTROL ONLY) SEDIMENT POND SECTIONS & DETAILS

wood.

AREA

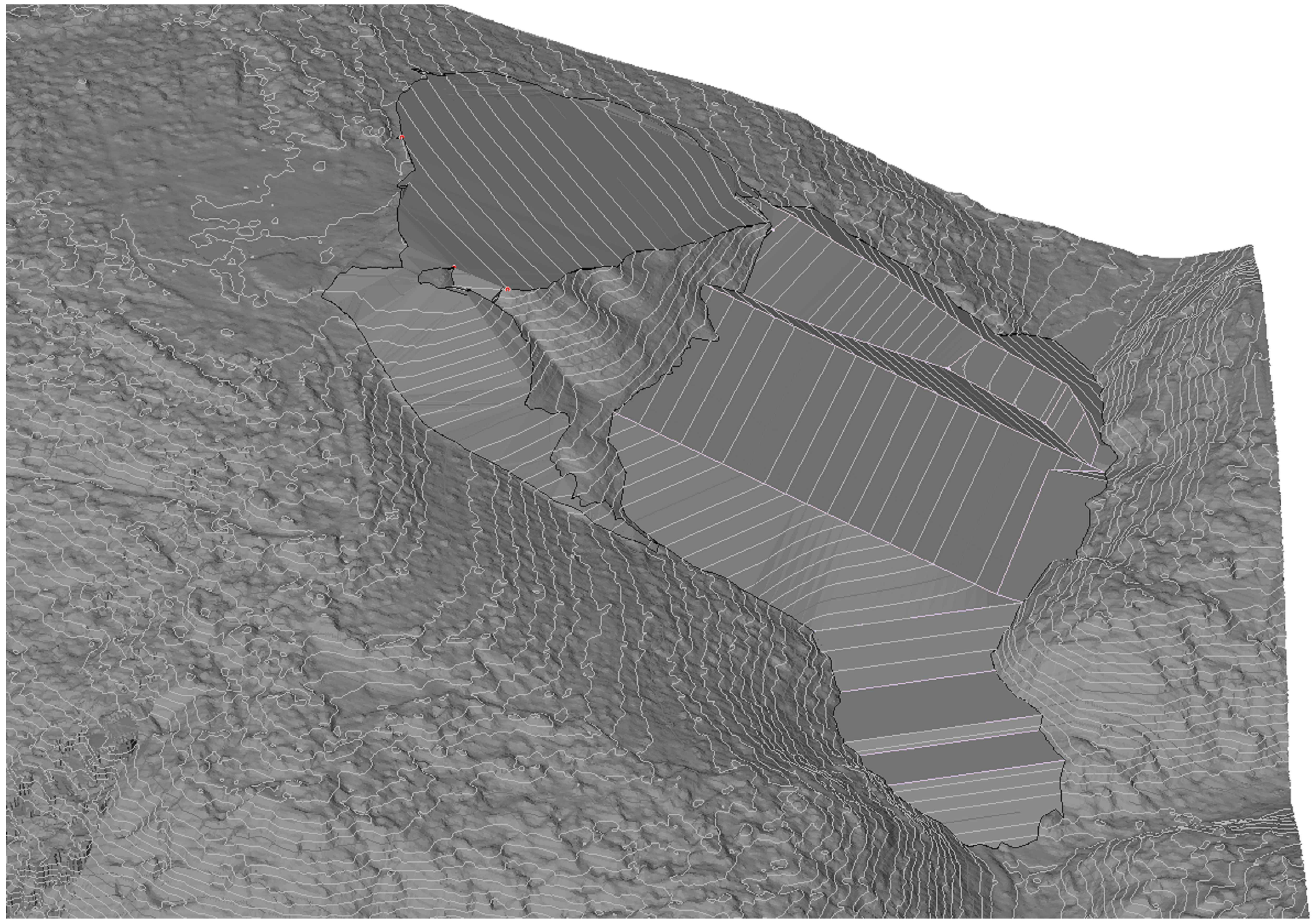
CLIENT DWG NO.

DRAWING NO.: VE52705E.WC1.4

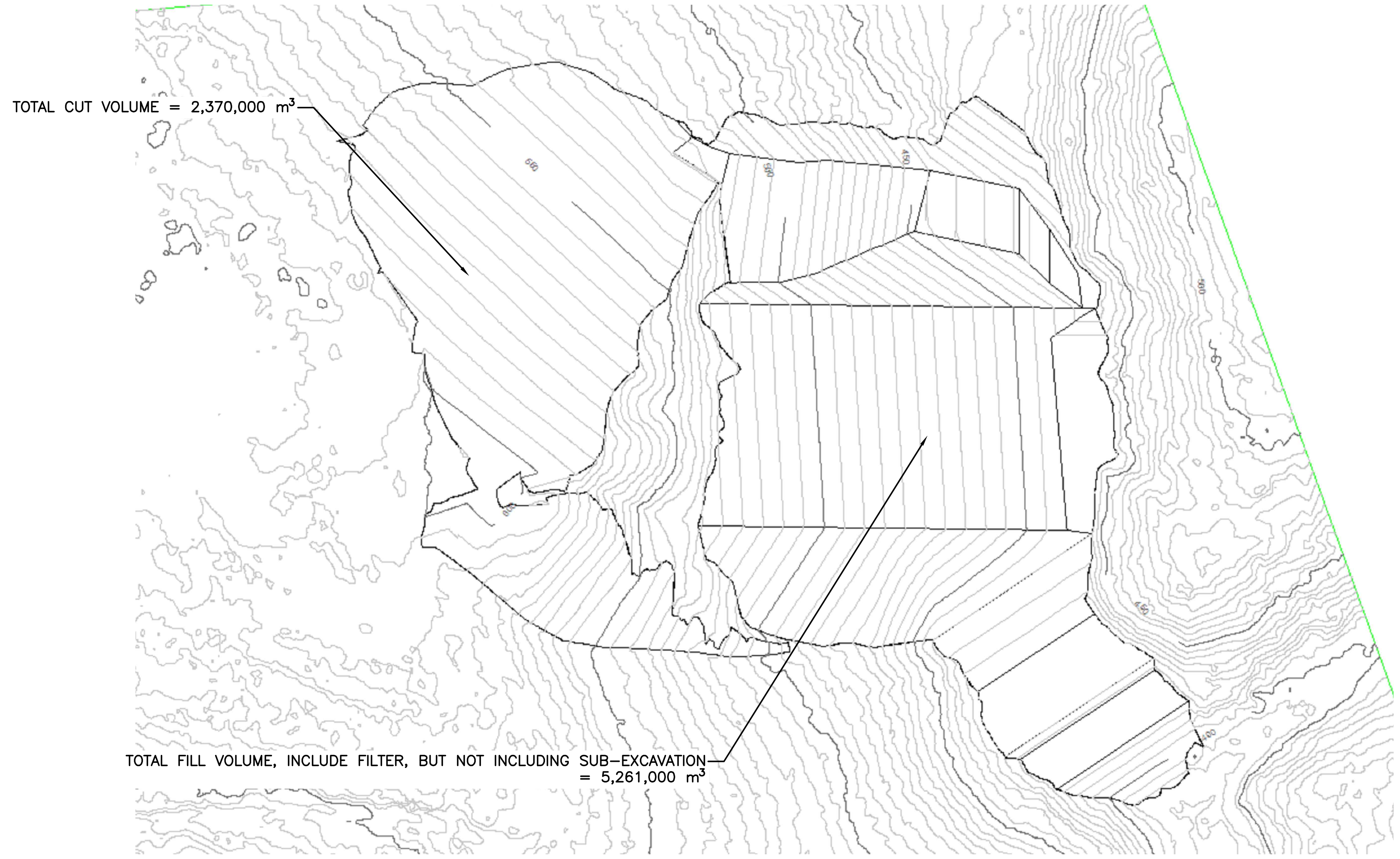
REV

SAVED: 14-N...-19 2:31 PM PLOTTED: 15-N...-19 2:33 PM USER: LIN, KEVIN

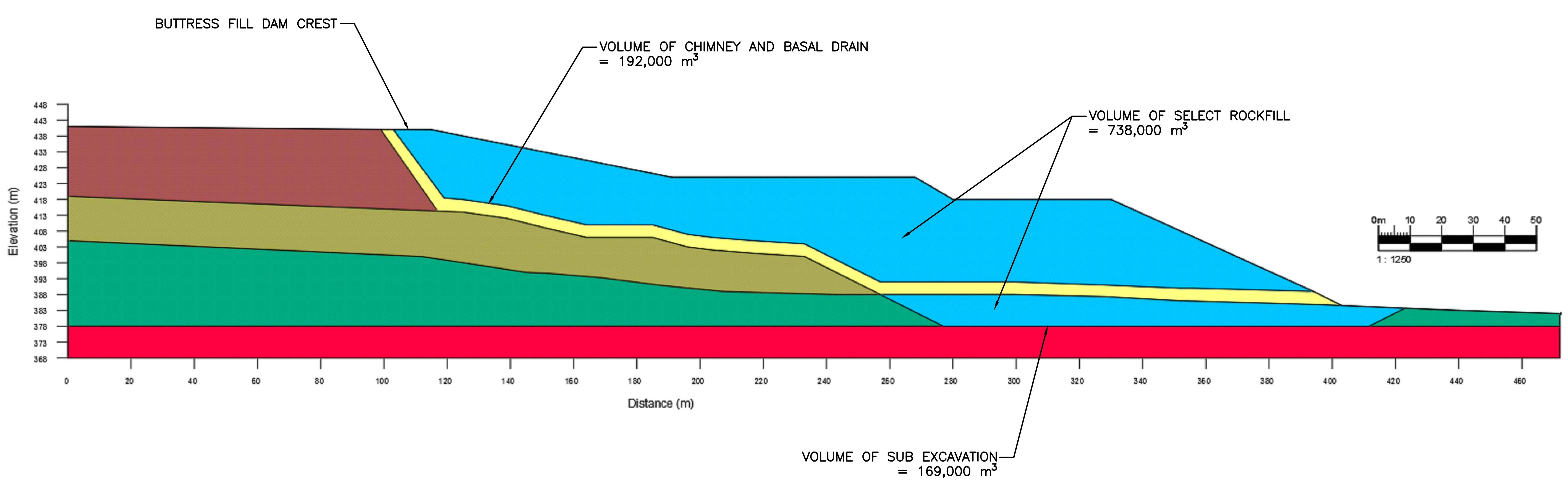
WC2 (In-Place Stabilization)



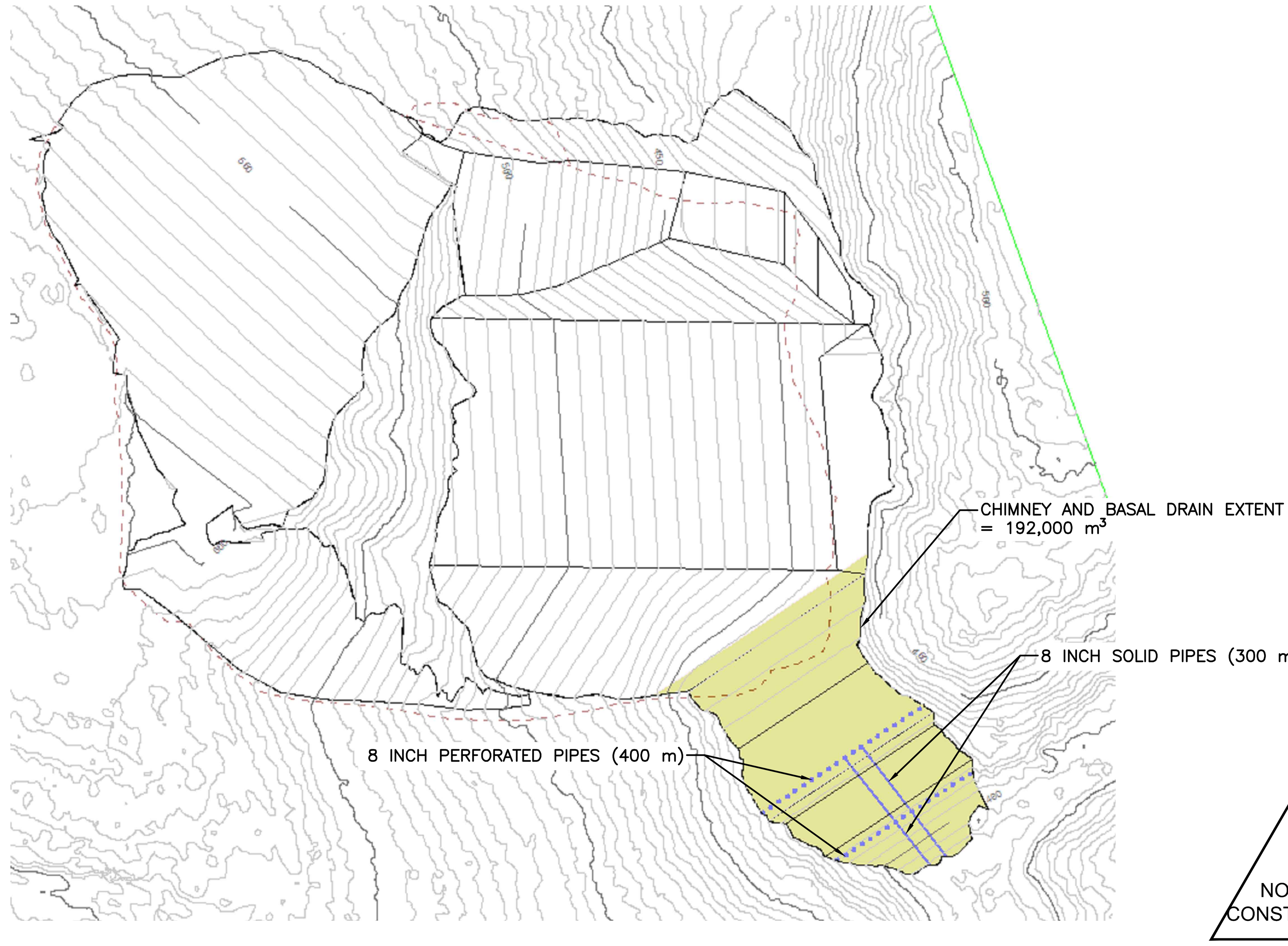
GENERAL ARRANGEMENT OF WC2 CONCEPT LOOKING NORTH



PLAN VIEW – TAILINGS CUTS, BUTTRESS FILL DAM, AND TOE BERM EXTENT



PROFILE VIEW – BUTTRESS FILL DAM



PLAN VIEW – CHIMNEY AND BASAL DRAIN AND 8 INCH DRAIN PIPES EXTENT

NOT FOR CONSTRUCTION

REF	NUMBER	TITLE
6	VE52705E.WC2.7	SPILLWAY SECTIONS, SHEET 3 OF 3
5	VE52705E.WC2.6	SPILLWAY SECTIONS, SHEET 2 OF 3
4	VE52705E.WC2.5	SPILLWAY SECTIONS, SHEET 1 OF 3
3	VE52705E.WC2.4	SPILLWAY SECTIONS : DETAILS
2	VE52705E.WC2.3	PROFILE
1	VE52705E.WC2.2	PLAN

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	EM	10JUL19
DRN	JM	10JUL19
CHK	EM	10JUL19
APP		

SUBJECT
CLINTON CREEK REMEDIATION PROJECT
OPTION WC2 (IN PLACE STABILIZATION)
GENERAL ARRANGEMENT
AND ILLUSTRATION OF CONCEPT

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.WC2.1

REV

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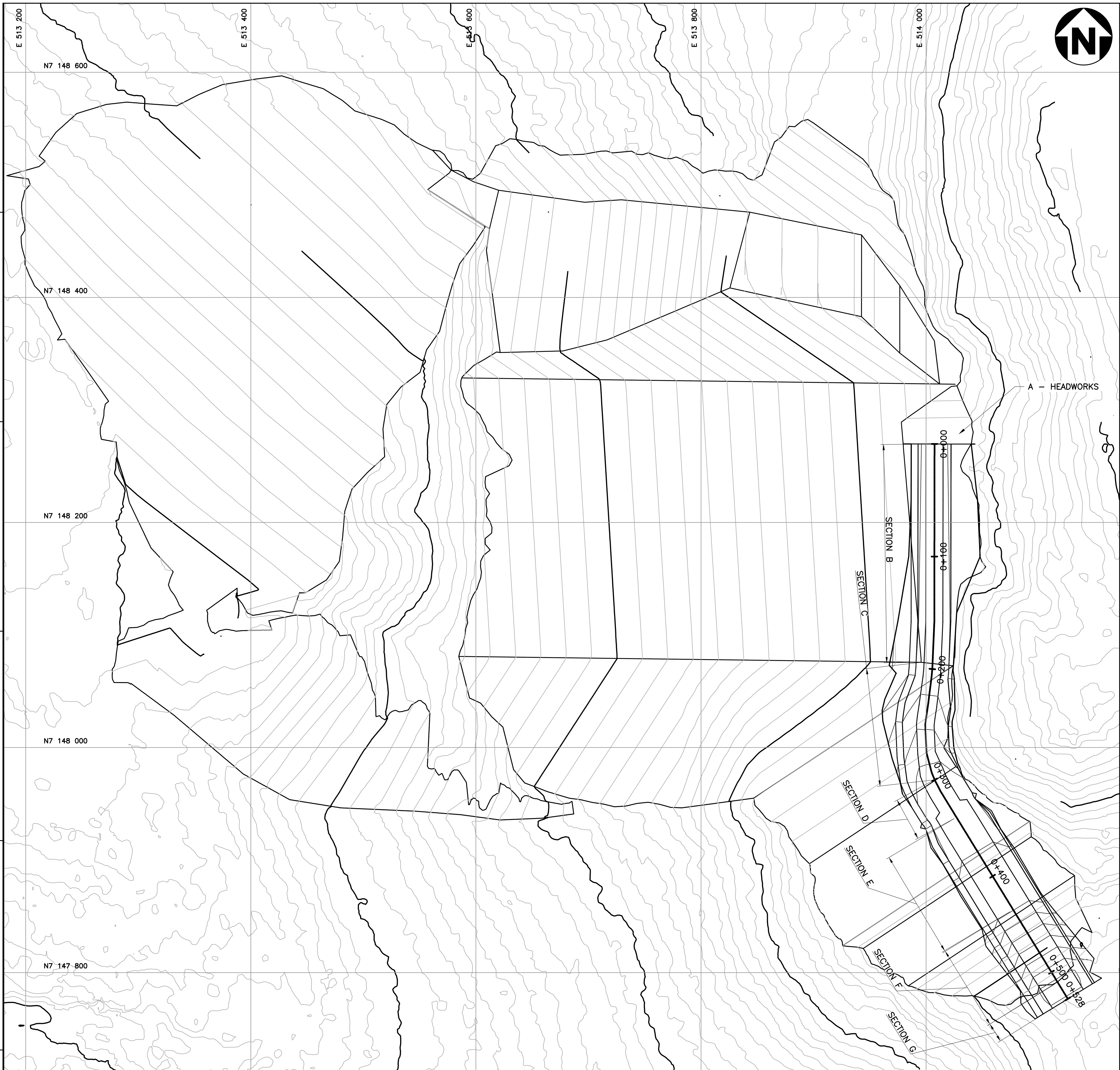

PLAN
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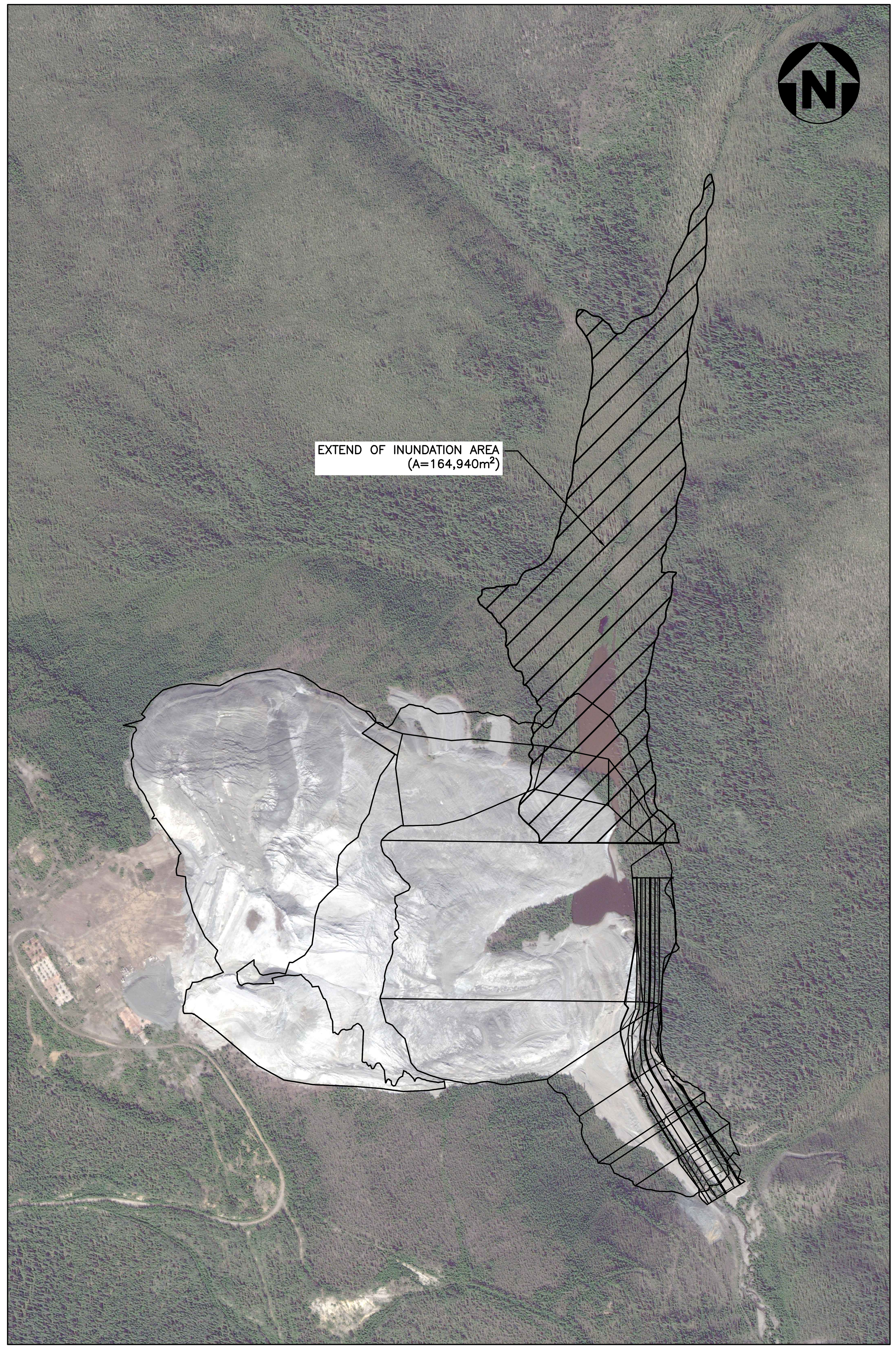

PLAN – INUNDATION AREA
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NOT FOR CONSTRUCTION

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REF	NUMBER	TITLE
6	VE52705E.WC2.7	SPILLWAY SECTIONS, SHEET 3 OF 3
5	VE52705E.WC2.6	SPILLWAY SECTIONS, SHEET 2 OF 3
4	VE52705E.WC2.5	SPILLWAY SECTIONS, SHEET 1 OF 3
3	VE52705E.WC2.4	SPILLWAY SECTIONS : DETAILS
2	VE52705E.WC2.3	PROFILE
1	VE52705E.WC2.1	GEN. ARRANGEMENT AND ILLUSTRATION OF CONCEPT
	REFERENCES	

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE
10% DESIGN

PROJECT NO.
VE52705E.100.2

SCALE
AS SHOWN

	BY	DDMMMYY
DES	GG	10JUL19
DRN	JM	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT
CLINTON CREEK REMEDIATION PROJECT
OPTION WC2 (IN PLACE STABILIZATION)
SPILLWAY PLAN

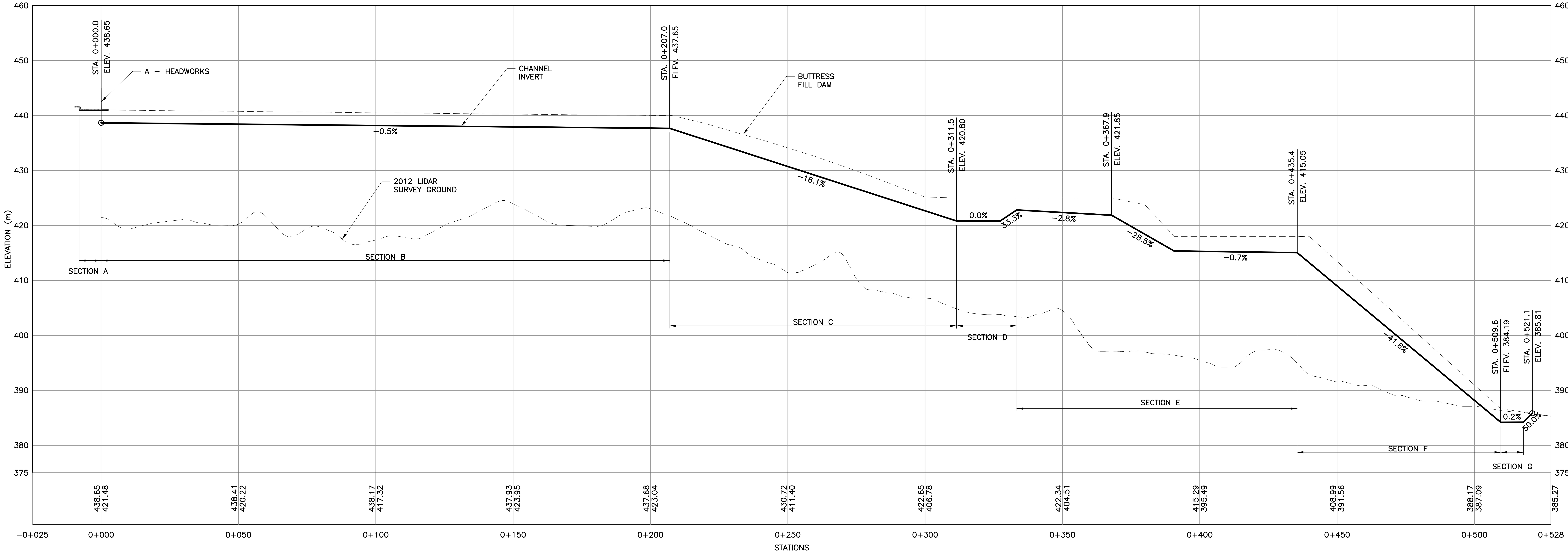
wood.

AREA

CLIENT DWG NO.

DRAWING NO.
VE52705E.WC2.2

REV



CHANNEL PROFILE

VER SCALE: 1:375
HOR SCALE: 1:750

0m 5 10 15 20
1:375

0m 10 20 30 40
1:750

REF	NUMBER	TITLE
6	VE52705E.WC2.7	SPILLWAY SECTIONS, SHEET 3 OF 3
5	VE52705E.WC2.6	SPILLWAY SECTIONS, SHEET 2 OF 3
4	VE52705E.WC2.5	SPILLWAY SECTIONS, SHEET 1 OF 3
3	VE52705E.WC2.4	SPILLWAY SECTIONS : DETAILS
2	VE52705E.WC2.2	PLAN
1	VE52705E.WC2.1	GEN. ARRANGEMENT AND ILLUSTRATION OF CONCEPT

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP	REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

STAMP/SEAL

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS SHOWN

	BY	DDMMMYY
DES	GG	10JUL19
DRN	JM	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION WC2 (IN PLACE STABILIZATION)
PROFILE

wood.

AREA

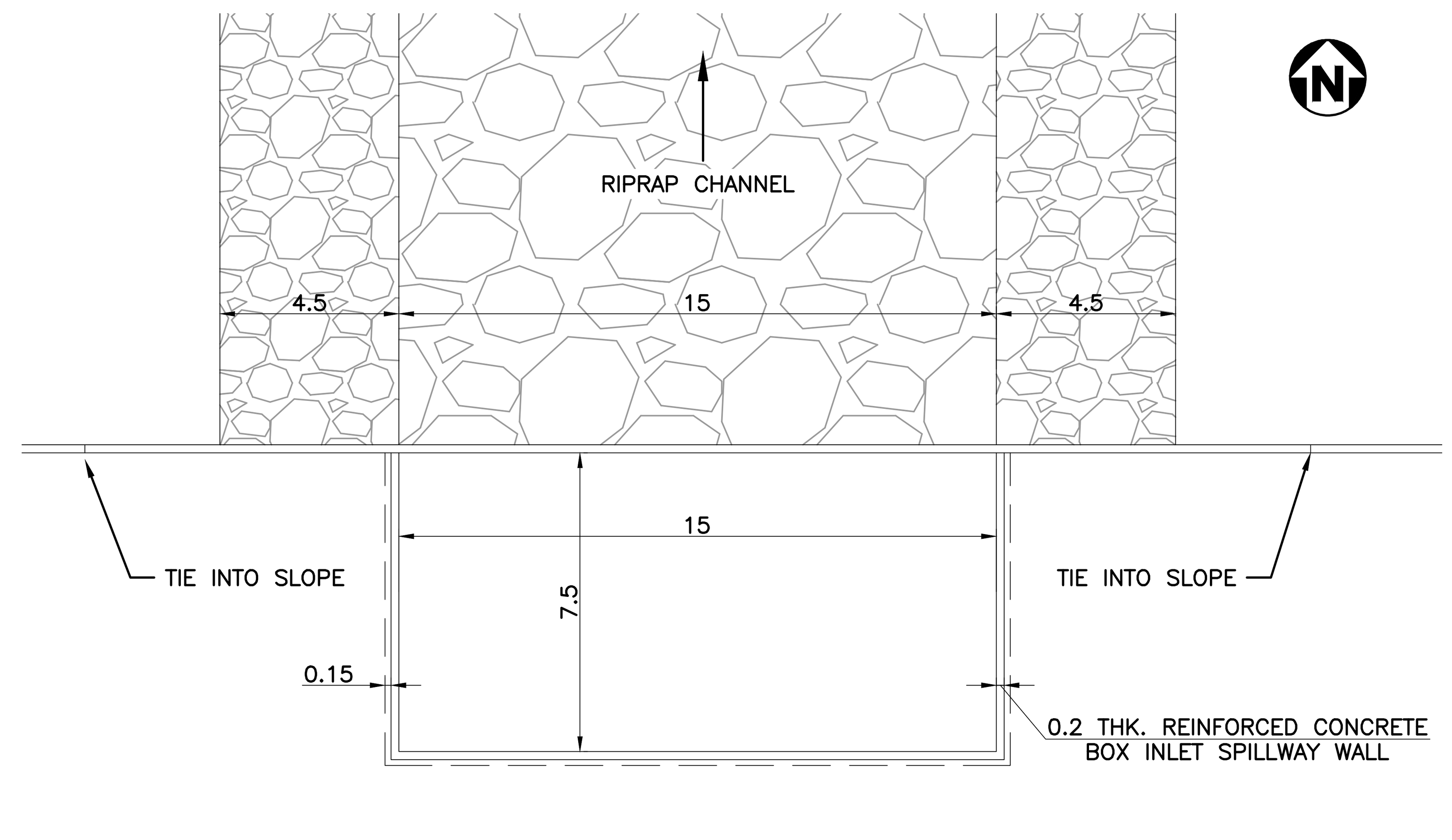
CLIENT DWG NO.

DRAWING NO.: VE52705E.WC2.3

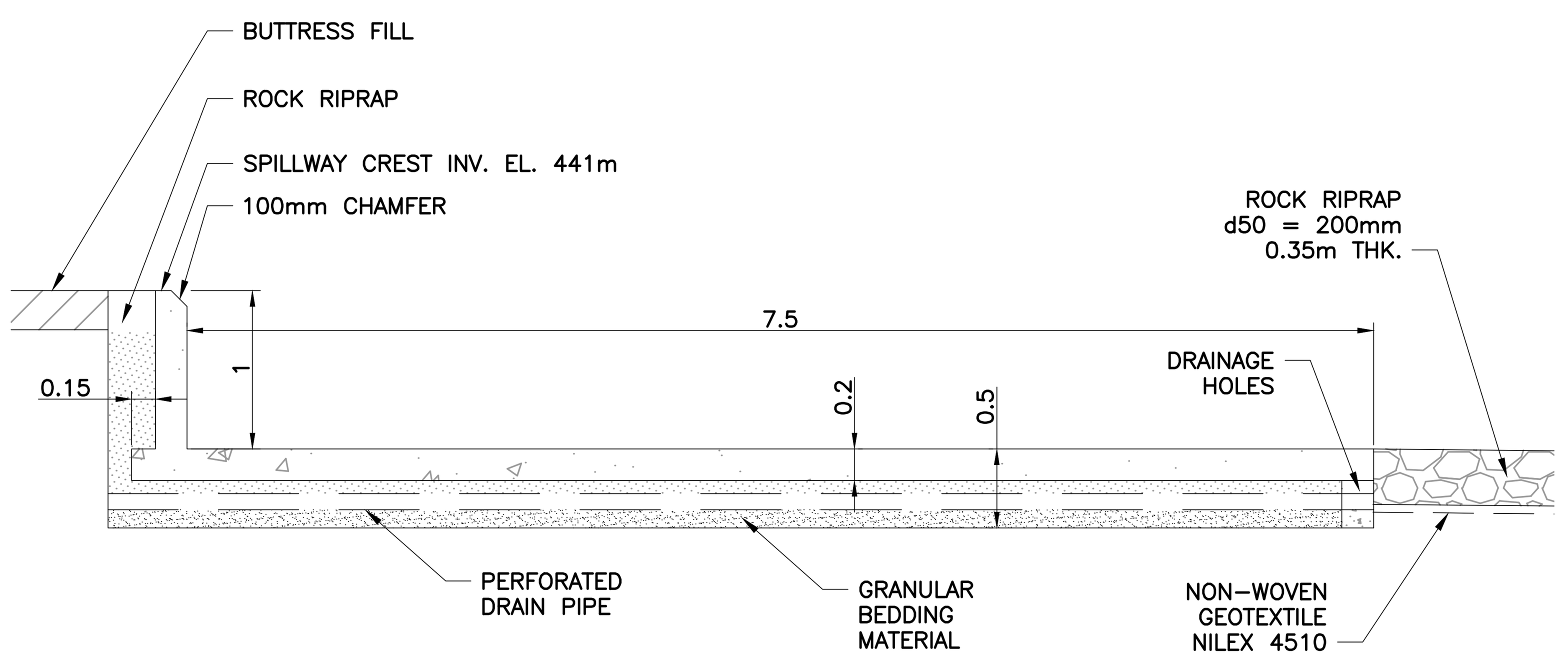
REV

CAD FILE: P:\CAD\VE\VE52705E.WC2.3.DWG

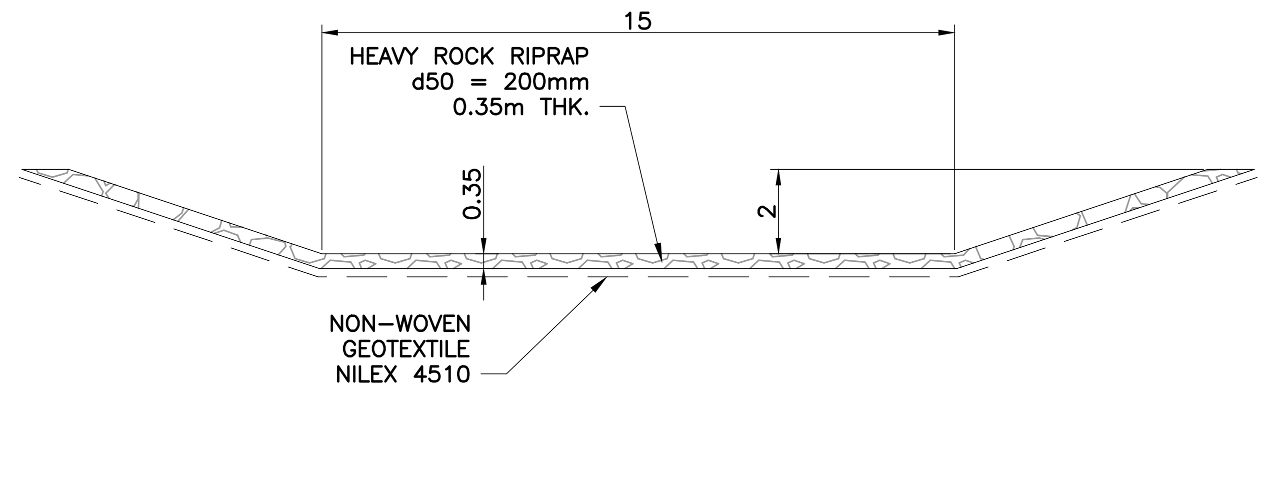
ISO A1-594x841



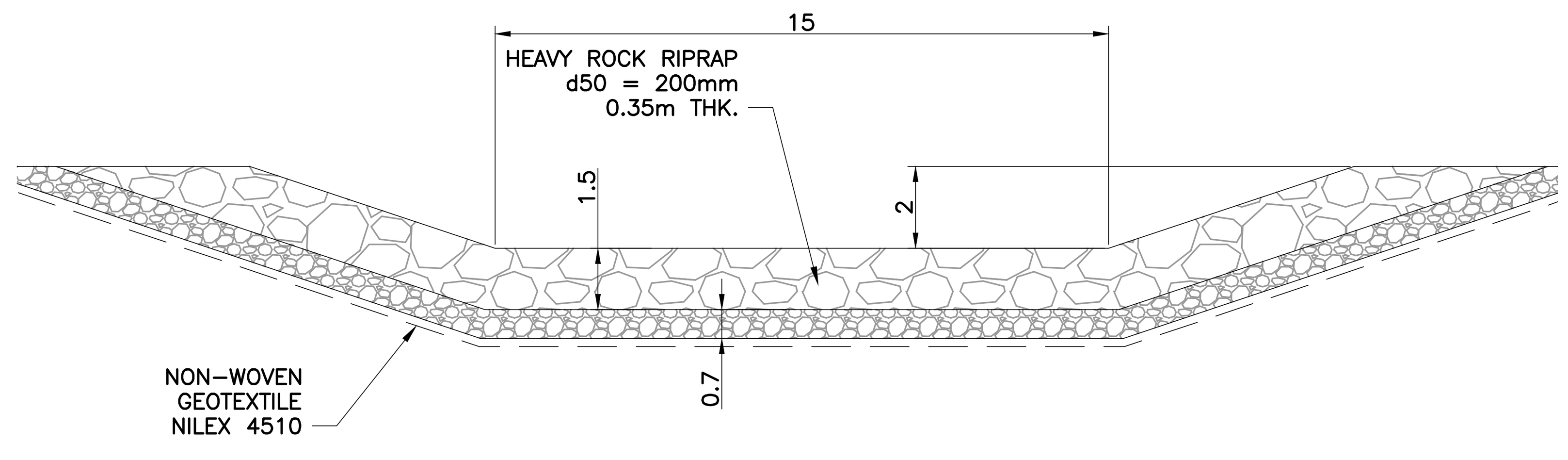
SECTION A PLAN – RECTANGULAR BOX INLET SPILLWAY
Scale 1:150



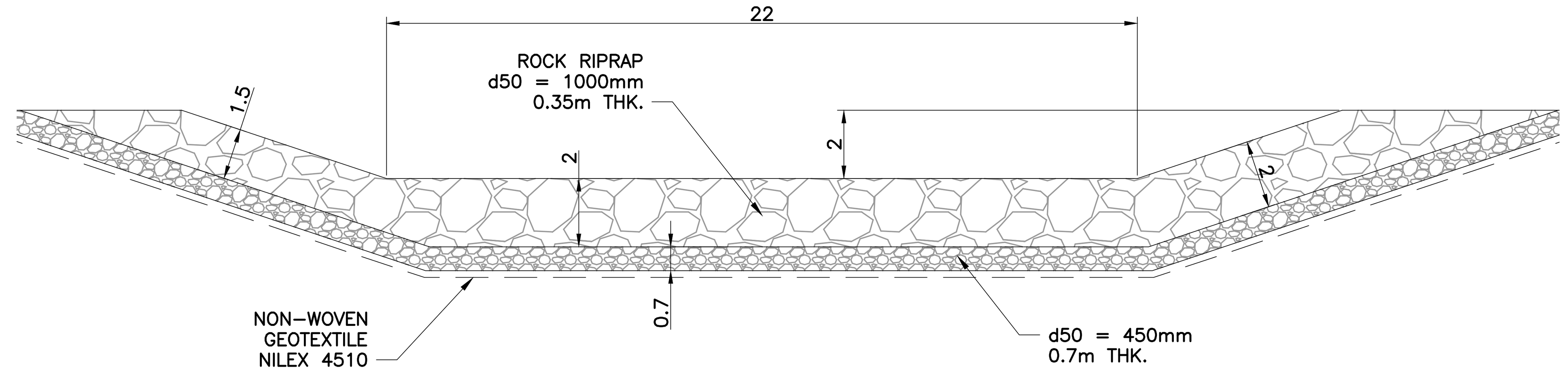
SECTION A PROFILE – RECTANGULAR BOX INLET SPILLWAY
Scale 1:40



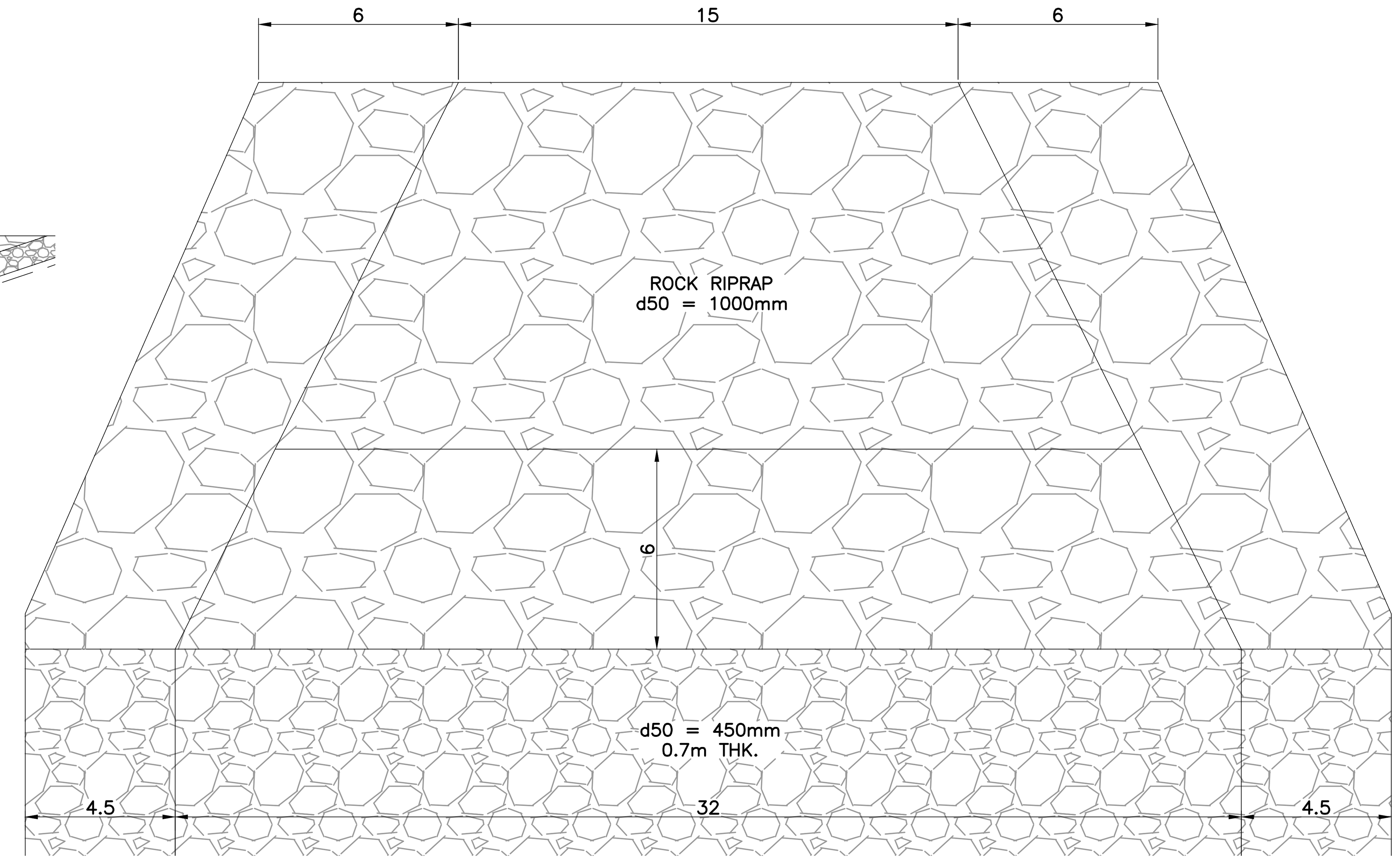
B / - SECTION
STATION 0+000 TO 0+215 Scale 1:150



C / - SECTION
STATION 0+215 TO 0+293 Scale 1:150



SECTION D PROFILE – THROUGH RIPRAP STILLING BASIN
STATION 0+293 TO 0+327
Scale 1:150



SECTION D PLAN – RIPRAP STILLING BASIN
STATION 0+293 TO 0+327
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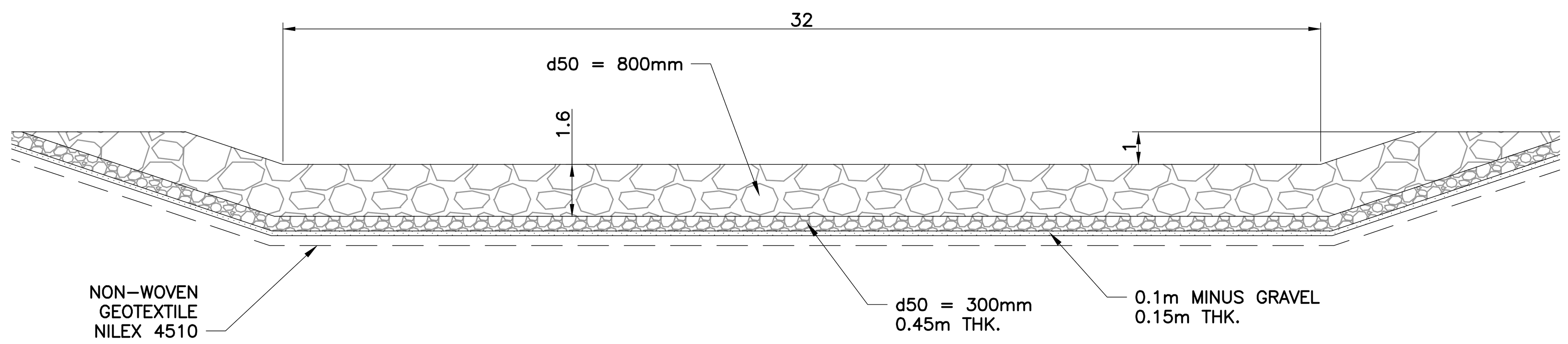
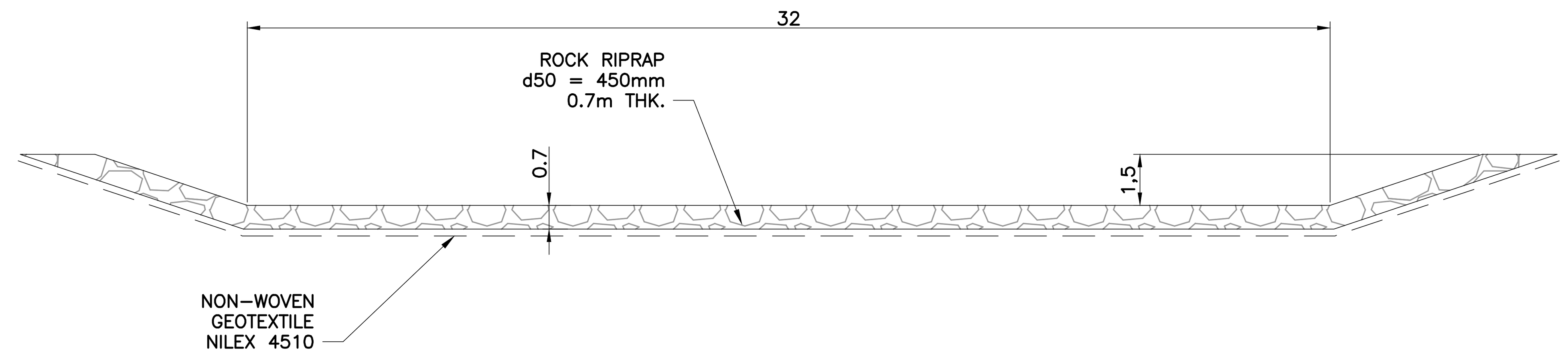
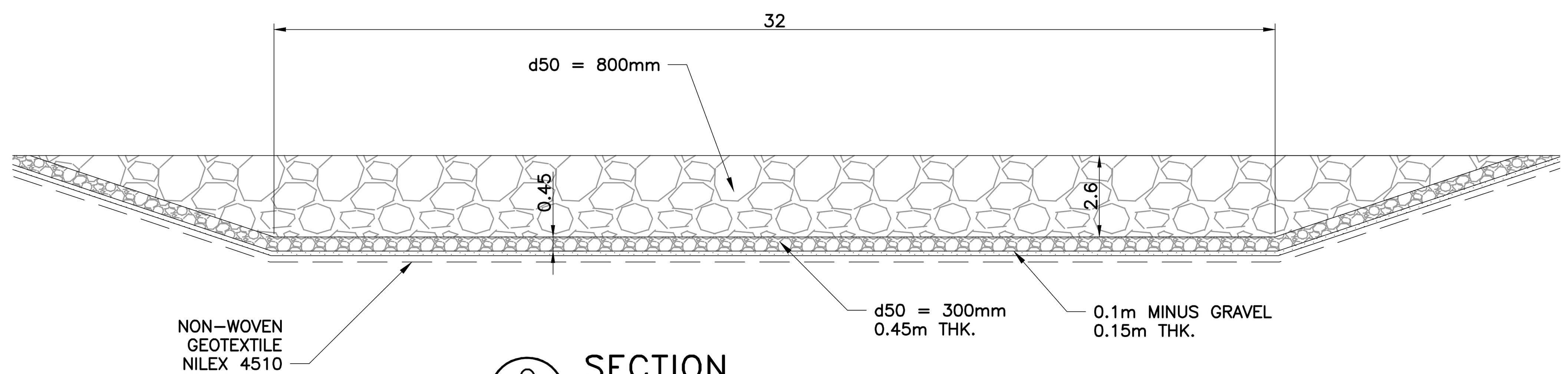


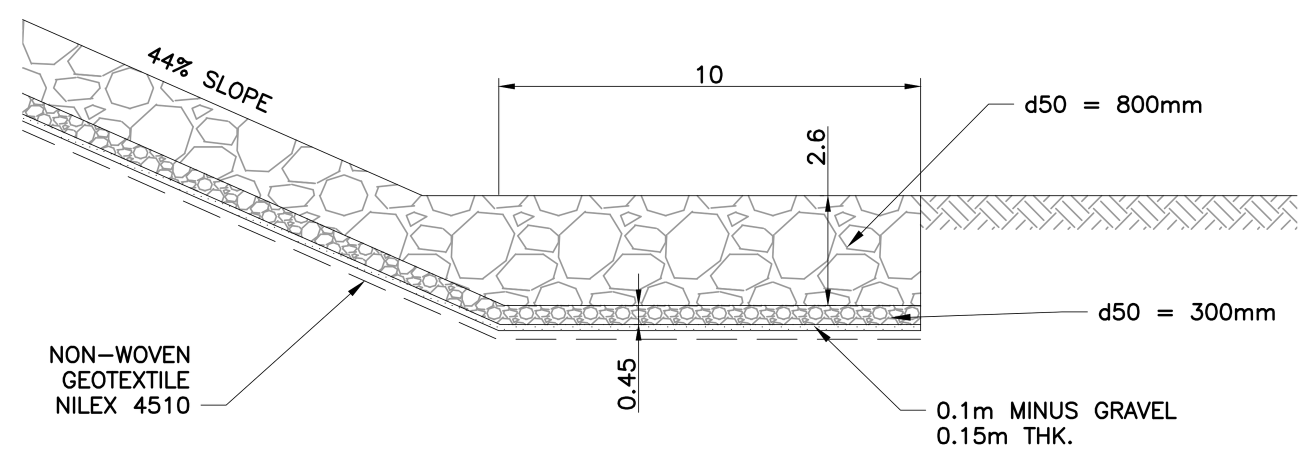
F / - SECTION
STATION 0+348 TO 0+505 Scale 1:150



E / - SECTION
STATION 0+327 TO 0+348 Scale 1:150

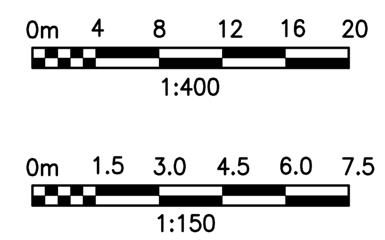


G / - SECTION
STATION 0+505 TO 0+520 Scale 1:150



SECTION G PROFILE – THROUGH TOW APRON
STATION 0+505 TO 0+520
Scale 1:150

NOT FOR CONSTRUCTION



REF	NUMBER	TITLE
6	VE52705E.WC2.7	SPILLWAY SECTIONS, SHEET 3 OF 3
5	VE52705E.WC2.6	SPILLWAY SECTIONS, SHEET 2 OF 3
4	VE52705E.WC2.5	SPILLWAY SECTIONS, SHEET 1 OF 3
3	VE52705E.WC2.3	PROFILE
2	VE52705E.WC2.2	PLAN
1	VE52705E.WC2.1	GEN. ARRANGEMENT AND ILLUSTRATION OF CONCEPT

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP	REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS SHOWN

	BY	DDMMMYY
DES	GG	10JUL19
DRN	JM	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT: CLINTON CREEK REMEDIATION PROJECT
OPTION WC2 (IN PLACE STABILIZATION)
SPILLWAY DETAILS AND SECTIONS

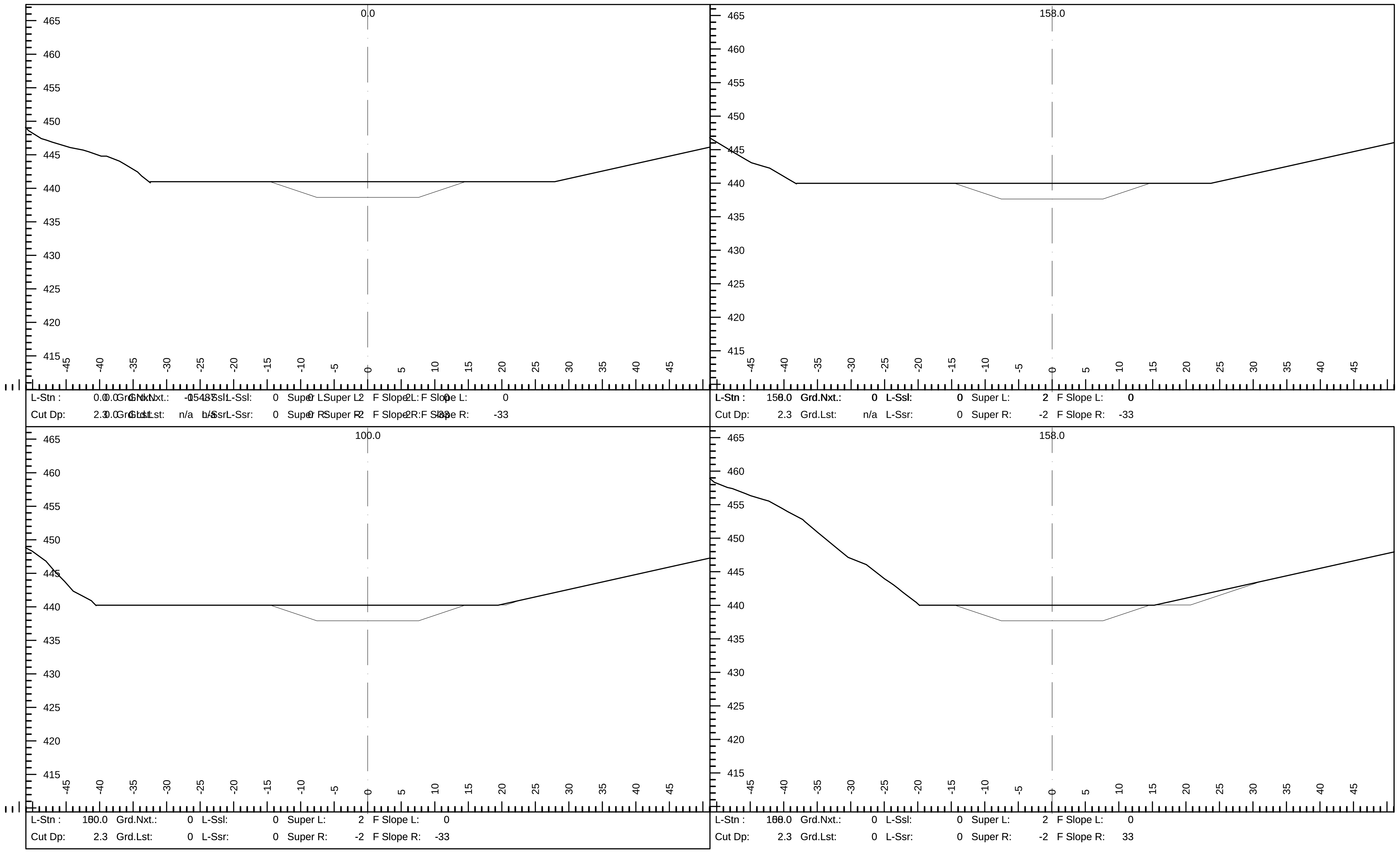
wood.

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.WC2.4

REV



NOT FOR CONSTRUCTION

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REF	NUMBER	TITLE
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5	VE52705E.WC2.6	SPILLWAY SECTIONS, SHEET 2 OF 3
4	VE52705E.WC2.4	SPILLWAY SECTIONS DETAILS
3	VE52705E.WC2.3	PROFILE
2	VE52705E.WC2.2	PLAN
1	VE52705E.WC2.1	GEN. ARRANGEMENT AND ILLUSTRATION OF CONCEPT

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

APPROVED FOR __________

CLIENT PROJECT MGR DEPARTMENT MGR PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS SHOWN

	BY	DDMMMYY
DES	HY	10JUL19
DRN	JM	10JUL19
CHK	HY	10JUL19
APP		

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
OPTION WC2 (IN PLACE STABILIZATION)
SPILLWAY SECTIONS
SHEET 1 OF 3

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.WC2.5

REV

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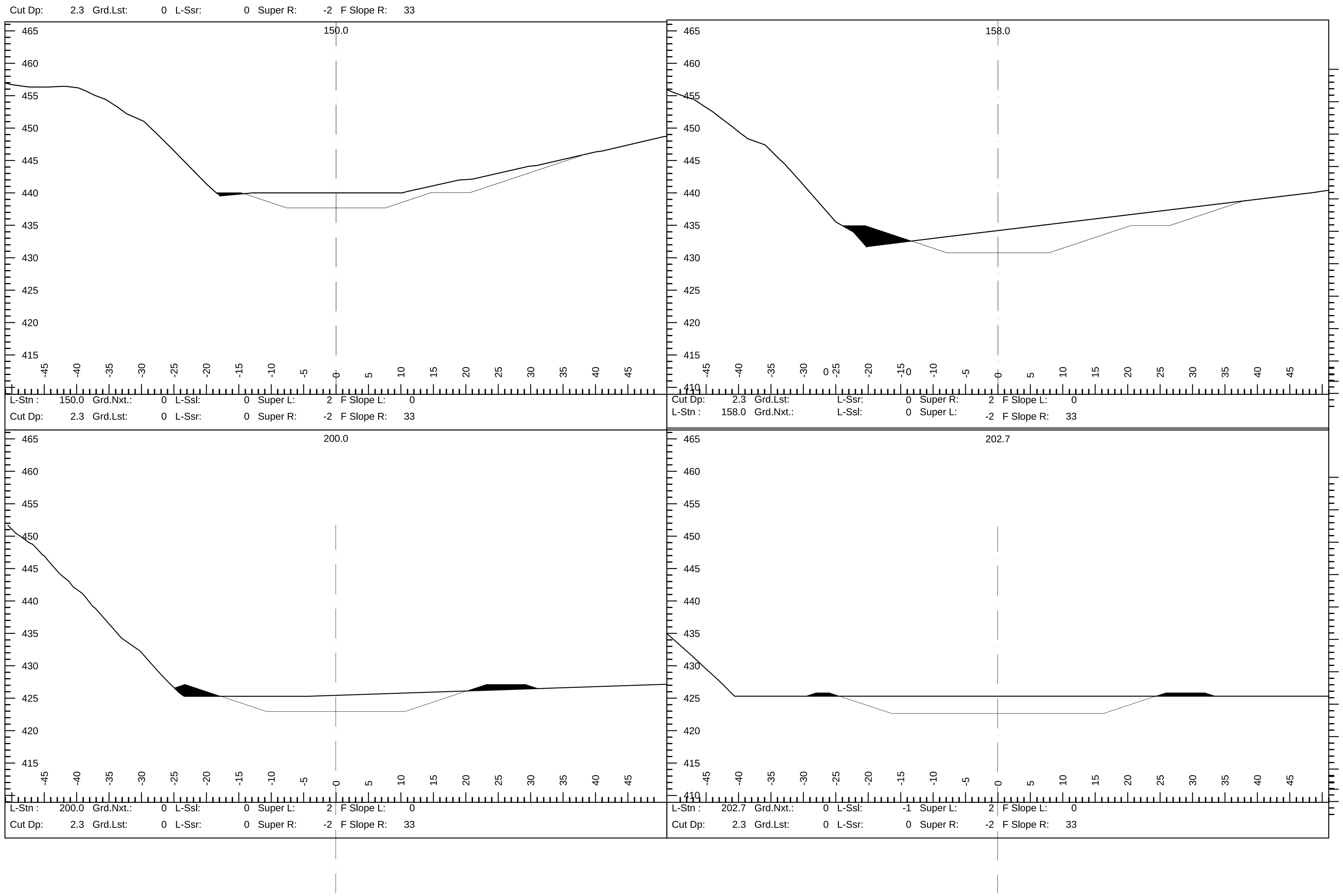

NOT FOR CONSTRUCTION

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REF	NUMBER	TITLE
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5	VE52705E.WC2.5	SPILLWAY SECTIONS, SHEET 1 OF 3
4	VE52705E.WC2.4	SPILLWAY SECTIONS DETAILS
3	VE52705E.WC2.3	PROFILE
2	VE52705E.WC2.2	PLAN
1	VE52705E.WC2.1	GEN. ARRANGEMENT AND ILLUSTRATION OF CONCEPT

REFERENCES

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS SHOWN

	BY	DDMMMYY
DES	HY	10JUL19
DRN	JM	10JUL19
CHK	HY	10JUL19
APP		

Yukon

SUBJECT
CLINTON CREEK REMEDIATION PROJECT
OPTION WC2 (IN PLACE STABILIZATION)
SPILLWAY SECTIONS
SHEET 2 OF 3

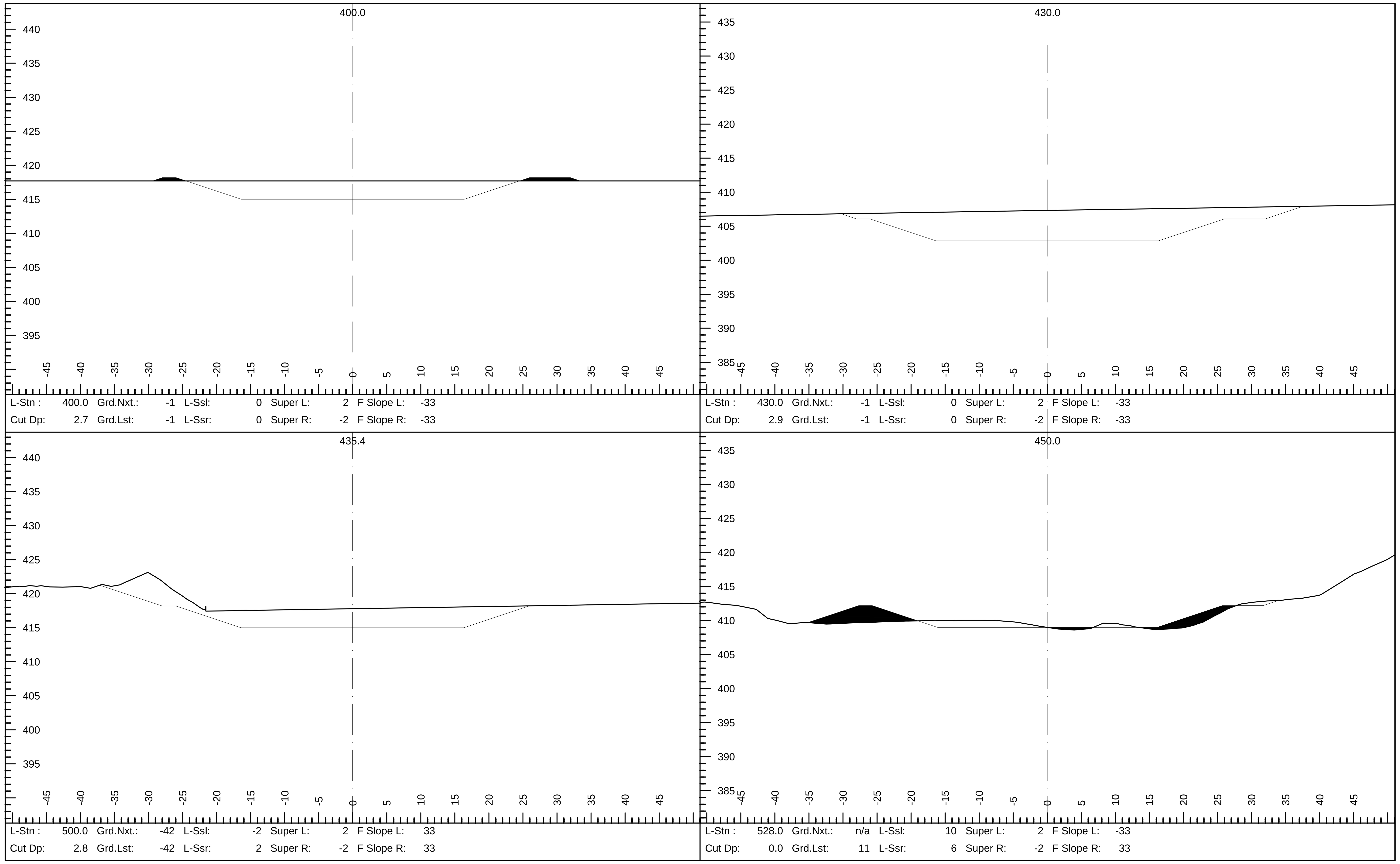
wood.

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.WC2.6

REV



NOT FOR CONSTRUCTION

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REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REFERENCES

REF	NUMBER	TITLE
6	VE52705E.WC2.6	SPILLWAY SECTIONS, SHEET 2 OF 3
5	VE52705E.WC2.5	SPILLWAY SECTIONS, SHEET 1 OF 3
4	VE52705E.WC2.4	SPILLWAY SECTIONS : DETAILS
3	VE52705E.WC2.3	PROFILE
2	VE52705E.WC2.2	PLAN
1	VE52705E.WC2.1	GEN. ARRANGEMENT AND ILLUSTRATION OF CONCEPT

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: AS SHOWN

	BY	DDMMMYY
DES	HY	10JUL19
DRN	JM	10JUL19
CHK	HY	10JUL19
APP		

SUBJECT
CLINTON CREEK REMEDIATION PROJECT
OPTION WC2 (IN PLACE STABILIZATION)
SPILLWAY SECTIONS
SHEET 3 OF 3

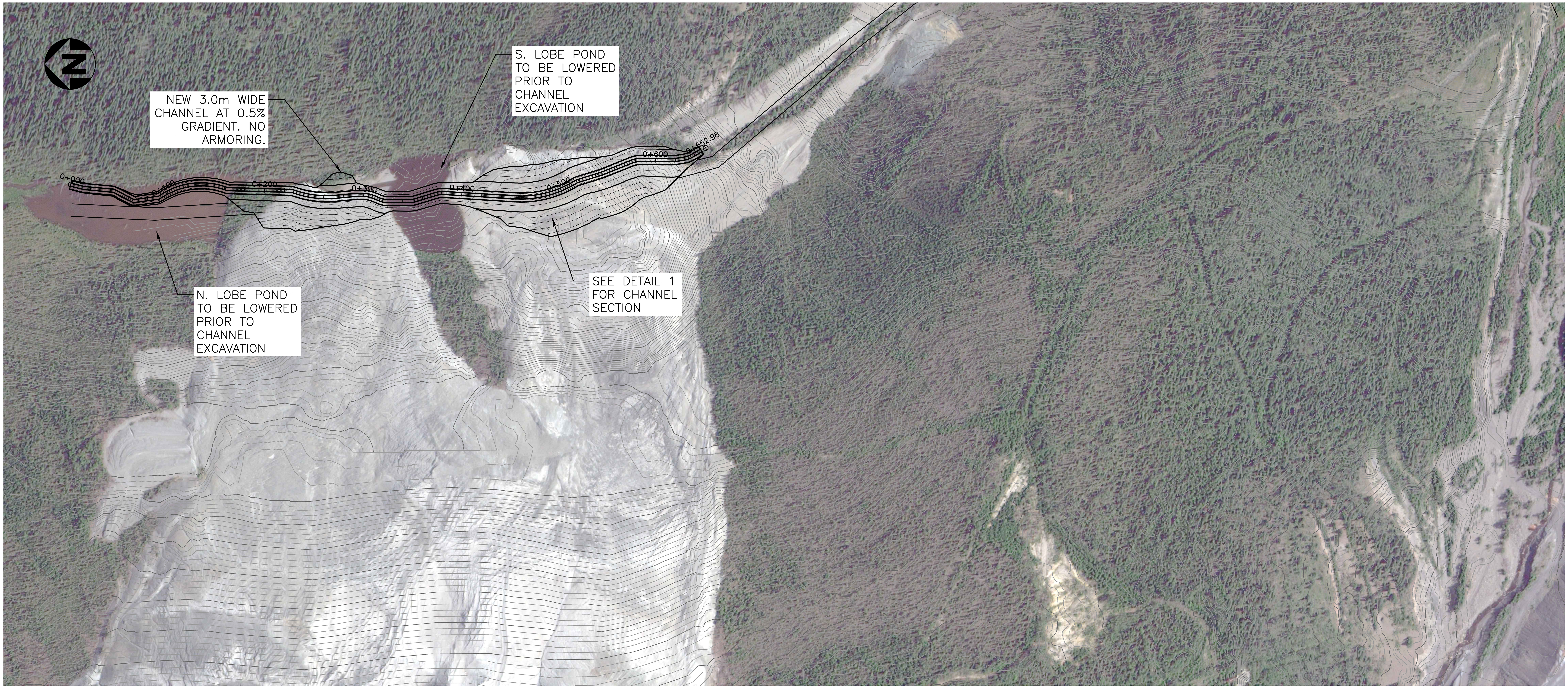
AREA

CLIENT DWG NO.

DRAWING NO. VE52705E.WC2.7

REV

WC3 (Tailings Isolation vs. Relocation)



PLAN
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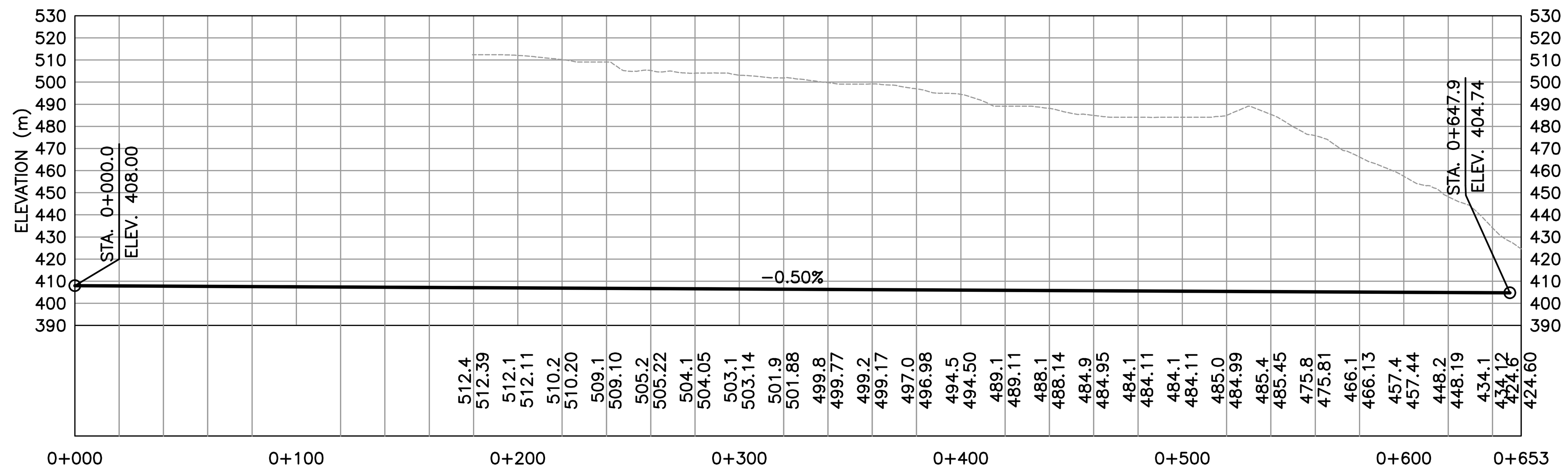

PROFILE
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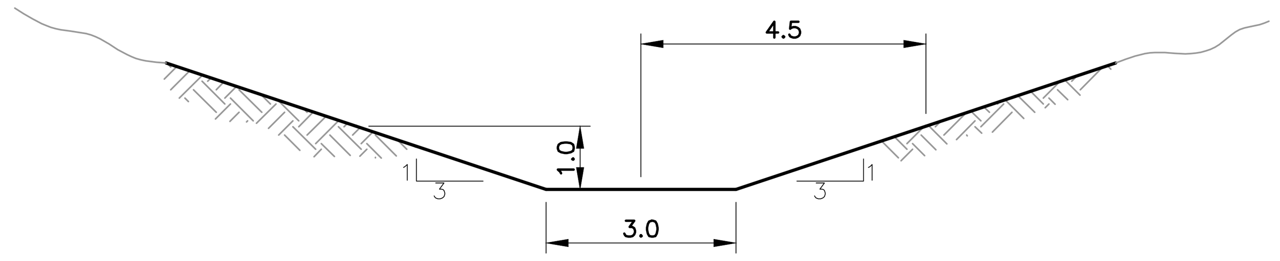

TYPICAL SECTION

DETAIL 1 / –
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1:100

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NOT FOR CONSTRUCTION

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REF	NUMBER	TITLE
1	VE52705E.WC3.2	HAUL ROAD PLAN PROFILE : DETAILS

REFERENCES

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	GG	12JUL19
DRN	JM	12JUL19
CHK	GG	12JUL19
APP		

Yukon

wood.

SUBJECT
CLINTON CREEK REMEDIATION PROJECT
OPTION WC3
(TAILINGS ISOLATION VIA RELOCATION)
PLAN, PROFILE AND SECTION

AREA

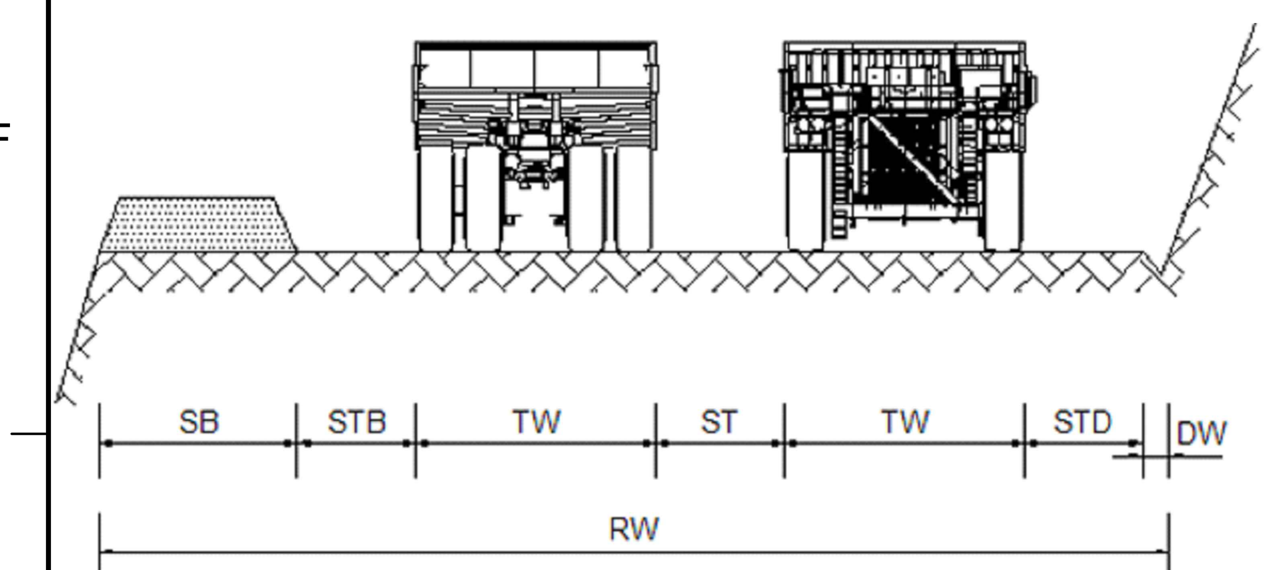
CLIENT DWG NO.

DRAWING NO.: VE52705E.WC3.1

REV

SAVED: 29-Aug-19 8:11 AM PLOTTED: 15-N -19 3:00 PM USER: LIN, KEVIN

ISO A1-594x841

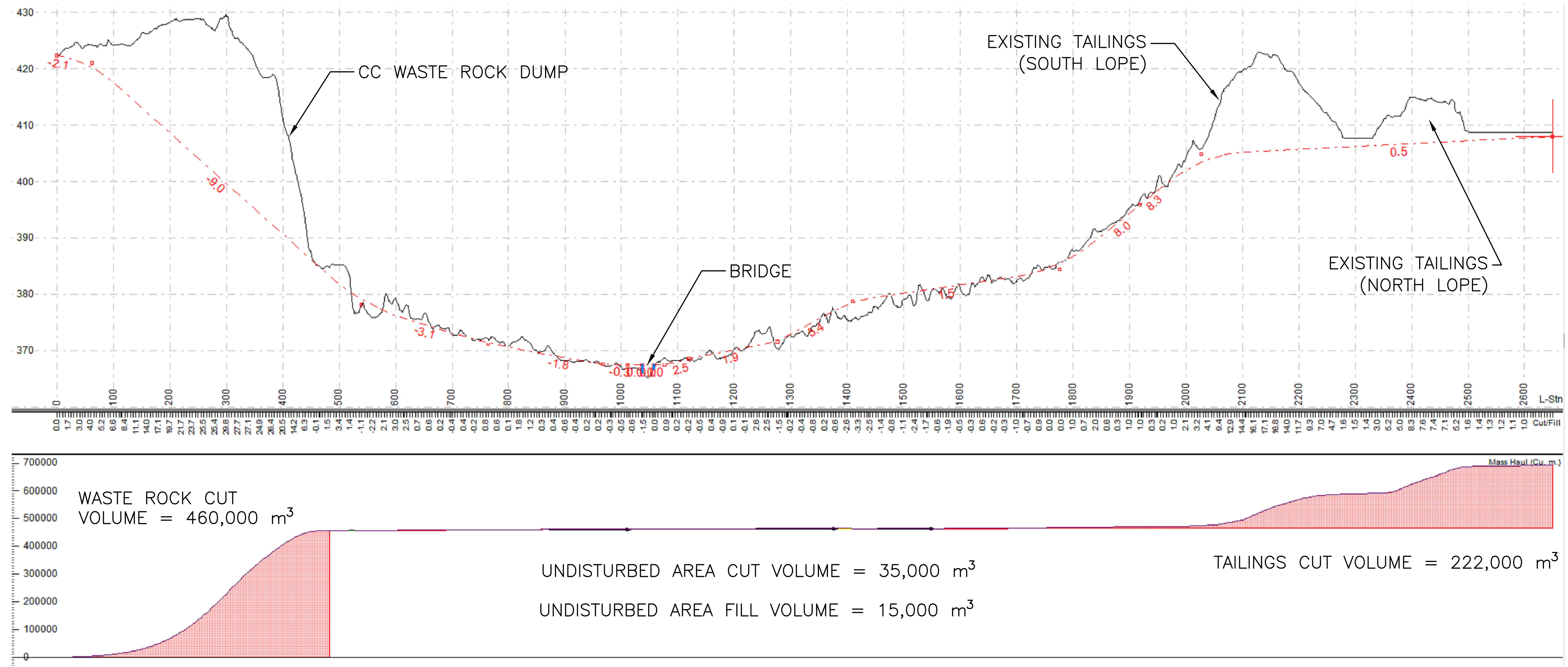


SB:	Safety Berm	2.52	m
STB:	Space Between Truck and Safety Berm	1.39	m
TW:	Truck Width	4.17	m
ST:	Space Between Trucks	1.39	m
TW:	Truck Width	4.17	m
STD:	Space Between Truck and Ditch	1.39	m
DW:	Ditch Width	1.50	m
RW:	Ramp Width	16.52	m

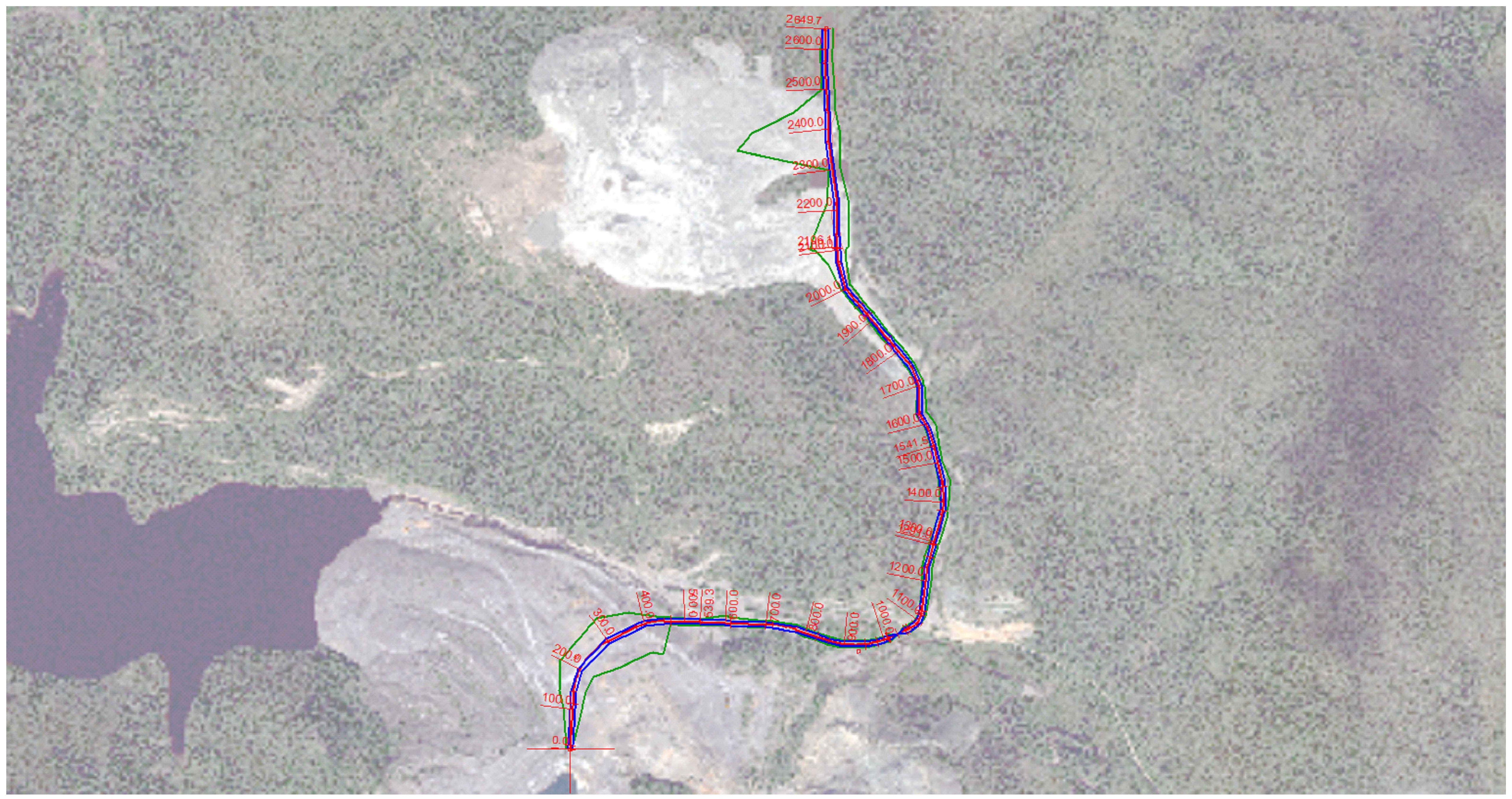
Roas lane excluding safety berm and ditch:
6.25 = per lane width (m)
12.50 +ditch = Two lane + ditch
Ditch width varies in the model

Truck Width - CAT 740	4.17	m	Selected
Rolling Surface Width Rule of Thumb =	12.50	m	
Tire Radius	0.95	m	

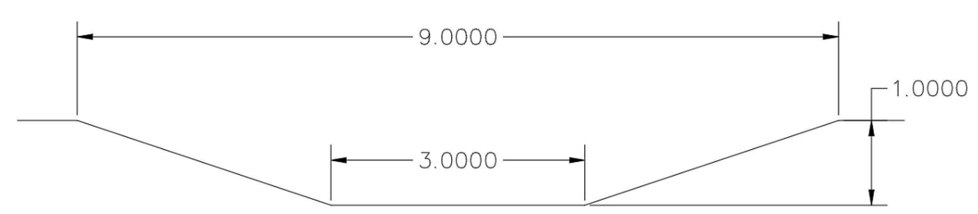
HAUL ROAD SECTION DESIGN



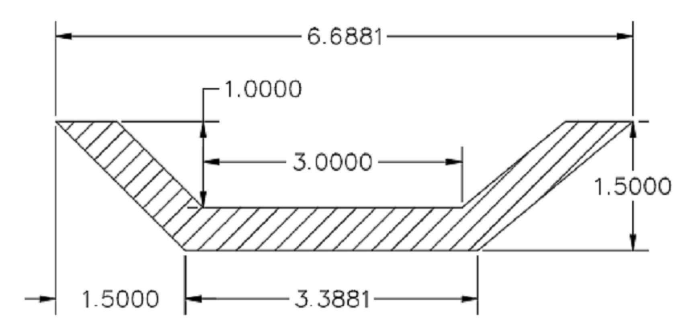
WOLVERINE CREEK HAUL ROAD PROFILE AND CUT/FILL BALANCE



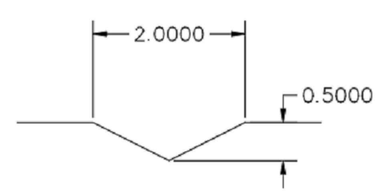
WOLVERINE CREEK HAUL ROAD ALIGNMENT



1– CHANNEL DIMENSIONS AT THE WOLVERINE CREEK WITH 0.5% SLOPE, NO RIPRAP, 3H:1V (TAILINGS AREA)



2– STEEP PORTIONS OF THE WOLVERINE CREEK AREA RIPRAP REQUIRED, 1H:1V



3– TYPICAL SIDE DITCH ALONG THE HAUL ROAD CLINTON CREEK TO OPEN PIT SECTION, NO RIPRAP, 2H:1V

NOT FOR CONSTRUCTION

REF	NUMBER	TITLE
1	VE52705E.WC3.1	PLAN, PROFILE AND SECTION

APPROVED FOR

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	HY	12JUL19
DRN	JM	12JUL19
CHK	HY	12JUL19
APP		

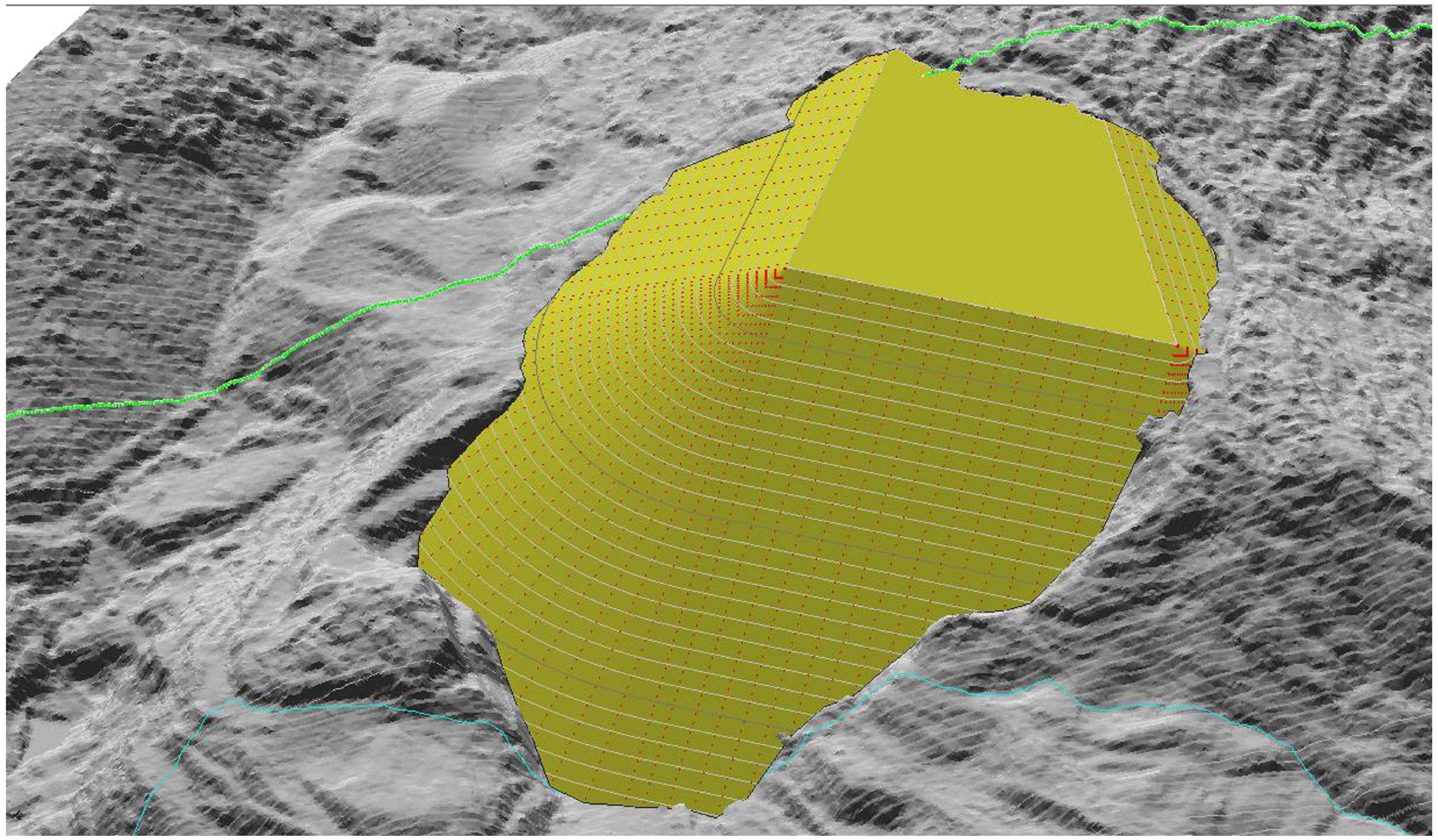
Yukon

wood.

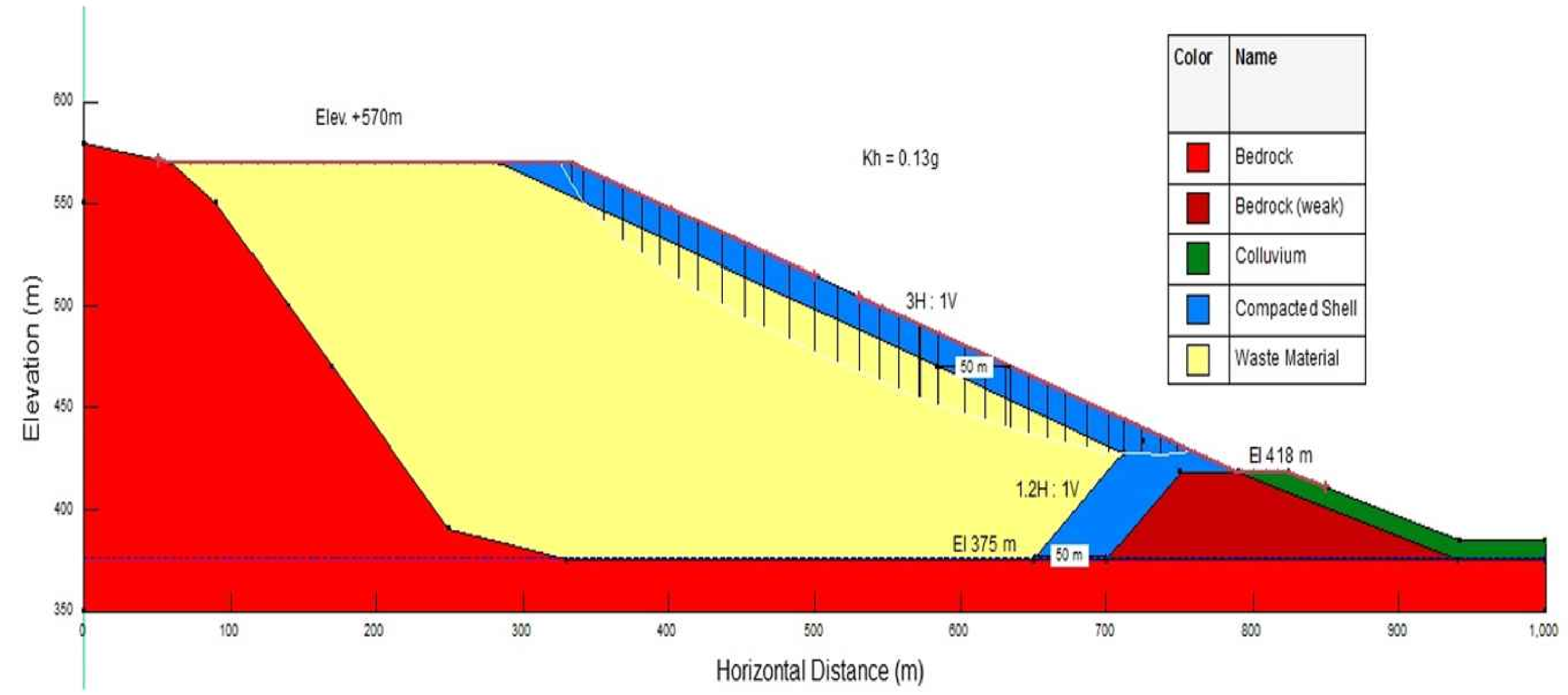
SUBJECT: CLINTON CREEK REMEDIATION PROJECT OPTION WC3 (TAILINGS ISOLATION VIA RELOCATION) HAUL ROAD PLAN PROFILE & DETAILS

DRAWING NO.: VE52705E.WC3.2

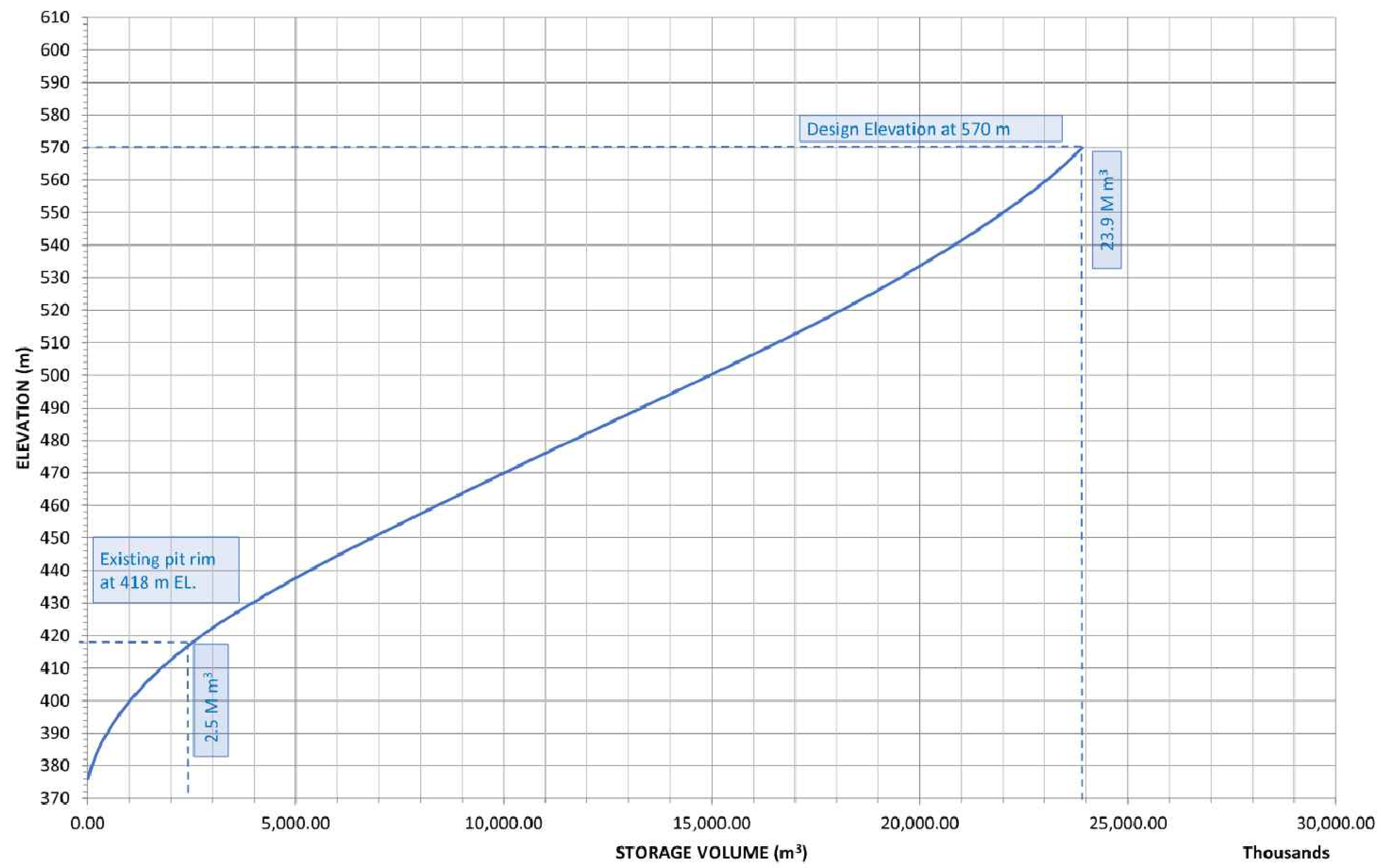
Porcupine Pit Storage Structure



PLAN OF PPSS LOOKING SOUTH–SOUTHWEST



TYPICAL PPSS SECTION



PPSS STORAGE ELEVATION CURVE

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP	REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP	REF	NUMBER	TITLE

REFERENCES

STAMP/SEAL

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	BG	10JUL19
DRN	LB	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT

CLINTON CREEK REMEDIATION PROJECT
PORCUPINE PIT STORAGE STRUCTURE

wood.

AREA

CLIENT DWG NO.

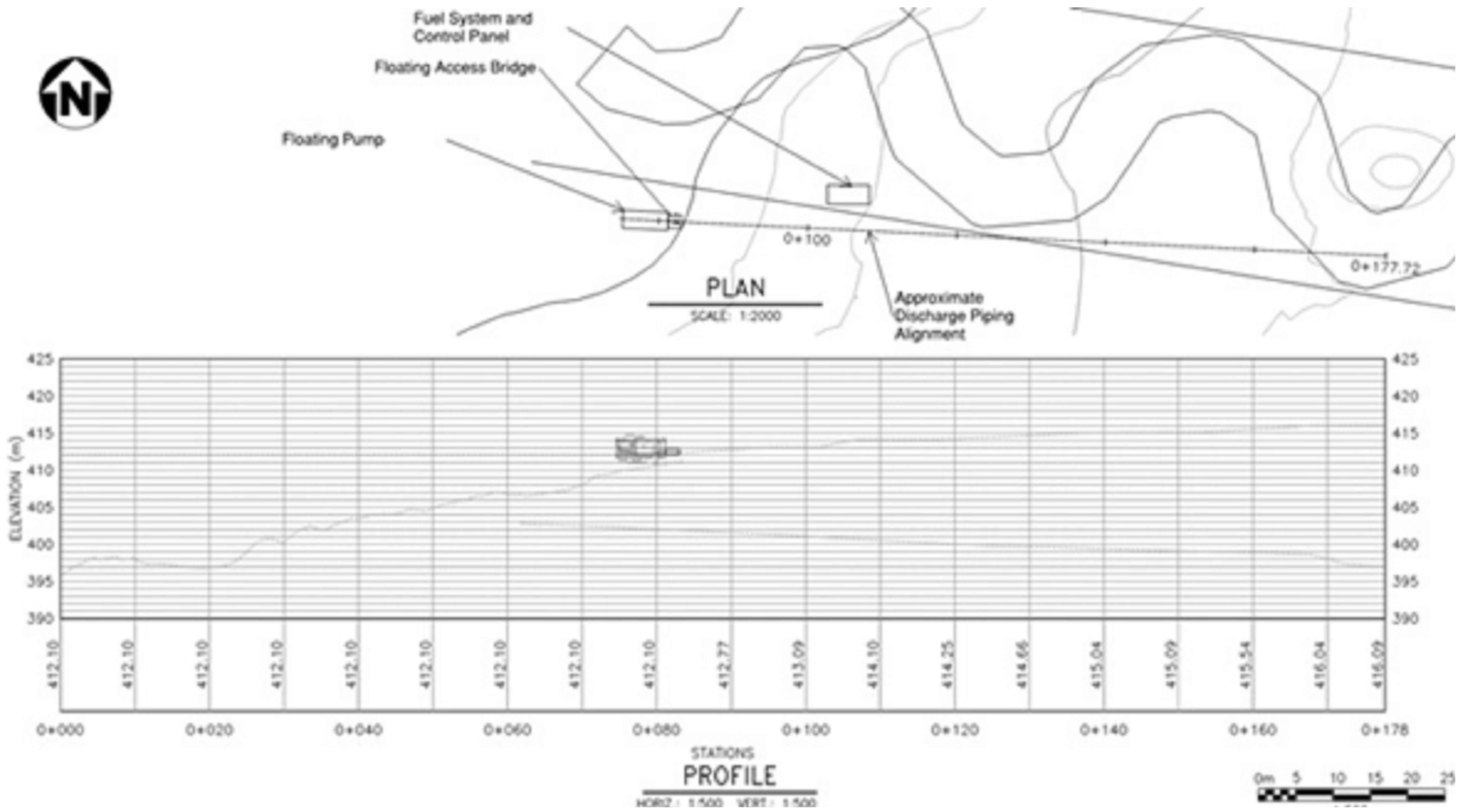
DRAWING NO.: VE25705E.PPSS.1

REV

CAD FILE: P:\CAD\CIVIPCSS.1\VE25705E.PPSS.1.DWG

SAVED: 28-Aug-19 3:42 PM PLOTTED: 28-Aug-19 3:45 PM USER: BREZINA, LUKAS

Drawdown Concept



PLAN & PROFILE OF PUMPING LAYOUT

ILLUSTRATION OF TYPICAL PUMPING SYSTEM CONFIGURATION

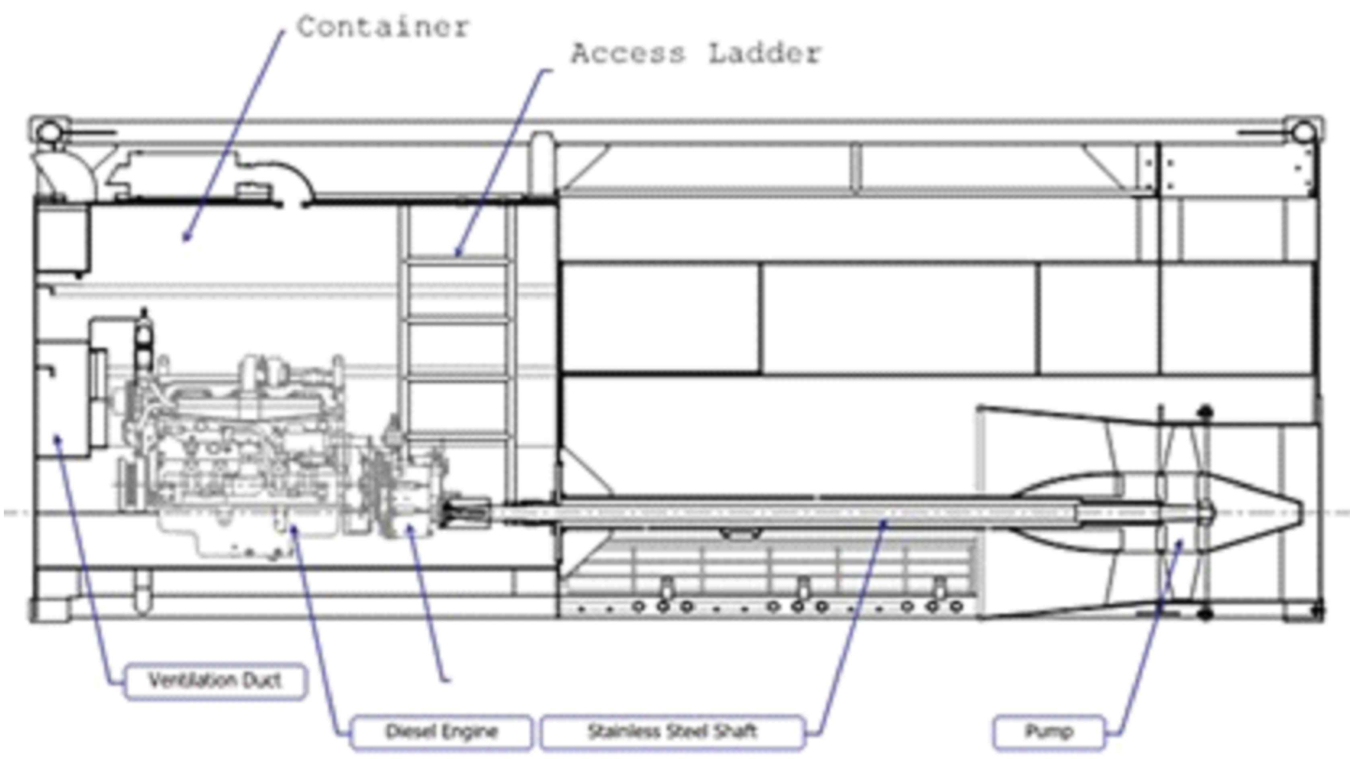


ILLUSTRATION OF TYPICAL PUMPING SYSTEM BARGE

REV	DDMMMYY	REVISION / ISSUE DESCRIPTION	DRN	CHK	APP	APP	APP	APP

REF	NUMBER	TITLE
REFERENCES		

STAMP/SEAL

APPROVED FOR ________

CLIENT PROJECT MGR | DEPARTMENT MGR | PROJECT MGR

PROJECT PHASE: 10% DESIGN

PROJECT NO.: VE52705E.100.2

SCALE: VARIES

	BY	DDMMMYY
DES	BG	10JUL19
DRN	LB	10JUL19
CHK	GG	10JUL19
APP		

Yukon

SUBJECT: CLINTON CREEK REMEDIATION PROJECT
LAKE DRAWDOWN PUMPING SYSTEM CONCEPT

wood.

AREA

CLIENT DWG NO.

DRAWING NO.: VE52705E.DRAWDOWNS.1

REV

SAVED: 21-Aug-19 3:08 PM PLOTTED: 21-Aug-19 3:17 PM USER: BREZINA, LUKAS

Appendix A
CC1 Geothermal Analysis

4445 Lougheed Hwy
Burnaby, BC V5C 0E4
T: +1 604-294-3811
www.woodplc.com

Memo

To:	File
Company:	Clinton Creek Mine
From:	A Tchekhovski
Date:	5 July 2019
Review:	Ed McRoberts
Ref:	VE52705
Re:	Geothermal Analyses for Permafrost Thawing

1.0 INTRODUCTION

The memo has been issued by Wood Environment & Infrastructure Solutions, a Division of Wood Canada Limited (Wood) to the Government of Yukon in regard to the Clinton Creek Asbestos Mine, located approximately 75 kilometres northwest of Dawson, YK. The purpose of the geothermal analyses was to determine amount of energy required for thawing ice reach relict permafrost under the spillway alignment of the Hudgeon Lake. The results of the performed geothermal analyses are recommended for the use as an energetic base to design and maintain an electrical/steam heating system which allows thawing the permafrost for a determined period of time and a determined space between heater holes advanced through icy permafrost. The cost of the energetic base should be combined with costs of other elements of the heating system, such as number of heater holes, length of heating lines and energy production rates for various heater temperatures and for various heater devices. Using such methodology, a minimal cost of the thawing can be obtained for various periods of time.

The present geothermal analyses considered that the heater holes are spaced at a distance of 4 m, 5 m, and 6 m (Figure 1). For each of the distances, three periods of thawing time were considered: 12 months, 18 months and 24 months, meaning that nine energy amounts were calculated in total.

2.0 CONCEPTUAL APPROACH

For accurate calculation of the energy amount, the grid of the geothermal model should be dense and uniform for X and Y coordinates. For the present study, the grid nodes were spaced 5 mm apart. The maximum grid contained 38841 nodes and 76800 finite elements.

The geothermal grid of the analyses is shown in Figure 2. The portion of the grid (10 m long) beyond the heater grid was used for calculation of the heat loss into the surrounding unfrozen soil.

For each of the energy amount, several geothermal analyses were carried out, applying various heater temperatures in the middle of the heater grid (see Figure 2). The minimal temperature of the heater which provided full thawing of the heater grid (Figure 2) was used to calculate the energy amount needed for thawing 1 m^3 of icy permafrost. At the end of thawing period of time, the average temperature of the heater grid was calculated and the energy amount was calculated by the following formula:

$$E = T*c + L; \qquad (1)$$

where: E – energy amount, MJ/m^3;
T – average temperature of the heater grid, ^oC;
c – unfrozen heat capacity, $MJ/m^3/^oC$;
L – latent heat, MJ/m^3.

At the end of thawing period of time, the average temperature of the warmed up unfrozen soil was also calculated and the energy loss per 1 m^2 was calculated by the following formula:

$$E_{loss} = A * T_s * \ c_s \ ; \qquad (2)$$

where: E_{loss}– energy loss, MJ/m^2;
T_s– average warmed up temperature of the surrounding unfrozen soil, ^oC;
c_s– heat capacity of the surrounding unfrozen soil, $MJ/m^3/^oC$;
A –specific unit for length, m.

3.0 GEOTHERMAL MODEL TO PREDICT PERMAFROST THAWING

For the current study, 2-dimensional versions of SIMTEMP software (developed in-house by Wood) were used to analyze the temperature regime of the thawing permafrost under the proposed CC1 spillway for Hudgeon Lake. The program uses the finite element method to compute a numerical solution for the heat transfer problem. Physical/mathematical algorithms used in the SIMTEMP model have been published and the simulation process has been verified against well-known analytical solutions and with numerical solutions produced by other commercial/non-commercial geothermal modelling software. Wood has successfully used the SIMTEMP program for a variety of geothermal applications over the last 20 years.

The general form of two-dimensional equation for transient heat transfer is written:

$$C(T,x,y)\frac{dT}{dt} = k(T,x,y)\frac{\partial^2 T}{\partial x^2} + k(T,x,y)\frac{\partial^2 T}{\partial y^2}; \qquad (3)$$

where: C(Tuxy) – volumetric heat capacity;
k(T,x,y) – thermal conductivity;
T – temperature;
t – time.

Using Goodman's and Kirchoff's substitutes to the left and right portions of Equation 3, respectively, the non-linear equation is transformed to a quasi-linear equation which is written as follows:

$$\frac{dH}{dt} = \frac{\partial^2 F}{\partial x^2} + \frac{\partial^2 F}{\partial y^2}; \qquad (4)$$

where: H – enthalpy (Goodman's substitute);
F – temperature flux (Kirchoff's substitute).

Equation 4 is solved numerically using the finite element method in SIMTEMP software.

4.0 FROZEN AND UNFROZEN SOIL PROPERTIES

Results of drilling in BH18-03 through icy permafrost (interval 30-38 m) and unfrozen soil below were used for the geothermal modelling. The frozen and unfrozen materials were represented by various clays with approximate average moisture content of 100 and 15 percent, respectively. Based on the moisture content data and assuming the specific gravity of the modelled soil as 2.68, the dry density of the soils was calculated and thermal properties were selected based on our experience and literature data (see Table 1).

Table 1: Physical and Thermal Properties of Soils

Soil	Dry Density, kg/m^3	Moisture Content, %	Thermal Cond., W/m/°K		Heat Capacity, MJ/m^3/°K		Latent Heat, MJ/m^3
			Frozen	Unfrozen	Frozen	Unfrozen	
Icy frozen	728	100	2.03	1.75	2.093	3.580	243.851
Unfrozen	1900	15	1.86	1.63	2.052	2.763	95.464

5.0 INITIAL AND BOUNDARY CONDITIONS OF MODEL

The initial temperature of the permafrost was assumed to be -0.1°C, while the initial temperature of the unfrozen soil was assumed to be +0.1°C. Conditions of the zero heat flux were realized on the boundaries of the geothermal grid (Figure 2).

6.0 RESULTS OF MODELLING AND LAYOUT OF HEATERS

The results of the modelling are shown in Table 2 below. The table demonstrates the amount of energy (MJ/m^3) required to thaw 1 m^3 of frozen soil and the amount of energy (MJ/m^2) which will be lost for warming up 1 m^2 unfrozen soil around the permafrost layer.

Table 2: Energy Amounts Required for Permafrost Thawing

Thawing Time, month	Hole Grid, m x m/ftxft	Required Temperature of Heater, °C/°F	Energy, MJ/m^3 (BTU/ft^3)	Temperature Warming Beyond Permafrost Layer at, °C/°F	Loss Energy into Surrounding Unfrozen Soil, MJ/m^2 (BTU/ft^2)
24	6x6/19.68x19.68	74/165	297.549(7985.98)	1.05/1.89	2.902(77.887)
24	5x5/16.4x16.4	47/117	282.299(7576.68)	0.85/1.53	2.349(63.045)
24	4x4/13.12x13.12	27.5/82	270.664(7264.41)	0.64/1.15	1.769(47.478)

Thawing Time, month	Hole Grid, m x m/ftxft	Required Temperature of Heater, °C/°F	Energy, MJ/m^3 (BTU/ft^3)	Temperature Warming Beyond Permafrost Layer at, °C/°F	Loss Energy into Surrounding Unfrozen Soil, MJ/m^2 (BTU/ft^2)
18	6x6/19.68x19.68	103.5/218	312.943(8399.14)	1.28/2.30	3.537(94.930)
18	5x5/16.4x16.4	65/149	293.361(7873.57)	1.00/1.80	2.763(74.157)
18	4x4/13.12x13.12	37.5/100	277.144(7438.32)	0.74/1.33	2.045(54.886)
12	6x6/19.68x19.68	171/340	346.593(9302.28)	1.66/2.99	4.587(123.111)
12	5x5/16.4x16.4	104.5/220	315.556(8469.27)	1.26/2.27	3.482(93.454)
12	4x4/13.12x13.12	59/138	291.463(7822.63)	0.92/1.66	2.542(68.225)

As was expected, the amount of energy required to thaw frozen soil depends on the assumed heater grid and time of thawing. Table 2 shows that the maximum amount of energy is required if the heater grid is 6x6 m and the thawing time limited to 12 months. A minimum amount of energy is required if the heater grid is 4x4 m and thawing time extended to 24 months.

Table 2 also shows that loss of energy to warm up unfrozen soil around permafrost is insignificant. For instance, the maximum and minimum energies required for thawing 1 m^3 of frozen soil are approximately 346 and 270 MJ, respectively, while amount of energy for warming surrounding unfrozen soil is approximately 4.6 and 1.8 MJ, respectively. It is possible to assess percent of energy loss into the unfrozen soil, if dimensions of the permafrost layer will be known.

Figures 1 and 3 show the recommended layout of the heater holes along vertical and horizontal perimeters of the permafrost layer. The distance from the permafrost perimeters to the first line of the heater holes should be not more than 50 percent of the heater grid.

7.0 THAWING METHOD

The main advantage using a steam method would be for thawing permafrost of sandy composition. For such conditions, the steam method will be much more effective due to the application of both conductive and convective heat transfer. However, a clayey permafrost composition eliminates the effectiveness of convective heat transfer. Based on this, it was considered that application of electrical electrodes would be more optimal for the permafrost/soil conditions at Clinton. Our limited experience for permafrost thawing in other Arctic regions suggests that steaming will require complexity in both the installation and maintenance, especially for long lines. Moreover, it seems that loss of heat from the lines will be greater for steam.

Figures

FIGURE 1 : HEATER LAYOUT (PLAN VIEW)

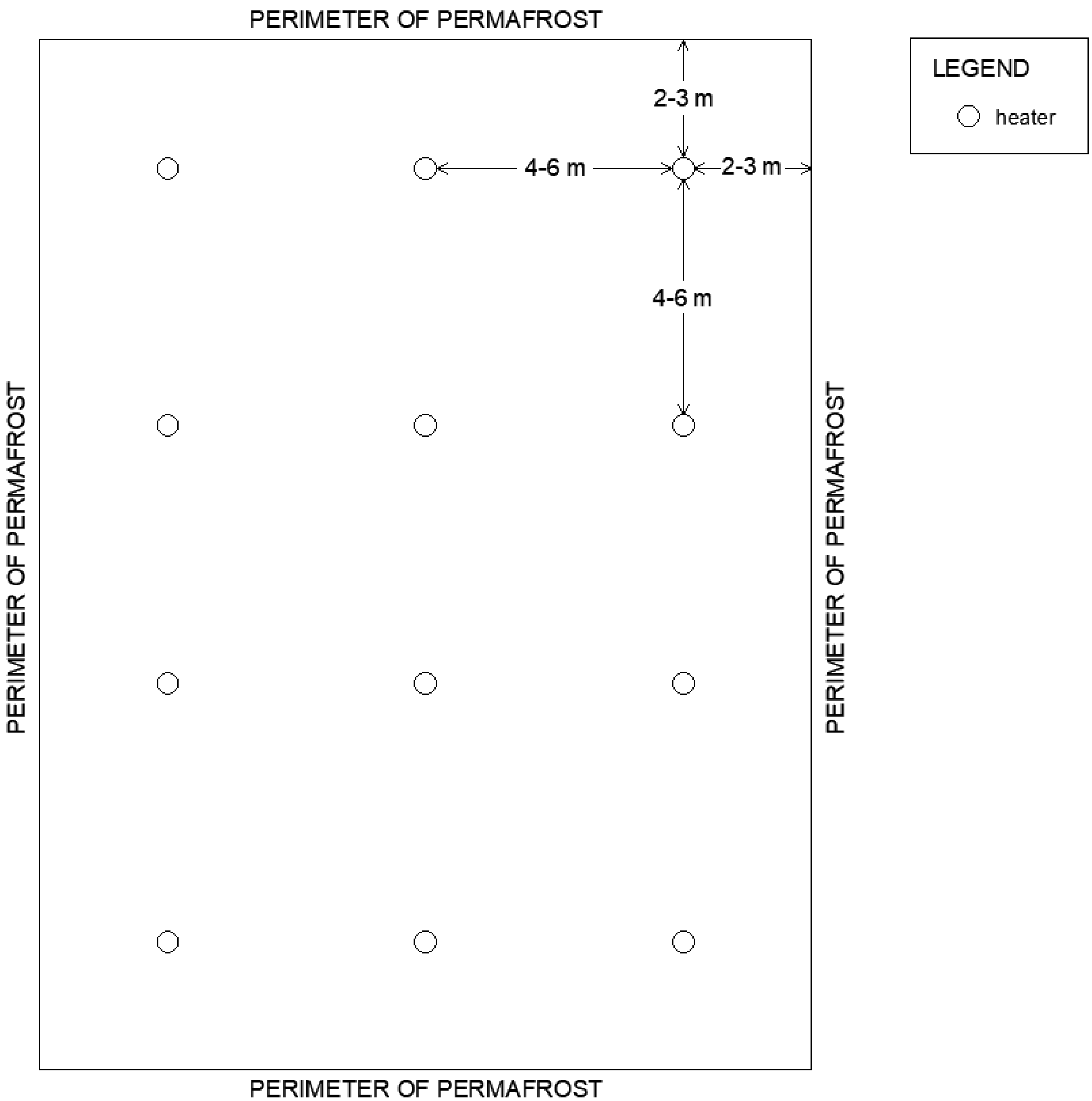


FIGURE 2 : DIMENSIONS OF GEOTHERMAL GRID AND BOUNDARY CONDITIONS

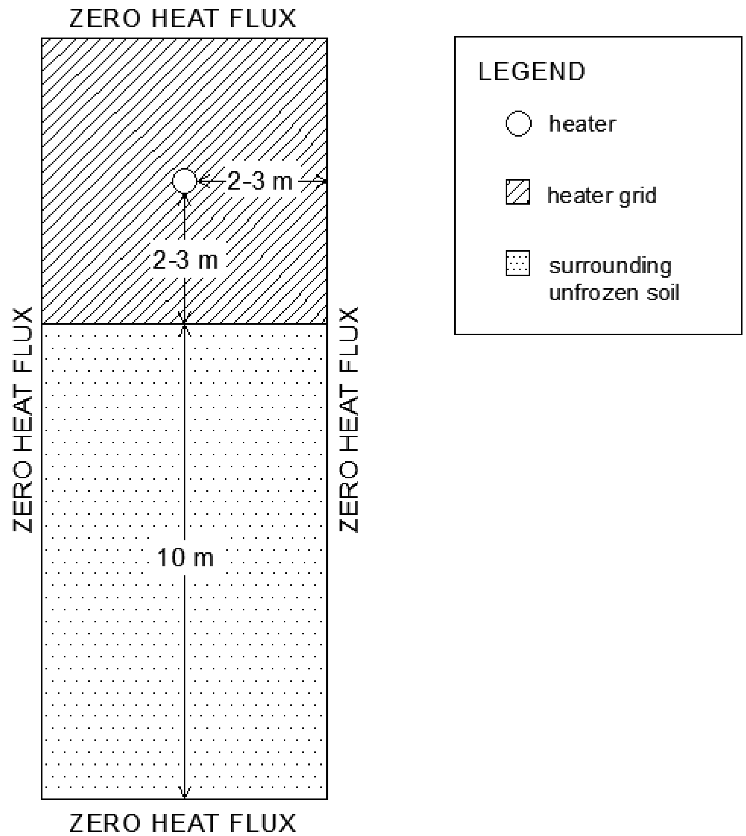
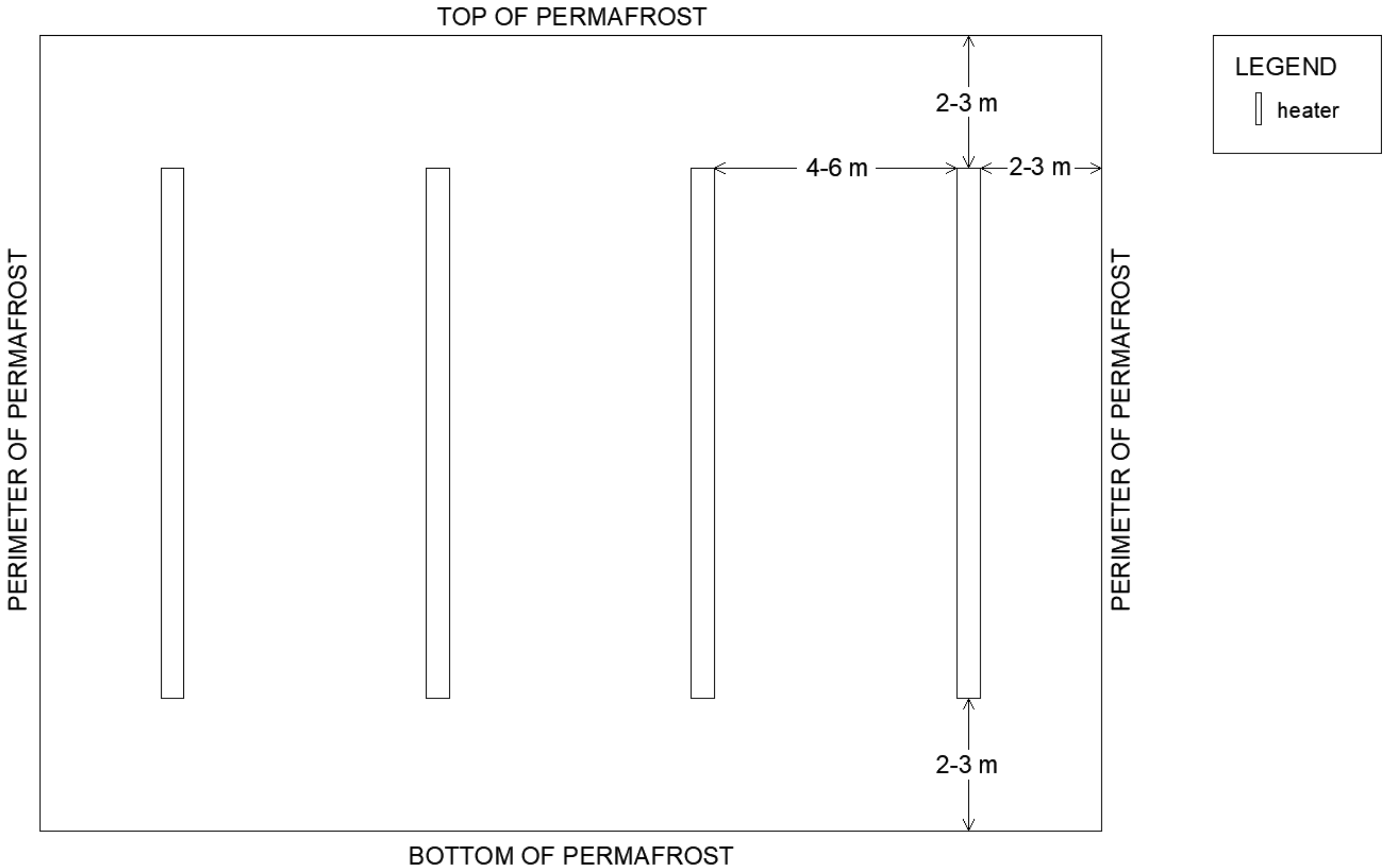


FIGURE 3 : HEATER LAYOUT (CROSS-SECTION)



Appendix B
CC1 Heat Injection Assessment

Clinton Creek – Permafrost

Mechanical Report

Based on the Geothermal Analyses for Permafrost Thawing prepared by Wood, we explored a couple of suitable thawing arrangements. In view of the site location, and the estimated thawing period, we had tried to simplify the system, that will make the constructability less complicated, and will require lesser effort for the operator to operate and maintain the system.

These are the THREE Options:

1) Hydronic OPEN loop method – HEATED WATER – The River water (referred to as the “media” in this report) shall be heated to accelerate the thawing process and protect the line from freezing.

2) Hydronic CLOSED loop method – HEATED WATER – This will be a closed loop arrangement. The primary circuit shall be 30% propylene glycol, and the secondary circuit shall be water.

3) Electrical Heating This option will use a unique heating method, the use of finned tube heater encased by a heavy gauge pipe is proposed. The radiant heat from the heating element will be transmitted to the outer surface of the pipe, and the thawing will be thru conduction.

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Option 1

<u>Mechanical Components:</u>

1. Feed Pump (Submersible)
2. Filtration Unit
3. Water Storage Tank
4. Heat Exchanger – Plate and Frame
5. Heater – Mobile Type – Propane Fired/Diesel Fired
6. Propane Storage Tank
7. Heating Pump
8. Power Generating Unit (Generator – For Pump/Control).
9. Header (Carbon Steel) c/w valves

Concept:

This arrangement includes drawing water from the nearby lake (Hudgeon Lake) towards the water storage tank. The water will be drawn by a submersible pump, The inlet water needs to be provided with a filtration skid to prevent accumulation of sediments/debris.

The tank shall be installed in a central location to optimize the header routing. This option will require the media to be heated in order to shorten the thawing process. In this evaluation, we will consider media temperature to about 120 deg. F. In order to provide a better thermal efficiency and protect it from freezing the tank is proposed to be insulated.

The heating loop will be coming from a mobile heating unit. The primary heating loop from the heater will be around 190 deg. F. The heating loop is proposed to be 30% Propylene Glycol, and the heater is a complete packaged unit that comes with controller, pump, and instrumentation in it.

To heat up the stored water, a water circulating pump will be needed and a Plate and Frame heat exchanger. These components are ideally to be skid mounted and provided with an equipment shelter to protect it from freezing and from the harsh environment to ensure its reliability. As described above, the stored water is to be heated to 120 deg. F.

A skid mounted centrifugal pump will be used to distribute the heated water to various points in the area. The tank storage tank will have its dedicated nozzle for this purpose, and the header towards the thawing points shall be insulated flexible hoses. This will significantly reduce heat loss and is widely used in similar applications. The media pressure shall be controlled to have enough to distribute the water to the required thawing points.

The thawing grid in this evaluation is @ 5′ x 5′, and the heating water is @ 120 deg. F. The energy provided is approximately 4262.5 Btu/sq. ft. However, the media will be allowed to fluctuate to +/- 20 deg. F depending on the weather. The water temperature drawn from the river is estimated to be @ 45 deg. F.

Refer to Figure 1 for the schematic diagram.

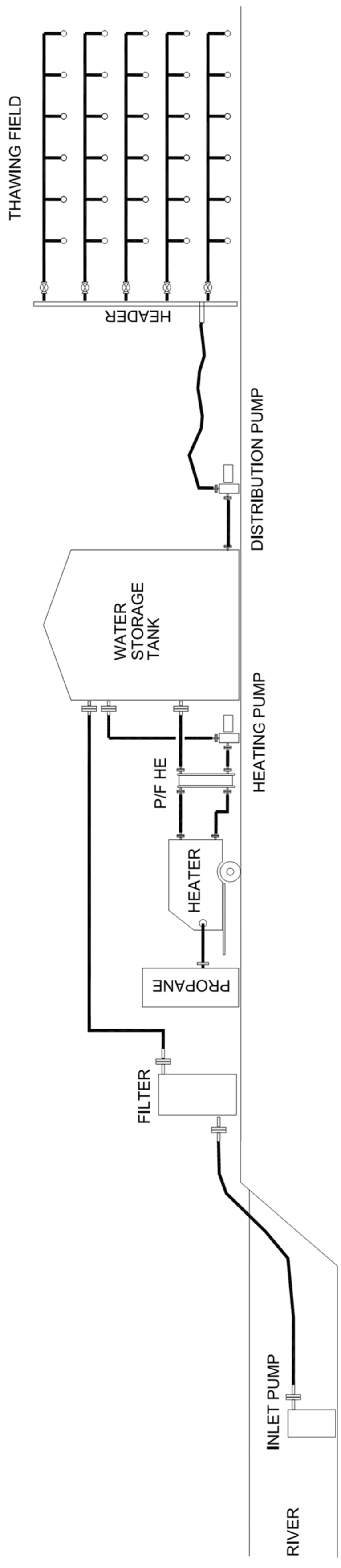


FIGURE 1 - HEATED WATER - PERMAFROST THAWING ARRANGEMENT

Mechanical Components Catalogue:

1. Submersible Pump

Submersible Propeller Pump Type ABS VUP M8 and M9

SULZER

50 Hz

Submersible propeller pump type ABS VUP series are used where larger water volumes must be pumped up to relatively low heads (up to approx. 10 m).
They are ideal for storm water pumping stations, for polder dewatering, for storm water protection, for irrigation and dewatering, for cooling and process water and for a multitude of other applications.

Construction

- The water-tight fully flood-proof motor and the pump section form a compact and robust unit.
- Water pressure sealed connection chamber, with two stage cable entry, protected against excessive cable tension and bending.
- Bimetallic thermal sensors in the stator which open at 140 °C.
- Rotor and rotor shaft dynamically balanced, upper and lower bearings lubricated-for-life, maintenance-free.
- Optimum motor cooling by directing the medium being pumped over the motor.
- Double shaft sealing.
- Lower sealing by means of a silicon carbide mechanical seal, independent of the direction of rotation.
- Upper mechanical seal in carbon/chrome steel, independant of direction of rotation.
- Oil chamber with seal monitor sensor to indicate water leakage through mechanical seal.
- Hydraulic parts with axial propeller with 3 or 4 adjustable blades and inlet diffuser on discharge side.
- Gearbox available from 250 kW for VUP 1001 to VUP 1202.
- These pumps are available both in standard and explosion-proof versions in accordance with international standards e.g. ATEX II 2G Ex db IIB T4 Gb.

Motor

Water pressure sealed high efficiency motors, (3-phase, squirrel cage induction motors), from 160 to 650 kW and depending on hydraulic requirements as 4- to 12-pole versions.
Voltage: 400 V, 3~, 50 Hz (other voltages on request)
Insulation components: Class H (winding protection by 140 °C sensor)
Protection type: IP68
Start-up: DOL (direct on line), star-delta, or soft starter.

Pump selection

To access more detailed information like pump performance curves, dimensional drawings, product description and motor performance curves, please use our ABSEL program:
http://absel.sulzer.com/ Hydraulic selection:
-> Enter: Duty point
-> Select: Hydraulics
-> Select: Motor

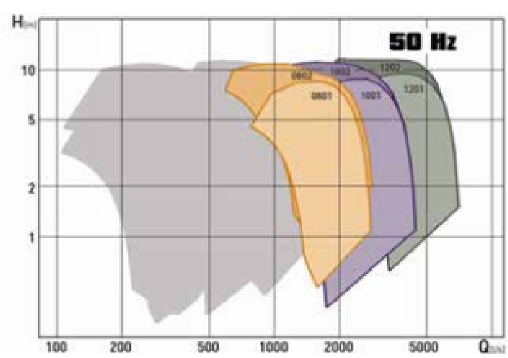
Hydraulics

You have the choice of the following hydraulics for the nominal pipe diameter 1000 to 1400 mm.
For power demand beyond available range M8/M9 please refer to technical data sheet VUPX - PE4 to PE6 or VUPX - PE7.

Hydraulics / Propeller type

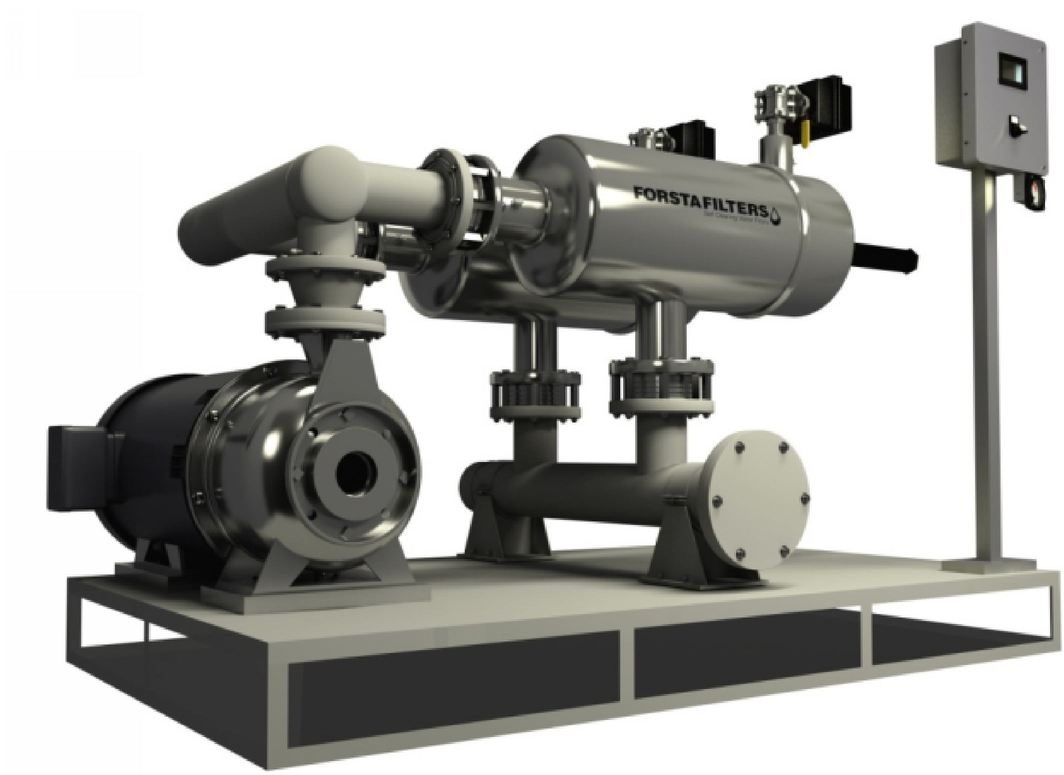
Hydraulics / Propeller type	
VUP 0801	3-blades, adjustable
VUP 0802	4-blades, adjustable
VUP 1001	3-blades, adjustable
VUP 1002	4-blades, adjustable
VUP 1201	3-blades, adjustable
VUP 1202	4-blades, adjustable

Performance field



2. River water Filtration Unit

industrial water filter station. Skid Mounted units provide a comprehensive solution to virtually any industrial, irrigation or municipal application.



Manifolded 180 Series filters shown below provide a cost-effective method to filter high flow systems. Configurations to meet client and project needs.

Many industrial filtration applications have demands that vary according to source water quality. Total Suspended Solids (TSS) of rivers, wells, etc. often vary seasonally, placing undo demand on a filtration system with a single aperture (micron rating.)

Forsta custom filtration skids offer a solution that allows for ongoing calibration in the operating environment. Each filter is positioned for fast and easy screen change-outs according to the demand of the system.

3. Water Storage Tank

Benefits of Corrugated Steel Water Tanks

One of the main advantages to using corrugated steel water tanks is the tank's size and shipping requirements. While standard steel tanks are built and shipped to your location fully constructed, the corrugated water tanks ship in pieces for assembly on site. (Installation assistance is available!)

Unlike traditional steel tanks that are shipped fully constructed, these **Bolted Corrugated Steel Tanks (bolted-storage-tanks.html)can be disassembled, shipped, and stored at **a fraction of its assembled size**.*

- **Rainwater Collection (https://www.water-storage-tank.com/corrugatedsteelrainwatertanks.html)**
- Process Water Storage
- Water Treatment Tanks
- Fresh Water Storage Tanks
- Greywater
- Agriculture
- Mining
- **Fire Protection Tanks (https://www.water-storage-tank.com/fire-fighting-water-tanks.html)**
- Irrigation Water Storage
- **Frac Storage Tanks (https://www.water-storage-tank.com/fractank.html)**
- **Drinking Water Storage Tanks for Villages (drinkingwaterstoragetanksforvillage.html)**
- **Underwater Filming (https://www.water-storage-tank.com/open-top-tanks.html)**

4. Plate and Frame Heat Exchanger

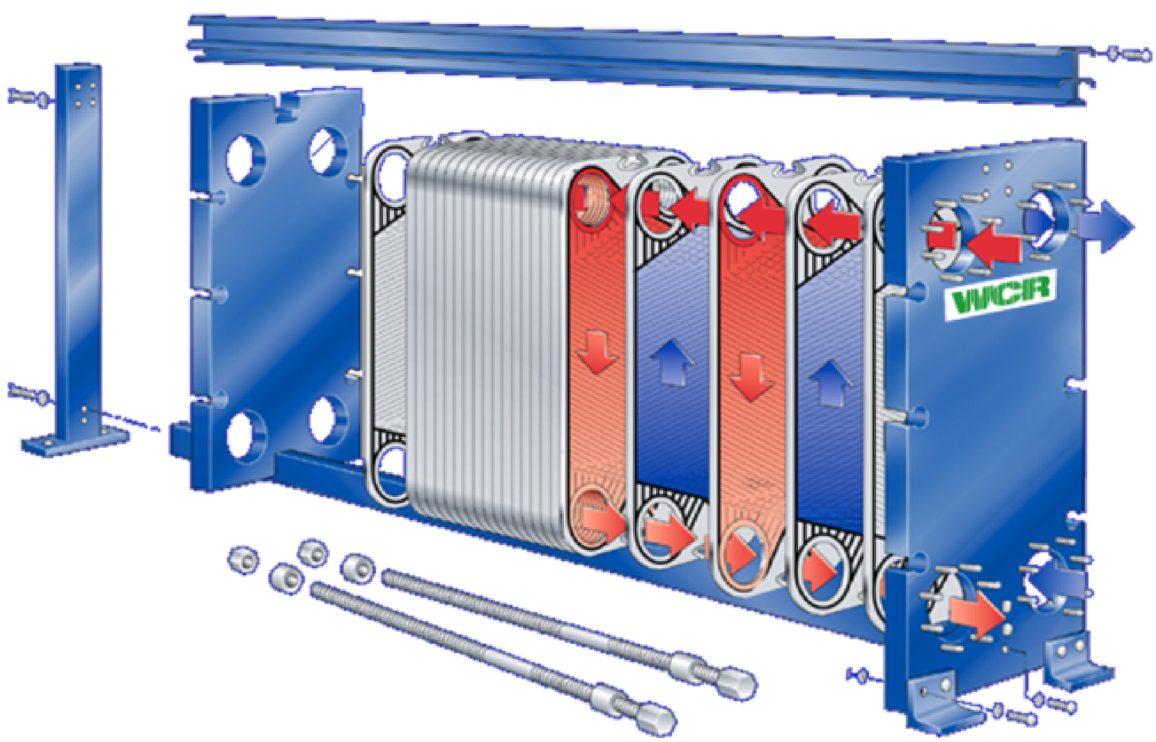
Plate Heat Exchangers

WCR Plate Heat Exchangers, also known as Plate & Frame Heat Exchangers are products of over 35 years in the plate heat exchanger industry. Being in heat exchanger parts, service, and refurbishment for such a long period, WCR has more cross-brand knowledge than anyone else. We've gained a tremendous wealth of information, as well as hired the top Application Engineers. We now offer competitive heat exchanger solutions that surpass other OEMs in performance, maintenance, and economy.

What is a Plate Heat Exchanger?

The plate type heat exchanger is the most efficient type of heat exchanger with its low cost, flexibility, easy maintenance, and high thermal transfer. WCR plate corrugations are designed to achieve turbulence across the entire heat transfer area. This produces the highest possible heat transfer coefficients with the lowest possible pressure drop, allowing for close temperature approaches. Subsequently, this leads to a smaller heat transfer area, smaller units and in some cases, fewer heat exchangers. This benefits the customer tremendously by requiring less space, reduced secondary flow rates and smaller pumps.

The WCR Plate Heat Exchanger consists of a specific number of gasketed plates which are fixed between a top carrying bar and a lower guide bar. The plates are compressed by means of tie bars between a stationary frame plate (the head) and a moveable frame (the follower). Fluids enter the plate heat exchanger through frame connections and are distributed inbetween the plates. The flow through alternate passages between the plates is controlled by the placement of gaskets. These are available in single and multi-pass arrangements, depending upon the application.



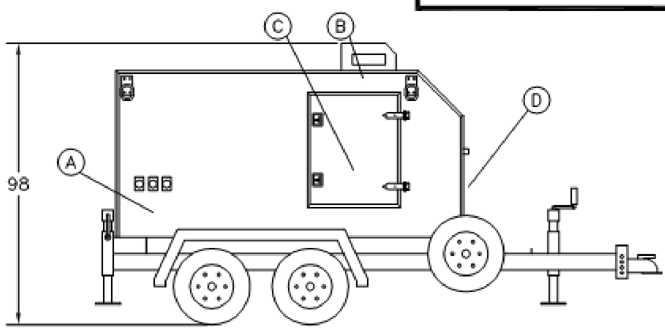
Also See: Plate Heat Exchanger Advantages, Applications, WCR Product Range, Request a Quote

5.0 Mobile Water Heating Unit

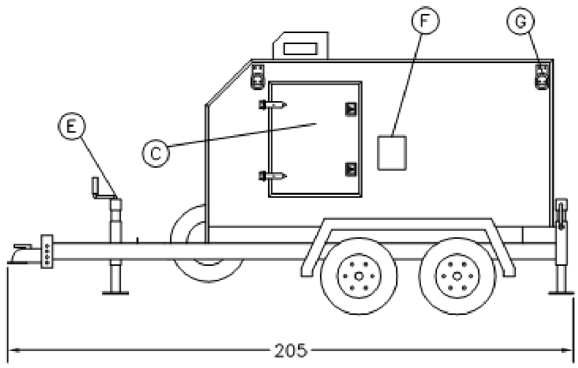
TEMPAIR®

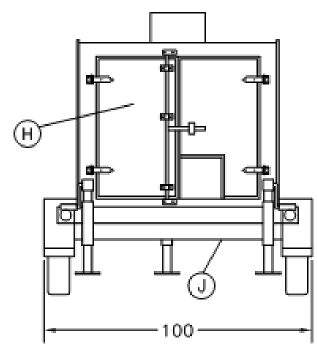
HVAC RENTAL SERVICES

HTHW-2000



Ⓐ POWER INLETS
Ⓑ BOILER EXHAUST
Ⓒ SERVICE ACCESS: BOILER,TANK,PUMPS
Ⓓ GAS INLET
Ⓔ JACKS
Ⓕ FUEL FILL (#1 FUEL OIL ONLY)
Ⓖ LIFTING EYES
Ⓗ SERVICE ACCESS, HOSE REELS
Ⓙ INTERNAL FUEL TANK: 150 GALLONS





UNIT SPECIFICATIONS:

POWER SUPPLY:	(2) 120V/1PH/60HZ/15A
	(1) 230V/1PH/60HZ/20A/4 WIRE
BTU/HOUR INPUT:	280,000

FUEL SUPPLY:

PROPANE:	10 PSI 3.0 GPH
NATURAL GAS:	1/4 - 10 PSI 280 CFH
FUEL OIL TYPE:	#1 2.0 GPH
GAS CONNECTION:	1" NPT

DIMENSIONS:

LENGTH:	205"
WIDTH:	100"
HEIGHT:	98"
WEIGHT:	7,400 lb
WEIGHT FULL FUEL:	8,400 lb

DRAWN: ACJ	UPDATED: JH
DATE: 01/15/01	DATE: 05/15/17

Temp-Air.com

HTHW-Series GROUND THAWING EQUIPMENT

Natural Gas, Propane Or Fuel Oil Units

DESCRIPTION:

The HTHW-Series allows you to bring your winter construction site to a work-ready state quickly, efficiently, and safely. The 50% propylene glycol mix (a low toxicity anti-freeze) is heated, run through a hose, and covered with curing blankets to thaw frozen ground. Hydro-Thaw units can thaw up to 6,000 sq. ft. of frozen ground, 12 inches deep per day* (*soil conditions and hose layout will affect frost removal rate).

FEATURES:

- Self-contained, mobile units can thaw isolated, remote locations.
- Prepares sites for winter dirt and concrete work.
- Protects sites from frost penetration and can eliminate the need for temporary winter enclosures.

HEATING • COOLING • DEHUMIDIFYING • AIR FILTRATION • THERMAL REMEDIATION

frozen ground and 12 inches deep per day. This all-in-one model contains an onboard generator to suit your power needs.

• Two hose reel circuits

• Self-contained towable unit

• Environmentally friendly propylene glycol

• Oilmate system allowing extended run time between oil and filter changes

• Contains built-in generator

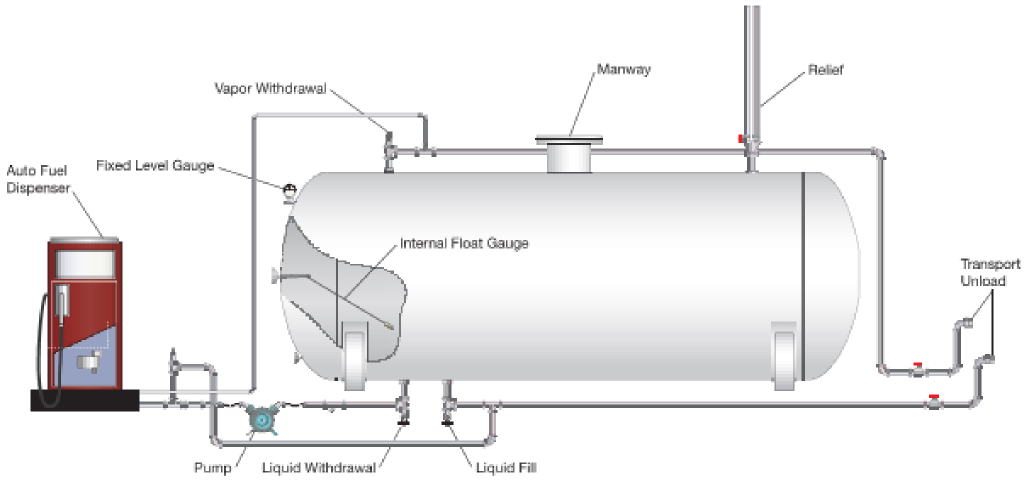
HTHW-2000G SPECIFICATIONS

DIMENSIONS (IN)	195x102x90
WEIGHT (LB)	7,860 (No Fuel); 8,910 (Full Fuel)
BTU/HR INPUT	280,000
FUEL USAGE (PROPANE)	2.65 GPH
BTU/HR OUTPUT	231,000
POWER SUPPLY (CENTRAL HEATING MODULE)	230/1/60/20; Two – 120/1/60/15; 8 kW Diesel Generator
FUEL TYPE	Fuel Oil
ON-BOARD FUEL CAPACITY	150 Gallons
HEATING CIRCUITS	2

6.0 Propane Storage Tank

lpg vessel sizing guide

HT-1115



Volume USWG	Diameter	Straight Shell Length	Overall Length
3,900	7'-0"	12'-4"	15'-2"
6,500	7'-0"	20'-11"	24'-10"
12,000	7'-0"	40'-6"	44'-4"
18,000	9'-1"	35'-6"	40'-5"
30,000	9'-1"	60'-3"	65'-2"
30,000	11'-0"	40'-4"	46'-2"
40,000	11'-0"	54'-5"	60'-3"
50,000	11'-0"	68'-5"	74'-3"
60,000	11'-0"	80'-6"	88'-10"

Custom sizes available

Vertical and horizontal LPG vessels are available as part of a complete autogas system.

7.0 Diesel Storage Tank

ABOVE-GROUND FUEL SYSTEMS

Generator Systems

Envirosafe's Generator Systems are designed specifically to supply generator or boilers. The Envirosafe generator fuel tank is fully compatible with a wide range of fuels. Our generator fuel tanks are available in either Flameshield (UL-142) or Fireguard (UL-2085) configurations and can be manufactured as a single tank or in split designs for the supply of two different fuel products. Each system we sell is built in our on-site manufacturing facility and is fabricated in accordance with The Steel Tank Institute's specifications as well as meeting all UL standards.

8.0 Pre-insulated Piping

Rhinoflex pre-insulated PEX and Polyethylene comes in the longest lengths available from any supplier of flexible pre-insulated piping. The charts provide dimensional data to allow the user to select the right Rhinoflex piping system for their needs. You can rely on Rovanco's "Thousands of Miles" of experience on hundreds of thousands of piping systems worldwide to help you select the right product for your piping systems! Rhinoflex is available with a PEX or HDPE carrier pipe.

There are more than 1,000 miles of flexible pre-insulated pipe with PEX or HDPE carrier pipe installed in the U.S. and more than 25,000 miles installed worldwide over a 30 year period!

Flexible pre-insulated piping has taken over the market for 5" and smaller pre-insulated pipe because it is a high quality product and it has the lowest installed cost of any pre-insulated pipe. The long lengths of flexible pre-insulated Rhinoflex result in few or no underground joints and up to 60% less labor resulting in an installed cost savings of 25 to 40%!

Coils can be handled easily by 2 people.

Rhinoflex can be pulled through road sleeves up to 1,000 ft or directionally bored under roadways, walkways, driveways, streams and ponds! If installed with pipe weights, it can be laid directly in a pond, lake, river or stream!

Rhinoflex can easily be cut to length with just a hacksaw. No special tools or equipment are required to install. Rovanco provides complete installation kits, accessory materials, installation instructions. No special training or skills are required.

Carrier Pipe

For ***hot service, PEX A*** is the highest quality crosslinked polyethylene pipe available with an oxygen diffusion barrier. NSF approved for domestic use.

For ***cold service,*** high density ***polyethylene*** carrier pipe is suitable for temperatures 140°F down to -20°F. Can be buttfused or electrofusion welded.

Insulation

The high thermal efficiency of ***flexible urethane*** foam allows for a ***smaller*** outer jacket size than some competitors, and ***lower heat losses.***

Outer Jacket

The polyethylene outer jacket is ***the heaviest available*** in the industry and ***corrugated*** to be ***flexible.*** It is ***"Rhino tough",*** providing the ultimate in long term protection.

9.0 Mechanical Enclosure

The Benefits of Modular Mechanical Enclosures

Posted on October 19, 2016

— Modular Built Mechanical Enclosures

Whitley Manufacturing custom designs and builds mechanical enclosures (equipment shelters) that meet the specifications for a variety of applications. Each enclosure can be custom designed to handle any configuration or function.

Mechanical Enclosure Applications

- HVAC
- Telecommunications Equipment
- IT/Network Equipment
- Processing Equipment
- Pumping Systems
- Boilers
- Chillers
- Generators
- Water/Sewage
- Battery Storage
- Cable Landing Stations

What are the Modular Benefits

Faster Modular project schedules are often 35% – 50% shorter, reducing time delays and thereby increasing ROI (in comparison to on-site). This is due to a well implimented production process. Furthermore, if the weather turns bad, the project stays on schedule.

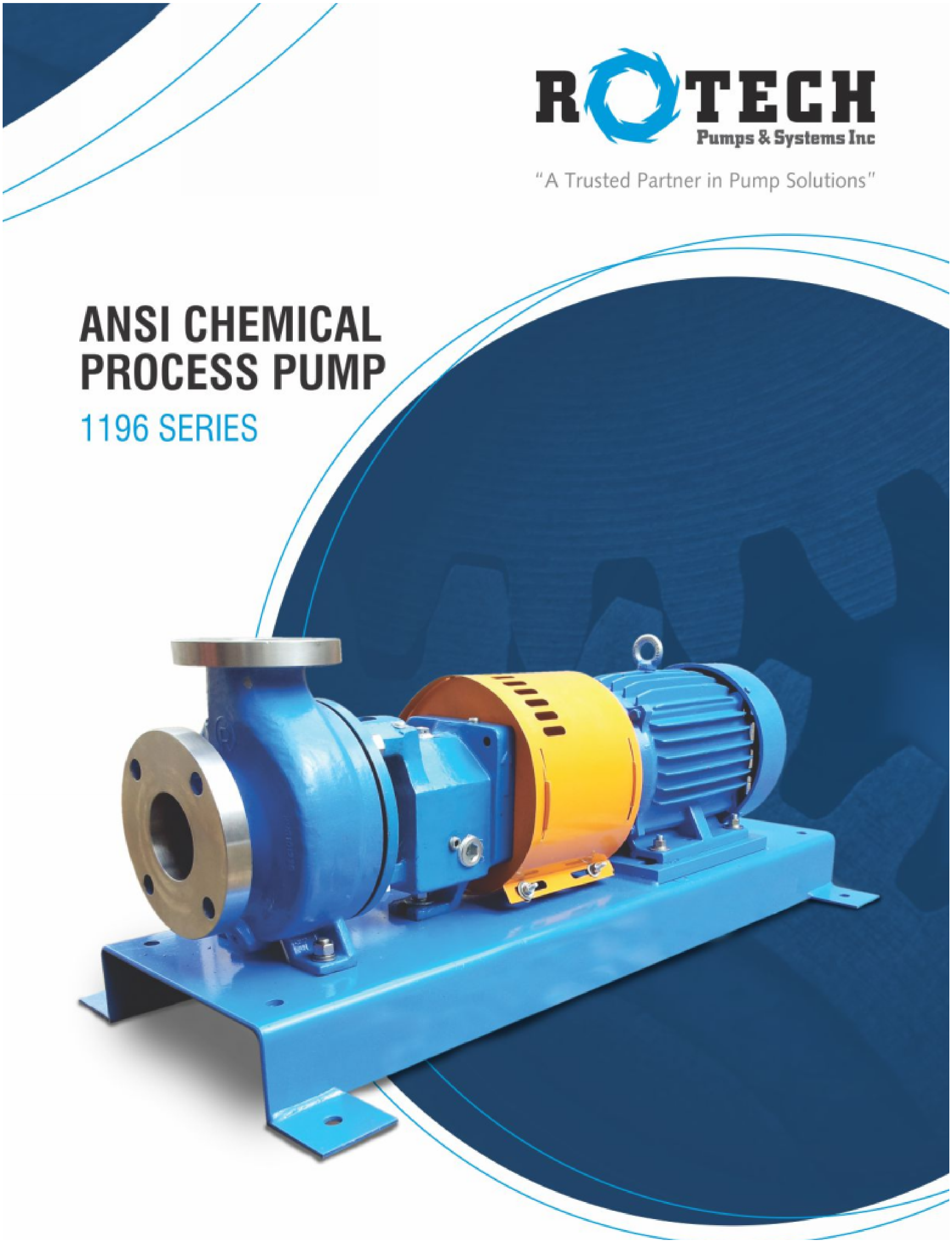
Reduced Waste Modular builders reduce material waste and costs. Manufacturers are good at minimizing waste and operating at high efficiency. Scrap from one project gets used on the next project online. Only the smallest scrap gets sent back to be recycled.

Limits Risk The modular manufacturing process limits the risk of accidents on hazardous job sites. Even the Safety Management in the Construction industry SmartMarket Report, states that 73% of modular builders have a fully inclusive safety program in place compared to 48 percent of non-modular builders.

Mechanical Enclosures Built for Productivity

Whitley builds the enclosure to simplify the equipment installation process. One way to do this is to section off the building in modules. For instance, we ship the base frame (or skid plate) and the "drop over" lid module (walls and roof) separately. This will make it easier and faster to get all the equipment mounted, plumbing ran and electrical systems integrated without the tight confines of the walls. For convenience, the lid and other components can be shipped at a later time.

10. Circulating Pump



Estimated Cost

The cost listed below is for budgetary purpose only (@ +/- 30% accuracy), this needs to be revised if the proposed system is selected (This is for 2 hectares coverage):

- Storage tank (21,000 gallons): $44,000.00 (Insulation is excluded)
- Insulation: $8,000
- Plate and Frame Heat Exchanger: $16,000.00
- Submersible Pump (@ 500 gpm) - $9,500.00
- Circulating Pump (750 gpm): $12,500.00
- Distribution Pump: (400 gpm): $9,000.00
- Diesel Storage Tank (Rental @ 2 years)- (1,100 gallons) - $16,000.00
- Mobile Heater: $76,000.00 (2 years) - Rental
- Pre-Insulated flex Piping: $12,000.00
- Enclosure: $16,000.00
- Piping + Valves: $35,000
- Filtration Skid: $16,000.00
- Instrumentation: $12,000

Approximate Cost: $330,000.00 – Estimated Price Excludes labor, power supply, shipment, spare part, engineering, permitting, and disposable materials.

We need to setup at least 3 skids similar to above, the total estimated cost (for equipment) is **1.2 Million Dollars**.

OPTION 2

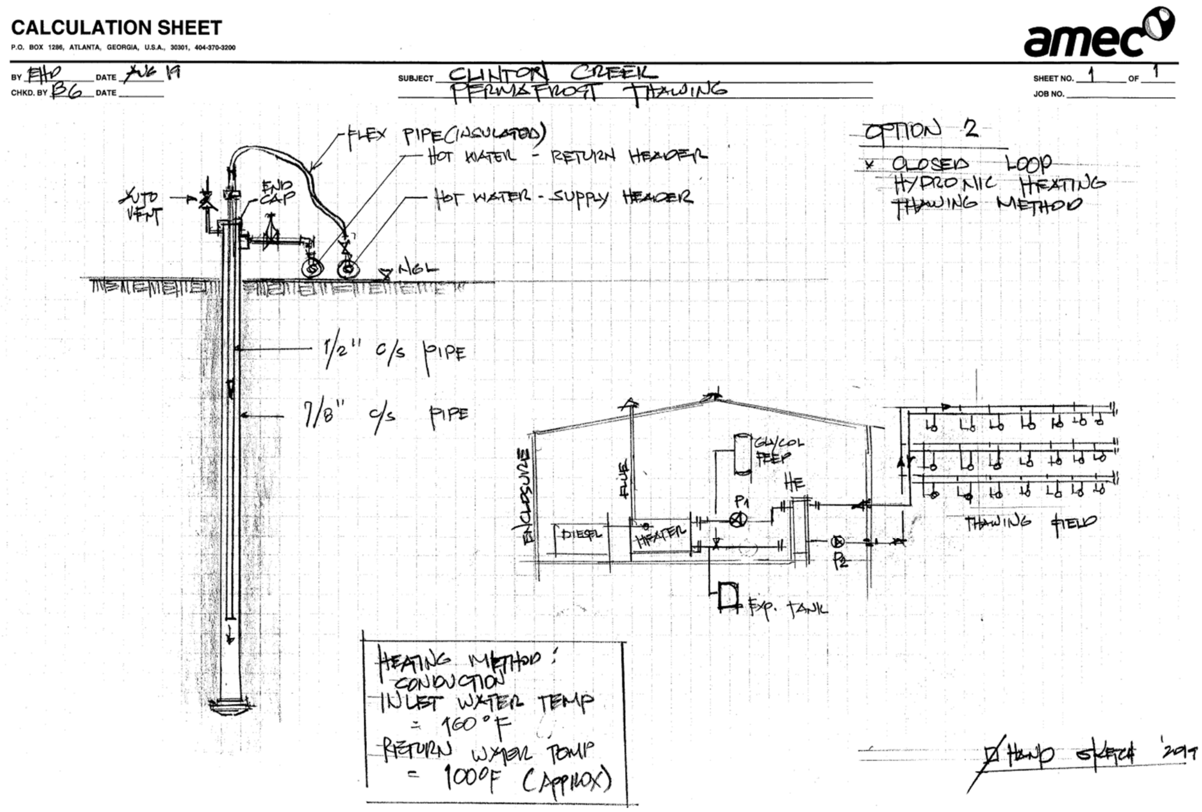
Closed Loop System: This system will require the following components:

1) Heating Boiler – Diesel Fired
2) Diesel Storage Tank
3) Glycol feed skid
4) Expansion Tank
5) Heat Exchanger
6) Pump (Primary)
7) Pump (Secondary)
8) Flexible Pre-insulated Header
9) Piping ang valves

Concept: The primary circuit is heated to at least 180 deg. F, the primary media is proposed to be 30% propylene glycol. In order to minimize the requirement of glycol, a secondary circuit is proposed, The secondary circuit shall be water. A plate and frame heat exchanger will be used in order to heat the secondary circuit to at least 160 deg. F, the estimated return temp of the secondary media is 130 deg. F. In order to make the heating loop flow self-balancing, the circuit is proposed to be a revered return loop. Refer to the attached sketch for general arrangement concept.

In this concept, the heated water shall be injected into the heating pipe, the heating pipe, and returned at the upper most part of the assembly. N automatic air vent valve is to be added to remove the air bubbles caused by the filling of pipe with hot water.

Option 2 – Schematic Diagram



OPTION 3

Electrical Heating System: This system will require the following components:

1) Fin Tube Heater – Single End
2) Local Control Panel
3) Central Panel
4) Enclosure
5) Power Generating Unit – (Turbine Generator)
6) LNG Processing Station
7) LNG Storage Tank

Concept:

This arrangement will be using the thermal heat generated by the electrical fin tube. The surface heating will not be able to penetrate deep enough to melt the permafrost in the pile. One of the possible alternative is to drive it down below the surface and deep enough to provide the required heat to thaw. This method is similar in principle with option 2, the depth of penetration is to be determined, and the reliability of the heating component will be carefully analyzed with the manufacturer.

It will be essential to have a Diesel Generator set provided to this system if there is no available power source on site. Diesel gen will be more versatile and is easier to set in this type of application, although to ensure the system reliability, a back-up system is highly recommended. Diesel generator bulk tank shall be provided suitable for at least 6 weeks of continuous operation (this will vary depending on the site accessibility).

A single end fin tube heater shall be encased with a heavy gauge 7/8" diameter pipe. Each circuit shall be provided with a local control panel to provide the required power cable and to provide its control to each heating point. Each local control panel shall be connected to the central control panel.

This system will have several drawback including the possible burnout of the heating element and has a much higher electrical demand due to the rating of each element (at least 7 kW per assembly). That will require higher fuel demand and must have a back-up unit.

Advantages of Option 3:

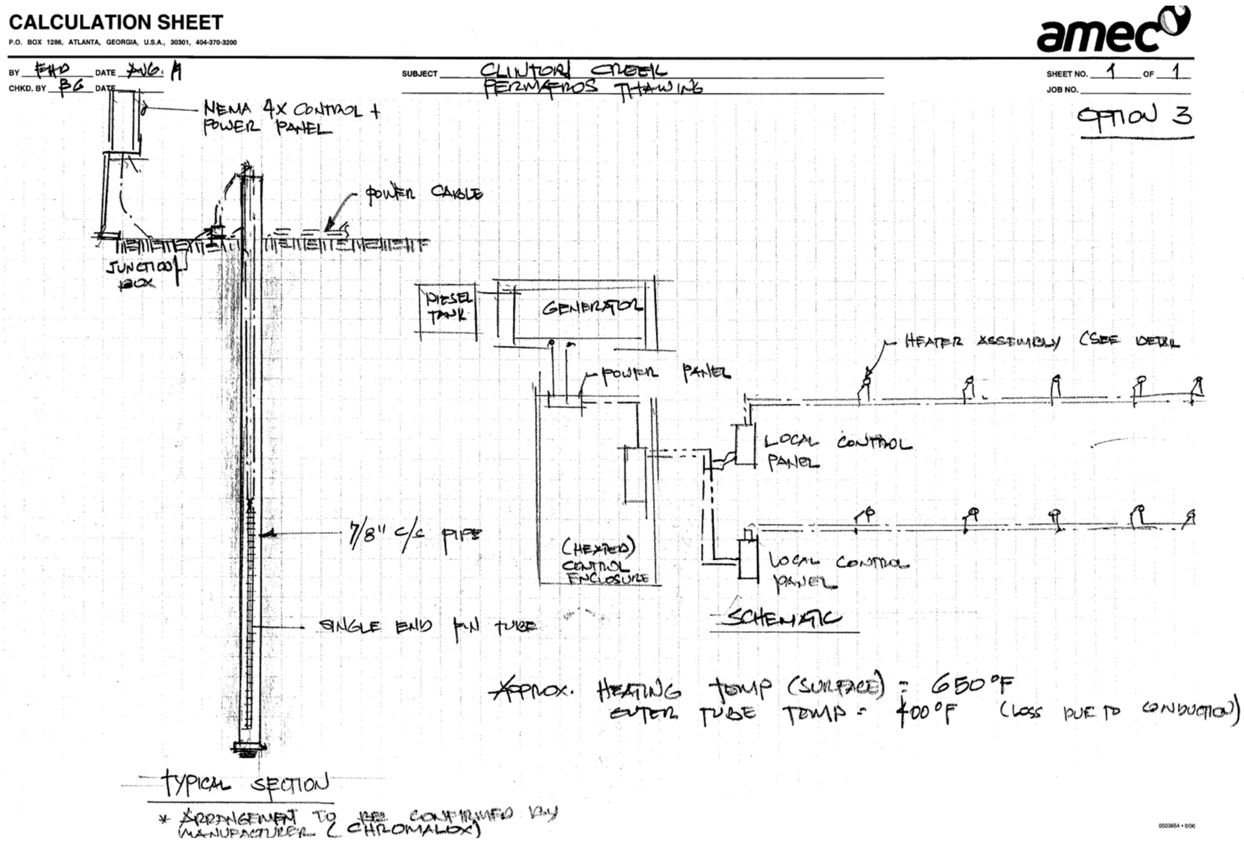
- No mechanical rotating equipment is required (Except for the Diesel Generator)
- Simple arrangement, and lesser manpower requirement.
- Replacement of heating element will be easier.

Disadvantages of Option 3

- This system is fully enclosed and might caused to a frequent heating element burnout.

- The heating element will radiate heat towards the casing (pipe), there might be more heat losses due to this as the heat will radiate towards the pipe and not towards the soil surface, so this might not be an efficient system.
- There must be an operator monitoring the operation round the clock, as a failure of one heater will cause a possible refreezing of the soil.
- This system will require a large LNG (Liquefied Natural Gas Station).

Option 3 - Schematic Diagram



Extract from Wood Document

Thawing Method

The main advantage using a steam method would be for thawing permafrost of sandy composition. For such conditions, the steam method will be much more effective due to application both, conductive and convective heat transfer. However, a clayey composition of thawing permafrost eliminates effectiveness of the convective heat transfer. Based on this, it was considered that application of electrical electrodes would be more optimal for the present permafrost/soil conditions. Our limited experience for permafrost thawing in other Arctic regions allows also to state that the steam method will be more complicated for installation and maintenance, especially for long communication lines. Moreover, it seems that loss of heat from the communication lines will be greater for the steam communication lines. Wood can compare the heat loss in communication lines for both thawing methods

Reference Values

Table 1: Physical and Thermal Properties of Soils

Soil	Dry Density, kg/m³	Moisture Content, %	Thermal Cond., W/m/°K		Heat Capacity, MJ/m³/°K		Latent Heat, MJ/m³
			Frozen	Unfrozen	Frozen	Unfrozen	
Icy frozen	728	100	2.03	1.75	2.093	3.580	243.851
Unfrozen	1900	15	1.86	1.63	2.052	2.763	95.464

Table 2: Energy Amounts Required for Permafrost Thawing

Thawing time, month	Hole grid, m x m/ftxft	Required temperature of heater, °C/°F	Energy, MJ/m³ (BTU/ft³)	Temperature warming beyond permafrost layer at, °C/°F	Loss energy into surrounding unfrozen soil, MJ/m² (BTU/ft²)
24	6x6/19.68x19.68	74/165	297.549(7985.98)	1.05/1.89	2.902(77.887)
24	5x5/16.4x16.4	47/117	282.299(7576.68)	0.85/1.53	2.349(63.045)
24	4x4/13.12x13.12	27.5/82	270.664(7264.41)	0.64/1.15	1.769(47.478)
18	6x6/19.68x19.68	103.5/218	312.943(8399.14)	1.28/2.30	3.537(94.930)
18	5x5/16.4x16.4	65/149	293.361(7873.57)	1.00/1.80	2.763(74.157)
18	4x4/13.12x13.12	37.5/100	277.144(7438.32)	0.74/1.33	2.045(54.886)
12	6x6/19.68x19.68	171/340	346.593(9302.28)	1.66/2.99	4.587(123.111)
12	5x5/16.4x16.4	104.5/220	315.556(8469.27)	1.26/2.27	3.482(93.454)

12	4x4/13.12x13.12	59/138	291.463(7822.63)	0.92/1.66	2.542(68.225)

Appendix C
CC1 Densification Assessment

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Memo

To:	File		
From:	Surinder Garewal, MEng, PEng	**Reviewer**	Ed McRoberts, PhD, PEng (YT)
	Makram El Sabbagh, MSc, PEng	**Wood File No.:**	VE52705
Date:	26 July 2019		
Re:	**Liquefaction Assessment and Post Liquefaction Settlements for CC1 Closure Option**		

1.0 Introduction

1.1 Scope

This memorandum summarizes the results of a liquefaction assessment and post liquefaction settlements in the event of a design earthquake in the spillway channel for the CC1 Closure Option for the Clinton Creek Remediation project.

The CC1 option involves flattening of the waste rock pile slopes by removal of the waste rock and construction of a 1160 m long spillway channel to provide water passage from Hudgeon Lake to Clinton Creek. The spillway channel runs in an east-west direction and consists of a series of sheet pile supported drop structures along its alignment.

2.0 Data Review

Field investigation data along the spillway alignment was reviewed to obtain the subsurface conditions for seismic analyses purposes. The data was obtained from the 2018 boreholes and previous drillhole information (2016 and one borehole from 1977).

The general subsurface profile (below the spillway) generally consists of 15 m to 20 m of waste rock over 5 m to 10 m thick colluvium/alluvium over bedrock. 10 m thick ice-rich material below the waste rock is present in the west end of the spillway alignment and this thins down towards the east. The spillway elevation lowers towards the eastern half of its alignment where bedrock is likely present at shallow depth (as interpreted from the borehole data).

The deposits were investigated by LPT/SPT and are shown in Figure 1. There was no CPT data obtained in the Clinton Creek Waste Dump due to damage concerns with boulder content. The SPT data required correction to transform LPT tests to the standard SPT values.

The fines content range (passing the #200 sieve) for waste dump materials is from 5% to 40% with a reasonable average being 30% and a sensible low fines content of 15%.

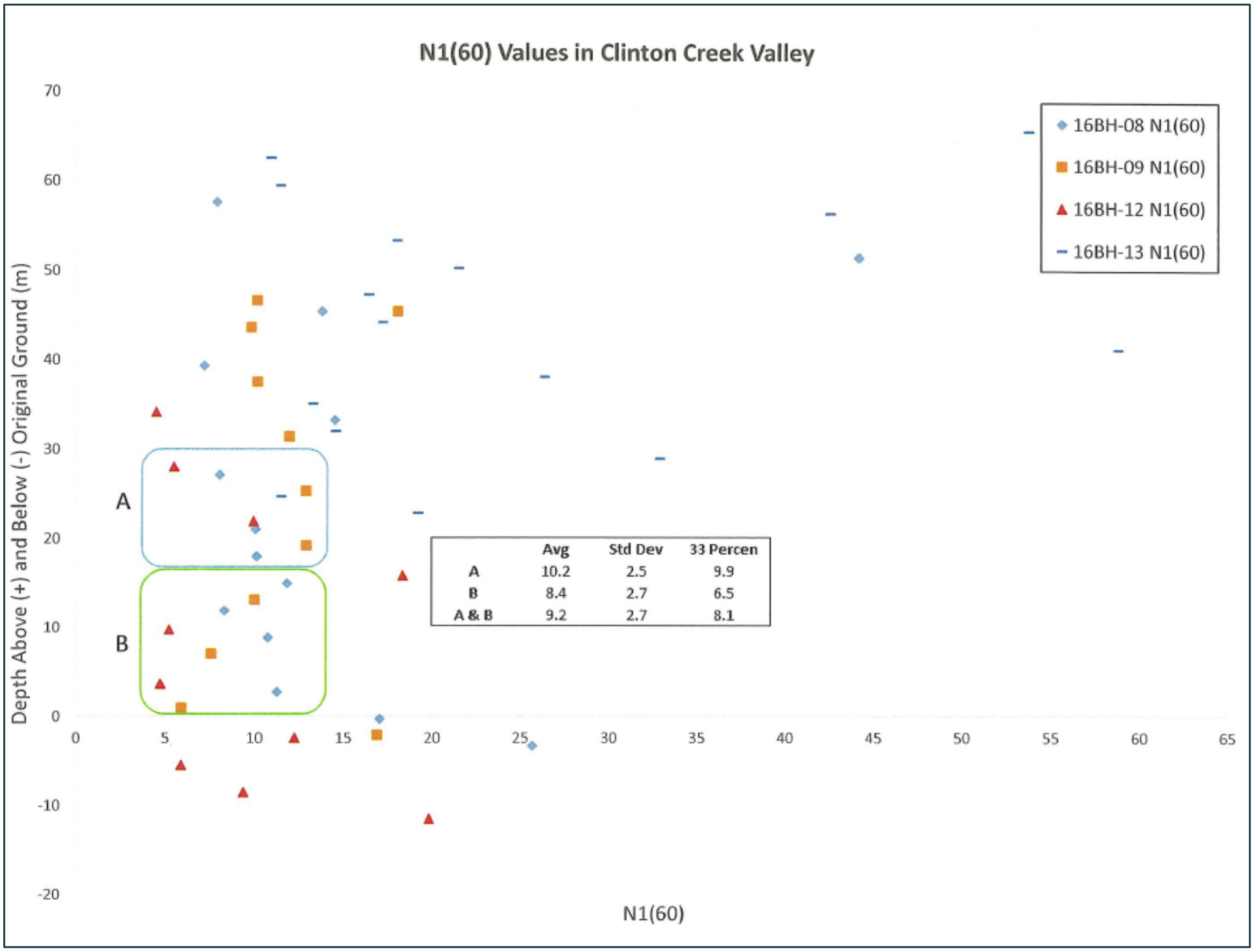

Figure 1: SPT Data for Clinton Creek Valley Waste Landside Dam Waste Dumps

SPT interpretation for the Clinton Creek dumps focus on the looser range of data, in the anticipation that higher data could represent frozen zones, or interaction with coarse rock fragments. Note that a lower bound N1(60) = 5, and a 33 Percentile value in the lower 10 m Zone B of Figure 1 = 6.5.

3.0 Liquefaction Triggering Analyses and Results

Triggering of liquefaction can occur due to the dynamic effect of cyclic ground motions due to earthquakes.

3.1 Cyclic Stress Method

The Cyclic Stress Method (CSM) predicts the triggering of liquefaction based on interpretations of case records supplemented by laboratory testing. Herein we rely on the updates to the method as found in Idriss and Boulanger (2014).

Analyses have been undertaken using the following parameters:

- Design Earthquake Magnitude of 6.2
- Peak acceleration at 2% in 50 years (1/2,475) = 0.27
- Average fines content of 30% correction ΔN = 5.4

- Design N1(60) equivalent clean sand (N1(60)cs) = N1(60) + 5.4

Two sections along the spillway profile were used for analyses where field SPT data was available. The sections were 100 m and 250 m from the spillway entrance (west end of the channel). Data for the analyses was obtained from the boreholes closest to each of the respective locations.

The general target for the CSM FOS_{liq} is typically 1.2 to 1.3 to reliably conclude that liquefaction will not be triggered.

The liquefaction triggering analysis for the section at 100 m from the channel entrance predicted a FOS_{liq} of between 0.5 to 1.1 at depths of up to 46.5m below the spillway elevation. One zone in the waste rock predicted a FOS_{liq} of 1.5, which corresponded to a N1(60)cs of 23. This higher blowcount was likely affected by the presence of permafrost or rock fragments within the waste rock. Using the methodology by Ishihara and Yoshimine (1992), the corresponding estimated volumetric strains (except for the higher N1(60)cs of 23) ranged between 1% and 4% and total anticipated settlement of 1.2m was obtained. 1.2m of settlement over a depth of 46.5m corresponds to an average volumetric strain of 2.6%.

The analysis for the section at 250 m from the channel entrance predicted a FOS_{liq} of between 0.7 to 1.1 in the upper 23m. Between 23m depth and the top of bedrock encountered at a depth of 30m below the spillway, the FOS_{liq} is 1.8 or higher, which is the result of N1(60)cs values ranging between 22 and 31. These blowcount values are believed to have been affected by the presence of permafrost or gravel. In the upper 23m, an estimated volumetric strain of 1% to 3% was obtained, which corresponds to total anticipated settlement of 0.5m. 0.5m of settlement over a depth of 23m corresponds to an average volumetric strain of 2.2%.

Due to the thinning of the overburden and presence of bedrock closer to the surface east of the above two sections, settlements are expected to be smaller in this portion of the spillway. These settlements were estimated to reduce to 0.3 m and 0.2 m eastward about 450 m from the spillway entrance and will eventually become negligible.

3.2 Ground Improvement

Based on the results of settlement computations eight sheet pile drop structures immediately east of the spillway entrance (Station 0+000) will require ground improvement in order to mitigate the effects of seismically induced settlements on these structures. These structures are subject to seismically induced settlements of about 1.2 m at the west end (Station 0+000 to 0+ 200) with settlements reducing to 0.5 m (Station 0+200 to 0+ 450) and 0.3 m (Station 0+450 to 0+ 600). Settlements east of Station 0+600 are expected to be 0.2 m or less and therefore will not require ground improvement.

Ground improvement will comprise of stone columns installed in the following manner:

- A densified zone all around the sheet piles installed in a rectangular pattern and at a distance of about 2.5 m from the sheet piles. The width of the zone of stone columns around the sheet piles will be about 5 m with the columns extending from the ground surface to the top of bedrock;
- A densified zone immediately below the sheet piles between the outer densified area. This will be a 5 m wide zone extending from the bottom of the sheet pile to the top of bedrock; and
- A non-densified zone with loose stone immediately around the sheet pile and between the outer densified zone. This will be a 5 m wide zone extending from the bottom of the sheet pile to the ground surface.

Figure 2 shows a typical sketch of the stone column layout as described above.

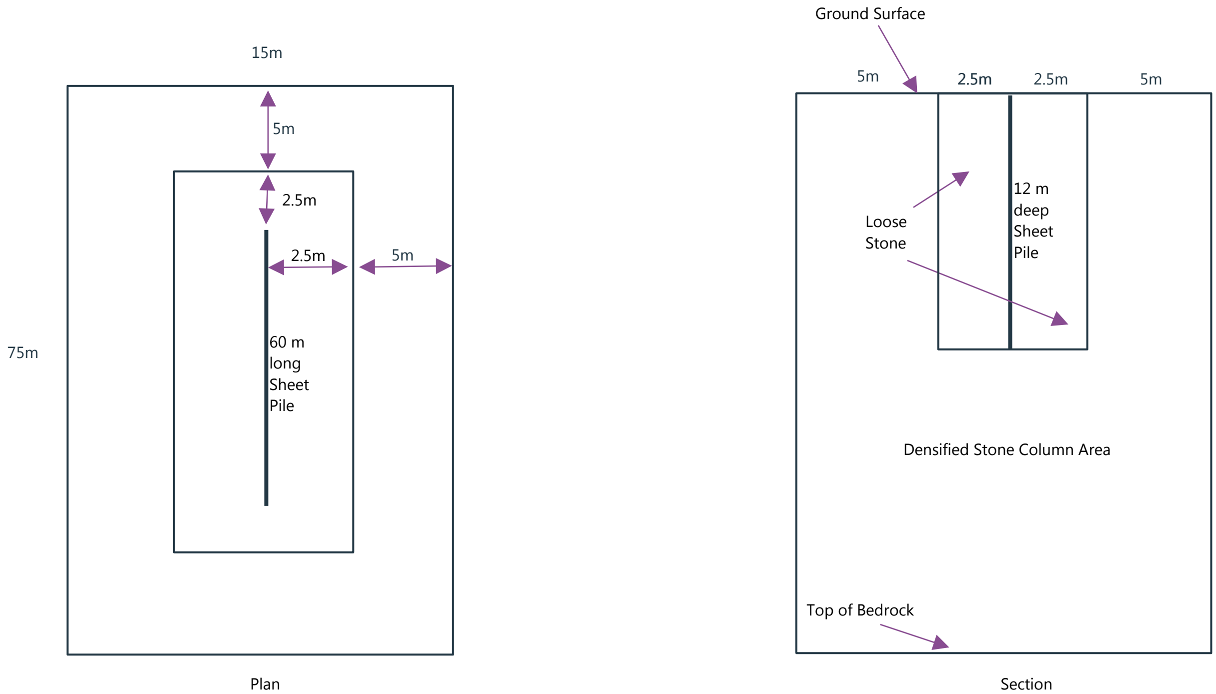

Figure 2: Stone Column Arrangement

No stone columns are required in the spillway channel between sheet piles since potential effects of seismically induced settlements here are not expected to cause major adverse effects on the functionality of the channel.

Estimated cost for stone columns is based on the volume of the treated ground. Volume of treated ground has been computed based on the depth to bedrock from the ground surface in the subject area, which ranges from about 40 m in the west portion of the spillway and gradually reduces to about 15 m in the east end. Estimated volume of ground improvement is 240,000 cu m and estimated budgetary costs are Can $2.5 million, before taxes. These costs assume the stone for the columns will be available and provided locally.

4.0 References

Idriss I. and Boulanger R. (2014). *CPT and SPT Liquefaction Triggering Procedures*. Report UCD/CGN-14/01. University of California at Davis.

Appendix D
Design Decision Log – Clinton Creek

TITLE:	**Technical Decision Record Log - CCRP - 10% Design Phase**				
PROJECT NAME:	**Clinton Creek Remediation Project**				
CONCEPT:	**Common Elements and Clinton Creek Concepts**				
CLIENT:	**Government of Yukon**			**VE52705E**	
TDR No.	**Area/Discipline**	**Design Element**	**Alternatives Considered for the Element**	**Decision Made**	**Remarks / Rationale**
Common Scope Components					
C-001	Hydrotechnical	Hudgeon Lake Drawdowns	1 - Gravity drainage structures 2 - Siphons 3 - Pumping	Drawdown via pumping	Pumping provides flexibility with respect to capacity, operating requirements and the ability to quickly adjust drawdown rates to match geotechnical constraints relating to piezometric levels in the waste dump. More detailed comparative assessments post 10% might alter selections to optimize costs; however, potential cost differentials were judged unlikely to influence concept select decisions.
CC1 - Retention of Hudgeon Lake					
CC1-001	Geotechnical	Ground Thawing (in areas of ice risk colluvium) under spillway	1 - Hydronic OPEN loop method: HEATED WATER – lake water would be heated to accelerate the thawing process and protect lines from freezing; 2 - Hydronic CLOSED loop method: HEATED WATER – this would be a closed loop arrangement with a primary circuit comprised of 30% propylene glycol, and the secondary circuit, lake water; and 3 - Electrical Heating: This option employs finned radiant heaters.	Electrical Heating	For the purposes of this 10% design phase, it was assumed that the electric heating option would be applied to the thawing scope for the following reasons: •The use of hydraulic technologies introduces uncertainties with respect to the associated influences on local piezometric regimes, seepage outcomes and thermal dynamics; •Electric systems are comparatively common in these applications and offer fewer uncertainties with respect to operating logistics and outcomes; and •Electric systems can be more readily and reliably adapted to winter operations.
CC1-002	Geotechnical	Ground Densification (in areas of ice rich colluvium) under spillway	1 - Stone columns 2 - Blast densification 3 - Cut/compaction/cover	Stone columns	Construction of stone columns was judged likely to be the most cost effective means of providing the required ground improvements local to the ice rich colluvium extents and spillway alignment. Alternatives would have been difficult or expensive to apply to the specific zones in play.
CC1-003	Hydrotechnical	Spillway type	1 - Concrete chute with stilling basin 2 - Rock riprap chute 3 - Rock channel with vertical drops 4 - Alternative flexible liner (mega-ditch, concrete cloth)	Rock channel with vertical drops.	Geotechnical characterization of the site proved that a rigid spillway, like a concrete chute, would be susceptible to severe damage from settlement due to permafrost thawing and natural settlement within the waste pile. A constant gradient rock lined chute (approx 4% gradient, 800 m long, 30 m wide) was considered but would have required rock with d50=1000 to accomodate the IDF. Vertical drops using sheet piles reduced the rock size required and was considered a more robust design.
CC1-004	Hydrotechnical	Spillway Drop Structure Configuration	1 - Multiple, low height drops 2 - Single drop	Multiple drops	Multiple drops configured along the entire spillway alignment were selected to attenuate the energy dissipation requirements for any particular drop structure. Concentrating drops would require much more robust structures that currently available characterization data suggest may not be feasible (or at least cannot be validated as viable at this 10% design stage).
CC1-005	Hydrotechnical	Spillway Drop Structure Construction	1 - Sheet piles 2 - Second piles 3 - Cost-in-place concrete	Sheet piles	Sheet piles are known to perform well in these drop structure applications and were judged likely to provide more certainty in outcomes at competitive costs than the alternatives. Sheet piles also provide more capability to accommodate subsurface movements than comparatively brittle concrete alternatives.
CC1-006	Hydrotechnical	Geo-fabric & filter underlying spillway	1 - Non-woven geotextile 2 - Impermeable geomembrane 3 - aggregate filters	Non-woven geotextile and bituminous geomembrane	Aggregate filters were avoided due to the cost of importing suitable quarried material. The low flow channel will be underlain by bituminous geomembrane to prevent low flows from infiltrating into the foundation material; the high flow section will have only non-woven geotextile since the flood flows will be of short duration, and cost is reduced.

TITLE:	**Technical Decision Record Log - CCRP - 10% Design Phase**				
PROJECT NAME:	**Clinton Creek Remediation Project**				
CONCEPT:	**Common Elements and Clinton Creek Concepts**				
CLIENT:	**Government of Yukon**			**VE52705E**	
TDR No.	**Area/Discipline**	**Design Element**	**Alternatives Considered for the Element**	**Decision Made**	**Remarks / Rationale**
CC2 - Regime Channel					
CC2-001	Hydrotechnical	Design flow	1 - 1/3 between 1000 year and PMF 2 - 1000 year	1000 year	Dam breach assessment demonstrated that the consequence of a headcutting breach of the remaining impoundment was low. Per CDA guidelines, the 1000 year event was selected as the worst case for a low consequence dam.
CC2-002	Hydrotechnical	Lake outlet level & channel slope	Regime channel with: 1% slope 2% slope 3% slope	2.5% slope	Prior to mining the channel slope was naturally just over 1%. However if the regime channel was designed at such a shallow slope, the lake would be gone. A balance was struck between a steep slope, requiring large rock armouring and shallower slopes that reduced the lake level. a 2.5% slope was found to be a good balance between the two.
CC2-003	Hydrotechnical	Approach apron and outlet apron	1 - No apron 2 - Apron	Apron	Wood concluded some scour and erosion protection would be required at the inlet and outlet. Considering the design intention, to mimic a natural channel as far as possible, materials other than rock were avoided. At the inlet, sufficient rock was used to allow for some slipping into the lake. At the outlet, an apron was designed with key in to a nominal scour depth of 2 m.
CC3 - Lake Removal					
CC3-001	Hydrotechnical	Channel alignment	1 - Linear 2 - Meandering	Meandering	The meandering channel was based on the channel configuration digitised from pre-mine aerial photography. To reduce the amount of waste rock that would need to be moved, the channel was moved slightly to the north.
CC3-002	Hydrotechnical	Channel armouing	1 - Armour 2 - No Armour	No armour	The intention is to let the channel develop over the long term to find its natural regime. Armouring would be expensive and would contradict the design philosophy.
CC3-003	Hydrotechnical	Sediment Pond	1 - Sediment pond 2 - No sediment pond	Sediment pond	There is an unknown quantity of sediment accumulated on the lake bottom. This will produce a medium term increase in TSS in the channel downstream. Elevated TSS levels will affect fish spawning and therefore a temporary sediment pond has been designed to control seidment until TSS levels drop in the stream.
CC3-004	Hydrotechnical	Former lake reservoir sediment conntrol	1 - Construct pilot trench 2 - No trench	No trench	The potential for excessive sediment loads in downstream discharges under CC3 could be partially mitigated by constructing a base flow trench through the former lake area upstream of the waste dump footprint. However, this would be difficult, costly and potentially disruptive given the lack of access and the irregular ground and debris conditions that are likely to be encountered. It has been assumed the final lake drawdown can be set at an elevation within the upper levels of the debris field in a way that retains some sediment retention capability in the former reservoir area, while maintaining the general 'lake removal' tenet of the CC3 design concept

Appendix E
Design Decision Log – Wolverine Creek

TITLE:	**Technical Decision Record Log - CCRP - 10% Design Phase**				
PROJECT NAME:	**Clinton Creek Remediation Project**				
CONCEPT:	**Wolverine Creek Concepts**				
CLIENT:	**Government of Yukon**			**VE52705E**	
TDR No.	**Area/Discipline**	**Design Element**	**Alternatives Considered for the Element**	**Decision Made**	**Remarks / Rationale**
WC1 - Sediment Control Only					
WC1-001	Hydrotechnical	Sediment trap location	Wolverine Creek Wolverine Creek/Clinton Creek Confluence	Wolverine Creek/Clinton Creek Confluence	Wolverine Creek is too steep to build a sediment trap with sufficient volume to be effective.
WC1-002	Hydrotechnical	Sediment trap design	Linear settling pond Infiltration	Infiltration	Considered necessary to trap asbestos fibres and fines without the use of flocculant or coagulant
WC1-003	Hydrotechnical	Design flow	TBC	TBC	TBC
WC2 - In-Place Stabilization					
WC2-001	Geotechnical	North Slope Stabilization	1 - Perimeter toe berm 2 - Slope reductions	Perimeter toe berm	Using toe berms minimizes tailings relocation volumes, thereby preserving the intent of the in-place stabilization concept. The berm concept developed also provides relative certainty in outcomes. Post 10% design optimization might validate greater use of slope reductions; however, the associated cost reductions were judged unlikely to be material for concept select deliberations.
WC2-002	Geotechnical	Buttress Fill	1 - Partial use of waste dump spoil 2 - All buttress fill from tails	Partial use of waste dump spoil	Use of tailings and buttress fill was limited to minimize volumes requiring removal from upslope to satisfy stability requirements. This preserves the in-place stabilization concept and makes some utilization of the dump spoil volumes that will be generated by all of the Clinton options. Again, post 10% design optimization may shift the balance of spoil vs. tailings volumes used as buttress fill.
WC2-003	Geotechnical	Ice Rich Permafrost in Buttress fill Dam abutments and foundations, Perimeter Berms	1 - Pre-thawing densification 2 - Excavation and replacement	Excavation and replacement	Excavation and replacement provides a more quantifiable mitigation with relative certainty in outcomes. Post 10% design optimization may alter this selection, particularly if there are potentials for integrating with a CC1 thawing program; however, any cost reductions were judged unlikely to be material for concept select deliberations.
WC2-004	Hydrotechnical	Spillway design flow	1 - 1/3 between 1000 year and PMF 2 - 1000 year	1000 year	No dam breach assessment was undertaken as part of this scope of work; however it was assumed that the ultimate design would be sufficiently robust to practically eliminate the likelihood of a breach allowing liquefied tailings to be released. Therefore, the presumption was that the consequence assessment would rate this structure low. 1000 year design flow per CDA upper range for closure passive care.
WC2-005	Hydrotechnical	Spillway inlet	1 - Open channel 2 - Weir (broad crested, box, bellmouth) 3 - Control structure (sluices)	Box inlet weir	The box inlet was considerd to be a cost effective structure that would allow passive control inflow to the conveyance channel. In relation to the overall cost of this scheme, the cost of the inlet structure will form a minor item and some optimisation of the design is possible.
WC2-006	Hydrotechnical	Spillway channel design width	Narrow channel deeper design flow (15 m base width) Broad channel - shallow flow (32 m base width)	Both	Along the top of the buttress, the gradient was kept shallow and this permitted the use of small riprap armouring in a 15 m wide channel. This transitions to a 32 m wide section for the steeper (16%) open trapezoidal channel designed for in bank flow and interstitial flow for the 46% slope section per USBR guidelines on overtopping riprap embankments.
WC2-007	Hydrotechnical	Spillway chute section (16% gradient section)	Open channel chute with stilling basin Channel with drop structures	Open channel chute with stilling basin	An open channel chute was considered to be most cost effective. The 16% section is fairly short and the gradient is within a permissible riprap design provided sufficient energy dissipation is provided at the outlet.

TITLE:	**Technical Decision Record Log - CCRP - 10% Design Phase**				
PROJECT NAME:	**Clinton Creek Remediation Project**				
CONCEPT:	**Wolverine Creek Concepts**				
CLIENT:	**Government of Yukon**			**VE52705E**	
TDR No.	**Area/Discipline**	**Design Element**	**Alternatives Considered for the Element**	**Decision Made**	**Remarks / Rationale**
WC2-008	Hydrotechnical	Spillway chute section (46% gradient section)	Open channel chute Interstitial flow	Both	The design of the 46% section is intended to be primarily interstitial following guidelines provided by USBR on protecting embankments from overtopping using riprap. Acknowledging the interstitial flow may be affected by snow and ice, the section was also designed with an open channel trapezoidal section so if the interstital spaces are frozen, the open channel section will convey flood flows.
WC2-009	Hydrotechnical	Outlet apron	Stilling basin Apron	Apron	It was concluded that since the flow would be interstitial, sufficient energy dissipation will occur through the rocks to negate the need for a full energy disspator. An apron was included primarily for the protection of the toe of the riprap slope. USBR has proven a simple apron as effective in this circumstance.
WC3 - Tailings Isolation					
WC3-001	All	Design Concept	1 - In-Place Isolation 2 - Isolation via Relocation (to PPSS)	Isolation via Relocation (to PPSS)	The in-place stabilization variant of WC3 originally envisaged: • Reducing the tailings slope, covering them and providing for conveyance of creek flows (e.g., via the 3.75H:1V cut/fill slope (with the slope toe defined along the centre-line of Wolverine Creek) contemplated in WorleyParsons (2014) LCCA Option E, supplemented with a drain-field to control pore pressures in the liquefiable tailings); or • Supporting the upper tailings with a mid slope shear key, relocating the lower tailings to the Porcupine Creek Storage Structure and re-establishing a flow channel in the creek valley. The first of these approaches would be technically viable only if the tailings are not liquefiable or drained to less than 85% saturation. As the current data indicates the tailings are liquefiable and drainage is considered impractical, this option was removed from final consideration. Further, Wood has rejected the mid slope shear key concept because it introduces execution risks (i.e., upslope liquefaction failures) that would be challenging to mitigate. Developing a closure plan around this concept would generate uncertainties, costs and risks that are unlikely to be tolerable. These considerations led to a conclusion that the WC3 variant that involves relocation of the tails to the Porcupine Pit Storage Structure is the only viable isolation option meeting the intent of this closure option.
WC3-002	Execution	Materials Management	1 - Truck and shovel 2 - Conveyors 3 - Hydrotransport 4 - Draglines (e.g., Sauermon Scopers)	Truck and shovel	Truck and shovel operations were judged the simplest to quantify and cost with certainty for this 10% design phase. Conveyors and hydrotransport were judged likely to attract implausible CAPEX and OPEX (particularly for the winter operations needed to maintain a plausible execution schedule) in this application. Hydrotranport would also create a water management requirement/liability that is difficult to bound at this stage. Final selection of a materials management approach for this large scale relocation of tailings would likely be best left to prospective contractors during the tendering phase (i.e., proprietary equipment and/or expertise may ultimately offer some economies here).
WC3-003	Execution	Materials Management	1 - Upgrade existing mill site access road 2 - Develop new haul road adjacent Wolverine Creek	New Wolverine Creek haul road	A new haul road on the Wolverine Creek side significantly reduces the haul distance (and hence costs) and avoids many of the significant geotechnical challenges that would likely be required to upgrade the existing mill site access road (these upgrades are a requirement for any plausible materials management execution plan and schedule).
WC3-004	Hydrotechnical	Channel alignment	Linear Meandering	Meandering	The meandering channel was based on the channel configuration digitised from pre-mine aerial photography.

TITLE:	Technical Decision Record Log - CCRP - 10% Design Phase				
PROJECT NAME:	**Clinton Creek Remediation Project**				
CONCEPT:	**Wolverine Creek Concepts**				
CLIENT:	**Government of Yukon**			**VE52705E**	
TDR No.	**Area/Discipline**	**Design Element**	**Alternatives Considered for the Element**	**Decision Made**	**Remarks / Rationale**
WC3-005	Hydrotechnical	Design Flood for pilot channel	1 in 200 year 1 in 2 year	1 in 2 year	The low flow channel was designed to a 1 in 2 year standard. The section will overtop on a regular basis similar to natural channels. The channel in time will evolve to a natural form resembling the pre-mine channel. No armouring will be used.