CITY OF FERNIE
FLOOD MITIGATION PLAN

Prepared for:

City of Fernie
Fernie, British Columbia

Prepared by:

Northwest Hydraulic Consultants Ltd.
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EXECUTIVE SUMMARY

The City of Fernie (Fernie) has been proactive in managing flood hazards through assessment of hydrotechnical hazards, regulation of development to reduce flood risk, and construction of flood protection infrastructure. In recent years, Fernie evaluated flood hazards within the city associated with the Elk River, Fairy Creek, Coal Creek, and Brewery Creek. Fernie has retained NHC to further the past work by identifying shortcomings or gaps in the existing flood protection infrastructure and prepare a mitigation plan to reduce the risk of flooding.

To support the mitigation plan, NHC performed field inspection, topographical survey, geotechnical investigation, and desktop assessment of Fernie's flood protection infrastructure. The assessment is based on standards and guidelines issued by the province as well as best practices and products used within the province and elsewhere.

Both structural and non-structural measures were identified. Structural mitigation measures are centred at locations of known problems, dense population, and where issues became evident from the assessment. This includes raising of several dikes (Northlands, Annex, West Fernie, Mountview), extension of two dikes (Northlands, West Fernie), one new dike (3rd Street), improved erosion protection (Northlands, Mountview, Coal Creek Bin Wall), stormwater improvements, and upgrades to the Shadow Creek culvert at Hwy 3.

Identified structural mitigation measures were prioritized based on a score that reflects the level of risk that can be reduced by that measure. The risk score was calculated by first assigning a score between 1 and 5 for likelihood of flooding for each measure (i.e., likelihood if measure is not constructed) and a score between 1 and 3 for consequence of flooding. The product of the two scores resulted is the risk score, which can be used to prioritize projects (higher score = higher priority). The consequence score is based on the number of homes within the potentially flood area. Some areas have intrinsic value beyond that evident from this scoring; such as the commercial districts of Ghostrider and Annex areas and the primary transportation route (Hwy 3) that passes through areas behind the Annex and Northlands dike.

Structural measures are often costly to obtain right-of-way, construct, maintain, repair, and replace; thus making them suitable primarily for locations of high consequence – such as densely populated areas. Non-structural mitigation measures are typically the first choice for reducing flood risk and are often required in addition or regardless of any structural mitigation measures. The non-structural measures presented included emergency response planning, regulatory controls on land use within the floodplain, awareness and education, and monitoring and maintenance. Risk to feasibility ratios were not developed for the non-structural measures; however they are likely to have the greatest reduction in risk to cost ratio as they can benefit large numbers of people and are typically substantially lower cost than structural measures. It is recommended that this report and attachments be read in entirety prior to applying any of the findings.

The recommended structural and non-structural measures and estimated cost are summarized below.

Location	Structural Mitigation Measure	Priority Rank	Cost
Northlands Dike	Raising, extension, erosion protection	1	$ 1,580,000
Annex Dike	Raising, erosion protection	2	$ 4,634,000
Mountview Dike	Raising, extension, erosion protection	3	$ 1,881,000
3rd Street	New dike, grading and paving road	4	$ 749,000
Shadow Creek at Hwy 3	Install flapgate	5	$ 68,000
West Fernie Dike	Dike raising, extension (Option A)	6	$ 4,341,000
Riverside Dike	Erosion protection	7	$ 783,000
Coal Creek Bin Wall	Erosion protection	8	$ 69,000
Pine & Park Ave bridges	Erosion protection	-	$74,000
Stormwater outfalls	Install flapgates	-	$ 32,000
Location	**Non-Structural Mitigation Measure**	**Priority Rank**	**Cost**
Citywide	Flood response plan	-	$15,000
Northlands Dike	Dike breach mapping	-	$50,000
Coal Creek watershed	Install Coal Creek gage	-	$50,000
Citywide	Public awareness campaign	-	$40,000
Locations per section 3.2.5	Vegetation removal	-	$20,000

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1 INTRODUCTION

This flood mitigation plan was prepared for the City of Fernie (Fernie) by Northwest Hydraulic Consultants Ltd. (NHC) based on field inspection, topographic survey, geotechnical investigation, and desktop assessment of existing flood protection infrastructure. NHC was supported in this effort by Fernie, Groundtech Engineering Ltd. (Groundtech), and Align Survey Ltd. (Align).

1.1 Background and Purpose

The City of Fernie is located along both banks of the Elk River in southeastern British Columbia. Flooding of the Elk River and tributaries has been part of the history of Fernie since the city was established in 1904 (BGC, 2013). Fernie has been proactive in managing this hazard through assessment of the local flood hazards, regulation of development to manage flood risk, and construction of flood protection infrastructure. Over the last four years, Fernie retained NHC to evaluate the flood hazards associated with the Elk River, Fairy Creek, Coal Creek, and Brewery Creek. Through this work, NHC developed floodplain maps for the reach of each of the water courses within Fernie (NHC, 2014, 2017).

Fernie now intends to develop a plan to mitigate the flood hazards. Accordingly, the purpose of this study is to identify deficiencies in the existing flood protection infrastructure and prepare a mitigation plan to reduce the risk of flooding. This mitigation plan presents the criteria used the assess Fernie's flood protection system, recommended mitigation measures to address vulnerable areas, and prioritization of the recommended measures. The mitigation plan is expected to provide a road map to Fernie as to the measures required to improve the level of flood protection from Elk River and Coal Creek.

1.2 Definitions

Following are definitions of key terms used in this work.

Design Flood Level

In British Columbia, the design flood level is typically taken as the water level associated with a 200-year design flood event; i.e., a flood event with an expected annual exceedance probability (AEP) of 1:200 (MFLNRORD, 2018; MWLAP, 2003). Where an event has exceeded the 200-year event, the largest flood recorded (referred to as the flood of record) is often used as the basis for the design event; examples of this include the lower Fraser River and the Elk River. The water level is typically calculated through simulation of the design flood event using a numerical hydraulic model. In some instances, the design flood level may be established from observations from the flood of record or from a physical hydraulic model.

Flood Construction Level

The flood construction level, or FCL, is the design level used for buildings within the floodplain to limit risk of damage from flood waters. The FCL is determined by adding a freeboard to the design flood level. The risk of flooding is reduced through land-use regulations that require living space, areas used for the storage of goods damageable by floodwaters, and any electrical switchgear to be above the FCL. Specifically, the FCL defines the minimum level for the underside of a wooden floor system or top of a concrete slab.

As stated in *Section 3.6* of the provincial guidelines (MFLNRORD, 2018), residential, commercial, and institutional developments already protected by dikes are also required to meet these criteria; *"Buildings and manufactured homes in areas protected by standard dikes should meet minimum FCLs".* This perceived duplication of protection has been adopted in BC (unlike Alberta) to account for potential failure of dikes (such as occurred at the left bank of Coal Creek during the 1995 flood), seepage through or under dikes, and internal flooding from stormwater and inflow trapped on the landside of the dike. Dikes are used in addition to building floodproofing where there is a high flood risk, to limit frequency of flooding, inundation of low-lying infrastructure (such as roads and garages), high-velocity flow, and potential inflow of sediment, debris, and contaminants into the community. Conversely, areas not densely populated or not at high risk to flooding rarely warrant dikes.

Provincial guidance for design crest elevation for dikes does not specifically refer to the FCL. However, the definition of the design crest elevation in BC is the same as the definition of the FCL[1] (MWLAP, 2003). This report therefore presents them synonymously.

Despite the similarity, a community may however determine that a greater or different level of protection is warranted for dike design than for structures within the floodplain. Typically, this would be achieved by further increasing the design event (i.e. AEP of 1:500 or 1:1000) or considering alternative freeboard. In some cases, this may result in exemptions being defined for buildings protected by the dike, potentially in contradiction to the provincial land use guidelines. Some communities have adopted exceptions to the FCL for specific areas protected by dikes. For example; the City of Chilliwack *Floodplain Regulation Bylaw 2018 No. 4519* states in *Section 20.3* and *20.4* that some commercial uses are exempt from the floodplain bylaw (and hence FCL requirement) if they are constructed to a minimum elevation of 0.15 or 0.3 m above the crown of adjacent roads (depending on specific location).

Flood Risk

Flood risk is the probability of loss resulting from a flood. The loss can be direct, such as loss of a home or business, or indirect, such as changed perception of the community. Assessment of potential loss or consequence generally includes identification of hazards, potential receptors susceptible to the hazards (i.e. people, economy, environment, cultural values), and exposure and vulnerability of the receptors

[1] Exception is dikes for agricultural land, which are often limited to an AEP of 1:50, (MWLAP, 2003).

with respect to the hazard; as depicted in the following figure. The resulting flood risk is the probability of the flood event occurring and leading to the identified impacts.

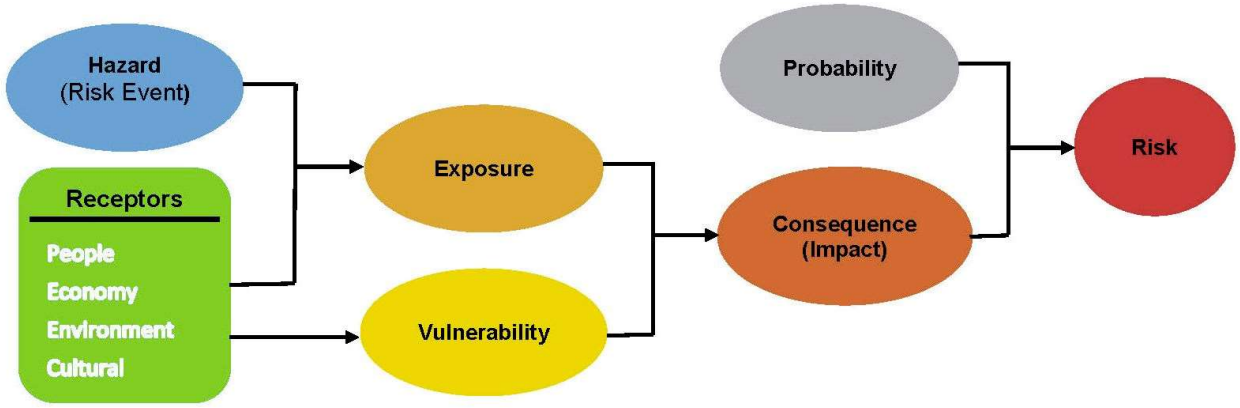


Figure 1-1 Components of risk assessment

Detailed assessment of flood risk can require extensive definition of flood risk events and consequences for the range of receptors and probabilities. This can be time consuming and difficult to ascertain, requiring a variety of specific data for the area and assessment by a wide range of experts. Most flood risk assessments are simplified through:

- Reducing the number of hazard events considered,
- Reducing the number of receptors considered (i.e. number of homes),
- Limiting analysis to direct impacts, and
- Using exposure as a proxy for impact (e.g., number of homes in potential inundated area versus magnitude of damage potentially caused by flood inundation).

Flood Risk Mitigation

Flood risk mitigation is generally accomplished through reducing the exposure and vulnerability to the hazard. In some circumstances, mitigation may also include flood hazard reduction, such as upstream storage or diverting floods around the community. Flood risk mitigation measures are often categorized as structural and non-structural; the terminology used within this report. However, alternative characterization has been used by other studies such as 'protect' (similar to the structural measures presented within this report), 'adapt' (similar to the non-structural measures presented within this report), and 'retreat' (relocation of infrastructure, homes, or communities).

1.3 Scope: Field Assessment

NHC's scope of work included field assessment in the form of visual inspection, topographical survey, and geotechnical investigation, followed by desktop assessment and development of a mitigation plan. Each of these tasks is described below.

1.3.1 Visual Inspection

NHC (Dwain Boyer and Daniel Maldoff) performed a visual inspection of flood protection features in Fernie from July 17 to 19, 2018. During the inspection, the inspectors photo-documented the flood protection features in Fernie, took notes about the physical condition of such features, and where possible, measurements were taken (e.g., crest width). The following facilities were inspected: Elk River dikes, Coal Creek Bin Wall, two bridges on Coal Creek, Mutz Creek flood gate, and Shadow Creek culvert. A follow-up field visit was performed in December 2018 by Align to locate and photo-document stormwater outfalls that could not be located during the July inspection. A location map of facilities inspected is shown in Exhibit 1 of Appendix A; photos are provided in Appendix C.

It should be noted that the visual inspection offers an assessment of conditions related to the flood protection system at the time of inspection. Conditions such as changing land use or extreme climate events in the future may call for a renewed assessment.

1.3.2 Topographical Survey

A topographical survey of all dikes was performed by Align between July 27 and August 10, 2018. Elevations were surveyed at cross sections every 25 m of less along each dike included in the study. Vertical datum of the survey data is CVD28BC and horizontal datum is NAD 83 (CSRS) 4.0.0.B.C.1, UTM Zone 11 BC. CVD28BC was chosen to be the vertical datum for this study to ensure consistency with the Elk River hydraulic model outside Fernie's boundaries, which uses this datum.

The results of the survey are presented in the form of dike profiles and cross-sections presented in Appendix B. An electronic file of the survey results has been provided to Fernie by NHC via email.

1.3.3 Geotechnical Investigation

Geotechnical site investigation was performed by Groundtech (Douglas A. Clapp and Isabel Ferreira) from August 7 to 10, 2018. The investigation was conducted with a visual assessment of the dike and using boreholes (B1 to B13) drilled with a sonic rig to depths between 7.62 m of 16.76 m. All boreholes were completed with piezometers to allow for groundwater depth monitoring. The resulting geotechnical report is provided in Appendix D.

Geotechnical findings specific to individual dikes are discussed in detailed discussions in Section 3. Some general findings, which apply to all dikes, are provided below:

1) Subgrade soils have adequate bearing capacity to support dike raising to the FCL.

2) Seepage rate through the dikes is expected to be high. However, limiting this seepage by constructing cutoff walls would be difficult and expensive to construct. Further, high groundwater would still be an issue. Use of low permeability soils during upgrade may provide a cost-effective means of reducing seepage to some extent.

3) Rapid drawdown is not a concern, based on the estimated permeability of dike and foundation soils.

4) Preliminary slope stability analysis indicates a side slope of 2.5H:1V will provide suitable stability if the head difference between the waterside and landside of the dike is 3.5 m or less, and the landside of the dike is at least 1 m higher than the river side of the dike.

5) Expected consolidation settlement is in the order of 25 mm.

1.3.4 Desktop Assessment and Mitigation Plan Development

Based on field inspections, topographical survey, and geotechnical investigation, NHC performed a desktop assessment to compare Fernie's flood protection infrastructure with applicable standards. The assessment forms the basis for this mitigation plan. Recommended measures, provided in Section 4, are presented in conceptual format and it is expected that detailed designs will be developed at a later stage when measures are taken up by Fernie for implementation. The recommended measures have been prioritized in Section 5 based on a risk score assigned to each.

1.4 Scope: Structures Assessed

The infrastructure and flood protection structures covered by NHC's assessment are listed in the table below and shown in Exhibit 1 of Appendix A. Exhibit 2 of Appendix A shows stationing for each dike.

Table 1.1 Infrastructure assessed

Type	Name (GPS ID assigned by province)
Dikes or flood walls	Northlands Dike (ID 61) Annex Dike (ID 58, 59) West Fernie Dike (ID 164) Coal Creek Bin Wall (ID 57) Mountview Dike (ID 60) Riverside Dike[2] (ID 357)
Culverts or flood gates	Shadow Creek culvert Stormwater outlets through the dikes (incl. Mutz Creek flood gate)
Bridges	Park Avenue bridge over Coal Creek Pine Avenue bridge over Coal Creek

It should be noted that the berm located on the left bank of the Elk River near Fernie's northern boundary (north of the Northlands Dike between the Elk River and the Fernie RV Resort) has not been considered in this study. This structure is not part of Fernie's flood protection strategy. According to provincial dike records, the structure (ID 360) is owned or administered by Tembec Industries Ltd. Further consideration for reliance or improvement of this structure has not been made by this study for the following reasons:

1) The structure is located within a geomorphically active reach of the floodway and could be subject to substantial channel changes and redirection, challenging maintenance of the structure.
2) As it is in the floodway, increasing the elevation of this structure is expected to increase flood levels upstream and/or local channel velocities, and hence transfer flood risk to other properties.
3) In the past, Fernie appears to have made an informed decision to develop the northern line of protection (on the Elk River left bank) along the Northlands Dike. Improving the northern berm to a dike may make Northlands Dike redundant.

[2] Riverside Dike (ID 357) is identified as a dike by MFLNRORD but is in fact only a bank, the shoulder of which is at the level of the surrounding ground and there is no landside slope. Nonetheless, for consistency with other records, the term 'dike' will continue to be used with reference to this structure.

2 BASIS FOR MITIGATION PLANNING

The facility assessment performed by NHC as well as mitigation measures suggested here are based on standards and guidelines issued by the province as well as best practices and products used within the province and elsewhere, which are described in this section.

2.1 Criteria for Structural Mitigation Measures

2.1.1 Design Elevation

In British Columbia, the standard for minimum dike crest elevation provided by the Ministry of Water, Land and Air Protection (MWLAP, 2003) is the higher of:

1) The elevation of the 200-year instantaneous flow plus 0.3 m freeboard, or
2) The elevation of the 200-year daily flow plus 0.6 m freeboard

Some municipalities or regions in BC have adopted a more conservative design flood and greater freeboard (EGBC, 2018). In recent years, a minimum freeboard of 0.6 m has often been used with an instantaneous design event[3], as suggested in the recent provincial guidelines for sea dikes (MOE, 2011). In addition, locations that have experienced floods greater than the 200-year flow often use this higher flow as the design flow; referred to as the flood of record. Examples of this include the lower Fraser River and the Elk River.

The 2013 June 21st flood is the largest recorded flood of the Elk River at Fernie. This event is on the order of a 500-year event. This event was used as the basis for determining flood levels along the Elk River in Fernie. As part of the previous mapping study, NHC (2017) investigated the projected increases in magnitude of extreme floods along the Elk River associated with global climate change to the year 2100. While the review indicated that higher flows are possible in the future, the trends were not statistically significant. Therefore, in accordance with Engineers and Geoscientists of BC (EGBC) Floodplain Mapping Guidelines (2017), the design flood was increased by 10% to account for this uncertainty. This results roughly in a 0.2 to 0.3 m increase in water level during the flood event. This resulting design water level, based on the 2013 instantaneous flood increased by 10%, was increased by 0.6 m freeboard to define the FCL.

The flood event that occurred 2013 June 21 is substantially greater than the 200-year flood used in the previous floodplain mapping that was performed in 1979. With the addition of the modest allowance for climate change, the design flood event used in the 2017 study is over 50% greater than that used in the previous mapping. Based on local river hydraulics, it is expected that this would result in a design flood level on the order of 0.6 to 1.8 m above those presented in the 1979 floodplain maps. The 2017

[3] Some examples of use of a minimum of 0.6 m freeboard above the instantaneous flood flow within BC: flood hazard study and mapping in Prince George, the lower Fraser River, Maple Ridge, Squamish, City of Fernie, and North Vancouver (KWL, 2014 and 2016, NHC, 2008, 2014, 2016).

floodplain mapping study compared historic and current FCL throughout Fernie, and found that the 2017 floodplain maps suggest an FCL typically 0.8 m above the 1979 maps; but this difference ranged from 0 to 1.5 m. Further complicating a direct comparison with the 1979 study are differences in survey techniques (modern geoid representation of the earth versus historic level survey and curvature corrections) and inability to confirm contemporary survey with the historic benchmarks used in the 1979 study.

The FCL presented by the 2017 floodplain maps has been adopted for this study as the elevation for assessment and design of Elk River dikes. Similar levels, although based on the 200-year instantaneous flood level instead of a flood of record, have been adopted for Coal Creek (NHC, 2014).

2.1.2 Dike Slope Improvements

The provincial standard for dikes less than 2 m high is as follows (MWLAP, 2003) (see Figure 2-1):

1) Landside slopes without seepage control measures: No steeper than 3H:1V
2) Landside slopes with seepage control measures: No steeper than 2H:1V
3) Waterside slopes without erosion control: No steeper than 2.5H:1V
4) Waterside slopes with erosion control: No steeper than 2H:1V

However, based on geotechnical investigation of Fernie's dikes, Groundtech recommended that a side slope of 2.5H:1V will provide suitable stability if the head difference between the land side and river side of the dike is 3.5 m or less (see Section 5.4, Appendix D). Accordingly, side slopes for Fernie's dikes were evaluated on basis of the geotechnical engineer's recommendations rather than general Ministry of Water, Land and Air Protection (MWLAP) guidelines.

2.1.3 Dike Crest Widening

The provincial standard for dike crest width is 4 m (see Figure 2-1), which has been recommended primarily to accommodate future dike raising and for easier access for construction, inspection, and maintenance; the standard was 3.66 m (12 ft) prior to 2004. Therefore, in considering crest widths in Fernie, a departure from the 4 m width standard was not considered as a significant issue unless the crest width was so narrow as to impede access.

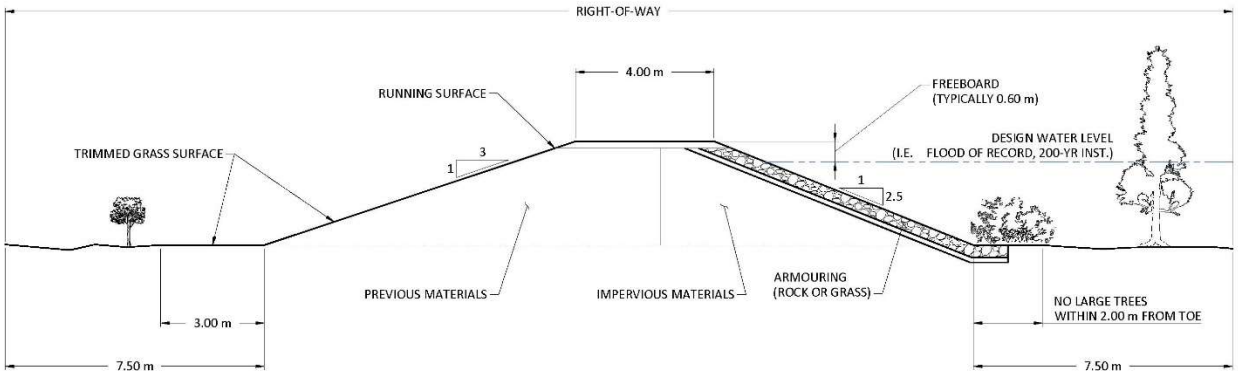


Figure 2-1 Idealized dike cross-section based on MWLAP guidelines

2.1.4 New Dikes or Dike Extension

Where the FCL is higher than ground elevation and the location warrants a new dike or extension of the existing dike, MWLAP's Dike Design and Construction Guide (2003) has been adopted as the source of standards. The document contains design criteria for dike alignments, dike geometry, setbacks, seepage protection, dike materials, and freeboard. The standard for seismic design for dikes is provided by the Ministry of Natural Resource Operations (MNRO, 2010).

Development of new dikes or extension of existing dikes is often costly due to land acquisition, construction, surveillance, and maintenance. Rarely have new dikes been constructed in BC in the last 30 years due to the high cost (*per. comm. with former Head Inspector of Dikes, Neil Peters*). Locations at high risk, with extensive development, and where land is available for a dike are the only locations where new dikes or dike extension should be considered. In addition, a high level of community support is often required for such projects.

2.1.5 Erosion Protection Improvements

Traditionally, engineering solutions such as riprap have been used to treat eroding streambanks. Although the voids within riprap can provide shelter for fish, riprap is generally considered negative to habitat value due to loss of riparian vegetation, loss of overhanging banks, and potential barrier between terrestrial and aquatic habitats. Alternative approaches may be applicable, such as set back of infrastructure from the bank, bioengineering approaches along the bank, or construction of spurs to deflect flows from a bank.

During detailed design of erosion protection measures on Fernie dikes, both traditional riprap armouring and alternative solutions should be considered. The choice of which approach to use (or a combination of approaches) should be made at the detailed design stage based on the site-specific consequence of failure as well as design shear stresses which are influenced by the water depth, water velocity, dike slope, and wave action. Typically, bioengineering approaches are not used to protect high consequence structures (such as dikes around densely populated areas) unless alternative resilience is included in the design (such as set back dikes or riprap armouring keyed into the bank).

Detailed design standards for erosion protection features such as riprap size, gradation, and thickness are provided by Ministry of Environment, Lands & Parks (MELP, 2000). A typical cross-section of a bank protected by riprap is shown in Figure 2-2.

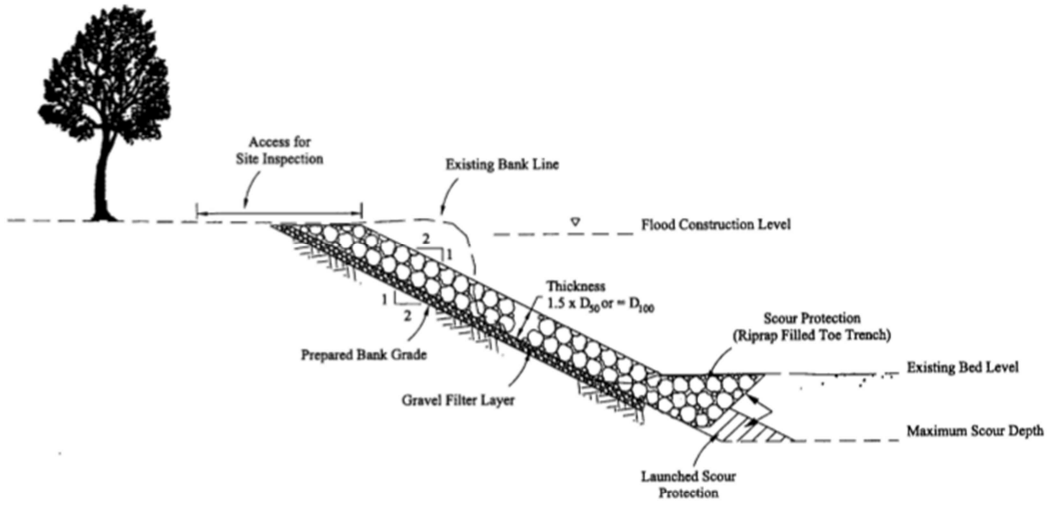


Figure 2-2 Typical riprap cross-section (Source: MELP)

Fisheries and Oceans Canada (2003) and Allen and Fischenich (2001) provide details of soil bioengineering alternatives to traditional stabilization measures. A typical cross-section of a bank protected by a brush mattress is shown in Figure 2-3. Such an approach is not normally suitable for dike construction on this scale of river unless the dikes are set back from the flow or alternative back-up protection is also provided (i.e. riprap buried under the slopes surface).

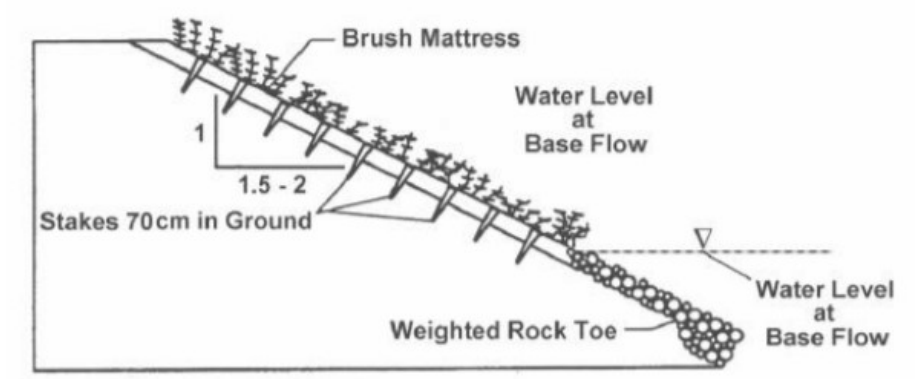


Figure 2-3 Typical brush mattress-protected bank (source: Allen and Fischenich (2001))

Flood Boxes

Floodboxes allow the gravity discharge of the internal drainage water from behind the dike into the watercourse when the water level in the watercourse is lower than the level behind the dike. Floodboxes consists of culverts through the dike with gates at the outlet to prevent backflow from the watercourse (MELP, 2001). General standards for pipes crossings dikes and outfalls are provided by MWLAP (2003) and Ministry of Forests, Lands, and Natural Resource Operations (MFLNRO, 2014). A

typical top-mounted flapgate for a stormwater outfall is shown below. Where a culvert is used for fish passage, side-mounted flapgates are recommended.

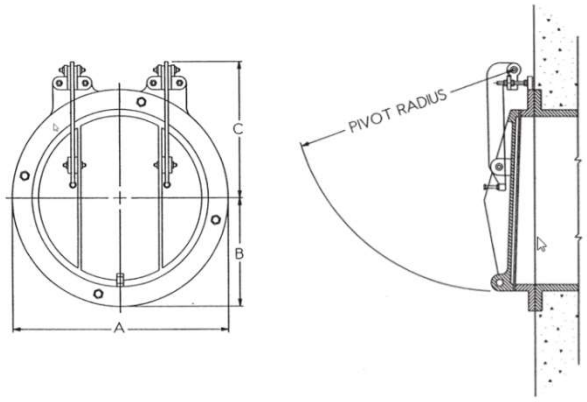


Figure 2-4 Typical stormwater flapgate (Source: Hydro Gate Model 50C)

2.1.7 Erosion Potential at Bridges

Assessment of erosion potential at bridges was performed in accordance with hydrotechnical criteria developed by BC Ministry of Transportation and Infrastructure (MOTI, 2013a).

2.1.8 Dredging, Storage and Diversion

Upstream storage can attenuate a flood by retaining water during the peak of the flood, delaying its release effectively reduces the peak flow experienced downstream. Storage is generally provided by large dams which are financed as hydro electric power projects with some flood control provided at the cost of reduced power production. Due to this trade off, often flood protection is limited to more frequent events limiting the applicability to Elk River flooding at Fernie.

Diversion of flow can reduce the stress placed on low dikes by increasing the capacity past a community. Diversions are generally only practical where there is alternative receiving waterbody (e.g. Assiniboine River diversion near Portage la Prairie) and there is adequate space to divert substantial portions of the flow (e.g. Red River diversion at Winnipeg); neither of which are present at Fernie.

River-bed dredging can also increase channel capacity and has been used as a flood hazard reduction measure in the past. While dredging may have flood reduction benefits in some instances, its benefit is often limited in duration (due to on going sediment loading) and limited in location to the area being dredged. Removed gravel is frequently replaced by deposition in a relatively short amount of time. This can result over a series of moderate events, resulting in a need for ongoing maintenance dredging (potentially annually), or at the onset of a large event voiding any benefit. Use of dredging may be most appropriate for local changes in direction of flows to limit erosion pressures or water levels during moderate events (e.g., to improve drainage), but it is generally not found effective to provide relief during significant floods over large areas which is the context of this study. Furthermore, it is often found to be damaging to the environment.

Increases in flood capacity are more often realized through setting dikes back and increasing the width of the floodway. Many of the dikes within Fernie are already set back from the river, and development on the landside of the dikes prevents further setback of the existing structures.

2.1.9 Summary of Assessment Criteria for Structural Measures

Table 2.1 Assessment criteria for structural measures

Parameter	Assessment Criteria
Dike crest elevation	Elk River: FCL from 2017 Elk River Floodplain Mapping (2013 peak instantaneous flow with 10% increase for climate change, plus 0.6 m freeboard) (NHC, 2017) Coal Creek: 2014 Coal Creek Floodplain Mapping (200-year return period peak instantaneous flow, plus 0.6 m freeboard) (NHC, 2014)
Dike slopes	No steeper than 2.5:1 (as per geotechnical engineer's recommendation)
Crest width	4.0 m recommended by MWLAP primarily to accommodate future dike raising and access; the standard was 3.66 m prior to 2004. Departure from the 4 m not considered a significant issue unless crest width so narrow as to impede access.
Erosion protection	The following conditions must not be present: toe scour, riprap loss, material degrading, bed degradation, outflanking, or rock displacement.
Vegetation	The following conditions must not be present: woody vegetation and/or thick brush on dike slopes or adjacent to the dike, vegetation obscuring dike inspection, or trees on dike slope within 2 m of toe.
Encroachment	Encroachments must not interfere with operation and maintenance activities and internal drainage courses
Flood boxes	Must not show signs of significant deterioration, blockage or recent damage

2.2 Non-Structural Mitigation Measures

Neither structural nor non-structural mitigation measures are meant to work in exclusivity; both types of measures are required and they work in mutually complementary fashion. However, it should be noted that non-structural mitigation measures are preferred since they can often be implemented with relatively small investment.

2.2.1 Flood Emergency Response Planning

Preparation of emergency response plans (ERP) by local authorities is mandated by BC law (BC, 1996). The province provides guidance on planning for various aspects of flood emergency response including plan preparation, pre- and during-flood actions, and post-flood management (BC, 2016; PEP, 1999). In addition to a general ERP, Fernie has also developed a Flood Response Plan which includes preparing for flood season, flood response, communications during a flood response, and recovery.

2.2.2 Land-use Management

The province provides guidelines to help local governments develop and implement land-use management plans and make development decisions for flood hazard areas (MFLNRORD, 2018). Part 14 of the Local Government Act (BC, 2015) provides local governments with several land-use management tools to promote flood safety. For example, the Act empowers local authorities to establish development permit areas, designate certain lands as floodplains through bylaws, enact zones to promote safe developments in floodplains, and implement measures such as setbacks.

2.2.3 Education

Education of flood risk can help property-owners prepare for future floods and be aware of the nature of floods, evacuation routes, and evacuation procedures. The recent floodplain mapping exercise performed by Fernie suggests that flood inundation extents are greater than previous maps; people that may have once considered themselves safe from a flood should now be aware of the risks.

2.2.4 Vegetation Management

Uncontrolled vegetation on dikes can affect the structural integrity of dikes, obscure visibility during inspection, impede access for maintenance and inspection, and hinder emergency flood fighting operations. If Fernie's Vegetation Management Plan (City of Fernie, 2010) doesn't address all aspects of dike vegetation maintenance, provincial or federal guidelines can be referred to. Joint province-federal guidelines (MELP and DFO, 1999) state that vegetation should not be allowed on dike crests while landside slopes should be kept clear of vegetation other than trimmed grass. Controlled vegetation clumps which are devoid of potentially large growth and/or excessive vegetation are acceptable in riprap bank protection (see Figure 2-5).

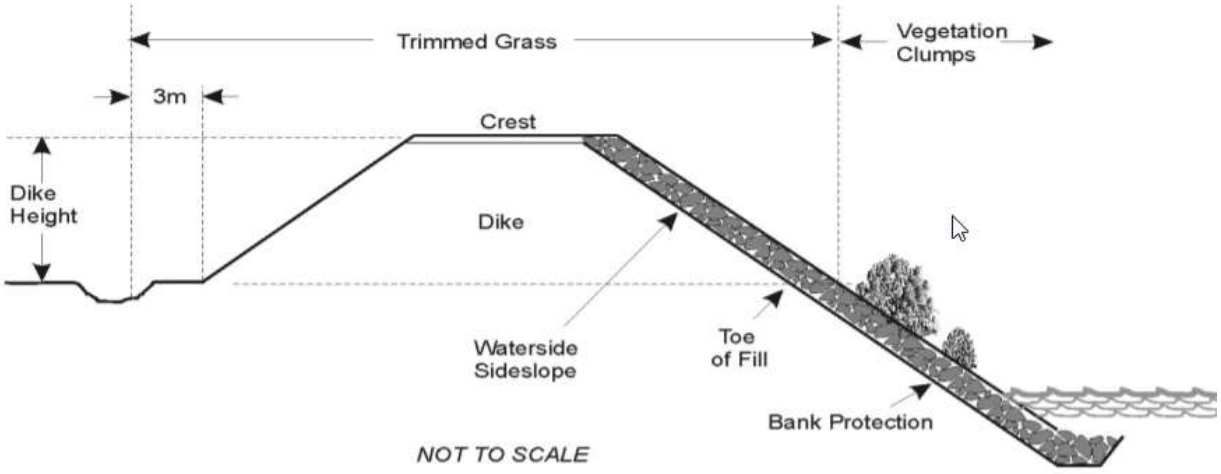


Figure 2-5 Recommended vegetation management for armoured dike (source: MELP and DFO (1999))

2.3 Cost Estimating Approach

Cost estimation for structural mitigation measures was performed at a 'planning' level of estimating which is defined by MOTI (2013b) as being "based on sufficient knowledge of site conditions adequate to identify high level risk". The expected accuracy range for this level of estimating is +/- 35%. Unit prices were applied for bulk materials, such as fill, granular filter, and riprap. A supplementary construction cost line item was added to account for construction survey, material testing, mobilization, clearing, grubbing, control of water, erosion, and sediment, site restoration (cleanup, seeding, planting), and demobilization. Cost estimates are based on recent NHC projects in the region.

Calculated construction costs were inflated to reflect soft costs and contingencies. Soft costs were assumed to be 15% of construction costs. A contingency rate of 35% was used, as recommended by MOTI (2013b). All costs presented in this report have been rounded to the nearest thousand.

Costs associated with potential utility relocation or right-of-way acquisition were not accounted for. Costs for operation, maintenance, surveillance (OMS) or other non-structural mitigation measures have not been included. Both structural and non-structural mitigation measures are likely to require rework, maintenance, or partial replacement in the future; such costs have not been considered.

3 RECOMMENDATIONS FOR FLOOD MITIGATION

NHC's recommendations for flood mitigation are presented under two parts – structural mitigation (Section 3.1) and non-structural mitigation (Section 3.2).

3.1 Structural Mitigation

The structural mitigation measures are predominantly those that are physical, permanent, construction works. Exhibit E contains the posters used in NHC's presentation to the Fernie community on February 19, 2019, which show the proposed structural mitigation measures.

Alternative temporary measures may be implemented, such as emergency placement of fill, sand bags, bulk bags, use of water inflated barriers (i.e. Aquadams or WIPP[4]), erected panel flood barriers (i.e. Geodesign Barriers[4]), or other temporary flood protection to close gaps between flood protection or within openings of low lying buildings or structures (i.e. EKO barriers[4] or Floodgate[4]). Such works are typically costly to procure for large linear locations and require storage, maintenance, and emergency installation. They are expected to generally be costlier than the permanent structural mitigation measures presented since the majority of the permanent measures presented are improvements to

[4] Aquadams are available through AquaDam (http://www.aquadam.net/)
Water-inflated Flood Barriers (WIPP), Geodesign Barriers, EKO Barriers, and Floodgate are available through Hydro Response Ltd. (http://www.hydroresponse.com/).

existing infrastructure. However, where there is community opposition or if other constraints for permanent works becomes apparent, such temporary emergency solutions may become suitable alternatives to the measures presented below.

It should be noted that most of the recommended structural mitigation actions will require approval from the provincial Inspector of Dikes, in accordance with the Dike Maintenance Act. Further, if a new dike is constructed (e.g., along 3rd Street), Fernie will have to act as the diking authority, taking ownership of and responsibility for monitoring and maintenance of the dike.

3.1.1 Shadow Creek Culvert

A) Assessment Findings

Physical Condition Assessment

The Shadow Creek culvert is located at the crossing of Shadow Creek under Hwy 3 in the Ghostrider subdivision of Fernie (Figure 3-1). The culvert is an ungated 1.6 m diameter corrugated metal pipe, approximately 50 m long.



Figure 3-1 Location of Shadow Creek culvert and view of its downstream end

The Hwy 3 embankment acts as a dike in this location but, as shown in Figure 3-2, the embankment would be unable to prevent flooding in the Ghostrider subdivision because of uncontrolled backflow of Elk River floods through the Shadow Creek culvert.

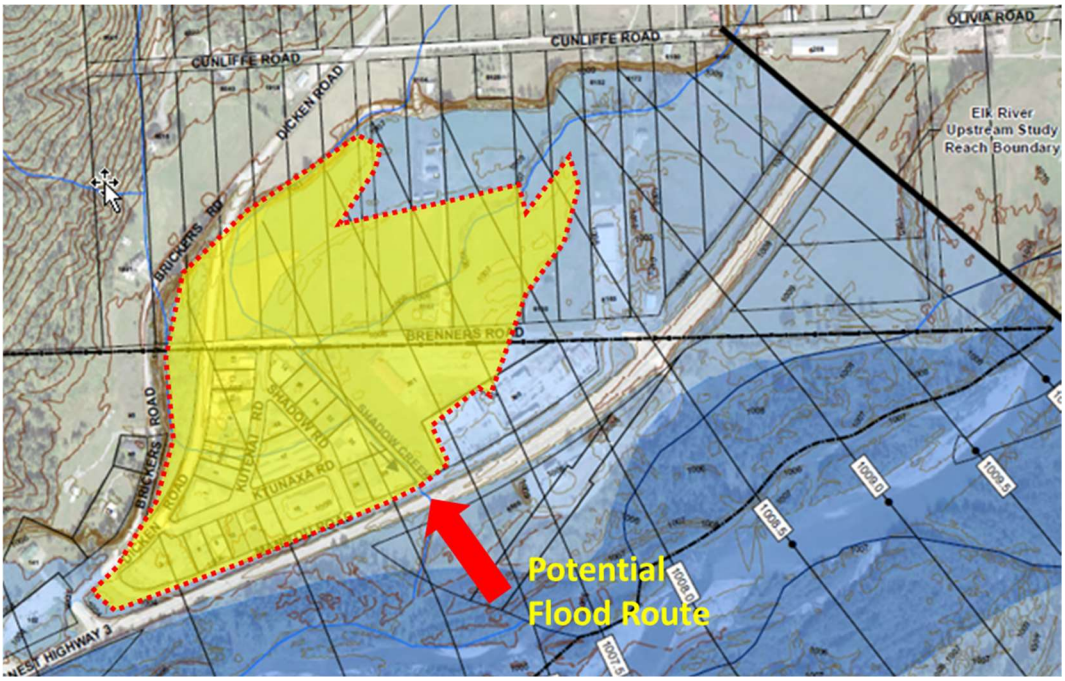


Figure 3-2 **Estimated flooding in Ghostrider subdivision** (yellow shaded area shows area potentially flooded by Elk River backflowing through the Shadow Creek culvert)

Hydrologic Assessment

While detailed hydrologic assessment of Shadow Creek was not envisioned for this study, a preliminary assessment is presented. The watershed of Shadow Creek is approximately 6.6 km^2, which is comparable with the size of the nearby Hosmer Creek watershed (6.4 km^2) which has been gauged by Water Survey of Canada (WSC) from1982 to 2016 (WSC 08NK026).

The estimated 50-year peak daily flow for Hosmer Creek based on the WSC flow record is 3.4 m^3/s. Adjusting for the minor difference in areas of the two watersheds, this results in a daily flow estimate of 3.3 m^3/s for Shadow Creek at the Hwy 3 culvert. There is a low-lying area (approximately 9.6 ha) upstream of the Shadow Creek culvert that can provide storage in the event that high flows in the Elk River do not allow the culvert to drain effectively. Assuming an average depth of 1 m in the low-lying area, it is estimated that the area can provide storage for approximately 8 hours with limited impacts to properties.

B) Recommendations

It is recommended that a flood control gate be installed at the downstream end of the Shadow Creek culvert under Hwy 3 to prevent backflow through this culvert. The gate should not impede fish passage under normal flow conditions and allow outflow of Shadow Creek when upstream water levels are greater than Elk River water levels. Options for the gate include a side mounted aluminum floodgate, a manually operated flap gate, or a self-regulating floodgate. The cost of procurement and installation for

the side mounted floodgate is estimated to be $68,000[5]. This culvert is likely owned and maintained by MOTI, so coordination with MOTI would be required to proceed with this measure.

The hydrologic analysis presented above indicates that the existing low-lying area can provide approximately 8 hours of storage (with limited damage to assets) in the event that high flows in the Elk River prevent the Shadow Creek culvert from draining. However, high water levels in the Elk River lasting more than 8 hours would limit outflow from Shadow Creek (more so without a flood gate) and would then require pumping or diversion of Shadow Creek to avoid flood damages.

A second culvert (Brickner Creek) under the highway is located 400 m southwest of the Shadow Creek culvert. Consideration for a flood gate on this culvert should also be made. Requirement for fish passage through this other culvert should be confirmed prior to use of a gate that may restrict fish passage.

3.1.2 Northlands Dike

A) Assessment Findings

The Northlands Dike is approximately 470 m long and is located north of the Annex neighborhood on the left bank of the Elk River (see Exhibit 1 in Appendix A). The dike is also referred to as the Maiden Lake Dike.

Table 3.1 summarizes findings of the visual inspection and geotechnical investigation performed by drilling three boreholes – B1, B2, and B13 (see Figure 2 in Geotechnical Report, Appendix D).

[5] This estimate reflects several conservative assumptions – such as that as that a self-regulated gate is used - which can only be validated during the detailed design phase. The actual initial construction cost could be considerably less than the estimate if alternative approaches are selected (e.g. manually operated gate).

Table 3.1 Assessment of Northlands Dike

Parameter	Assessment
Dike crest elevation	Lower than the FCL for almost its entire length (see dike profile and section views in Appendix B), the average departure from FCL being approximately 1 m. The dike does not tie in with high ground at its upstream end.
Side slopes	Acceptable for most of the dike reach. Steeper than recommended slope in a short reach near 0+477.
Crest width	Width less than 4.0 m at the following approximate stations: 1) 0+100 to 0+200 2) 0+400 However, departure from the recommended width is not significant enough to hinder access and is thus not considered to be a significant issue.
Erosion protection	Found to be inadequate (i.e., weathered to a size below that expected necessary for adequate armouring) between stations 0+350 and 0+450.
Encroachment	No deficiency observed.
ROW/Access	No issues were identified with existing dike. Extending the dike on the eastern end will require Fernie to obtain rights of way.
Geotechnical assessment	1. Dike and underlying materials: Soil conditions encountered would not significantly impact dike design. 2. Foundation soil bearing capacity: Subgrade soils tested at Northlands Dike site were found to adequately support dike raising. 3. Embankment seepage and underseepage: Dike materials were found to be permeable enough to allow the phreatic surface to track the water surface of the river. However, based on experience in the 1995 flood, interior flooding can be attributed to both dike seepage and groundwater. Therefore, cutoff walls may not be entirely effective; instead, seepage and groundwater-caused interior flooding should be managed with pumping. 4. Slope stability: See above under 'Side slopes'. 5. Liquefaction: The susceptibility of the underlying clay soils ranges from non-susceptible to susceptible, but no mitigation recommended because of factor of safety and low probability. 6. Settlement: Settlement of 25 mm is estimated, which is not significant or actionable in light of 0.6 m freeboard allowance.

B) Recommendations

It is recommended that the Northlands Dike be raised from station 0+000 to 0+450 to the FCL. Approximately 1 m of raising will be required for the entire reach. When dike raising is performed, the dike cross-section should be built to meet the top width and slope standards discussed in Section 2.1. After accounting for increases in dike height and restoration of top widths and side slopes, the dike footprint is expected to increase from 2.5 m to 4.0 m on either side. It is unlikely that additional right-of-

way be needed to be acquired to raise the dike. However, there are power poles and overhead power lines in the area, and utility relocation may be required.

Erosion protection improvements should be carried out between stations 0+350 and 0+450 (see Exhibit 2 in Appendix A for dike stationing). This section of dike is adjacent to the river and depending on current flow paths can be subjected to impinging high flows during a flood. Currently this dike section is armoured with riprap. Practical improvement to this site is limited to supplementing the existing riprap. Other alternatives would require increasing the site footprint either landward (such as setting back the dike) or towards the river (such as adding a bench to add allow for riparian planting).

The dike should be extended at its upstream end to obtain a tie-in with high ground located on the northeastern side of the intersection of 6th Avenue and Fairway Drive. Two alternative configurations are feasible (see Figure 3-3):

1) Option A - The extended dike is situated east of 6th Avenue, which entails ramping up 6th Avenue to go over the dike. A temporary barrier was not explored for the 6th Avenue crossing because a temporary barrier would entirely preclude emergency traffic to and from the area north of the Northlands Dike. This option will require acquisition of right of way through private property. Two existing culverts under 18th Street (see Exhibit 4 in Appendix A) will have to be treated as floodboxes (i.e., provide backflow protection and structural strength for additional loading). Additional culverts under 6th Avenue may also need to be removed and flow rerouted around the dike.
2) Option B - The extended dike would be situated west of 6th Avenue, which would entail ramping up 18th Street to go over the dike. The dike would have an opening at 6th Avenue protected with temporary barriers[6] such as an emergency road floodgate or portable flood barrier such as Aqua Dam (ramping up 6th Avenue to go over the dike is not an option because of the presence of developed parcels on both sides of the road immediately south of the proposed dike alignment).

Option A has an advantage with respect to traffic movement since it provides passive protection and allows traffic movement along 6th Avenue at any time. Further, Option A will protect the property at the corner of 18th Street and 6th Avenue.

Option B requires 6th Avenue to be blocked temporarily by a removable flood barrier during high flow events. Further, this option will exclude the property at the corner of 18th Street and 6th Avenue from the protected area. It should be noted that a low dike already exists along the Option B alignment with a pedestrian path along its crest, but it is low (0.2 to 0.8 m above adjacent ground) and relatively narrow.

Because Option A offers greater benefits, it is the recommended option for Northlands Dike extension. The length of the extended dike along the Option A alignment will be between approximately 220 m.

[6] Note that while a temporary barrier is not an option for Option A, it is a viable option for Option B because 18th Street offers a viable ingress-egress route for the area north of Northlands Dike when the temporary barrier is in place.

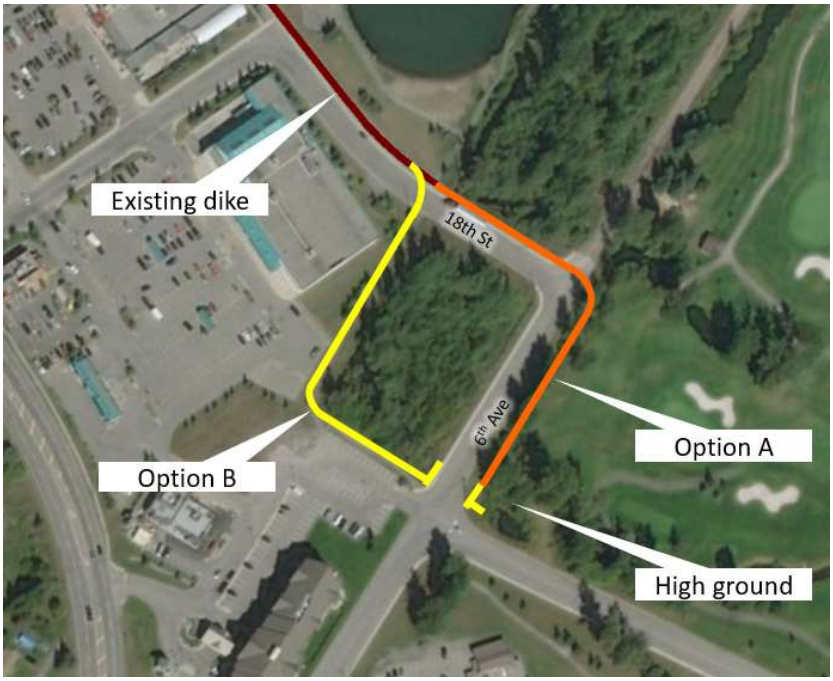


Figure 3-3 Northlands dike extension options

Recommended mitigation measures and planning-level cost estimates for dike raising and erosion protection are presented in Table 3.2 and those for dike extension (Option A) are presented in Table 3.3. Option B would require less fill than Option A, but includes a second road crossing (temporary or permanent). The cost for Option B is expected to be similar to that for Option A. The cost of land/easement acquisition or utility relocation has not been accounted.

Table 3.2 Northlands Dike raising and erosion protection

Mitigation Measure	Location	Cost Estimate
Dike raising	0+000 to 0+450	$442,000
Erosion protection	0+350 and 0+450	$124,000
Supplementary Construction	N/A	$50,000
Subtotal		$616,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$924,000

Note: Total cost has been rounded to nearest thousand.

Table 3.3 Northlands Dike extension (Option A)

Mitigation Measure	Location	Cost Estimate
Dike extension	220 m new diking for tie-in (Option A)	$ 233,000
Supplementary Construction	Includes grading and paving of new road	$ 204,000
Subtotal		$ 437,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$ 656,000

Note: Total cost has been rounded to nearest thousand.

3.1.3 Annex Dike

A) Assessment Findings

The Annex Dike is approximately 1,800 m long and extends from the Leo T. Nimsick Bridge to West Bridge on the left bank of Elk River (see Exhibit 1 in Appendix A). The upstream-most 250 m and downstream-most 400 m of dike are located directly along the river bank. The middle 1150 m of dike is set back 40 to 140 m from the river bank. In this area, a secondary dike is located on the waterside of Annex Dike, immediate adjacent to the Elk River (to avoid confusion, this secondary structure is called a 'river training berm').

Where the dike is directly at the Elk River bank, riprap armouring continues up the slope of the dike to the dike crest. Where the dike is set back from the river, its slope is surfaced with grass. It appears that the river training berm was originally armoured with riprap as part of its construction, but that armouring has gradually been eroded or weathered over time.

Table 3.4 summarizes findings of visual inspection and geotechnical investigation performed by drilling three boreholes – B3, B4, and B5 (see Figures 2 and 3 in Geotechnical Report, Appendix D).

Table 3.4 Assessment of Annex Dike

Parameter	Assessment
Dike crest elevation	Lower than the FCL along the entire length of the dike (see dike profile and section views in Appendix B)[7]. The average departure from FCL is approximately 0.6 m with maximum departure of 1 m.
Side slopes	Found to be steeper than recommended gradient between stations 0+750 to 1+500.
Crest width	Width less than 4.0 m for majority of the dike length. However, departure from the recommended width is not significant enough to hinder access and is not considered to be a significant issue.
Erosion protection	Between stations 0+000 to 0+250, riprap is locally over-steepened at the toe with perched elements undermined by erosion. Waterside slope of the has active erosion with a near-vertical toe near 0+250. Between stations 1+500 to 1+824, riprap is weathered and rocks are in various stages of disintegration. Completely-disintegrated rocks have left voids in riprap. The river training berm, which originally appears to have been armoured originally, does not have any riprap remaining.
Encroachment	No deficiency observed.
ROW/Access	No issues with right of way or access were identified with existing dike.
Geotechnical assessment	Findings for Annex Dike are identical to those for Northlands Dike (see Table 3.1).

B) Recommendations

It is recommended that the Annex Dike be raised along its entire length to the FCL. Between 0.5 m to 1 m of raising will be required. When dike raising is performed, the dike cross-section should be built to meet the top width and slope requirements discussed in Section 2.1. After accounting for increase in dike height and restoration of top widths and side slopes, the dike footprint is expected to increase from 1.3 m to 4.0 m on either side. Additional right-of-way may be required to accomplish dike raising in southern portion of the dike (approximately stations 1+000 to 1+824) where private property is located immediately adjacent to the dike.

Erosion protection improvements should be carried out at the locations indicated in Table 3.4. Because this bank is currently protected by riprap, with improvements consisting of in-filling areas of inadequate

[7] Note that the Annex Dike profile shows lack of tie-in with high ground at both ends of the dike. This representation is a result of the survey not picking up elevation points on the Hwy 3 embankment (at both ends of the dike – North Fernie Bridge and West Fernie Bridge at upstream and downstream ends respectively) which is high and acts as a tie-in to high ground.

riprap, vegetative protection will not be an option. No mitigation is measured for the missing riprap on the river training berm as the channel in the area is stable and the current banks have maintained their location during past significant floods (e.g., 1995 and 2013) as evidenced by well-established vegetation on the landside of the river training berm. However, the river training berm should be monitored annually, and further armouring may be required if lateral stability of the channel diminishes.

Recommended mitigation measures and planning-level cost estimates for the dike are summarized in Table 3.5. The cost of land/easement acquisition or utility relocation has not been accounted.

Table 3.5 Annex Dike flood mitigation measures

Mitigation Measure	Location	Cost Estimate
Dike raising	0+000 to 1+825	$ 2,096,000
Erosion protection repair	0+000 to 0+250 and 1+500 to 1+824	$ 793,000
Supplementary Construction	N/A	$ 200,000
Subtotal		$ 3,089,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$4,634,000

Note: Total cost has been rounded to nearest thousand.

3.1.4 New Dike along 3rd Street

A) Assessment Findings

The area near the intersection of 3rd Street and 6th Avenue is not currently protected by a dike, as the Annex Dike ends immediately upstream of Hwy 3. This exposes the area to river flooding which could affect approximately 45 parcels (see Figure 3-5 and flood profile in Appendix B). The potential threat was highlighted in the 1995 flood when sandbags had to be placed along 3rd Street to divert floodwaters.



Figure 3-4 Aerial photograph of flooding at 3rd Street downstream of West Bridge, 2013 June 22



Figure 3-5 Flooding in 3rd St/6th Ave area (delineated by red boundary; yellow boundary marks location of proposed dike)

B) Recommendations

It is recommended that a dike be constructed on the left bank of Elk River along 3rd Street (see proposed alignment in Figure 3-6). The length of the dike would be approximately 270 m, connecting the embankment of Hwy 3 with high ground located east of 5th Avenue.

Presently, 3rd Street is approximately 11 m wide which allows two opposite lanes of traffic and a parking shoulder on the waterside of the road. An overhead power line and three power poles are located on the southwestern edge of 3rd Street. The area between the outside edge of the shoulder and the Elk

River bank is occupied by riparian vegetation.

The proposed dike will result in the following impacts on existing public utilities and natural features:

1) Leave adequate width on 3rd Street for two lanes of travel but no allowance for parking or future expansion.
2) 3rd Street will be required to be ramped up to the levee crest on both sides of the dike near its eastern end.
3) Three power poles along 3rd Street will have to be relocated and the power lines crossing over 3rd Street at its intersection with 6th Avenue will have to be raised to allow safe overhead clearance for vehicular traffic.
4) Approximately 0.5 ha of riparian vegetation will be required to be removed to accommodate the dike.

No armouring of the dike is proposed as it is set back from the Elk River (by approximately 25 m at the upstream end and 80 m at the downstream end) and channel alignment is controlled in large part by the upstream bridge abutment and approach road embankment. Based on an estimated dike height above existing ground of 2.1 m and top width, side slopes, and right of way as shown in Figure 2-1, approximately 0.7 hectares of land will be required to be acquired (or, if Fernie already owns it, it will need to be reserved or dedicated for the dike).

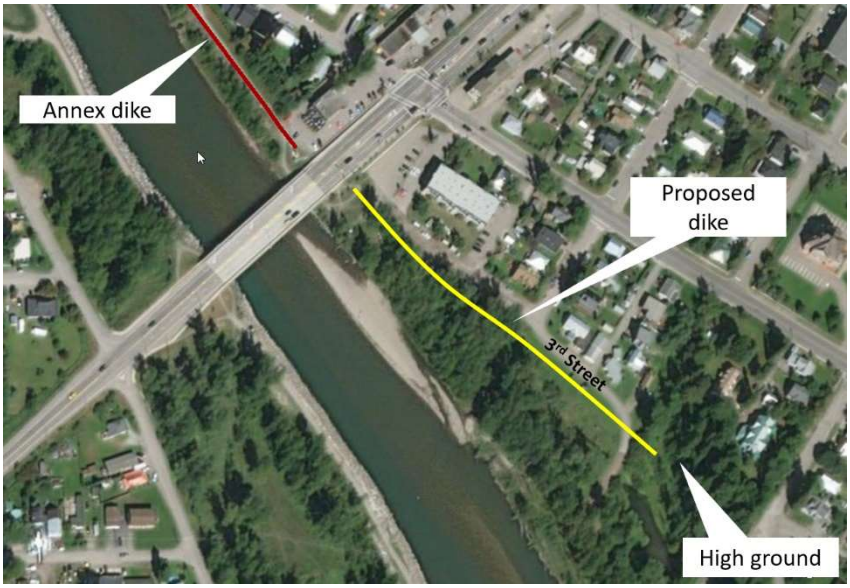


Figure 3-6 Potential alignment of dike along 3rd Street

Estimated costs are provided in Table 3.6. The cost of land/easement acquisition or utility relocation has not been accounted.

Table 3.6 Proposed dike along 3rd Street

Mitigation Measure	Location	Cost Estimate
Dike construction	Along 3rd Street	$ 233,000
Supplementary Construction	Includes grading and paving for new road	$ 266,000
Subtotal		$ 499,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$749,000

Note: Total cost has been rounded to nearest thousand.

3.1.5 West Fernie Dike

A) Assessment Findings

The West Fernie Dike is approximately 1,200 m long, located along the right bank of the Elk River from 230 m upstream of West Bridge to Hesketh Street, 1000 m downstream of West Bridge (see Exhibit 1 in Appendix A). A manually-operated system of gates at the upstream end of the dike and at the outlet of Mutz Creek allows for diversion and backflow prevention during high Elk River water levels and unimpeded fish passage during normal water levels.

Table 3.7 summarizes findings of visual inspection and geotechnical investigation performed by drilling three boreholes – B6, B7, and B8 (see Figures 3 and 4 in Geotechnical Report provided in Appendix D). Further, results of geotechnical investigations performed by McElhanney in 2013 were also reviewed.

Table 3.7 Assessment of West Fernie Dike

Parameter	Assessment
Dike crest elevation	Lower than the FCL along a significant portion of dike length (see dike profile and section views in Appendix B). The deficiency is approximately 0.5 m for most of the length of the dike, which is within the 0.6 m freeboard. The dike does not tie in with high ground at its downstream end.
Side slopes	Found to be steeper than the recommended gradient between stations 0+000 to 0+500.
Crest width	Width is generally greater than 4.0 m except at two locations (0+750 and 1+326). However, departure from the recommended width is minor and does not hinder access for inspection, maintenance, or construction.
Erosion protection	No deficiency observed.
Encroachment	No deficiency observed.
ROW/Access	No deficiency observed.
Geotechnical assessment	See Table 3.1. Findings for West Fernie Dike are identical to those for Northlands Dike.

B) Recommendations

It is recommended that the West Fernie Dike be raised along its entire length to the FCL. Approximately 0.5 m of raising will be required for most of the length. Top widths and side slopes may need to adjusted to meet the standards described in Section 2.[8] After accounting for increase in dike height and restoration of top widths and side slopes, the dike footprint is expected to increase from 1.25 m to 4.0 m on either side. It is unlikely that additional right-of-way would be required to accomplish dike raising except at the southeast corner of the West Fernie. Planning-level cost estimate for dike raising is provided in Table 3.8.

[8] Where the FCL is higher than the existing dike top by less than 100 mm (e.g., station 0+250), raising can be achieved by adding a running surface on top of the dike instead of a structural raising (which requires reworking the side slopes).

Table 3.8 West Fernie Dike raising

Mitigation Measure	Location	Cost Estimate
Dike raising	Dike raising 0+000 to 1+326	$ 2,096,000
Supplementary Construction	N/A	$ 200,000
Subtotal		$ 2,296,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$ 3,444,000

Note: 1) Total cost has been rounded to nearest thousand.

The dike should be extended at its downstream end to obtain a tie-in with high ground located at the Hwy 3 embankment. Three alternative configurations were considered for the tie-in closure (see Figure 3-7):

1) Option A - Extend dike north along Hesketh Street, then west along McDonald Avenue.
2) Option B – Extend the dike along the southern edge of the properties between west end of dike and Hwy 3 embankment; this could be a permanent structure or simply the foundation for a temporary structure to be erected when expected to be needed.
3) Option C – Extend dike west on the ground between the Elk River and the existing wetland (McDonald Pond).

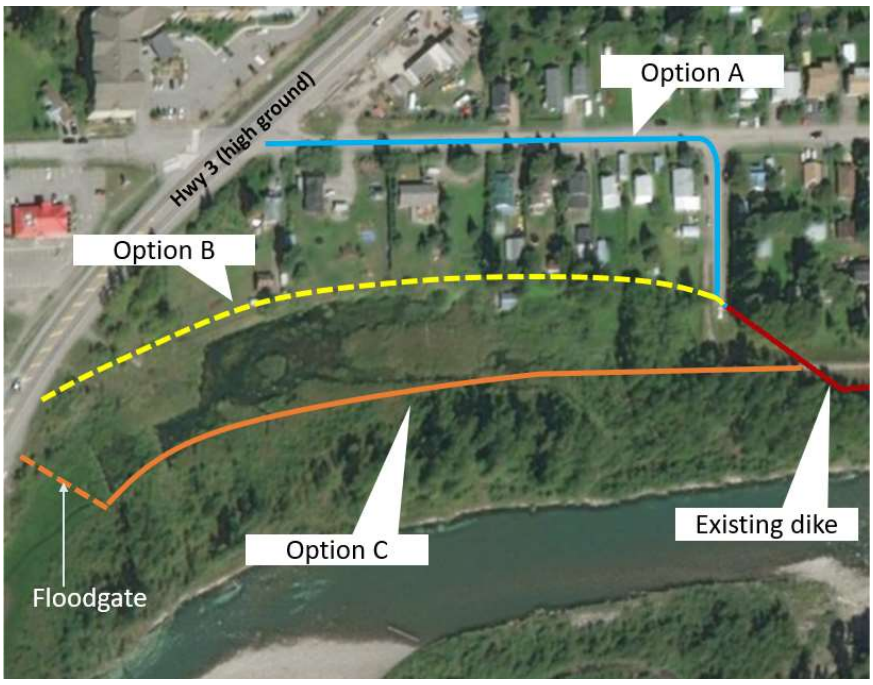


Figure 3-7 West Fernie dike extension options

Option A would entail significant impacts to McDonald Avenue and street-side utilities as the road would

be raised by approximately 1.5 m. Erosion protection will not be required because the dike would be significantly set back from the river bank. Right-of-way acquisition and construction on privately owned parcels on both sides of the road (i.e., ramped up driveways to the elevated McDonald Avenue) will be involved. This option would leave unprotected all properties south of Macdonald Avenue and west of Hesketh Street. Planning-level cost estimate for dike extension in accordance with Option A is provided in Table 3.9.

Table 3.9 West Fernie Dike extension – Option A

Mitigation Measure	Location	Cost Estimate
Dike extension	Along Macdonald Avenue	$314,000
Supplementary Construction	N/A	$284,000
Subtotal		$598,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$897,000

Note: 1) Total cost has been rounded to nearest thousand

Option B entails the use of a permanent dike or foundation for a temporary flood barrier along the south side of existing homes to close the gap between the west end of the dike and the Hwy 3 embankment. Assuming a temporary flood barrier is used, it could be sand bags, bulk bags, Hesco flood barriers, Geodesign barriers[4] or possibly a water inflated barrier[4]. An access road, path, or other foundation would need be constructed along the top of the bank south of the existing McDonald Avenue homes to allow for fast and stable deployment of the temporary flood barriers. Right-of-way acquisition would be required for this approach. Other than a short reach along one of the yards south of McDonald Avenue which has a relatively low elevation, the temporary protection is expected to be on the order of 2 m high. Planning-level cost estimate for temporary barriers in accordance with Option B is provided in Table 3.10 (estimate only represents procurement cost of barrier, not deployment cost).

Table 3.10 West Fernie Dike extension (temporary barriers) – Option B

Mitigation Measure	Location	Cost Estimate
Temporary barriers	Along homes south of Macdonald Ave	$260,000
Supplementary Construction	Permanent foundation for barriers	$60,000
Subtotal		$320,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$480,000

Note: 1) Total cost has been rounded to nearest thousand

Option C entails construction of a dike along the edge of the wetland south of McDonald Avenue. While this can be implemented without acquisition of private property or significant impacts to private properties, the option will likely have greater environmental impacts. The proposed extended portion of the dike would be outside of a bend on Elk River, across from an existing point bar, and immediately downstream of a known source of extensive sediment (Coal Creek), all suggesting armouring and maintenance is likely to be a requirement for this alignment. However, this is not dissimilar to adjacent sections of the West Fernie dike. Low ground at the location would require the structure to be approximately 3.5 m high. The environmental, geotechnical, and constructability challenge may be reduced by alternative approaches such as use of a sheet pile wall; however, cost of such an approach is expected to be high.

The existing wetland south of McDonald Avenue is connected with the Elk River through a channel located immediately adjacent to Hwy 3 (see Figure 3-7). The extended dike proposed as Option 3 could either cross the channel to achieve a complete tie-in at Hwy 3, or it could be terminated east of the connecting channel. Whereas achieving a complete tie-in will prevent any flooding through the dike, it could impose environmental challenges associated with fish passage and water exchange (see the following paragraph). Terminating the dike short of the channel will alleviate some of the environmental concerns and reduce cost of the crossing, however shallow flooding (< 0.6 m) is likely to still occur on the properties south of McDonald Avenue (caused by backwater from Elk River). This shallow flooding can be protected against by temporary flood barriers (e.g., sand bags).

If the dike is extended across the channel to achieve a complete tie-in, steps must be taken to ensure hydraulic connectivity and fish passage between the wetland with the Elk River. This can be achieved by installing a floodgate that remains open during non-flooding periods (see Figure 3-8).



Figure 3-8 Example of fish-passage-friendly self-regulating floodgate in closed position (source: Franklin et al., 2018)

Erosion protection design should consider both traditional and bioengineering solutions (although the latter may be adopted only if accompanied by dike setback). For cost estimating purposes, a traditional solution was assumed since it provides a conservative estimate. Planning-level cost estimate for temporary barriers in accordance with Option C is provided in Table 3.11.

Table 3.11 West Fernie Dike extension and floodgate – Option C

Mitigation Measure	Location	Cost Estimate
Dike extension	370 m extension	$ 1,404,000
Erosion protection	On riverside slope	$ 413,000
Floodgate	At downstream end of extended dike	$ 125,000
Supplementary Construction	N/A	$ 200,000
Subtotal		$ 2,142,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$ 3,213,000

Note: 1) Total cost has been rounded to nearest thousand.
2) If the connecting channel is not crossed, the cost of the floodgate will not be incurred, but temporary sandbagging will be required in all flood events in the future

3.1.6 Coal Creek Bin Wall

A) Assessment Findings

The Coal Creek Bin Wall is approximately 235 m long and located on the left bank of Coal Creek (see Exhibit 1 in Appendix A). The top of the bin wall is slightly below the FCL at some locations, but the dike situated on the landside of the bin wall is consistently higher than the FCL. During field inspection, it was noted that riprap at the toe of the bin wall has been lost at two locations. The segments with inadequate riprap coverage, each 10-15 m long, are located 40 m downstream and 100 m upstream of Park Avenue bridge (Figure 3-9). Minors cracks in the pavement on the top of the bin wall were examined but were not deemed to be of structural concern. No other deficiencies were identified. Overall, the bin wall was found to be in acceptable condition for its intended function.

Voids in the bin wall have previously been discovered and filled at least at one location (*pers. comm. with Fernie Engineering*). Groundtech attempted to perform exploratory drilling within the bin wall to identify voids, but the track mounted drill intended for the task was unable to access the top of the bin wall. Alternative investigative strategies were looked into, such as ground penetrating radar (GPR) and localised test pits. However, these methods were not expected to be effective at detecting voids within the bin wall and were therefore not conducted.

B) Recommendations

It is recommended that riprap be replaced at the two locations where it was found to be missing. During riprap construction, the toe of the bin wall at these locations should be excavated to determine if the missing riprap extended below the toe of the bin wall and if loss of material from inside the bin wall is likely. Planning-level cost estimates are summarized in Table 3.12.



Figure 3-9 Location where riprap is to be added to toe of bin wall

Table 3.12 Coal Creek bin wall flood mitigation measures

Mitigation Measure	Location	Cost Estimate
Erosion protection repair	40 m d/s and 100 m u/s of Park Ave Bridge	$ 26,000
Supplementary Construction	N/A	$ 20,000
Subtotal		$ 46,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$ 69,000

Note: Total cost has been rounded to nearest thousand.

3.1.7 Mountview Dike

A) Assessment Findings

The Mountview Dike is approximately 1,900 m long and located to the north and west of the Mountview neighborhood on the left bank of the Elk River (see Exhibit 1 in Appendix A). A secondary dike is located on the waterside of Mountview Dike, immediate adjacent to the Elk River (to avoid confusion, this secondary structure is called a 'river training berm'). The river training berm protects the park on the waterside of the Mountview Dike.

Table 3.13 summarizes findings of visual inspection and geotechnical investigation performed by drilling three boreholes – B9, B10, and B11 (see Figures 4 and 5 in Geotechnical Report provided in Appendix D).

Table 3.13 Assessment of Mountview Dike

Parameter	Assessment
Dike crest elevation	Lower than the FCL along approximately 500 m of the dike (see dike profile and section views in Appendix B). However, the elevation deficiency is small enough to be within the 0.6 m freeboard zone except for one area where crest is 0.8 m below FCL. The dike does not tie in with high ground at its downstream end.
Side slopes	Found to be steeper than the recommended gradient at approximate stations: 1) 0+000 to 0+250 2) 0+750 3) 1+473
Crest width	Width is generally greater than 4.0 m except between 0+750 to 1+250. However, departure from the recommended width is minor and does not hinder access for inspection, maintenance, or construction.
Erosion protection	The dike is not armoured, but this is not a concern because of separation from Elk River by an approximately 40 m. The river training berm at the river bank is not armoured, except some scattered riprap is present on its waterside slope near the confluence of Coal Creek with Elk River. Coal Creek has the tendency of carrying a large sediment load, and lateral channel shifting has occurred historically at this confluence (NHC, 2008). The lack of sufficient riprap on the training berm near the confluence makes it vulnerable to erosion.
Encroachment	No deficiency observed.
ROW/Access	No deficiency observed.
Geotechnical assessment	See Table 3.1. Findings for Mountview Dike are identical to those for Northlands Dike.

B) Recommendations

It is recommended that the Mountview Dike be raised from station 0+000 to 1+326 to the FCL. Approximately 0.5 m of raising will be required. Top widths and side slopes should be built to meet the standards described in Section 2.[9] After accounting for the increase in dike height and restoration of top widths and side slopes, the dike footprint is expected to increase by 1.3 m to 3.0 m on either side. It is

[9] Where the FCL is higher than the existing dike top by less than 100 mm (e.g., station 0+200 to 0+400), raising may be able to be achieved by adding running surface on top of the dike instead of a structural raising (avoiding width and slope work).

estimated that land or easement acquisition will not be required based on current location of dike with respect to its surroundings (legal property titles and easements have not been verified).

Based on the current floodplain map and local flooding during the 2013 flood, the property downstream of the dike is susceptible to flooding. At moderate flood levels, this can affect the downstream most properties (including the City of Fernie pump station) and secondary access route to the Mountview area. At higher flood levels it could result in flooding many of the roads and properties at the south end of Mountview. The dike should be extended at its downstream end from station 1+475 to 1+875 to obtain a tie-in with high ground located near Minton Road. The proposed alignment of the extended dike is shown in shown in Figure 3-10. Of particular importance is to protect the secondary egress route from this community which would especially be required if the Coal Creek bridge is damaged during a combined Coal Creek and Elk River flood event.



Figure 3-10 Mountview Dike extension



Figure 3-11 Area protected by potential Mountview dike extension, photo of flooding June 2013

The vulnerability of the river training berm to erosion at the Elk River-Coal Creek confluence should be addressed either by installing erosion protection measures on the waterside slope of the training berm (Option A) or armouring the dike itself (Option B) as shown in Figure 3-12. Erosion protection design should consider both traditional and bioengineering solutions. For cost estimating purposes, a traditional solution was assumed since it provides a conservative estimate.

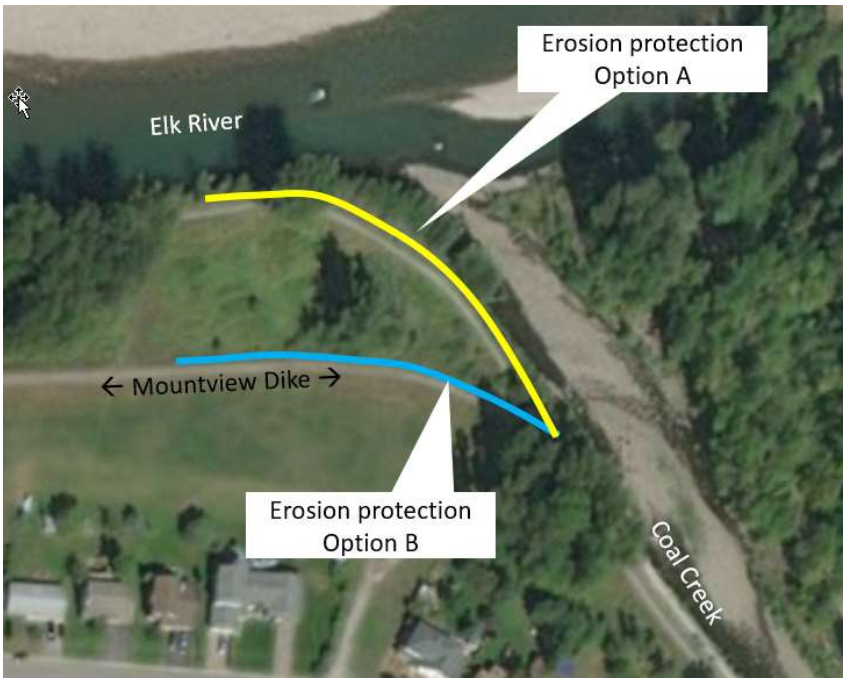


Figure 3-12 Mountview dike erosion protection options

Implementing Option A will help limit the potential channel migration and erosion threat to the primary dike. Option B, on the other hand, only provides protection once the channel has migrated. Option A will have more immediate impacts on riparian vegetation compared to Option B, but also provides some protection for the left bank vegetation downstream of the armouring. Because of its advantages over Option B, Option A is recommended.

As to the river training berm further downstream of this location, repairs of erosion protection are not warranted but the berm should be actively monitored and repaired if active erosion sites are observed.

Planning-level cost estimates for the dike raising and erosion protection are summarized in Table 3.14. Estimates for dike extension are summarized in Table 3.15.

Table 3.14 Mountview Dike raising and erosion protection

Mitigation Measure	Location	Cost Estimate
Dike raising	0+875 to 1+375	$ 701,000
Erosion protection	150 m of bank (Option A)	$ 187,000
Supplementary Construction	N/A	$ 50,000
Subtotal		$ 938,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$ 1,407,000

Note: Total cost has been rounded to nearest thousand.

Table 3.15 Mountview Dike extension

Mitigation Measure	Location	Cost Estimate
Dike extension	1+475 to 1+875	$ 286,000
Supplementary Construction	N/A	$ 30,000
Subtotal		$ 316,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$ 474,000

Note: Total cost has been rounded to nearest thousand.

3.1.8 Riverside Dike

A) Assessment Findings

While the Riverside Dike is recognized as a dike by FLNRORD, the structure is in fact an armoured bank. The shoulder of the bank is at the level of the surrounding ground and there is no landside slope, only a waterside slope. For consistency with FLNRORD classification, the term ‘dike’ is used for this structure in this report, but engineering criteria normally applicable to dikes was not used in the assessment.

The Riverside Dike is approximately 400 m long and is located north of the Riverside neighborhood on the right bank of the Elk River (see Exhibit 1 in Appendix A). The assessment was performed through

visual inspection and geotechnical investigation by drilling one borehole (identified as B12 in Figure 5 of Geotechnical Report, Appendix D).

A comparison of the elevation of the top of bank with the appropriate FCL revealed that the top of bank, or the natural ground continuous with the bank, is higher than the FCL (see bank profile and section views in Appendix B)[10]. Erosion protection was found to be inadequate along the entire reach of the dike.

B) Recommendations

It is recommended that erosion protection repairs be performed along the entire length of the Riverside Dike. Because this bank is subject to high velocity flows as well as deposition and redirection of flows, it is currently protected by riprap. Future improvements consisting should also consist of in-filling areas of inadequate riprap; vegetative protection will not be a possibility. Planning-level cost estimates for the work are summarized in Table 3.16.

Table 3.16 Riverside Dike flood mitigation measures

Mitigation Measure	Location	Cost Estimate
Erosion protection repair	0+000 to 0+381 (entire reach)	$ 472,000
Supplementary Construction	N/A	$ 50,000
Subtotal		$ 522,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$ 783,000

Note: Total cost has been rounded to nearest thousand.

Further development of the Riverside area may warrant further flood protection. Flow during high water levels may cut across this area if the river short-cuts this meander bend. If development of this area is to be relatively dense, then a setback dike should be considered as a condition for development. The dike should be set back ideally 60 m or more from the normal waters edge. There may also be interest from the Regional District of East Kootenay to continue the structure downstream past Vanlerberg Road. The capital cost of such a structure (typically taken on by the protected land owners) and subsequent cost of maintenance and surveillance of the structure may hinder plans for its implementation. Development of the Riverside area should consider resilience to flooding (i.e. construction to the FCL) as well as safe egress from the community during a flood. An alternative strategy to diking that addresses both considerations is to raise the entire area before undertaking development.

[10] While the profile in Appendix B shows the FCL as being higher than the bank between 0+280 and 0+381, the natural ground immediately adjacent to the bank is higher (see cross-sections in Appendix B).

3.2 Non-structural Mitigation

3.2.1 Flood Response Plan

Planning for floods and other emergencies should be undertaken by government, institutions, businesses, and residents. Preparations typically include identifying roles and procedures, establishment of emergency kits, and review of local vulnerabilities to a flood event (i.e. property access, location of electrical and mechanical infrastructure, etc.). The provincial government provides resources through Emergency Management BC on such planning; for example:

- EMBC website: https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery
- Publication: *Prepared BC, Household Preparedness Guide*
- Publication: *Flood Information for Homeowners and Home Buyers*

The City of Fernie has paper copies of these documents available at city hall.

Emergency response plan specific for the local government is also encouraged in the provincial dike maintenance guidelines (MELP, 2001). Fernie's Flood Response Plan (2011) is generally compliant with guidelines for emergency response planning issued by the province (PEP, 1999). However, the Plan was prepared in 2011 with the best available analysis at the time. Newer flood data is now available because of several studies commissioned by Fernie since then. The Flood Response Plan should be updated to reflect newer estimates of water surface levels and inundated areas as well as recent land development changes; particularly the Fernie RV Resort which is located within the floodway and potentially requires evacuation.

For purposes of planning dike breach emergencies, one of the most at-risk locations is the Northlands Dike (as evidenced by the high priority ranking assigned to it in Section 5). The dike is located where there is a wide active floodway within a sediment deposition zone. The potentially unstable channel alignment makes it susceptible to changing erosion potential, and the failure of this dike would flood the Annex and upstream businesses.

While dike breach scenarios were not mapped as part of this study, mapping such scenarios may help emergency response planning by giving responders an estimate of what occurs during a breach. While such mapping will be particularly useful for the protected area of Northlands Dike, it will have limited use in other areas of Fernie where dikes represent simply narrowing of the active floodplain instead of providing a barrier across historic flow paths.

The costs of updating the flood response plan and performing the engineering analysis to support dike breach mapping are estimated to be $15,000 and $50,000 respectively.

3.2.2 Flood Warning

Floods along the Elk River can peak quickly when intense rain events occur during a period of ongoing snowmelt. Both the 1995 and 2013 flood events experienced a substantial increase in flow over a relatively short period of time. Average daily flow for the days surrounding the 2013 flood event are plotted in Figure 3-13. During this flood, flow increased from an average daily flow of just over 500 m^3/s on June 20th to a peak flow of 1060 m^3/s on June 21st. This substantial spike in flow illustrates the limited warning prior to flood flows. Following the peak, flows receded slightly more gradually over the following two or three days.

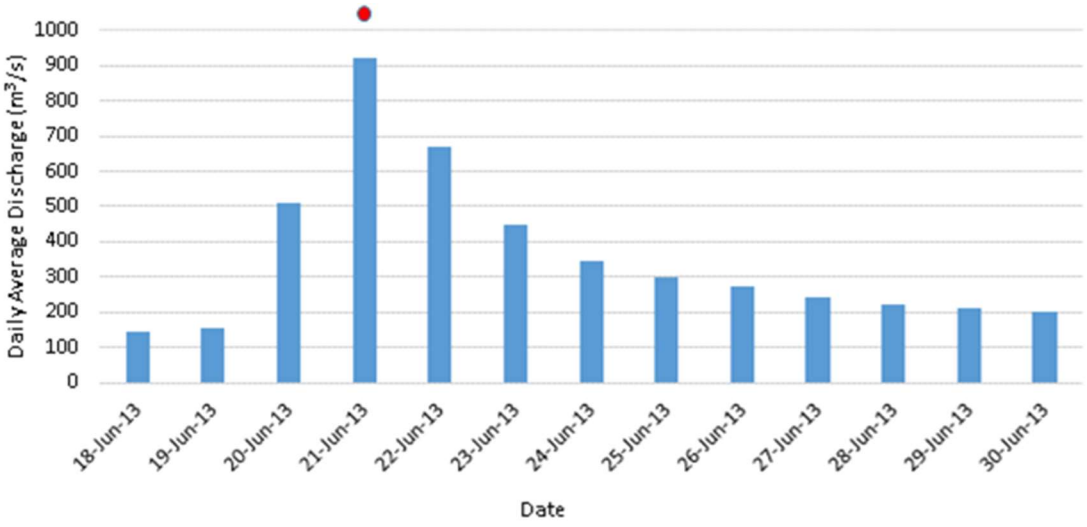


Figure 3-13 Daily average discharge 2013 flood event (dot represents peak instantaneous flow)

Currently, there is only one active gauge on the Elk River upstream of the study reach (Elk River Near Natal [08NK016]) and no active gauge on Elk River tributaries near the study reach. Based on recent floodplain mapping prepared by NHC for the RDEK, it is estimated that the peak flow of 2013 reached the City of Fernie roughly 4 hours after it passed the WSC Elk River near Natal gauge. This estimate is supported by comparison of the 2018 peak flow, which suggests a delay of roughly 4 hours (hourly flow data from the Elk River near Natal gauge is not available for the 2013 flood event). Based on watershed scaling, flow as observed at the Elk River near Natal gauge is expected to be roughly 60% of that observed at Elk River at Fernie gauge. In other words, if a flow of 400 m^3/s or more is observed near Natal, then flows in excess of 700 m^3/s can be expected at Fernie; roughly a 50-year event.

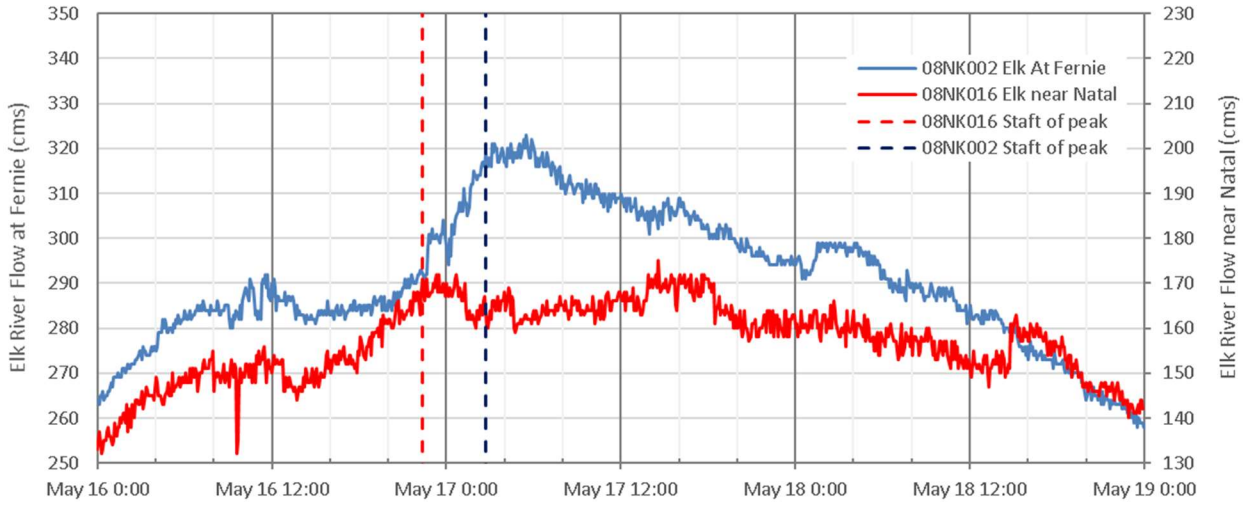


Figure 3-14 Comparison of flow reported for Elk River near Natal with Elk River at Fernie during the 2018 freshet

These gauges along with existing real time snow pack information (such as the BC Hydro alpine station) and weather forecasts provide information to help forecast floods. The BC River Forecast Centre provides flood forecasting during flood season (http://bcrfc.env.gov.bc.ca/warnings/index.htm).

Prior to 1996, WSC also operated gauges upstream of Sparwood which, if reinstated, could further inform flood forecasts for communities along the Elk River.

Coal Creek was the source of much of the damages within Fernie during past events (particularly 1995 when the Coal Creek Mountview Dike failed – since replaced with the bin wall). The steep slope, confined channel, infrastructure (bridges and bin wall), and transport of substantial sediment loads contributes to the high level of flood hazards associated with this creek. An upstream real-time water level and flow gauge would benefit the community in providing warning of potential flood events. Local operational gauges on smaller, unregulated, watersheds in the region are listed in the following table. The most relevant gauge, due to proximity and aspect, is Hosmer Creek which is not real time; i.e., only historic data is available. Although, this data may be suitable for regional analysis of historic flow records, it not useful for flood forecasting or warning. Ideally, a real time gauge would be installed along Coal Creek to provide real time tracking of water level and flow. The estimated one-time cost of installing and commissioning a gage is $50,000. Recurring costs associated with maintenance and calibration are not included in the estimate.

Table 3.17 Regional operational WSC gauges of medium to small watersheds

Station No.	Station Name	Area (km^2)	Distance (km^2)	Real Time
08NK026	Hosmer Cr above diversions	6.4	11 NE	No
08NK022	Line Creek at mouth	138	44 NNE	Yes
08NK018	Fording River at mouth	621	44 NNE	Yes

It is recommended that Fernie's ERP or flood response plan be updated to include current references to sources of flood warning such as the BC River Forecast Centre. Further, Fernie should coordinate with other stakeholders in the Elk River basin to increase the availability of upstream gauging data on Elk River and Coal Creek by advocating for the installation of new gauging stations or reinstatement of the Sparwood station.

3.2.3 Regulatory Controls

MWLAP (2004) recommends that local governments establish land use policies that promote new developments and buildings to be constructed in a manner that will reduce or prevent harm to life and property caused by floods. Among the land use management tools recommended by MWLAP are the Official Community Plan (OCP) and floodplain management bylaws. This is typically seen as the most effective approach to reduce flood risk. However, its effectiveness is limited to future development.

NHC's review found that Fernie is effectively using regulatory controls to promote reduction of flood damage to future development in accordance with provincial guidelines. Fernie's OCP (2014) prohibits the development of lands in flood hazard areas without a Hazard Lands Development Permit (Policy 9-C.2.21). Fernie's Floodplain Management Bylaw (2018) prohibits development or mandates building above FCL in floodways, flood fringes, overflow areas, or avulsion areas of Elk River and Coal Creek.

It should be noted that some communities have established regulatory controls that exceed the minimum provincial recommendations. For example, in areas where floodplains are highly susceptible to erosion by channel migration, a setback of 60 m from the natural boundary of the watercourse is used (e.g., City of Chilliwack, 2018) as opposed to the provincial recommendation of 30 m (which is also mandated by Fernie). Fernie may consider larger setback in the Riverside area where the location of the banks on the outside of a bend in Elk River, the presence of deposition on the opposite bank, and the need to leave room for a future dike present a case for an increased regulatory setback.

3.2.4 Awareness and Education

A provincial review of floods and wildfires (BCFWR, 2018) identified dissemination of awareness and education as one of the key pillars of a complete flood mitigation plan. Flood mapping is identified as the first step of awareness of the hazard (NRC/PSC, 2018).

Fernie has recently completed flood hazard mapping for Elk River and Coal Creek and identified flood hazard areas in its OCP. Public awareness campaigns can be developed around the completed mapping with minimal effort. These campaigns should include information on known flood hazards, flood proofing, emergency preparedness, and evacuation. At the very least, it is recommended that Fernie identify areas/homes within the floodway and flood fringe and provide information on flood preparedness to the residents of these high-risk areas. The cost of a public information and education campaign spread out over a five-year period is estimated to be $40,000.

Education around flood awareness should focus on broadcasting the following:

- Community resources with respect to flood hazards (such as information from Elk River Alliance, BC Flood Forecast Centre, Regional District of East Kootenay (RDEK) website, Fernie website, evacuation information)
- Resources to develop institutional, business, or personal emergency and flood response plans.
- Existing Flood Response Plan (particularly potentially inundated areas, evacuation procedures, transportation routes, local safe areas)
- Floodplain mapping
- Mechanism and timing of flooding (such as ice jams in the winter and rain-on-snow floods in the spring)

Fernie maintains a website to assist residents with emergency preparedness, where several items recommended above are already addressed: http://www.fernie.ca/EN/main/residents/emergency-services/emergency-preparedness.html.

3.2.5 Maintenance and Surveillance of Flood Protection Structures

Fernie should continue to inspect and maintain the dikes within its jurisdiction. The province has prepared several guidelines and checklists to support such procedures (MELP, 2001; MELP and DFO, 1999). Vegetation maintenance is one component of dike maintenance which limits potential seepage paths (roots), development of holes within the dike (caused by wind fall of trees), and allows slopes to be inspected for slumps, seepage, erosion, and burrowing animals.

During NHC's inspection excessive vegetation was noted at the locations noted in Table 3.18. It is recommended that Fernie perform clearing of vegetation at these locations and continually monitor and clear vegetation as per Fernie's existing vegetation management plan as well as MELP and DFO guidelines.

Table 3.18 Location of excessive vegetation

Dike	Location of vegetation (approximate)
Northlands dike	0+300 to 0+477
Annex dike	0+000 to 0+250 1+500 to 1+824
Mountview dike	0+000 to 0+100
Riverside dike	0+000 to 0+075

Note: See Exhibit 2 in Appendix A for stationing map

The cost of updating Fernie's vegetation management plan and performing one-time vegetation management is estimated to be $20,000.

4 ASSESSMENT OF BRIDGE AND STORMWATER INFRASTRUCTURE

Flood events and high flows within the Elk River and Coal Creek can affect or be impacted by Fernie infrastructure other than flood mitigation structures. This study included a review of selected Fernie bridges – Park Avenue and Pine Avenue - and stormwater outfalls to confirm their current condition and assess potential impacts of flood events.

4.1 Pine Avenue and Park Avenue Bridges

Two bridges crossing Coal Creek, Pine Avenue Bridge and Park Avenue Bridge, are located within the City of Fernie and maintained by Fernie. They were field-inspected during this project on the basis of MOTI criteria. Scores were assigned to each assessment criteria based on a 4-point point scoring system. Assessment findings for Pine Avenue Bridge and Park Avenue Bridge are shown Table 4.1 and Table 4.2 respectively.

Table 4.1 Pine Avenue Bridge Assessment

Parameter	Items Evaluated	Finding	Score
Debris Risk	Existing debris and debris potential, clearance through bridge opening (pier layout, vertical clearance, bridge alignment skew), watershed disturbances	Accumulation of debris observed downstream of bridge, but ability to pass debris through opening is not affected. The bridge has adequate clearance, minimal constriction and no piers.	3
Channel Bed Condition	Channel stability, bed aggradation or degradation	The channel sees episodic inputs of gravel and cobble from upstream and side slopes. This material periodically deposits as bars and eventually passes through reach. No aggradation. Degradation limited by concrete and bedrock across channel.	3

Parameter	Items Evaluated	Finding	Score
Channel Bank Conditions	Bank stability, bank erosion	No widespread bank erosion observed.	4
Skew	Alignment of bridge with flow	The bridge is well-aligned with the flow.	4
Adequacy of Waterway	Effective area of waterway versus floodway	The bridge has minimal narrowing of the channel, both for waterway and floodway.	4
Erosion Protection	Condition of erosion protection, presence of bank erosion	Left bank erosion protection upstream of bridge lacks toe key but is in good repair. Downstream left bank riprap has over-steep toe. Right bank is lined with bedrock.	3
Sub-structure Scour	General scour through waterway, local scour at piers, abutments and banks	Bedrock preventing scour through bridge opening.	4

Scores: excellent (4), good (3), fair (2), and poor (1)

Table 4.2 Park Avenue Bridge Assessment

Parameter	Items Evaluated	Finding	Score
Debris Risk	Existing debris and debris potential, clearance through bridge opening (pier layout, vertical clearance, bridge alignment skew), watershed disturbances	Accumulation of debris observed downstream of bridge. The bridge has adequate clearance, minimal constriction and no piers.	3
Channel Bed Condition	Channel stability, bed aggradation or degradation	The channel sees episodic inputs of gravel and cobble, which can leave bridge susceptible to changes in local flow patterns.	3
Channel Bank Conditions	Bank stability, bank erosion	Some bank erosion was seen upstream of the right abutment due to steep, high, sloughing slope, but does not appear to pose a significant risk to the bridge.	3
Skew	Alignment of bridge with flow	The bridge is aligned with the flow.	4
Adequacy of Waterway	Effective area of waterway versus floodway	The bridge has minimal narrowing of the channel, both for waterway and floodway.	4
Erosion Protection	Condition of erosion protection, presence of bank erosion	Erosion protection downstream of right abutment has missing elements along the toe, leaving the abutment exposed and vulnerable to scour.	2
Sub-structure Scour	General scour through waterway, local scour at piers, abutments and banks	Scour is undermining toe of riprap downstream of right abutment.	2

Scores: excellent (4), good (3), fair (2), poor (1), and very poor (0)

The following mitigation measures are recommended for the Pine Avenue Bridge:

1) Monitor (or optionally repair) erosion protection on the left bank downstream of the bridge abutment (Figure 4-1).

2) The toe riprap appears to have been lost due to undermining scour and/or mobilized during high flow. This has left an over-steep toe which leaves the remaining slope susceptible to failure if further toe stones are lost, and should be repaired



Figure 4-1 Left bank downstream of Pine Avenue Bridge showing undermined bank protection

Planning-level cost estimates for the work are summarized in Table 4.3.

Table 4.3 Pine Avenue Bridge erosion protection repair

Mitigation Measure	Location	Cost Estimate
Erosion protection repair	$17,000	$17,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$26,000

Note: Total cost has been rounded to nearest thousand.

The following mitigation measures are recommended for the Park Avenue Bridge:

1) Armour and re-slope the bank upstream of the right abutment (Figure 4-2).Currently, the rock along the toe of the bank appears to be mainly native material, inadequate for withstanding erosion and scour. The over-steepened slope is sloughing near the top of bank. Undermining of the slope fill could pose risk to the right bridge abutment.

2) Repair erosion protection downstream of right abutment and protect abutment from exposure to scour (Figure 4-3). This can be done by placement of additional riprap and rework of existing riprap. The current bank protection has been damaged by erosion and scour, with missing stones along the toe and leaving the bank susceptible to further erosion. Undermining of this slope could threaten the right abutment.

3) Place riprap along toe of left abutment (Figure 4-4). Currently, there is minimal riprap along the toe of the abutment, leaving it susceptible to damage by scour and erosion. The wooden formwork along the concrete abutment foundation is currently exposed, and the concrete footing appears to be at risk of being undermined. However, drawings for this bridge were not obtained and foundation and design scour elevations are unknown.



Figure 4-2 Right bank upstream of Park Avenue Bridge showing inadequate bank protection and sloughing near top of bank



Figure 4-3 Right bank downstream of Park Avenue Bridge showing undermined bank protection



Figure 4-4 Looking upstream along left abutment of Park Avenue Bridge showing inadequate protection along the toe

Planning-level cost estimates for the work are summarized in Table 4.4.

Table 4.4 Park Avenue Bridge erosion protection repair

Mitigation Measure	Location	Cost Estimate
Erosion protection repair	$32,000	$32,000
Total Cost (construction cost + 15% soft costs, 35% contingency)		$48,000

Note: Total cost has been rounded to nearest thousand.

4.2 Stormwater Outfall and Localized Improvements

4.2.1 Overview of Fernie's Stormwater System

Fernie's stormwater collection network is approximately 52 km long, of which 40 km is piped.

In general, stormwater issues associated with river flooding are associated with (1) inability to discharge collected stormwater to the receiving waters because of high tailwater or (2) backflow from the receiving waters into the stormwater system because of inadequate flow controls. Both possibilities, in Fernie's context, are discussed below.

Precipitation data for the period 1981-2010 at the Environment Canada meteorological station 'Fernie' was compared with Elk River flows for the same period measured at the Water Survey of Canada (WSC) station 'Elk River at Fernie'. This comparison shows that peak stormwater discharges – driven by local precipitation - to Elk River are likely to occur in November when high flows in Elk River are substantially lower than annual maximum flows that occur in late spring or summer.

In contrast, groundwater flows typically increase in the spring-summer in response to snow melt and decrease throughout the summer (see Section 4.5 in Geotech Report, Appendix D). Moderate local precipitation and high groundwater levels can result in ponding on the landside of dikes particularly as high Elk River levels prevent drainage through the dikes. This is expected to be most prevalent at low lying areas, where there is substantial surface inflows to the area, and any areas susceptible to backflooding from the Elk River (similar to Ghostrider area at Shadow Creek).

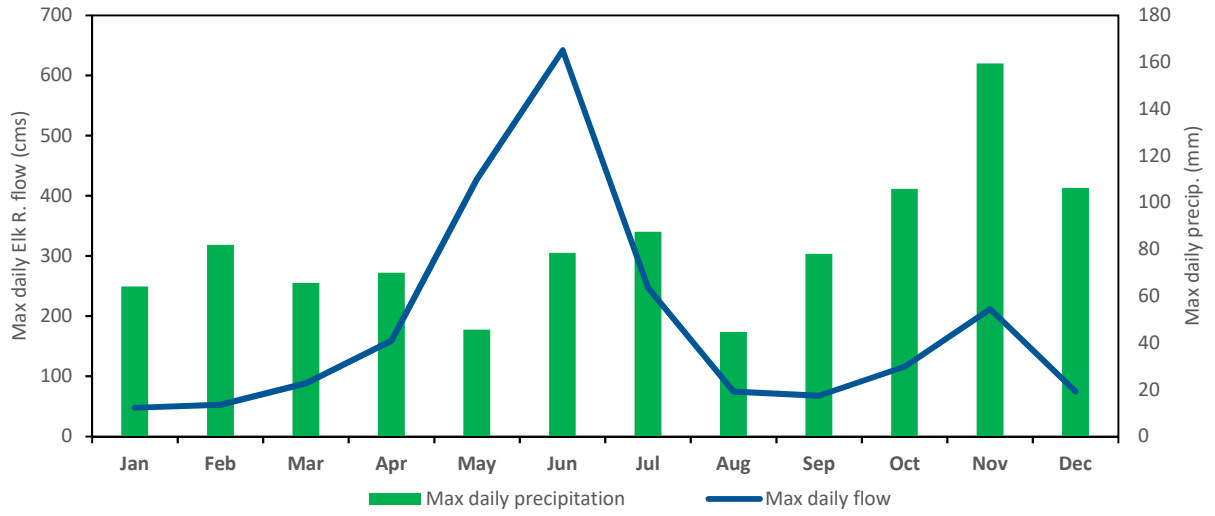


Figure 4-5 Comparison of maximum daily precipitation and Elk River flow, 1981-2010

4.2.2 Assessment Findings

Fernie's stormwater system was assessed with respect to impact during flood events. This assessment was based on a desktop review of previous hydraulic studies, field observations made in July and December 2018, and a review of the stormwater database provided by the Fernie. The assessment was limited to stormwater concerns related to dikes and river-caused flooding and does not address any issues intrinsic to the stormwater infrastructure (e.g., inadequate pipe capacity).

Low-lying areas vulnerable to stormwater flooding

Low-lying areas in Fernie may be vulnerable to stormwater flooding caused by high groundwater levels, intense rain, and seepage through permeable dikes and underlying soils. Flows in Fernie's creeks (e.g., Shadow Creek, McDougal Creek, Mutz Creek, McDonald Creek) will also be elevated during such events and outflow may be impeded by high Elk River water level.

Exhibit 3 in Appendix A includes a flood depth map of Fernie showing the difference between FCL and ground level. This map shows prominent low-lying areas in three locations:

- Northern part of the Annex neighborhood (between 15th St and 12th St)
- Southern part of Annex neighborhood (between 8th St and 6th St)
- Eastern part of West Fernie

Compared to other areas in Fernie, the three areas identified above are more likely to require pumping of interior flooding caused by river backflow through the stormwater system, dike seepage, or high groundwater.

Potential for backflow from river outfalls

As per MWLAP (2003), pipes that convey internal drainage from inside a dike to a watercourse should have flood gates installed at the outlet end to prevent backflow from the watercourse. Traditionally, top-mounted flap gates were used for this purpose, but MWLAP encourages use of side-mounted gates where fish passage is required (e.g. when the upstream waterway is an open channel). MOELP (1999) emphasizes that such backflow control gates should be subject to regular inspection and maintenance to prevent mechanical issues or obstruction by debris.

Stormwater is discharged to the Elk River and Coal Creek by gravity through several river outfalls, of which approximately 40 outfalls[11] are relevant to the flood mitigation plan since they drain areas protected by dikes (e.g., there are outfalls to Elk River along Burma Road on the right bank, but the area drained by the outfalls is not protected by dikes so backflow through the outfalls is not of concern).

Among the 40 outfalls identified by Fernie's GIS database, 36 outfalls could be field-identified (the remainder could not be identified possibly because of redundancy in the database or because the outfalls are buried under sediment). A review of the outfalls showed the following (see Exhibit 4 in Appendix A):

- 27 outfalls are gated (this includes the Mutz Creek outfall)
- 9 outfalls are not gated, of which:
    - 3 outfalls are on culverts that pass through existing dikes or embankments
    - 4 outfalls are on culverts that do not presently pass through dikes but will pass through proposed new or extended dikes
    - 2 outfalls are on culverts that do not pass through existing or proposed dikes

The following three outfalls are ungated and pass through existing dikes or embankments:

1) MH0898 (600 mm) located at 1+450 on Annex Dike
2) MH0919 (300 mm) located at 0+550 on Annex Dike
3) Brickers Creek outfall[12] near western end of Manitou Road

4.2.3 Recommendations

The three low-lying areas identified above are more likely than other dike-protected areas to require pumping during high flow events on the Elk River. They should be taken into account when planning the placement of emergency pumping facilities.

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[11] The number of outfalls is uncertain because some outfalls identified in Fernie's GIS database could not be located in the field after a thorough search in proximity of the expected locations (see Exhibit 4).

[12] The Brickner Creek outfall to Elk River in the Ghostrider subdivision (near U-Haul facility on Manitou Road) could not be observed in the field. In the interest of a conservative estimate, it is assumed this outfall is not gated. Because this outfall is connected with an urbanized and piped stormwater system, it is assumed to not require fish passage.

With regard to backflow from culvert outfalls, it is recommended that flapgates should be installed for backwater flow control at the three ungated outfalls identified above. The four ungated outfalls located at the location of the proposed 3rd Street Dike and Northlands Dike extension should be gated at the time that dike construction is performed.

The cost of retrofitting 3 stormwater outfalls with flapgates is estimated to be in the order of $32,000.

5 COMMUNITY ENGAGEMENT

NHC, along with Fernie staff, engaged members of the community through a stakeholder meeting held on February 19, 2019. Approximately 20 residents participated. Several City Council members also attended. NHC and Fernie staff made a presentation to the City Council on the same day. Below is a summary of questions and feedback received from the community and elected representatives, and how they were addressed in the mitigation plan:

1) **Comment:** A comment was received that a portion of the Ghostrider subdivision drains to Elk River through Brickner Creek, which has a river outfall near the U-Haul facility on Manitou Road. **Response**: This crossing has been added to the discussion of Shadow Creek outfall as well as stormwater outfalls. The cost of installing a gate at this outfall location has been included in the cost estimate.

2) **Comment**: Logging activity in the watershed of Coal Creek has increased in the recent past. How does it affect Fernie's vulnerability to floods?
Response: Forestry operations in upper watersheds can potentially alter the peak flow regime of streams and rivers by increasing the magnitude and frequency of annual maximum peak discharge events (Schnorbus and Alila, 2004). However, streamflow changes are generally hard to detect in watersheds where less than 30% of the area has been cleared (Forest Service BC, 1993). Typically, studies of increases in peak flow resulting from logging are based on changes to mean annual floods and may not substantially affect the more extreme design flood events. Furthermore, the impacts of forestry practices on peak flows are typically temporary, with hydrology recovering as land cover recovers (i.e. vegetation re-establishes). The allowance for climate change, the extreme event selected for design (approximately the 500-year event), and freeboard included in the FCL are expected to be appropriate to address the potential impacts of current forest practices.

3) **Question:** What can local residents do to mitigate flood impacts at an individual level?
Response: References have been provided in Section 3.2.4 to provincial and Fernie web resources for individuals on flood preparedness.

6 PRIORITIZATION OF MITIGATION MEASURES

6.1 Prioritization Approach

Structural mitigation measures were further evaluated to prioritize for implementation.[13] Non-structural measures were not evaluated for priority because they do not have localized and measurable impacts similar to structural measures. However, the fact that non-structural measures were not prioritized should not be taken to mean that they are less important or less urgent than structural measures. It is well-recognized that flood management should consist of both structural and non-structural measures, but non-structural measures are often preferred because their negative impacts are limited compared to structural measures (see, e.g., EGBC, 2018).

Each proposed structural mitigation measure was evaluated based on the level of risk that could be avoided by that measure. Flood risk is defined by EGBC as: "a measure of the [likelihood] and severity of an adverse effect to health, property, or the environment. Risk is often estimated by the product of [likelihood] and consequence" (EGBC, 2018). To identify the level of risk avoided through each mitigation in Fernie, a risk score was calculated as the product of likelihood of flooding (i.e., flood event overwhelming existing defences) and the consequence of the flood event.

6.2 Likelihood of Flooding

The likelihood of flooding was estimated on the basis of the dike assessment described in Section 3. The indicators of likelihood of flooding are height of dike crest below FCL and issues with erosion protection. The likelihood of flooding was assigned scores between 1 to 5 based on the criteria shown in Figure 6-1.

6.3 Consequence of Flooding

The consequence of flooding was estimated quantitatively based on number of habitable units in the protected area of each dike. First, the projected floodplain extents for Fernie were spatially overlaid on an assessment database of Fernie to determine the number of principal or accessory buildings within the flooded area (which will be the 'protected area' after mitigation measure is implemented). Then, zoning information was used in conjunction with Google Street View to estimate the number of units in multi-family buildings in each protected area. The number of such units in multi-family buildings was added to the original estimate to obtain a number of habitable units[14] (see Table 6.1).

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[13] Erosion protection at Pine Avenue and Park Avenue bridges, while structural in nature, was not priority relative to other flood protection measures. The riprap at the bridges protects a transportation facility rather than provide flood protection, and is difficult to prioritize in a way that is comparable to the other measures.

[14] It was necessary to make a simplifying assumption and assign equal weight to each 'habitable unit' which include residential units, businesses, or light industrial uses.

Table 6.1 Number of housing units in protected area of each dike or structure

Mitigation	Number of habitable units in protected area
Shadow Creek	30
Northlands Dike	917
Annex Dike	902
New dike along 3rd St	109
West Fernie Dike	260
Coal Creek Bin Wall	86
Mountview dike	345
Riverside Dike	139

The number of habitable units in each protected area represents the consequences of flooding if the proposed measure is not implemented. Consequence of flooding was assigned scores between 1 to 3 based on the criteria shown in Figure 6-1.

6.4 Risk Scoring and Priority Ranking

Based on the likelihood and consequence of flooding, each feature was assigned a risk score between 1 to 15 (higher score indicating higher risk), based on the matrix shown in Figure 6-1. The risk scores were then ranked 1-8 such that the measures with highest risk were assigned the highest priority (1 represents highest priority and 8 represents lowest priority). Table 6.2 shows the risk scores and priority rank assigned to each measure.

Likelihood of flooding		Risk score		
5	Crest lower than FCL by > 0.6 m + erosion issues	5	10	15
4	Crest lower than FCL by > 0.6 m, no erosion issues	4	8	12
3	Crest lower than FCL by < 0.6 m + erosion issues	3	6	9
2	Crest lower than FCL by < 0.6 m, no erosion issues	2	4	6
1	Crest elevation > FCL	1	2	3
	Consequences of flooding without mitigation	< 100 habitable units in protected area	100-500 habitable units in protected area	> 500 habitable units in protected area
		1	2	3

Figure 6-1 Risk scoring matrix

Table 6.2 Risk scores and priority ranking

Mitigation measure	Likelihood of flooding score	Consequence of flooding score	Risk score (likelihood x consequence)	Priority ranking
Shadow Creek Culvert	5	1	5	5
Northlands Dike[15]	5	3	15	1
Annex Dike	5	3	15	2
New dike along 3rd St	5	2	10	4
West Fernie Dike	2	2	4	6
Coal Creek Bin Wall	1	1	1	8
Mountview dike	5	2	10	3
Riverside Dike	1	2	2	7

7 RECOMMENDATIONS

Based on NHC's inspection, topographical survey, geotechnical investigation, and desktop assessment of Fernie's flood protection infrastructure, several structural and non-structural mitigations measures have been identified for addressing flood hazards in Fernie. The recommended measures, their priority rank (where applicable), and costs are shown in Table 7.1.

Structural mitigation measures are centred at locations of known problems, dense population, and where issues became evident from the assessment. This includes raising of several dikes (Northlands, Annex, West Fernie, Mountview), extension of three dikes (Northlands, West Fernie, Mountview), one new dike (3rd Street), improved erosion protection (Northlands, Mountview, Coal Creek Bin Wall), stormwater improvements, and upgrades to the Shadow Creek culvert at Hwy 3.

By identifying the likelihood of flooding associated with each measure (i.e., likelihood of flooding if that measure is not adopted) and the consequences of such flooding, a risk score was developed for each measure. A priority rank was assigned to each measure. The priority rank can be used to make decisions about implementing the recommended measures (a rank of 1 indicates highest priority and rank of 8 indicates lowest priority).

Non-structural mitigation measures presented include emergency response planning, regulatory controls on land use within the floodplain, awareness and education, and monitoring and maintenance. Priority ranks were not assigned to the non-structural measures.

[15] While Northlands Dike and Annex Dike have the same risk score, the former was assigned a higher priority rank because of the greater number of habitable units in its protected area. Similarly, Mountview Dike and the dike along 3rd Street had the same risk score, but the former was assigned a higher priority rank because of the greater number of habitable units.

Table 7.1 Summary of recommendations

Location	Structural Mitigation Measure	Priority Rank	Cost
Northlands Dike	Raising, extension, erosion protection	1	$ 1,580,000
Annex Dike	Raising, erosion protection	2	$ 4,634,000
Mountview Dike	Raising, extension, erosion protection	3	$ 1,881,000
3rd Street	New dike, grading and paving road	4	$ 749,000
Shadow Creek at Hwy 3	Install flapgate	5	$ 68,000
West Fernie Dike	Dike raising, extension (Option A)	6	$ 4,341,000
Riverside Dike	Erosion protection	7	$ 783,000
Coal Creek Bin Wall	Erosion protection	8	$ 69,000
Pine & Park Ave bridges	Erosion protection	-	$74,000
Stormwater outfalls	Install flapgates	-	$ 32,000
Location	**Non-Structural Mitigation Measure**	**Priority Rank**	**Cost**
Citywide	Flood response plan	-	$15,000
Northlands Dike	Dike breach mapping	-	$50,000
Coal Creek watershed	Install Coal Creek gage	-	$50,000
Citywide	Public awareness campaign	-	$40,000
Locations per section 3.2.5	Vegetation removal	-	$20,000

8 CLOSURE

We expect that this work and report meets your current needs. If you have any questions or would like to further discuss these findings, please contact Rahul Ranade or Dale Muir at our North Vancouver office at 604.980.6011 or by email at rranade@nhcweb.com or dmuir@nhcweb.com.

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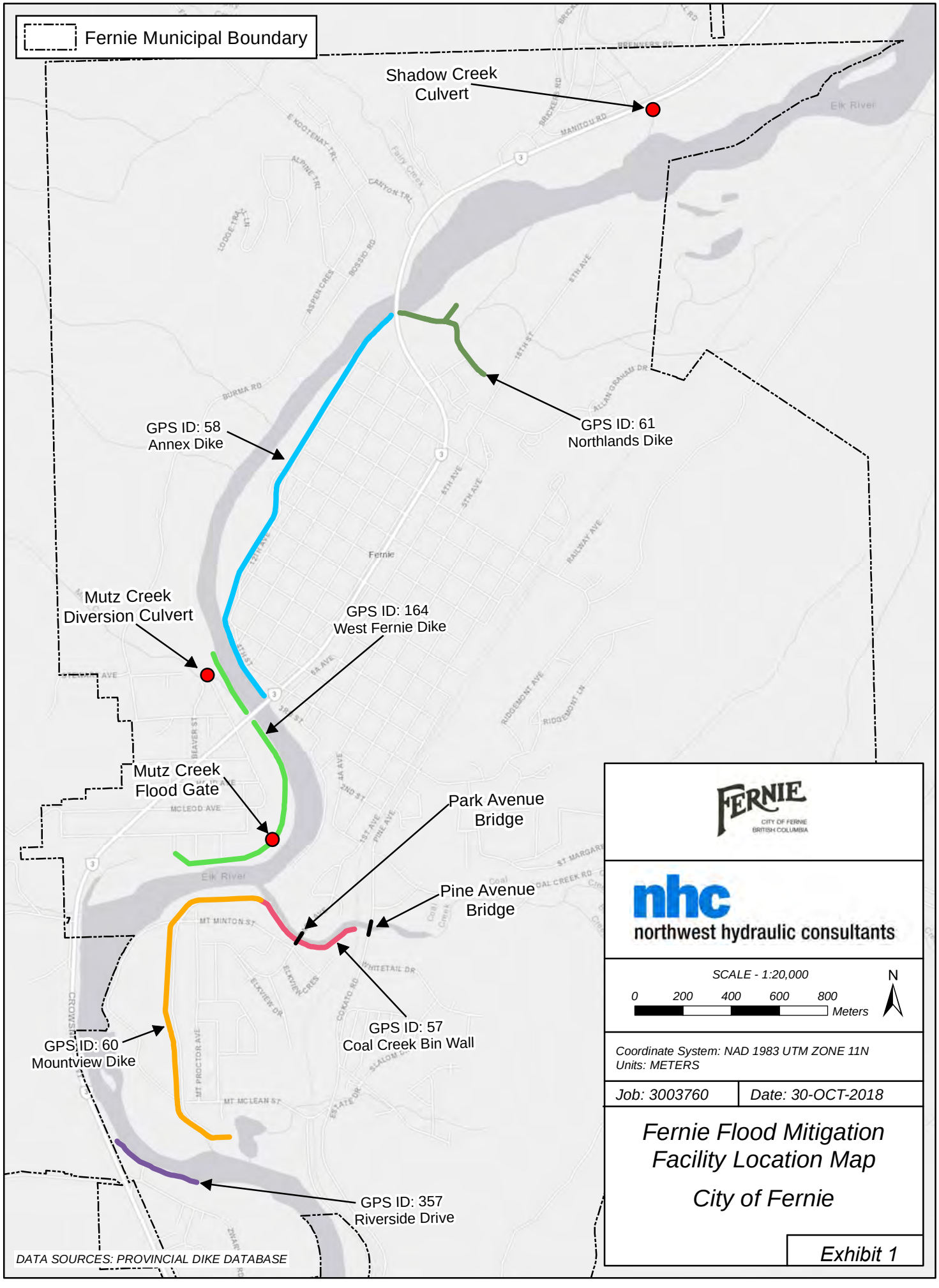
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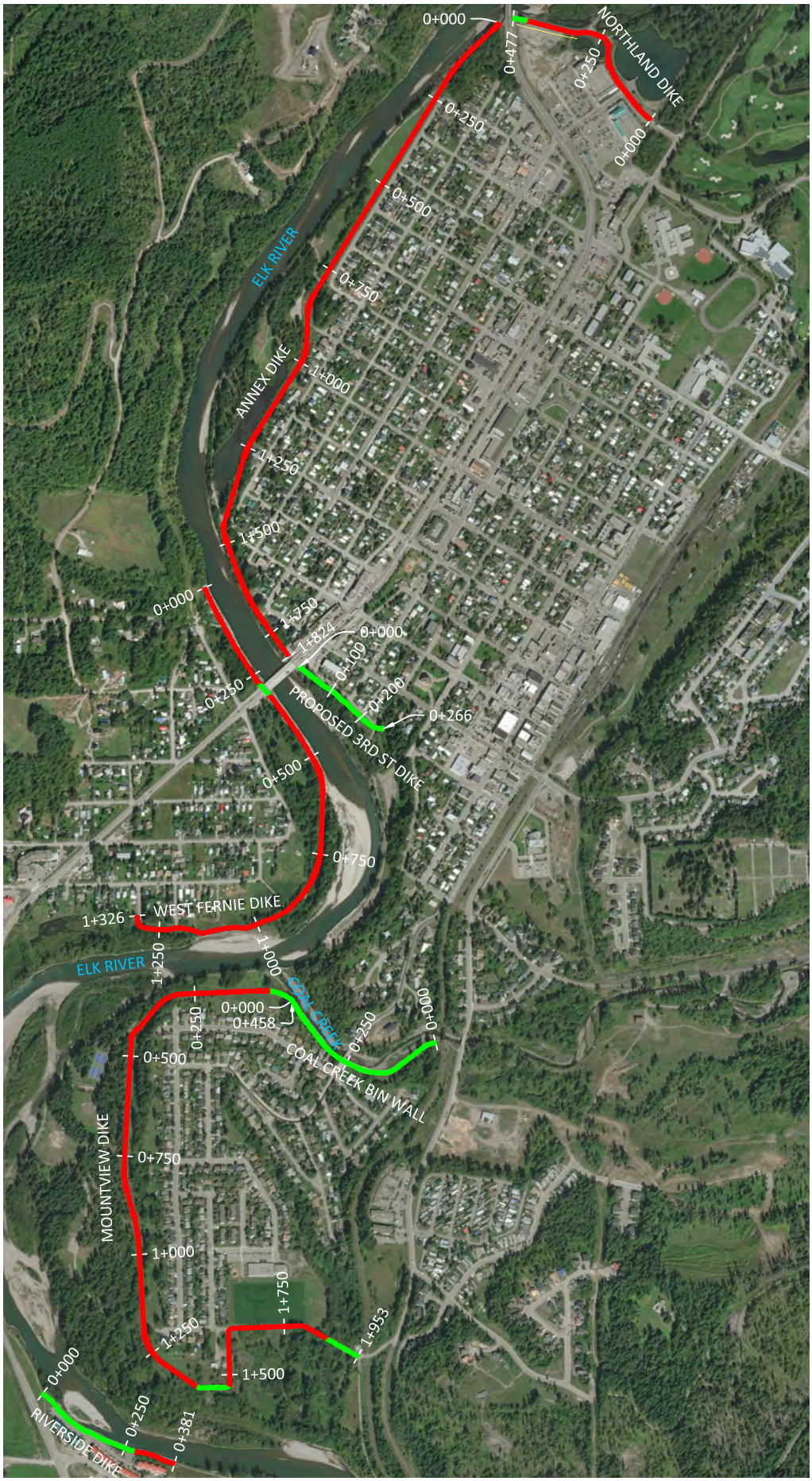
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APPENDIX A
EXHIBITS


Fernie Municipal Boundary
Shadow Creek Culvert
GPS ID: 58 Annex Dike
GPS ID: 61 Northlands Dike
Mutz Creek Diversion Culvert
GPS ID: 164 West Fernie Dike
Mutz Creek Flood Gate
Park Avenue Bridge
Pine Avenue Bridge
GPS ID: 57 Coal Creek Bin Wall
GPS ID: 60 Mountview Dike
GPS ID: 357 Riverside Drive
Fernie
Elk River
DATA SOURCES: PROVINCIAL DIKE DATABASE
FERNIE
CITY OF FERNIE
BRITISH COLUMBIA
nhc
northwest hydraulic consultants
SCALE - 1:20,000
0 200 400 600 800
Meters
N
Coordinate System: NAD 1983 UTM ZONE 11N
Units: METERS
Job: 3003760
Date: 30-OCT-2018
Fernie Flood Mitigation Facility Location Map
City of Fernie
Exhibit 1
BLH, \\mainfile-van\Projects\Active\3003760 Fernie Flood Mitigation\95 GIS\3003760_BLH_DikeMap1.mxd



PLAN - FERNIE
SCALE: 1:15000

LEGEND:

INADEQUATE CREST ELEVATION

ADEQUATE CREST ELEVATION

nhc northwest hydraulic consultants
30 Gostick Place
North Vancouver, BC
Canada V7M 3G3
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

DRAWING INFORMATION	
DATE	1 Mar 2019
DESIGNER	RRR
DRAFTER	CZZ
CHECKED	DPM
PROJECT No.	3003760

FERNIE FLOOD MITIGATION

Exhibit 2

Comparison of Crest Elevation and FCL
PLAN VIEW

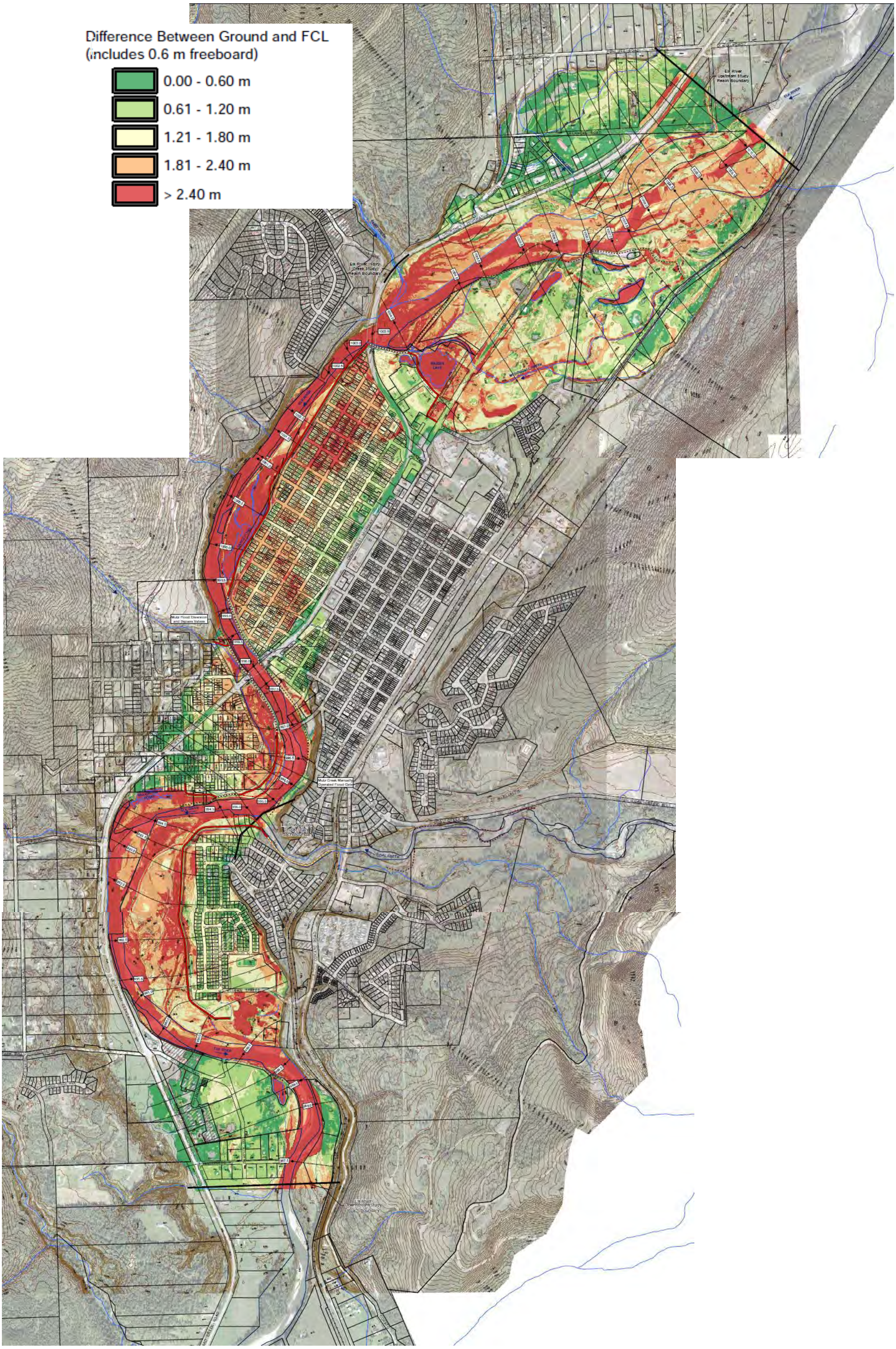
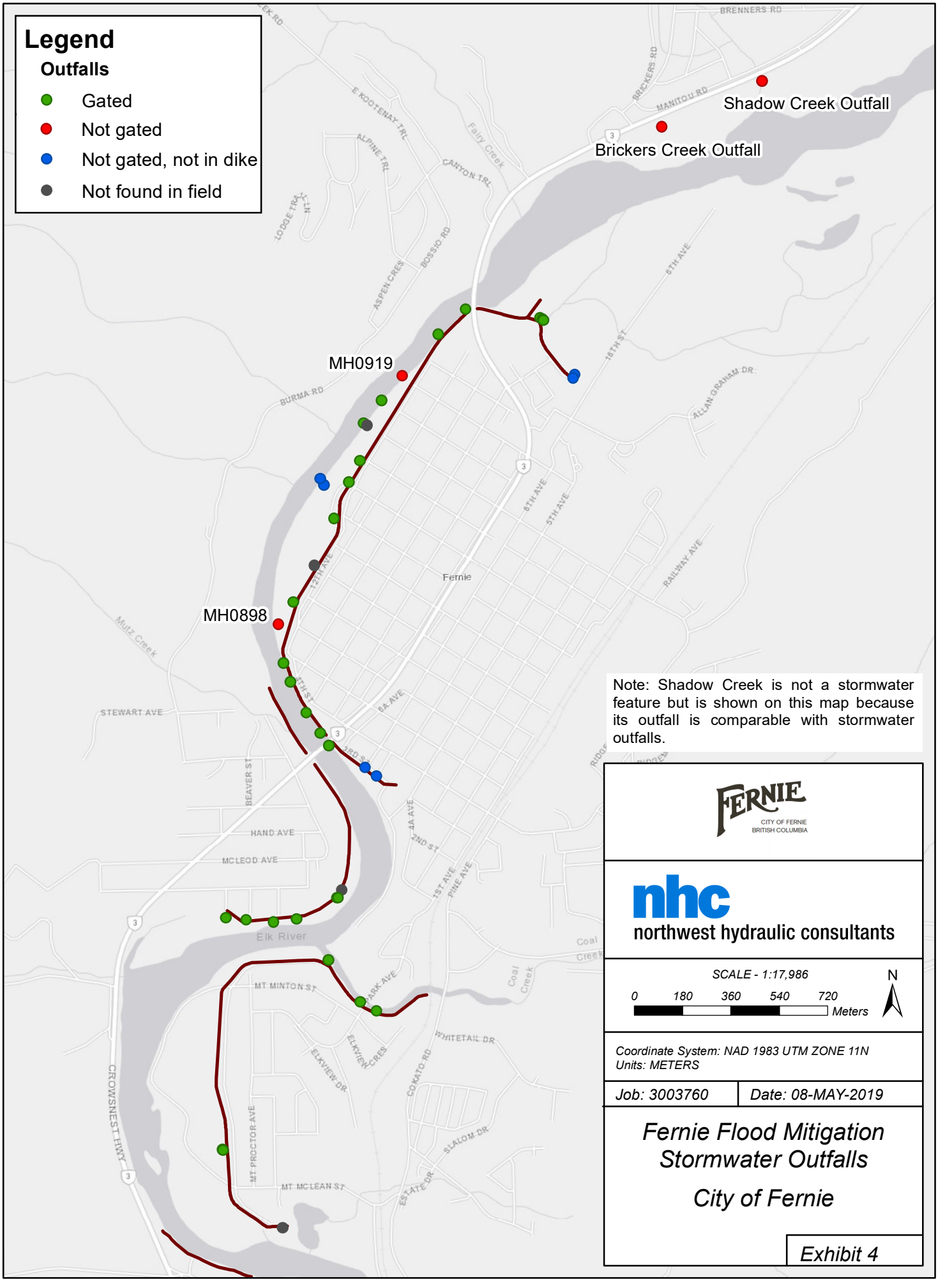


EXHIBIT 3

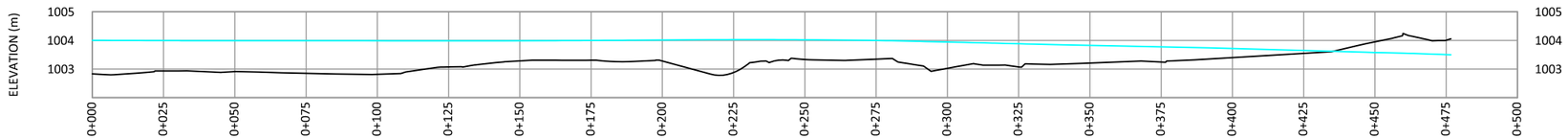
Flood Depth Map

Based on 2017 flood hazard study

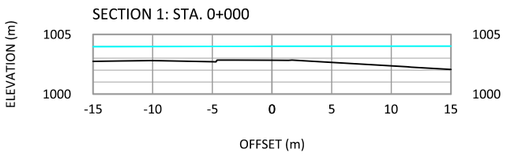


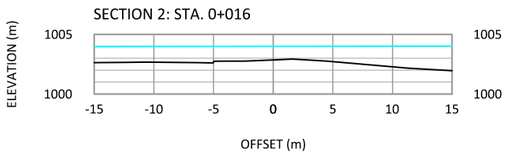
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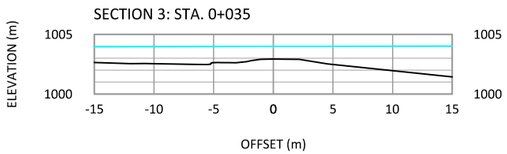
APPENDIX B
DIKE PROFILES AND CROSS-SECTIONS

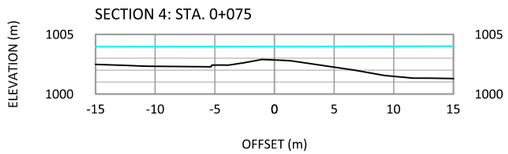


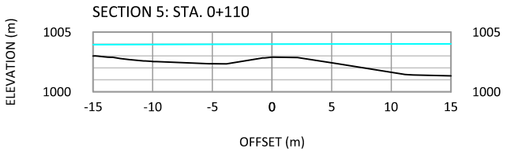
PROFILE - NORTHLAND DIKE
SCALE = 1:2000 V. EXAGGERATION 10X

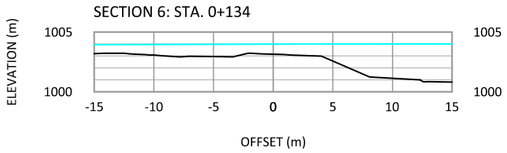


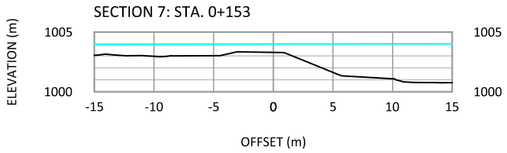


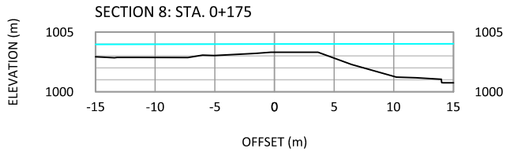


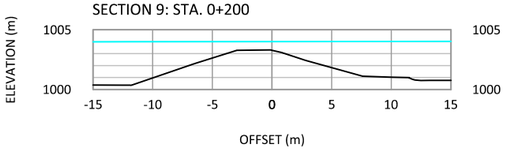


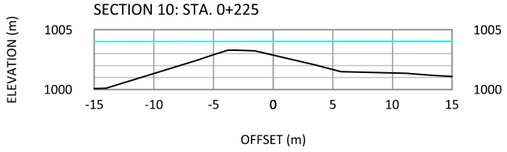


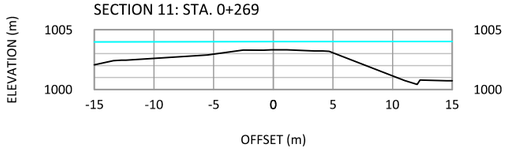


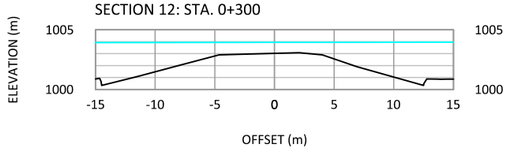


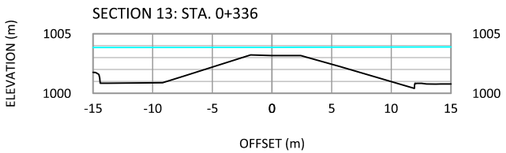


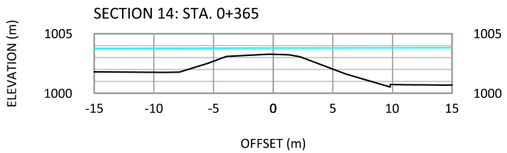


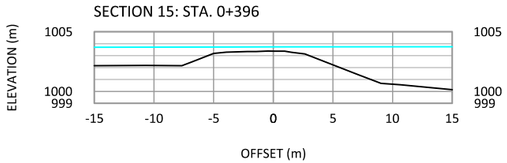


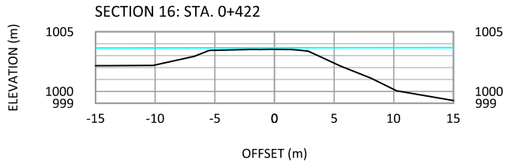


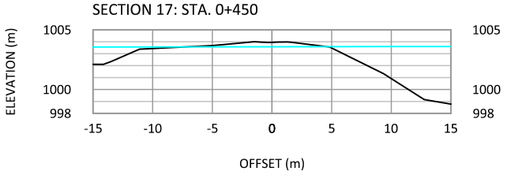












SECTION VIEWS - NORTHLAND DIKE
SCALE = 1:500

NOTES:
1. SECTION STATIONING IS NOT EVENLY SPACED BECAUSE EFFORTS WERE MADE TO MATCH REPRESENTED STATIONS WITH SURVEYED STATIONS.
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3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

FLOOD CONSTRUCTION LEVEL (FCL) ——————

DIKE CREST ELEVATION ——————

nhc northwest hydraulic consultants
30 Gostick Place
North Vancouver, BC
Canada V7M 3G3
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

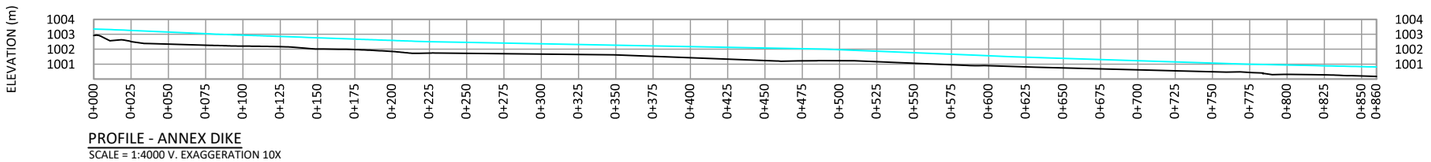
REVISIONS		

DRAWING INFORMATION	
DATE	31 Jan 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

FERNIE FLOOD MITIGATION
NORTHLANDS DIKE

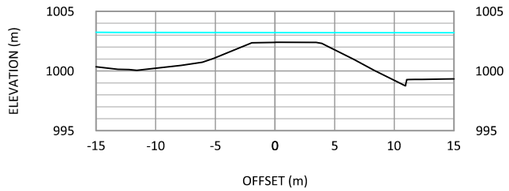
Comparison of Dike Crest Elevation and FCL
Profile Views

PROJECT NUMBER	3003760
DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

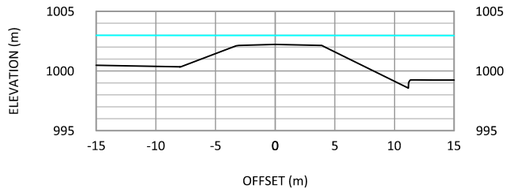


PROFILE - ANNEX DIKE
SCALE = 1:4000 V. EXAGGERATION 10X

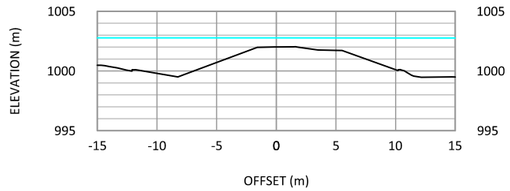
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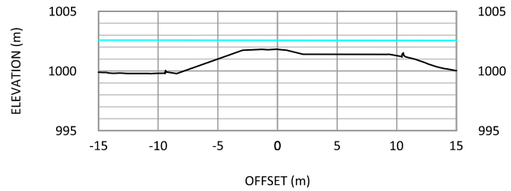
SECTION 2: STA. 0+091



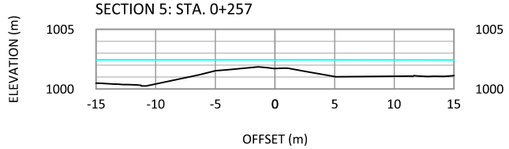
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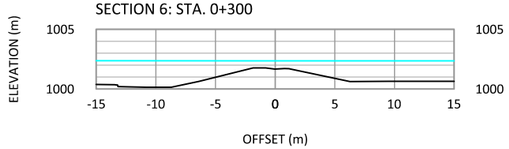
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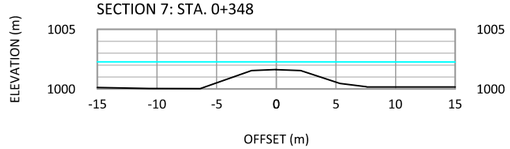
SECTION 5: STA. 0+257



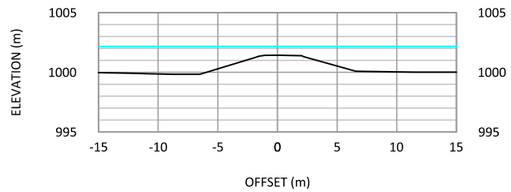
SECTION 6: STA. 0+300



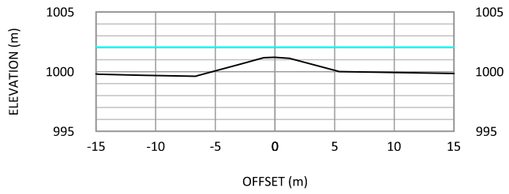
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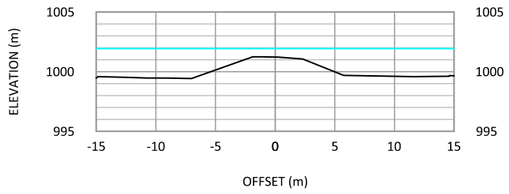
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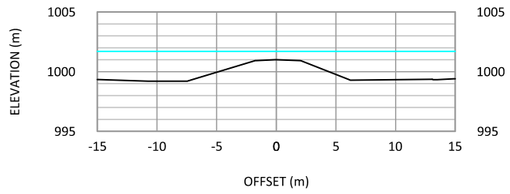
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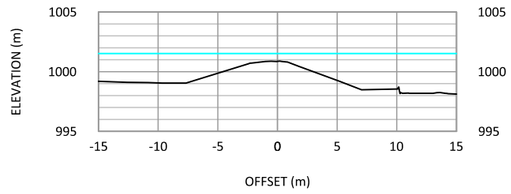
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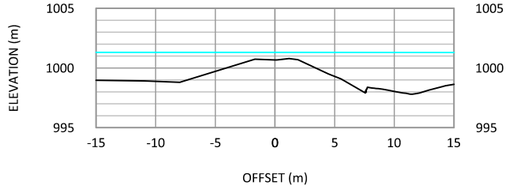
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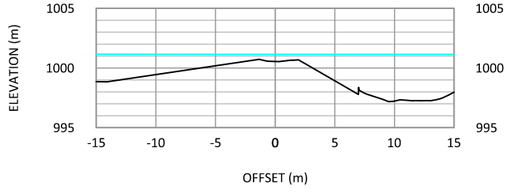
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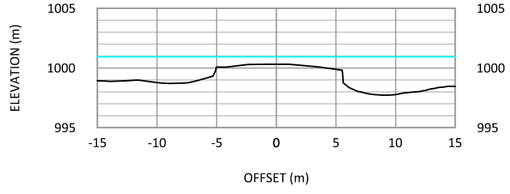
SECTION 13: STA. 0+676



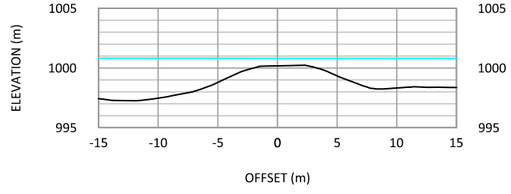
SECTION 14: STA. 0+727



SECTION 15: STA. 0+800



SECTION 16: STA. 0+857



SECTION VIEWS - ANNEX DIKE
SCALE = 1:500

NOTES:
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3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

FLOOD CONSTRUCTION LEVEL (FCL) ——————

DIKE CREST ELEVATION ----------

nhc northwest hydraulic consultants
30 Gostick Place
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Canada V7M 3G3
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

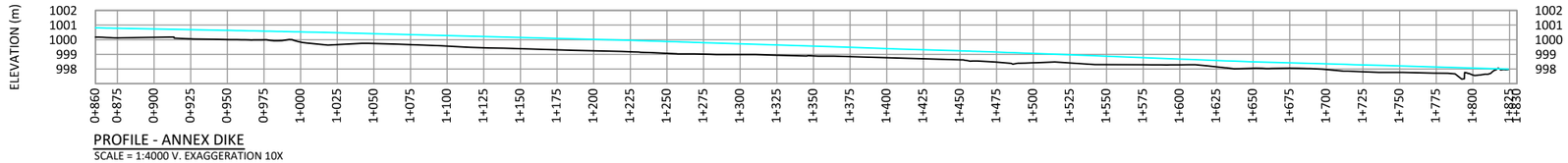
REVISIONS		

DRAWING INFORMATION	
DATE	31 Jan 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

FERNIE FLOOD MITIGATION
ANNEX DIKE

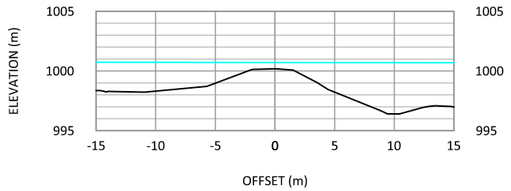
Comparison of Dike Crest Elevation and FCL
Profile Views

PROJECT NUMBER	3003760
DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

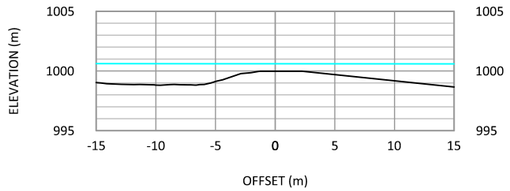


PROFILE - ANNEX DIKE
SCALE = 1:4000 V. EXAGGERATION 10X

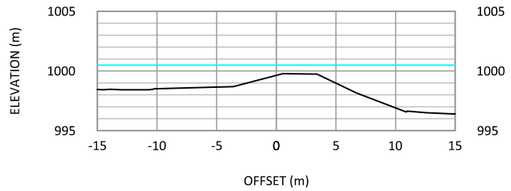
SECTION 17: STA. 0+912



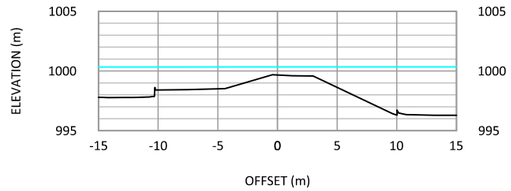
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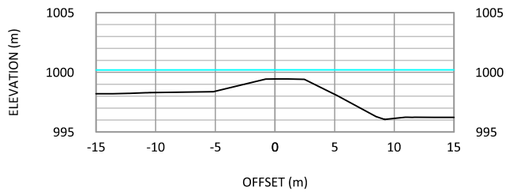
SECTION 19: STA. 1+019



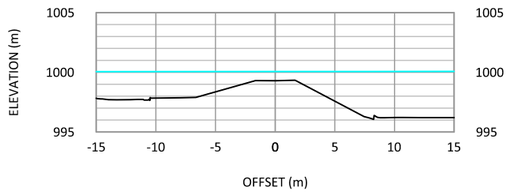
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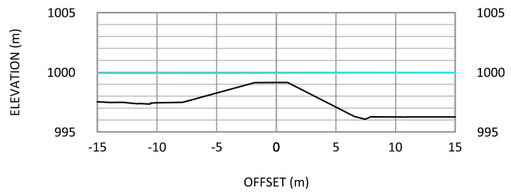
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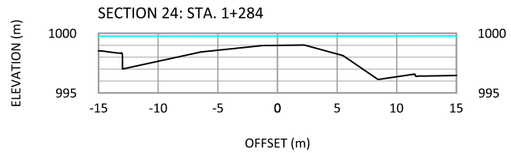
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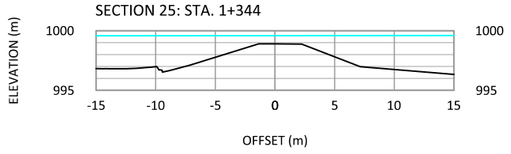
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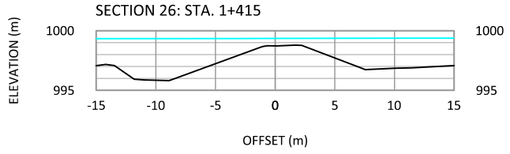
SECTION 24: STA. 1+284



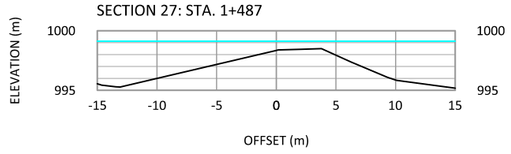
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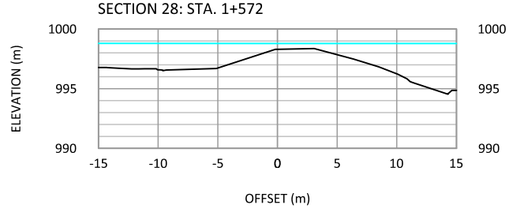
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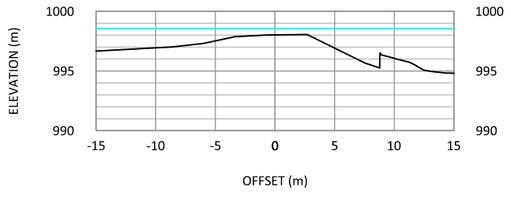
SECTION 27: STA. 1+487



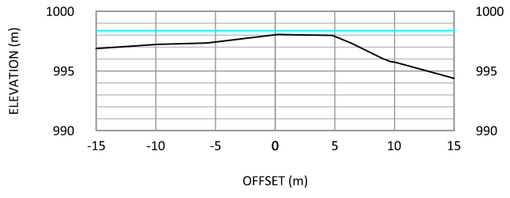
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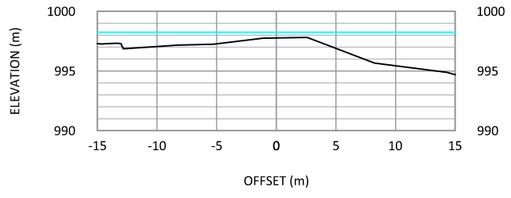
SECTION 29: STA. 1+636



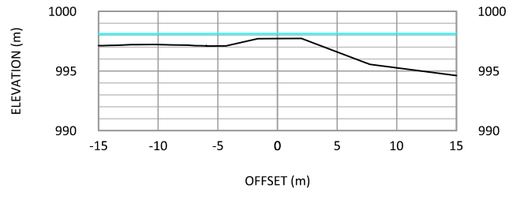
SECTION 30: STA. 1+688



SECTION 31: STA. 1+736



SECTION 32: STA. 1+783



SECTION VIEWS - ANNEX DIKE
SCALE = 1:500

NOTES:
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3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

FLOOD CONSTRUCTION LEVEL (FCL) ——————

DIKE CREST ELEVATION - - - - - - - - - -

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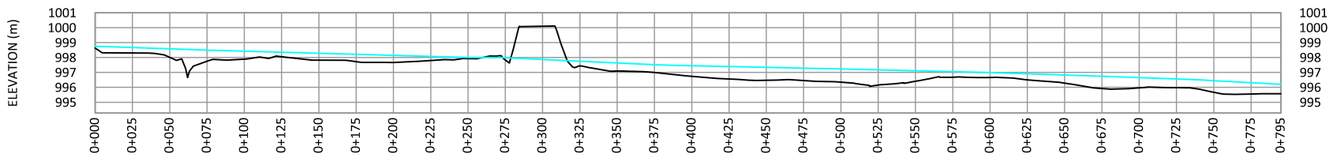
REVISIONS		

DRAWING INFORMATION	
DATE	31 Jan 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

FERNIE FLOOD MITIGATION
ANNEX DIKE

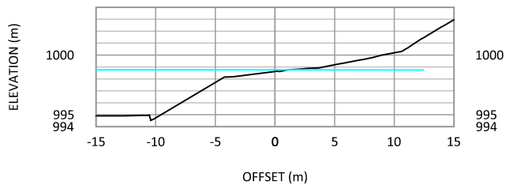
Comparison of Dike Crest Elevation and FCL
Profile Views

PROJECT NUMBER	3003760
DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

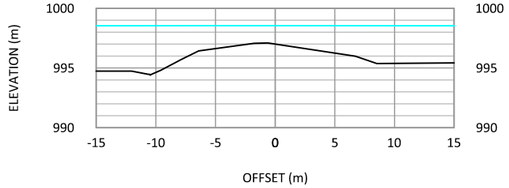


PROFILE - WEST FERNIE DIKE
SCALE = 1:4000 V. EXAGGERATION 10X

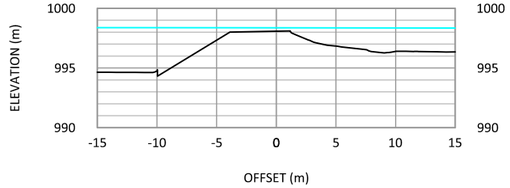
SECTION 1: STA. 0+000



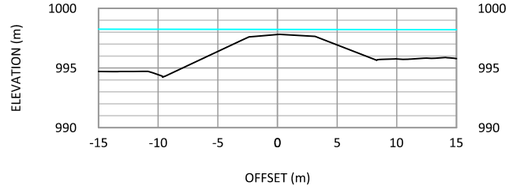
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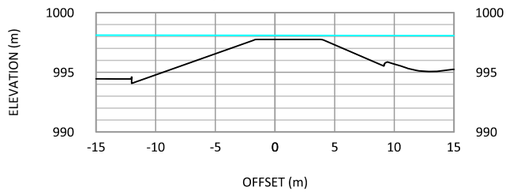
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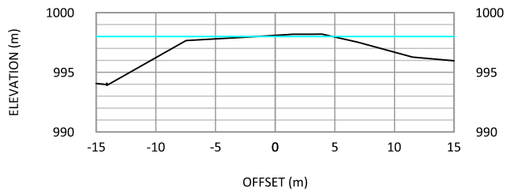
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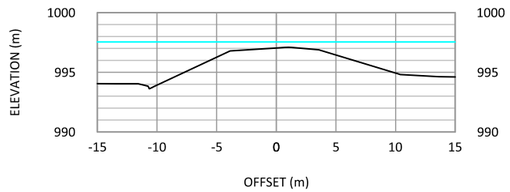
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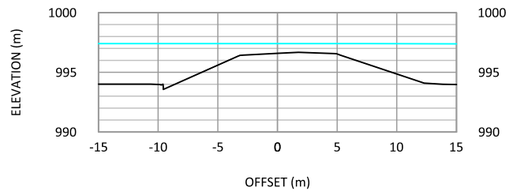
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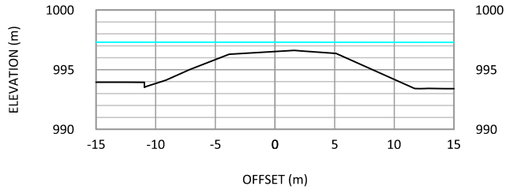
SECTION 7: STA. 0+369



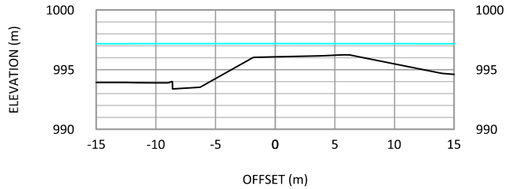
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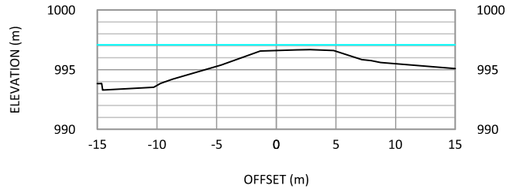
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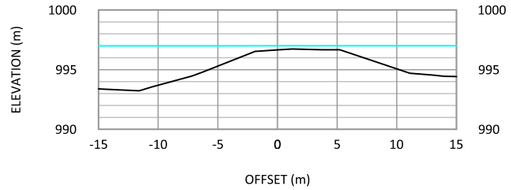
SECTION 10: STA. 0+520



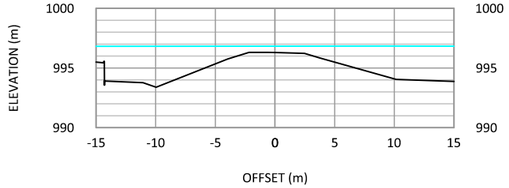
SECTION 11: STA. 0+560



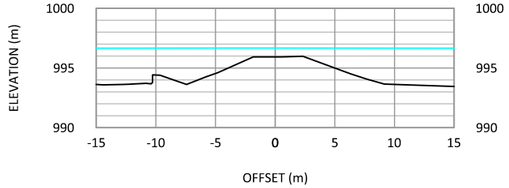
SECTION 12: STA. 0+596



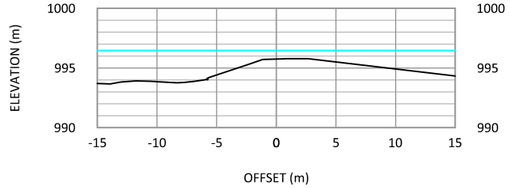
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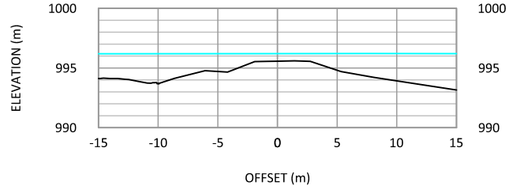
SECTION 14: STA. 0+695



SECTION 15: STA. 0+746



SECTION 16: STA. 0+795



SECTION VIEWS - WEST FERNIE DIKE
SCALE = 1:500

NOTES:
1. SECTION STATIONING IS NOT EVENLY SPACED BECAUSE EFFORTS WERE MADE TO MATCH REPRESENTED STATIONS WITH SURVEYED STATIONS.
2. ALL PROFILE VIEWS REPRESENT THE VIEW LOOKING DOWNSTREAM WITH REFERENCE TO THE ELK RIVER.
3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

FLOOD CONSTRUCTION LEVEL (FCL) ——————

DIKE CREST ELEVATION ----------

nhc northwest hydraulic consultants
30 Gostick Place
North Vancouver, BC
Canada V7M 3G3
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

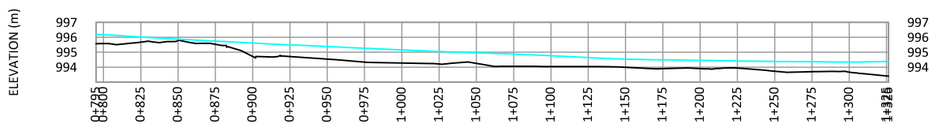
REVISIONS		

DRAWING INFORMATION	
DATE	31 Jan 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

FERNIE FLOOD MITIGATION
WEST FERNIE DIKE

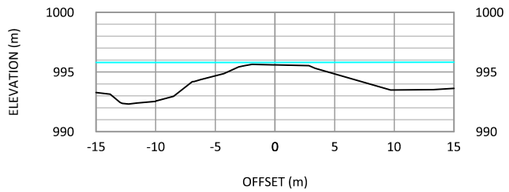
Comparison of Dike Crest Elevation and FCL Profile Views

PROJECT NUMBER	3003760
DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

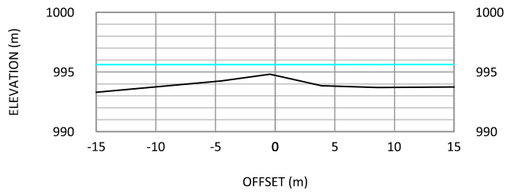


PROFILE - WEST FERNIE DIKE
SCALE = 1:4000 V. EXAGGERATION 10X

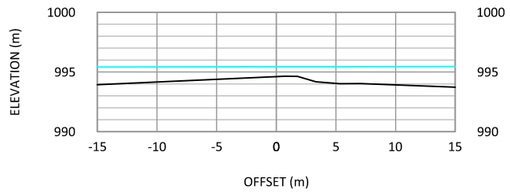
SECTION 17: STA. 0+865



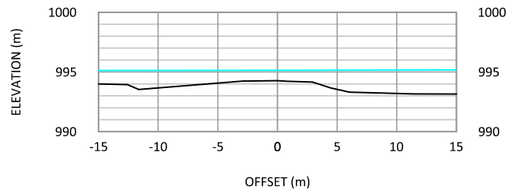
SECTION 18: STA. 0+900



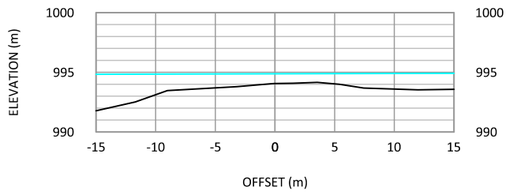
SECTION 19: STA. 0+939



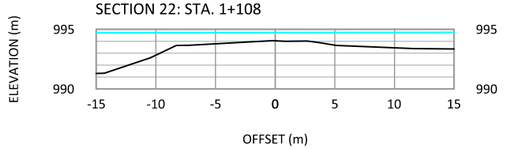
SECTION 20: STA. 1+004



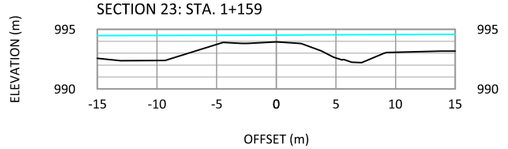
SECTION 21: STA. 1+074



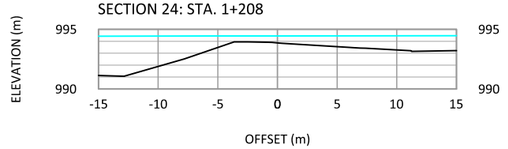
SECTION 22: STA. 1+108



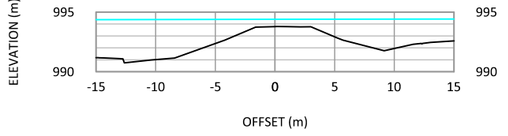
SECTION 23: STA. 1+159



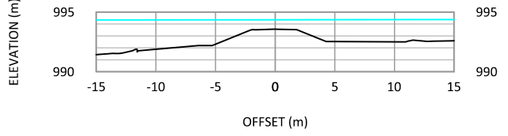
SECTION 24: STA. 1+208



SECTION 25: STA. 1+244



SECTION 26: STA. 1+309



SECTION VIEWS - WEST FERNIE DIKE
SCALE = 1:500

NOTES:
1. SECTION STATIONING IS NOT EVENLY SPACED BECAUSE EFFORTS WERE MADE TO MATCH REPRESENTED STATIONS WITH SURVEYED STATIONS.
2. ALL PROFILE VIEWS REPRESENT THE VIEW LOOKING DOWNSTREAM WITH REFERENCE TO THE ELK RIVER.
3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

FLOOD CONSTRUCTION LEVEL (FCL) ————

DIKE CREST ELEVATION ----------

nhc northwest hydraulic consultants
30 Gostick Place
North Vancouver, BC
Canada V7M 3G3
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

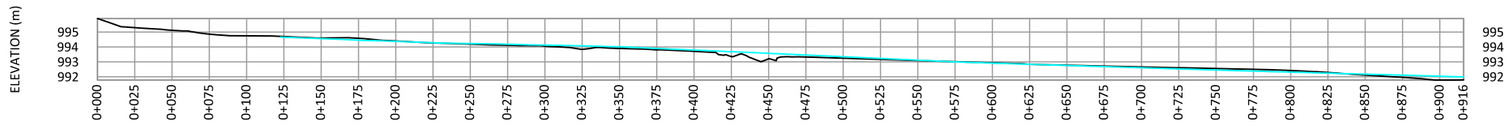
REVISIONS		

DRAWING INFORMATION	
DATE	31 Jan 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

FERNIE FLOOD MITIGATION
WEST FERNIE DIKE

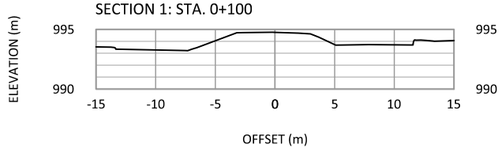
Comparison of Dike Crest Elevation and FCL
Profile Views

PROJECT NUMBER	3003760
DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

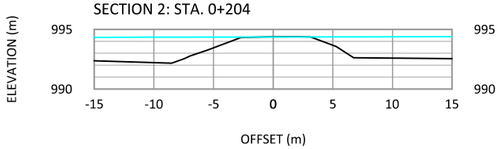


PROFILE - MOUNTVIEW DIKE
SCALE = 1:4000 V. EXAGGERATION 10X

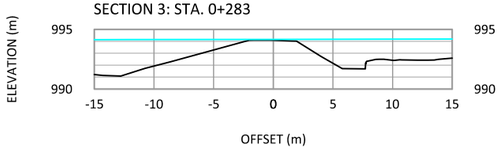
SECTION 1: STA. 0+100



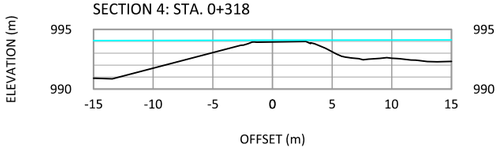
SECTION 2: STA. 0+204



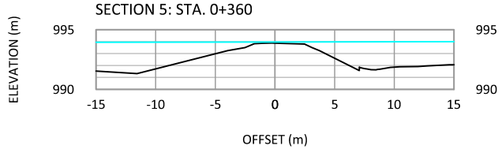
SECTION 3: STA. 0+283



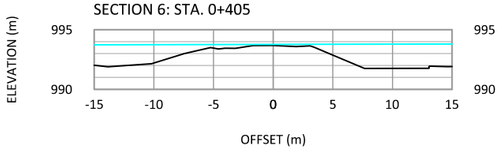
SECTION 4: STA. 0+318



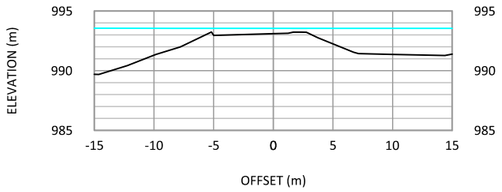
SECTION 5: STA. 0+360



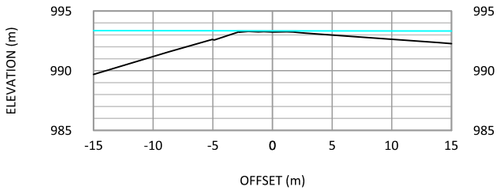
SECTION 6: STA. 0+405



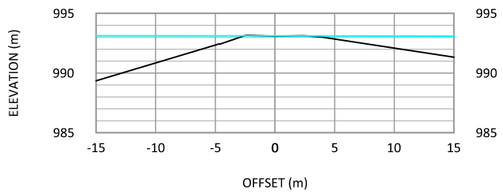
SECTION 7: STA. 0+454



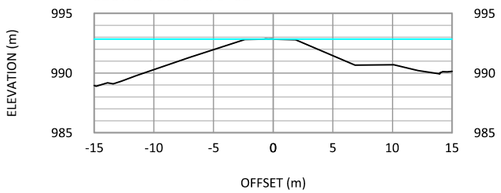
SECTION 8: STA. 0+500



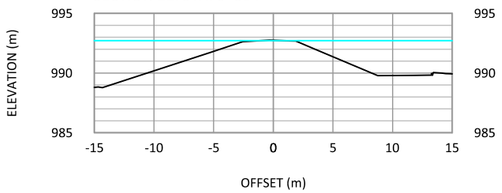
SECTION 9: STA. 0+550



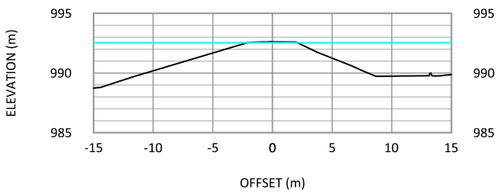
SECTION 10: STA. 0+624



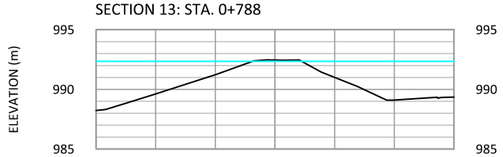
SECTION 11: STA. 0+664



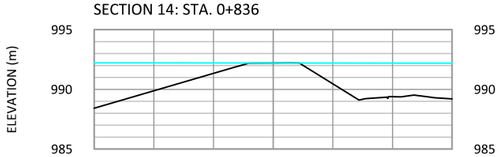
SECTION 12: STA. 0+718



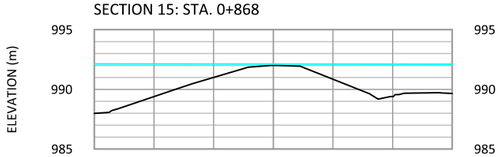
SECTION 13: STA. 0+788



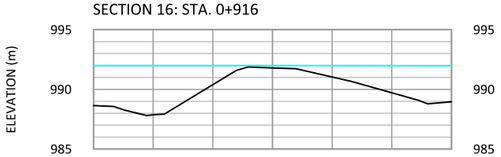
SECTION 14: STA. 0+836



SECTION 15: STA. 0+868



SECTION 16: STA. 0+916



SECTION VIEWS - MOUNTVIEW DIKE
SCALE = 1:500

NOTES:
1. SECTION STATIONING IS NOT EVENLY SPACED BECAUSE EFFORTS WERE MADE TO MATCH REPRESENTED STATIONS WITH SURVEYED STATIONS.
2. ALL PROFILE VIEWS REPRESENT THE VIEW LOOKING DOWNSTREAM WITH REFERENCE TO THE ELK RIVER.
3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

FLOOD CONSTRUCTION LEVEL (FCL) ——————

DIKE CREST ELEVATION - - - - - - - - - -

nhc northwest hydraulic consultants
30 Gostick Place
North Vancouver, BC
Canada V7M 3G3
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

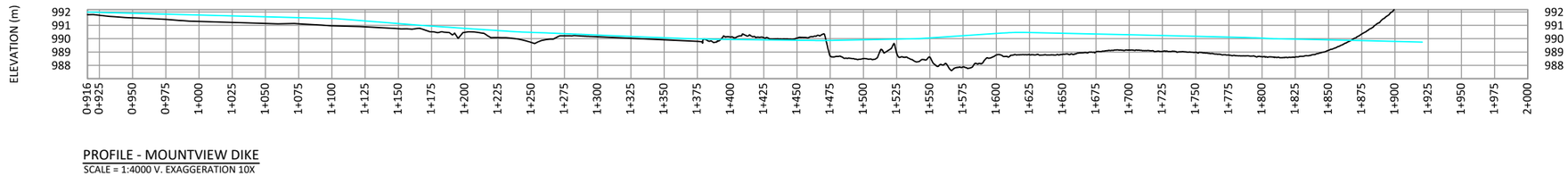
REVISIONS		

DRAWING INFORMATION	
DATE	1 Mar 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

FERNIE FLOOD MITIGATION
MOUNTVIEW DIKE

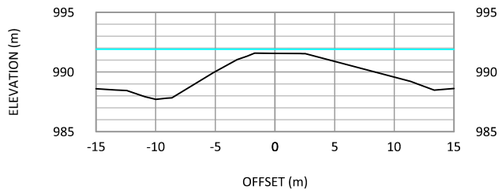
Comparison of Dike Crest Elevation and FCL Profile Views

PROJECT NUMBER	3003760
DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

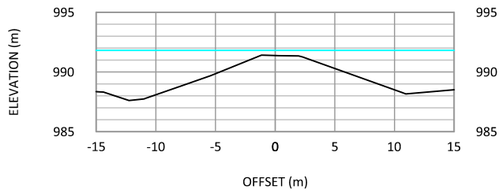


PROFILE - MOUNTVIEW DIKE
SCALE = 1:4000 V. EXAGGERATION 10X

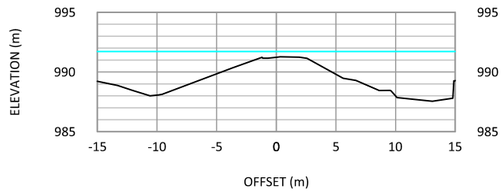
SECTION 17: STA. 0+950



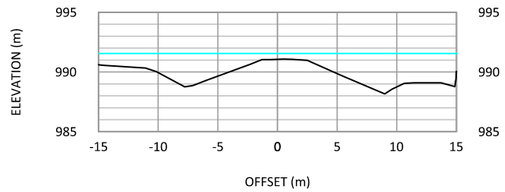
SECTION 18: STA. 0+984



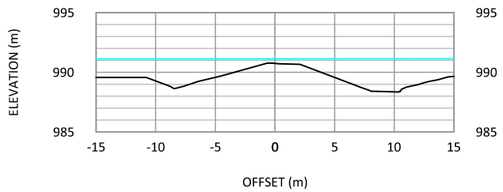
SECTION 19: STA. 1+020



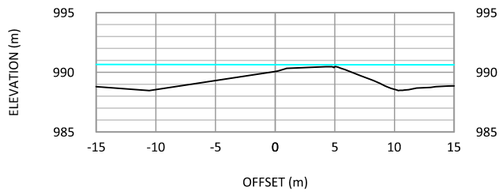
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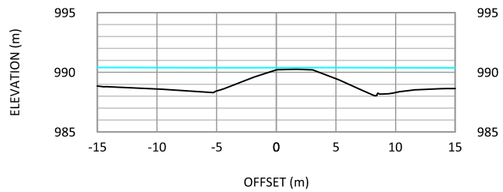
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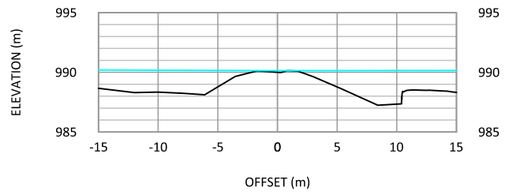
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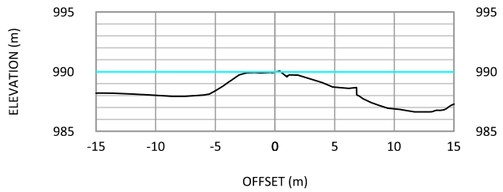
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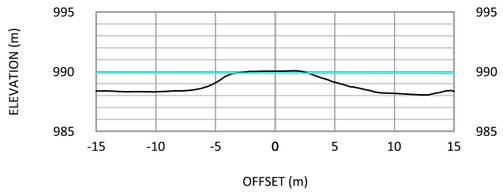
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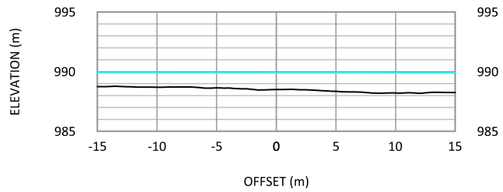
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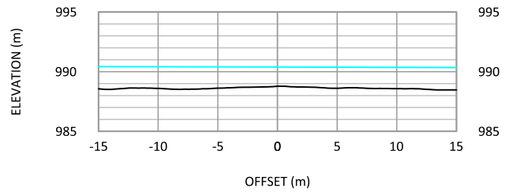
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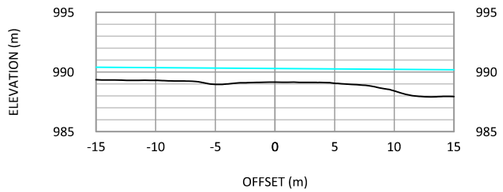
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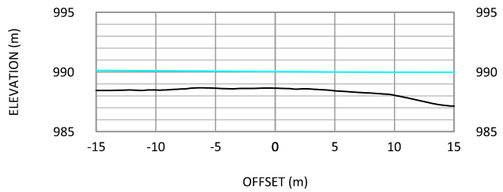
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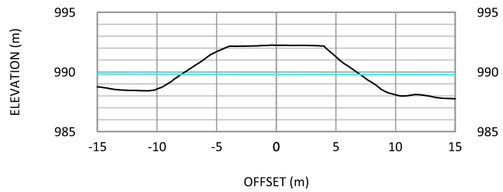
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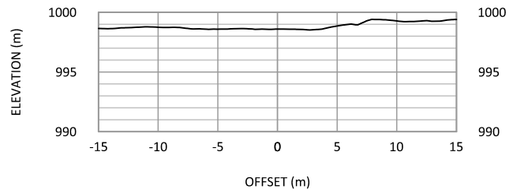
SECTION 30: STA. 1+800



SECTION 31: STA. 1+900



SECTION 32: STA. 1+950



SECTION VIEWS - MOUNTVIEW DIKE
SCALE = 1:500

NOTES:
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3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

FLOOD CONSTRUCTION LEVEL (FCL) ——————

DIKE CREST ELEVATION ----------

nhc northwest hydraulic consultants
30 Gostick Place
North Vancouver, BC
Canada V7M 3G3
Office: 604.980.6011
Fax: 604.980.9264
www.nhcweb.com

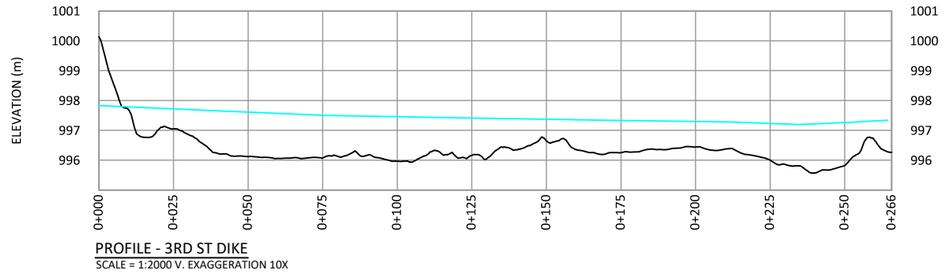
REVISIONS		

DRAWING INFORMATION	
DATE	1 Mar 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

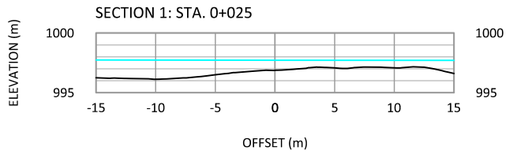
FERNIE FLOOD MITIGATION
MOUNTVIEW DIKE

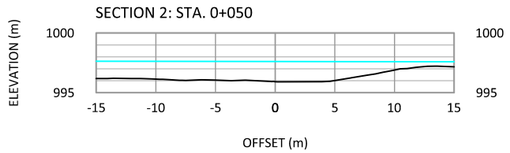
Comparison of Dike Crest Elevation and FCL
Profile Views

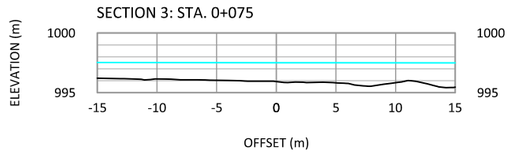
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DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

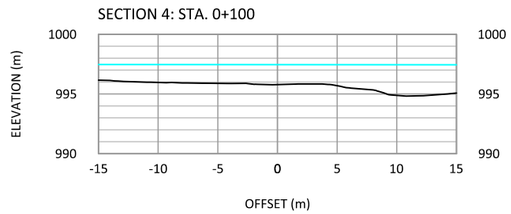


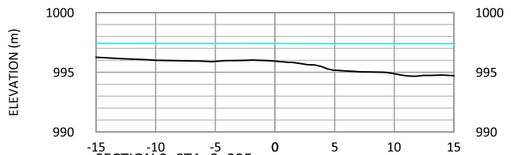
PROFILE - 3RD ST DIKE
SCALE = 1:2000 V. EXAGGERATION 10X

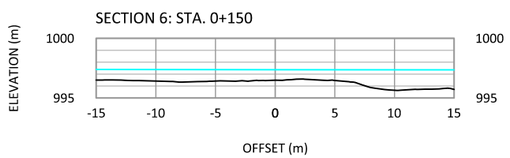


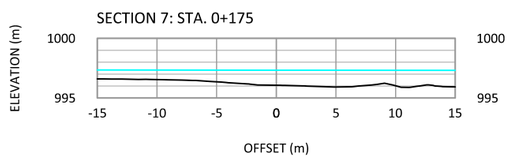


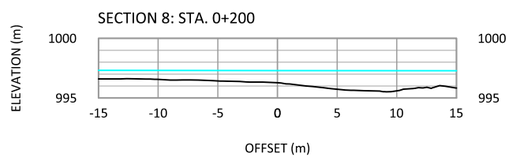


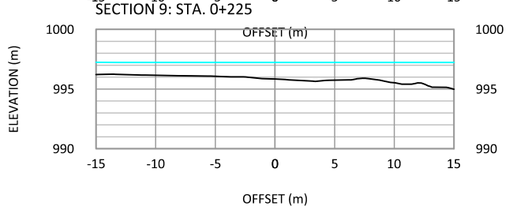


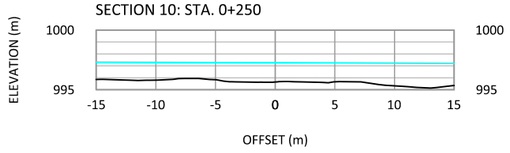












SECTION VIEWS - 3RD ST DIKE
SCALE = 1:500

NOTES:
1. SECTION STATIONING IS NOT EVENLY SPACED BECAUSE EFFORTS WERE MADE TO MATCH REPRESENTED STATIONS WITH SURVEYED STATIONS.
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LEGEND:

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nhc northwest hydraulic consultants
30 Gostick Place
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www.nhcweb.com

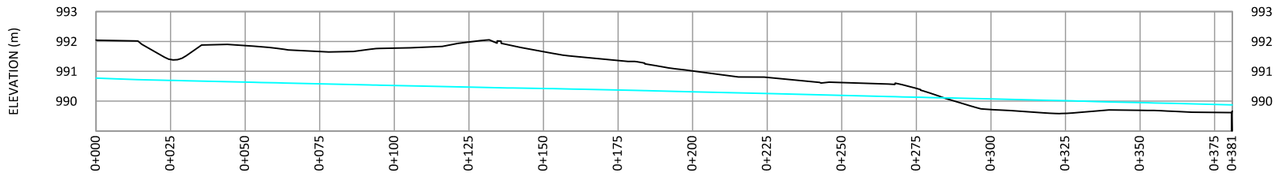
REVISIONS		

DRAWING INFORMATION	
DATE	31 Jan 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

FERNIE FLOOD MITIGATION
3rd STREET DIKE

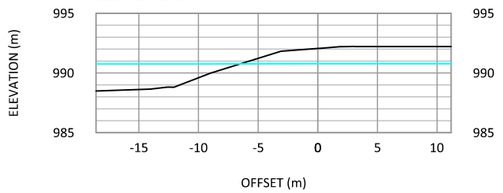
Comparison of Dike Crest Elevation and FCL
Profile Views

PROJECT NUMBER	3003760
DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

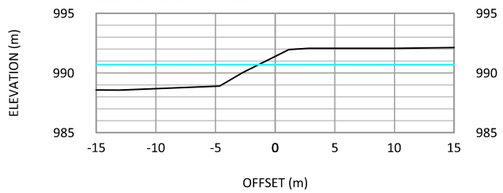


PROFILE - RIVERSIDE DIKE
SCALE = 1:2000 V. EXAGGERATION 10X

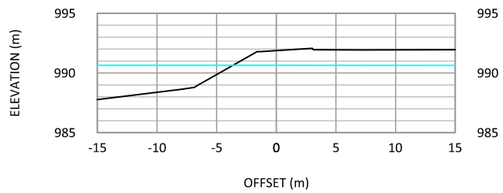
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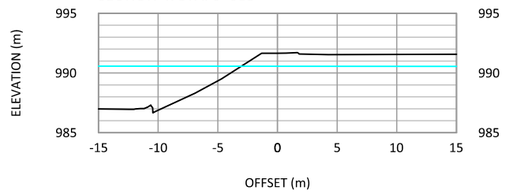
SECTION 2: STA. 0+025



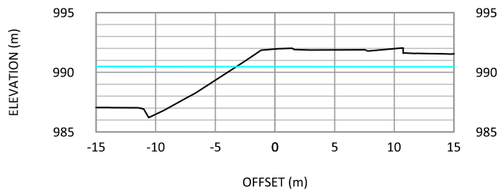
SECTION 3: STA. 0+048



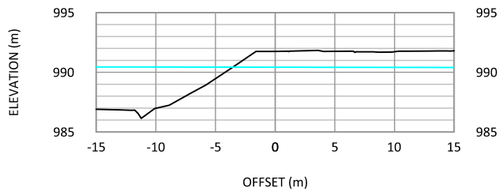
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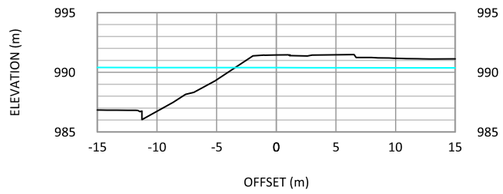
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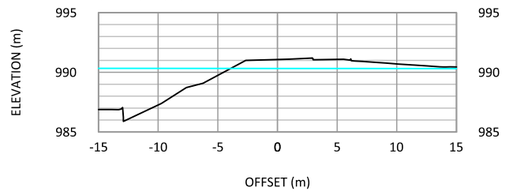
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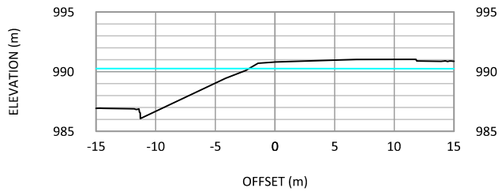
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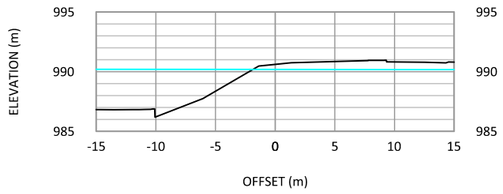
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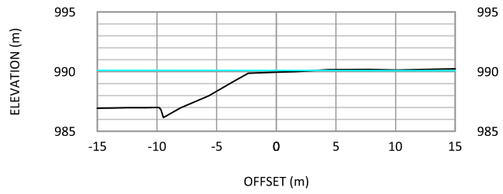
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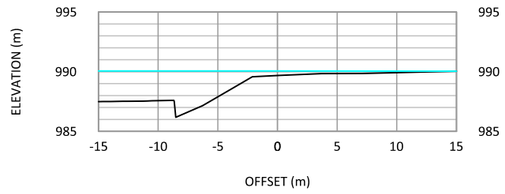
SECTION 10: STA. 0+253



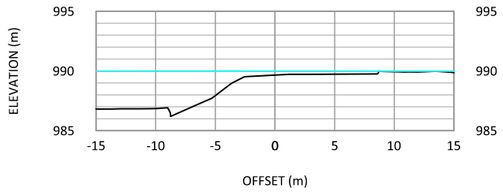
SECTION 11: STA. 0+289



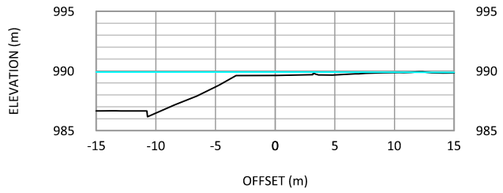
SECTION 12: STA. 0+308



SECTION 13: STA. 0+334



SECTION 14: STA. 0+367



SECTION VIEWS - RIVERSIDE DIKE
SCALE = 1:500

NOTES:
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3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

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nhc northwest hydraulic consultants
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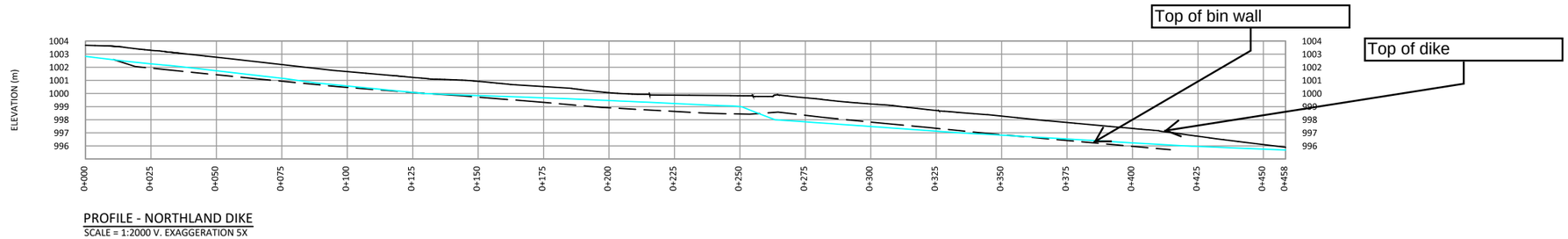
REVISIONS		

DRAWING INFORMATION	
DATE	31 Jan 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

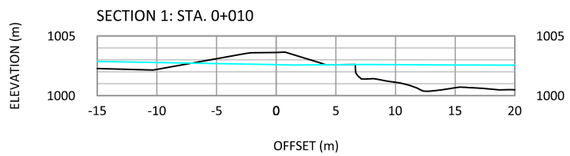
FERNIE FLOOD MITIGATION
RIVERSIDE DIKE

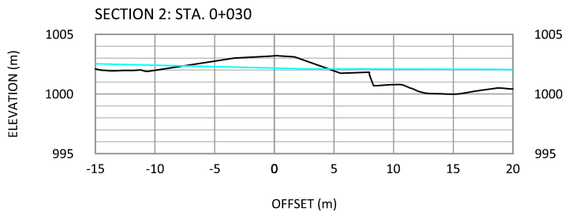
Comparison of Dike Crest Elevation and FCL
Profile Views

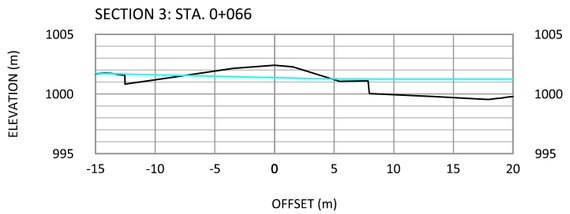
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DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

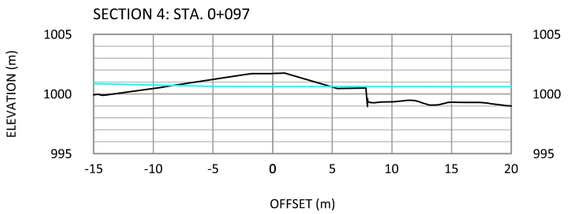


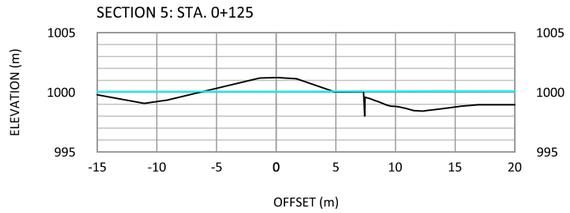
PROFILE - NORTHLAND DIKE
SCALE = 1:2000 V. EXAGGERATION 5X

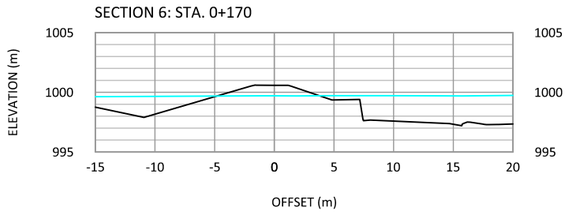


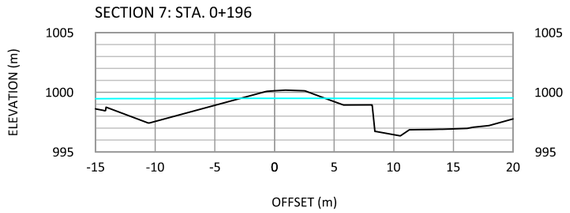


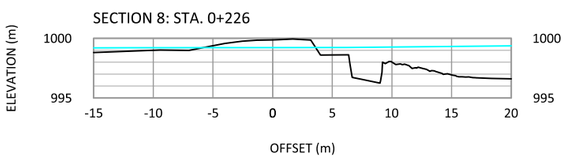


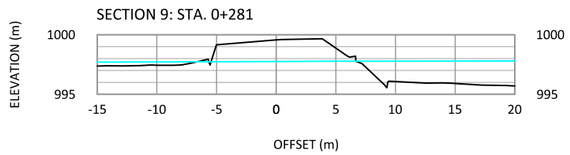


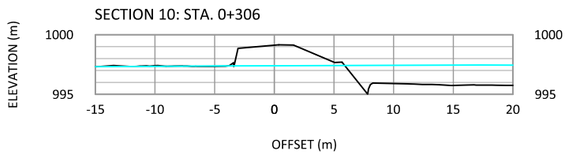


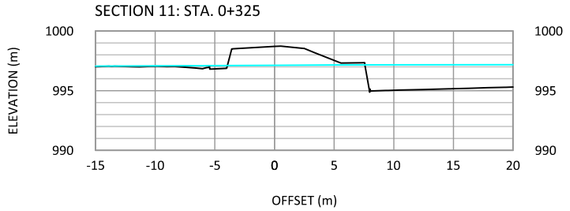


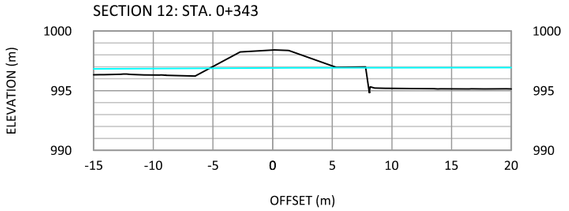


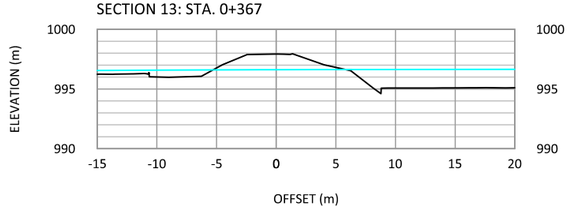


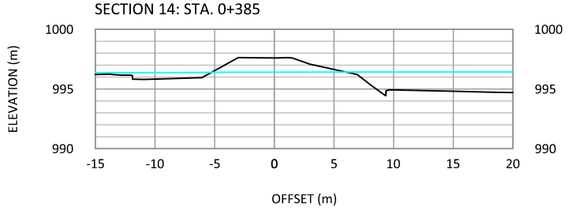


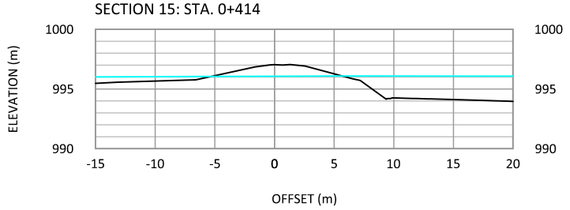


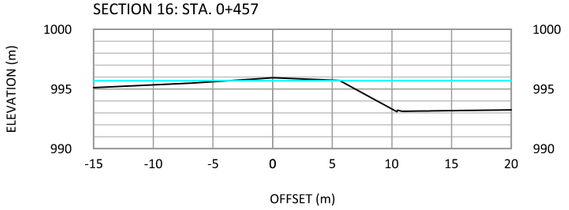












SECTION VIEWS - COAL CREEK BIN WALL
SCALE = 1:500

NOTES:
1. SECTION STATIONING IS NOT EVENLY SPACED BECAUSE EFFORTS WERE MADE TO MATCH REPRESENTED STATIONS WITH SURVEYED STATIONS.
2. ALL PROFILE VIEWS REPRESENT THE VIEW LOOKING DOWNSTREAM WITH REFERENCE TO THE ELK RIVER.
3. VERTICAL DATUM IS CANADIAN VERTICAL DATUM 1928 BRITISH COLUMBIA (CVD28BC).

LEGEND:

FLOOD CONSTRUCTION LEVEL (FCL) ——

DIKE CREST ELEVATION ——

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REVISIONS		

DRAWING INFORMATION	
DATE	31 Jan 2019
DESIGNED BY	RRR
DRAWN BY	CZZ
CHECKED BY	DPM
SHEET SIZE	B (11" x 17")

FERNIE FLOOD MITIGATION
COAL CREEK BINWALL

Comparison of Dike Crest Elevation and FCL
Profile Views

PROJECT NUMBER	3003760
DRAWING NUMBER	3003760-001
SHEET NUMBER	
REVISION	

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Northlands Dike



Photo 1 View looking west along crest of Northlands Dike



Photo 2 View looking west showing landside of Northlands Dike

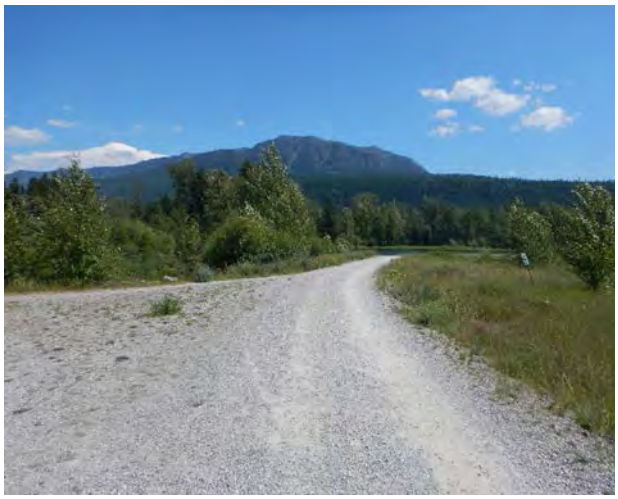


Photo 3 View looking south along crest of Northlands Dike



Photo 4 View looking south along Northlands Dike near Maiden Lake



Photo 5 Bank protection at left (south) abutment of Leo T. Nimsick Bridge



Photo 6 Bank protection along Northlands Dike 20 m to 46 m south of Leo T. Nimsick bridge, looking west



Photo 7 Bank protection along Northlands Dike at location greater than 46 m west of Leo T. Nimsick Bridge



Photo 8 Close-up view of Northlands Dike typical riprap at location greater than 46 m west of Leo T. Nimsick Bridge showing weathered riprap elements

Annex Dike



Photo 9 Bank protection near upstream end of Annex Dike, looking northeast with Leo T. Nimsick bridge in view



Photo 10 View of Annex Dike attack dike crest, looking southwest



Photo 11 Minor bank erosion adjacent to Annex attack dike, looking northeast



Photo 12 Human-induced bank erosion adjacent to Annex Dike attack dike, looking north



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Photo 15 **Annex Dike setback dike, looking northeast**



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Photo 21 Downstream end of West Fernie Dike, looking upstream (east)



Photo 22 Wetland near potential West Fernie Dike tie-in location, looking east



Photo 23 Houses adjacent to wetland near potential West Fernie Dike tie-in location, looking east



Photo 24 McDonald Ave near potential West Fernie Dike tie-in location, looking west

Elk River Left Bank Downstream of West Bridge



Photo 25 Elk River left bank downstream of West Bridge, looking downstream (south)



Photo 26 Elk River left bank downstream of West Bridge, looking upstream (north)



Photo 27 3rd St. parallel to Elk River left bank, looking north



Photo 28 Bank protection near boat launch downstream of left bank potential dike location, looking downstream (south)

Coal Creek Bin Wall



Photo 29 Upstream end of bin wall, left bank looking downstream (west) from railway bridge



Photo 30 Coal Creek Bin Wall adjacent to vegetated bar, looking downstream (northwest)



Photo 31 Coal Creek Bin Wall typical toe riprap, looking upstream (east)



Photo 32 Coal Creek Bin Wall typical toe riprap, looking downstream (west)



Photo 33 Toe riprap missing near downstream end of vegetated bar, looking upstream (northeast)



Photo 34 Top of bin wall showing typical concrete cracking at each joint, looking upstream (northeast)



Photo 35 Larger crack in concrete approximately 100 m upstream of Park Ave. Bridge, looking downstream (west)



Photo 36 Toe riprap missing near approximately 50 m downstream of Park Ave. Bridge, looking downstream (west)

Mountview/Airport Dike



Photo 37 Upstream end of Mountview/Airport Dike attack dike along Coal Creek just upstream of confluence with Elk River, looking upstream (south)



Photo 38 Minor bank erosion and sparse riprap along Mountview/Airport Dike attack dike just downstream of Coal Creek/Elk River confluence



Photo 39 Elk River side channel adjacent to Mountview/Airport attach dike, looking upstream (northeast)



Photo 40 Buried and sparse riprap adjacent to Elk River side channel along Mountview/Airport attack dike



Photo 41 **Mountview/Airport setback dike looking downstream (southwest)**



Photo 42 **Mountview/Airport setback dike looking upstream (northeast)**



Photo 43 **Water treatment pump station adjacent to downstream end of Mountview/Airport Dike**



Photo 44 **Mt McLean Drive, potential downstream dike tie-in location, looking west**

Riverside Bank Protection



Photo 45 Riverside Bank Protection, looking downstream (southeast)



Photo 46 Riverside Dike, looking upstream (northwest)



Photo 47 Sparse riprap found along Riverside Dike



Photo 48 Eroding bank protection near downstream end of Riverside Bank Protection segment, looking upstream (northwest)

Appurtenant Structures



Photo 49 Inlet of Shadow Creek culvert under Hwy 3, looking downstream south



Photo 50 Outlet of Shadow Creek culvert under Hwy 3



Photo 51 Mutz Creek diversion gates and overflow culvert near upstream end of West Fernie Dike



Photo 52 Mutz Creek outlet downstream flood gates near downstream end of West Fernie Dike

Park Avenue Bridge



Photo 53 Park Avenue Bridge, looking downstream (northwest)



Photo 54 High bank upstream of Park Avenue Bridge right abutment, looking downstream (north)



Photo 55 Exposed concrete footing with formwork left in place at Park Avenue Bridge left abutment



Photo 56 Bank protection on fill slope downstream of Park Avenue Bridge right abutment

Pine Avenue Bridge



Photo 57 Pine Avenue Bridge, looking upstream (west)



Photo 58 Coal creek banks upstream of Pine AvenueBridge, looking upstream (west) from bridge deck



Photo 59 Concrete ballast wall from previous bridge left in place under Pine Avenue Bridge left abutment



Photo 60 Concrete-covered pipe crossing just downstream of Pine Avenue Bridge, looking downstream (north) from bridge deck

APPENDIX D
GEOTECHNICAL REPORT

GROUNDTECH
ENGINEERING LTD.

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Phone-250.423.4829
Fax-250.423.4819
groundtech@shaw.ca

December 21, 2018

Northwest Hydraulic Consultants
30 Gostick Place
North Vancouver, BC

Attention: Mr. Dale Muir, P.Eng.

RE: GEOTECHNICAL SITE INVESTIGATION REPORT
FERNIE DIKE
CITY OF FERNIE FLOOD MITIGATION PLAN
FERNIE, BC

Dear Mr. Muir,

Please find enclosed two bound copies of the subject report as per your request.

If you have any questions or require additional information, please contact me any time at (250) 423-4829.

Yours truly,



D.A. Clapp, P.Eng.

DAC/dac
encl.

GEOTECHNICAL SITE INVESTIGATION REPORT
FERNIE DIKE
CITY OF FERNIE FLOOD MITIGATION PLAN
FERNIE, BC

Prepared For:
Northwest Hydraulic Consultants
North Vancouver, BC

Groundtech Engineering Ltd.
Box 688, Fernie, BC
250 423 4829

December 2018

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1.0 INTRODUCTION

This report documents the findings and recommendations of a geotechnical site investigation completed by Groundtech Engineering Ltd. (Groundtech) on engineered portions of the Fernie Dike. The dike owner for this project is the City of Fernie (COF). The geotechnical investigation was completed as a component of a Flood Mitigation Plan being coordinated by Northwest Hydraulic Consultants (NHC), the lead engineering consultant for the project.

A floodplain assessment for the Elk River in the vicinity of Fernie was completed by NHC in 2017; this assessment used updated flow data for the Elk River that included flow information for the 2013 flood event. The updated 200-year flood elevations were higher than the previous 200-year flood elevations and indicated most of the dike has to be raised to provide adequate flood and erosion protection.

The scope of work for the geotechnical investigation was defined in the COF's Request for Proposal. The scope of work is as follows:

A geotechnical investigation is required for the Engineered Dike Sections to confirm strength and permeability. Geotechnical investigations should include test pits and/or drill tests to classify materials, water table observations and compaction. These investigations should assess seismic susceptibility, bearing capacity and permeability of the underlying materials to ensure any proposed designs adequately address seepage and settlement. If geotechnical investigations reveal unsuitable conditions additional sub-excavation should be recommended.

Key references for this geotechnical investigation are documented in Section 7 of the report.

2.0 SITE LOCATION AND DESCRIPTION

The engineered sections of the Fernie Dike are shown on Figure 1. Four sections of the dike were investigated:

- Annex West Fernie (mostly setback dike)
- West Fernie (mostly setback dike)
- Mountview (mostly setback dike)
- Riverside (riverside dike/bank armouring)

The Northlands/Maiden Lake area was also investigated as a new dike is being considered for this area. Most of the dike sections investigated are setback dikes. Sections of the dike with riprap armouring include the section of the bank near the north bridge and a 1000 m long section of the west bank of the Elk River upstream and downstream of the West Fernie bridge, adjacent to West Fernie. The dike also has a small section that is armoured in West Fernie near Eckersley Street. Coal Creek also has riprap armouring downstream of the Mountview bridge. There is also a metal bin wall on the south bank of Coal Creek upstream of the Mountview bridge. The dike sections of interest are shown on Figure 1. Photos of the dike are found in Appendix II.

3.0 FIELD INVESTIGATION

Douglas A. Clapp, P.Eng., and Isabel Ferreira, E.I.T., both of Groundtech, completed the field investigation from August 7 to 10, 2018. The site investigation was conducted with a visual assessment of the dike. The soil and groundwater conditions were investigated using boreholes (B1 to B13) drilled with a sonic rig to

depths between 7.62 m of 16.76 m. All boreholes were completed with piezometers to allow for groundwater depth monitoring. The approximate borehole locations are shown on Figures 2 to 5.

Soils exposed in sonic samples and split spoon samples were visually classified and the associated stratigraphy was logged. The borehole logs are found in Appendix III. Soil strength was assessed using Standard Penetration Tests (SPT). SPT results are presented on the logs and in the report text as blows per 0.305 m (e.g., SPT 6 means 6 blows per 0.305 m). Torvane (Tor) and Pocket Penetrometer (PP) testing was also completed on sonic samples to measure undrained shear strength (S_u). Representative samples of selected materials were collected for future reference and/or possible laboratory testing. It should be noted that most of the SPT tests (blow counts) overestimated the soil density of the dike material and underlying foundation soils as these soils had significant gravel content. Blow counts thought to be affected by gravel are indicated on the logs by RE (i.e., rock effect). This was taken into account when assessing soil density.

Groundtech attempted to investigate the backfill conditions of the Coal Creek bin wall. However, it was considered unsafe to access the site with a tracked geotechnical drill rig. The use of Ground Penetrating Radar (GPR) was considered; however, discussions with GPR contractors indicated GPR results would likely be inconclusive. As such, a GPR investigation was not undertaken.

McElhaney completed a geotechnical investigation (see reference 3) on a portion of the dike in 2013. Soil information from this investigation has been incorporated in this report for completeness.

4.0 GEOTECHNICAL ASSESSMENT

4.1 Soil Conditions

Northlands/Maiden Lake Area

B1, B2 and B13 were drilled in this area. The existing dike section in this area is from the North Fernie bridge to near Maiden Lake. The area west of Maiden Lake and the pathway leading to the Best Western Hotel are being considered for a new dike.

B1 was drilled to a depth of 7.62 m just south of Maiden Lake. The B1 soil stratigraphy consisted of a thin top soil layer underlain to a depth of 1.8 m by compact, dry, sandy gravel with some silt (i.e. fill). Soils between depths of 1.8 m and 6.71 m consisted of compact (i.e., SPT 15 to 38) mixtures of sand and gravel with minor amounts of silt and cobbles. Firm (SPT 6) wet, clayey silt was found between depths of 6.71 m and 7.62 m. After drilling, B1 was probed with the split spoon to a depth of 16.76 m where hard soils were encountered. The thickness of the clayey silt layer is estimated at 10 m.

B2 was drilled on the dike section west of Maiden Lake to a depth of 8.23 m. The upper fill layer to a depth of 0.76 m consisted of dense, dry sand and gravel with a trace of silt. Compact (SPT 24), dry to wet mixtures of sand and gravel with traces of both silt and cobbles was encountered between depths of 0.76 m to 6.1 m; the interval between depths of 3.05 m and 3.81 m included interbeds of sand with a trace of silt. The lower most zones included very stiff (SPT 23), wet, clayey silt underlain by soft (Tor S_u 2 kPa), wet, clayey silt.

B13 was drilled on the pathway southwest of 19th Street that leads to the Best Western parking lot. There is a low lying, wet, forested area west of the pathway. The upper layers encountered included asphalt underlain by granular fill (dense, dry gravel and sand with a trace of silt) to a depth of 2.29 m. Middle zones included dense, wet gravel and sand with a trace of both silt and cobbles underlain by compact (SPT 11), wet sand with a trace of silt underlain by compact, wet gravel and sand with a trace of silt. The lower layers included dense, wet gravel with a trace of both sand and silt from depths of 5.79 m to 6.55 m. Soft

(SPT 4, Tor S_u 12 kPa), wet, clayey silt was found to a depth of 16.76 m; dense/hard soils were found at this depth by probing.

Annex Area

B3 to B5 were drilled on the dike in the Annex area.

B3 was drilled to a depth of 8.38 m. The upper fill layer in B3 consisted of compact, dry sand and gravel with a trace of silt. Underlying soils included compact, dry sand and gravel with some silt between depths of 0.76 m to 2.29 m underlain to 2.75 m by stiff to firm, moist mixtures of clay and silt with a trace of gravel. Compact, moist, silty sand with a trace to some clay was encountered between depths of 2.75 m to 3.0 m. Soils below this depth consisted of compact (SPT 30) mixtures of sand and gravel with trace amounts of both silt and cobbles. No silty clay layer was encountered in B3, but it may be present at deeper depths.

B4 was drilled to a depth of 8.23 m. The soil stratigraphy in B4 included compact, dry sand and gravel with some silt (i.e., fill) underlain by compact mixtures of sand and gravel with trace amounts of both silt and cobbles. Firm (SPT 5), wet, clayey silt was found between depths of 6.1 m and 7.0 m. The lowermost zone consisted of soft (Tor S_u 10 kPa), wet, clayey silt.

B5 was drilled near the West Fernie bridge over the Elk River to a depth of 8.38 m. The upper (i.e., 0 m to 2.74 m) fill layer consisted of dense, dry sand and gravel. Underlying soils, to a depth of 6.1 m, consisted of compact (SPT 15 to 19) mixtures of sand and gravel with trace amounts of both silt and gravel. The lowermost horizon consisted of soft (Torvane Su 10 - 13 kPa), wet, clayey silt with a trace of gravel.

West Fernie Area

B6 to B8 were drilled on the dike section in the West Fernie area.

B6 was drilled on the dike near Riverside Road to a depth of 9.9 m. Fill comprised of compact (SPT 19 to 32), dry gravel and sand with trace amounts of silt and cobbles was encountered to a depth of 2.74 m. Underlying soils consisted of very loose (SPT 2), silty sand with a trace of clay between depths of 2.74 m and 4.42 m. Compact, wet gravel and sand with a trace of silt was encountered to a depth of 6.1 m underlain to 7.9 m by soft (Torvane Su 15 kPa), wet clayey silt. The lowermost zone is interpreted to be till consisting of stiff (PP S_u 62 kPa) clayey silt with some sand and some gravel.

B7 was drilled to a depth of 8.38 m on the dike east of Hand Avenue. The upper fill layer consisted of compact, dry sand and gravel with some silt. The middle horizons consisted of compact (SPT 17), moist sand and gravel with trace amounts of both silt and cobbles in the lower portion of the interval. Very loose (SPT 2), wet, silty sand with a trace of clay was found between depths of 4.27 m and 6.1 m. A thin layer of compact (SPT 23), wet gravel and sand with a trace of silt was encountered to a depth of 6.4 m, underlain by soft (Tor Su 10 – 13 kPa), wet, clayey silt.

B8 was drilled/probed to a depth of 16.76 m. Fill consisting of compact (SPT 28), dry gravel and sand with trace amounts of both silt and cobbles was encountered to a depth of 1.52 m. Compact, dry to wet, gravel and sand with trace amounts of both silt and cobbles was encountered to a depth of 5.18 m. The lowermost zone consisted of soft (Tor Su 12 – 13), wet, clayey silt. Probing found dense/hard soils at a depth of 16.76 m. The thickness of the clayey silt layer is estimated at 11.6 m.

McElhaney TP1

TP1 was excavated to a depth of 4.2 m. Compact to dense, damp sandy gravel with a trace to some fines (i.e., fill) was encountered to a depth of 2.6 m. Fine to medium, compact, moist to wet sand with some

fines was encountered to a depth of 3.5 m. The lowermost layer consisted of stiff, moist fine sand and silt with a trace of clay.

McElhaney TP2

The upper fill soils consisted of compact, damp, sandy gravel with cobbles underlain by compact, damp sand and silt. Organics and sand were encountered between depths of 2.7 m and 3.0 m. The lowermost zone consisted of compact to dense gravel with some sand and a trace of fines. Total depth of TP2 was 4.0 m.

McElhaney TP3

Compact to dense, damp to moist, sandy gravel with a trace to some fines with a trace of cobbles (i.e., fill) was found to a depth of 1.6 m, underlain to 1.9 m with topsoil (i.e., organics, sand and fines). A thin layer of compact, damp medium to fine sand with a trace to some fines was identified between depths of 1.9 m and 2.1 m. Compact, damp, sandy gravel with a trace of fines was found to the bottom of the test pit at a depth of 3.6 m.

Mountview Area

B9 was drilled in the northern portion of the Mountview area on the dike section south of Coal Creek. The soils stratigraphy included dense, dry gravel and sand with some silt (i.e., fill) to a depth of 3.05 m. Underlying soils consisted of compact, moist, silty sand with some gravel, underlain by compact, silty sand with some gravel. Firm to soft, wet, clayey silt was found at a depth of 7.0 m. Probing encountered hard/dense soils at a depth of 15.5 m. The thickness of the soft clay layer is estimated at 8.5 m.

B10 was drilled to a depth of 8.23 m on the dike section west of the subdivision. The soils stratigraphy included a fill layer comprised of compact, dry sand and gravel with some silt. Compact, dry to wet mixtures of sand, gravel and silt were encountered between depths of 3.05 m and 6.10 m. The lowermost zone consisted of firm (Tor S_u 35 kPa), wet, clayey silt; probing indicates these soils extended to a depth of 8.83 m.

B11 was drilled/probed to a depth of 15.24 m near the Mt. McLean Street access to James White Park. The fill layer consisted of compact, dry mixtures of sand and gravel with some silt and a trace of cobbles. The underlying soils were similar in density and texture except the silt content varied from some to a trace (lower in the interval). Firm, wet, clayey silt was found in the 4.57 m to 5.1 m interval. The lowermost zone was comprised of soft (Tor Su 12 – 13 kPa), wet, clayey silt. The thickness of the clayey silt layer is estimated at 10 m.

Stanford Area

B12 was drilled just northwest of the Stanford Inn parking lot to a depth of 9.75 m. Granular fill was found to a depth of 3.05 m and is described as silty topsoil over compact, dry, mixtures of sand and gravel with a trace to some silt. Cobbly gravel with some sand and a trace of silt was found to a depth of 4.57 m. The lower interval consisted of soft (Tor Su 10 – 15 kPa), wet, clayey silt. Based on the stratigraphy of B11 the clayey silt layer could extend to a depth of approximately 15 m.

Soil Stratigraphy Considerations

The dike fill material generally consists of compact to dense mixtures of sand and gravel with a trace to some fines. There is a clay layer, at depth, below the ground surface in the area of the dike and proposed area for diking. The soils above the clay layer, to the underside of the existing dike, are generally coarse

grained, permeable soils. Table 1 below presents depth data for the clay layer:

Table 1
Depth Data for Clay Layer

Borehole/Cross-section	Top of Dike/Ground surface to Top of Clay Layer (m)	Bottom of Dike to Clay Layer (m)	Description of soils from underside of Dike to Clay Layer (m)
B1/XS1	6.7	NA	NA (no dike).
B13/XS2	6.55	NA	NA (no dike).
B2/XS3	6.1	4.6	Compact sand and gravel with a trace silt.
B3/XS4	NA	NA	Compact sand and gravel with some silt.
B4/XS5	6.4	4.58	Compact sand and gravel with a trace to some silt.
B5/XS6	6.4	5.64	Compact sand and gravel with a trace silt.
B6/XS7	6.1	3.36	Compact sand and gravel with a trace silt.
B7/XS8	6.4	5.96	Compact sand and gravel with a trace silt; very loose silty sand.
B8/XS9	5.2	3.68	Compact sand and gravel with a trace silt.
B9/XS10	7.0	3.95	Compact, silty sand and mixtures of sand and gravel with a trace to some silt.
B10/XS11	6.1	3.05	Compact sand and gravel with a trace to some silt.
B11/XS12	4.6	3.0	Compact sand and gravel with a trace to some silt.
B12/XS13	4.6	3.1	Compact sand and gravel with a trace to some silt
Average	5.99	3.9	

4.2 Soil Permeability Conditions

The dike and upper layers of the underlying soils are permeable. Table 2 presents permeability estimates for the dike and underlying materials:

Table 2 Soil Permeability		
Dike Material		
Sample	**Permeability m/sec**	**Method**
B1 S1	1.6×10^{-3}	Hazen
B2 S3	8.1×10^{-3}	Hazen
B9 S2	4×10^{-4}	Hazen
B11 S2	1.6×10^{-3}	Hazen
TP1 SA1	5.8×10^{-3}	Permeameter
TP2 SA3	4.6×10^{-4}	Permeameter
Average	**3.0×10^{-3}**	
Underlying Material		
B1 S8	1.4	Hazen
B2 S6-10	4.0×10^{-3}	Hazen
B3 S11	6.3×10^{-2}	Hazen
B5 S5-6	1.0×10^{-2}	Hazen
B5 S3	4×10^{-2}	Hazen
B9 S3-6	1.6×10^{-3}	Hazen
B12 S7	2.25×10^{-2}	Hazen
TP1 SA3	2.1×10^{-3}*	Permeameter
TP1 SA3	3.6×10^{-3}*	Hazen
TP1 SA4	$1 \times 10^{-4*}$	Permeameter
TP3 SA2	4.2×10^{-1}	Permeameter
Average	**2.2×10^{-1}**	

*Note:the average of the two values was used to calculate the overall average.

The Hazen method uses the D_{10} values from the gradation. For the samples that were assessed, the underlying soils are two orders of magnitude more permeable than the dike materials.

4.3 2013 Flood Conditions

NHC provided stage-time data for the 2013 Elk River peak flow event. Table 3 presents rate of fall data for the river stage for that event:

Table 3 Rate of Fall Data For Elk River 2013 Peak Flow Event	
Time Interval (hr)	Rate of Fall (cm/sec)
1	4.3×10^{-3}
6	9.9×10^{-3}
12	3.28×10^{-4}
24	5.0×10^{-4}
48	5.1×10^{-4}

Note: the rate of fall values are similar to the permeability values estimated for the dike materials.

4.4 Laboratory Test Results

Groundtech Tests

A washed gradation test (ASTM C136 and C117) was completed on 12 soil samples to determine gradational characteristics. Moisture content test was also completed on the samples. The test results are summarized in Table 4.

Table 4
Washed Gradation Test Data

Sample	Cobble (%)	Gravel (%)	Sand (%)	Silt (%)	Moisture Content (%)	Description
B1 S1		61.8	26	12.2	6.1	Sandy gravel, some silt
B1 S8		77.7	20.6	1.7	4.0	Sandy gravel, trace silt
B1 S13					27	
B2 S3		65.4	25.6	9.0	2.4	Sandy gravel, trace silt
B2 S6, S7, S8, S9, S10	4.3	56.8	28.3	10.6	6.8	Sandy gravel, some silt, trace cobble
B3 S5, S6, S7, S8		0.1	30.9	69	33.8	Sandy silt
B3 S11		75.5	19.4	5.1	5.7	Gravel, some sand, trace silt
B4 S14					23.4	
B5 S3		70.3	22.9	6.9	1.8	Sandy gravel, trace silt
B5 S5, S6		64	27.2	8.9	5.1	Sandy gravel, trace silt
B5 S10					25.4	
B7 S12					21.4	
B8 S13					25.2	
B9 S2		48.2	35.5	16.2	2.5	Gravel and sand, some silt
B9 S3, S4, S5, S6	13	51.5	22.9	12.5	6.8	Sandy gravel, some cobble, some silt
B11 S2	6.7	46.9	32.6	13.8	2.7	Sandy gravel, some silt, trace cobble
B11 S5					27.1	
B12 S7	34.1	44.4	13.5	8.1	2.4	Cobbly gravel, some sand, trace silt
B12 S11					25.6	
B12 S17					26.0	

Most of the above samples have good drainage characteristics.

Atterberg Limits tests (ASTM D4318) were completed on seven fine-grained soil samples to determine plastic and liquid limits. The test results are summarized in Table 5.

Table 5
Atterberg Limit Test Data

Borehole Sample	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)	Soil Classification as per Casagrande Chart
B2 S13	19.1	28	15	13	CL
B8 S13	25.2	26	17	9	CL
B9 S7	25.8	31	19	12	CL
B10 S6	25.8	30	19	11	CL
B11 S5	27.1	28	18	10	CL
B12 S11	25.6	26	18	8	CL
B12 S17	26	29	19	10	CL

The moisture contents for some of the samples are close to the liquid limit suggesting they may be normally consolidated. Normally consolidated soils have experienced effective stresses no higher in the past than at present. The lab test reports are found in Appendix IV.

An Oedometer test was completed by Golder Associates on one fine-grained sample to determine consolidation parameters. The test results, which includes the average consolidation parameters from five other silt/clay samples from the Fernie area, are presented in Table 6:

Table 6
Odeometer Test Data

Sample	Estimated Overconsolidation Ratio (OCR)	Compression Index C_c	Swell Index C_s
B6 S13	1.2	0.088	0.006
Average of five other samples from Fernie	n/a	0.16	0.02

The OCR value for sample B6 S13 indicates the soil is slightly over-consolidated. This means the sample has been exposed to slightly higher stresses in the past, relative to the present.

McElhaney completed a washed gradation test (ASTM C136 and C117) on one soil sample to determine gradational characteristics. A moisture content test was also completed on the sample. The test results are summarized in Table 7.

Table 7
McElhanney Washed Gradation Test Data

Sample	Cobble (%)	Gravel (%)	Sand (%)	Silt (%)	Moisture Content (%)	Description
TP2 SA3			58.4	41.6	23.2	Sand and silt (SM)

The above sample has significant silt content, indicating moderate to high frost action potential and poor drainage characteristics.

McElhaney completed washed gradation and hydrometer tests (ASTM C136, C117 and D422) on three soil samples. The test results are summarized in Table 8.

Table 8
McElhanney Hydrometer Test Data

Sample	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Moisture Content (%)	Description
TP1 SA3	0.5	84.2	15.3		37.8	Sand with some silt (SM)
TP1 SA4	0.8	49.7	46.6	2.9	40.9	Sand and silt with traces of clay and gravel (SM)
TP3 SA2	72.8	26.1	1.1	0	2.9	Sandy gravel trace silt (GP)

Samples TP1 SA3 and TP1 SA4 have significant silt content, indicating slight to high frost action potential and poor drainage characteristics.

4.5 Groundwater Conditions

Table 9 presents the results of the groundwater monitoring program:

Table 9 Groundwater Monitoring			
Borehole/Piezometer	**Depth to Groundwater (m)**		
	August 30, 2018	**October 29, 2018**	**Comments**
Northlands/Maiden Lake Area			
B1	2.74	2.71	
B2	4.14	4.1	
B13	2.91	2.9	
Annex Area			
B3	3.96	3.94	
B4	3.89	3.93	
B5	3.93	3.98	Adjacent to river
West Fernie Area			
B6	4.08	3.92	
B7	4.3	4.4	
B8	3.69	3.73	
Mountview Area			
B9	Dry	dry	
B10	5.99	6.12	
B11	4.2	4.15	
Stanford Area			
B12	4.42	4.34	Adjacent to river

In the Fernie area groundwater flows typically present seasonal trends with an increasing trend through the spring-early summer to a peak, then a declining trend for the remaining seasons. The groundwater regime is driven by snowmelt. The level of the Elk River also influences the groundwater levels. Short term increases also occur due to rainfall events.

Additional groundwater data will be acquired by Groundtech in 2019 (see Section 5.4 of the report).

4.6 Dike Conditions

Table 10 presents topographic data for the dike that is based on survey work completed by Align Surveys.

Table 10 Dike Dimensional Characteristics					
Northlands/Maiden Lake*					
	Landside Height (m)	**Landside Slope Angle (°)**	**Width (m)**	**Riverside Height (m)**	**Riverside Slope Angle (°)**
Average	1.1	18.0	8.0	2.95	21.5
Minimum	0.9	12.1	7.5	2.45	19.3
Maximum	1.4	21.4	8.8	3.92	24.7
Annex Area					
Average	1.39	13.4	3.8	2.0	17.4
Minimum	.06	0.8	2.2	0.2	1.4
Maximum	2.82	20.0	6.4	3.9	27.4
West Fernie Area					
Average	2.59	20.5	6.8	1.6	17.5
Minimum	0.24	9.5	3.6	.5	9
Maximum	4.15	32.1	16.6	3.0	26
Mountview Area					
Average	2.73	18.5	5.3	2.3	22.4
Minimum	1.0	5.0	3.1	1.1	14.1
Maximum	4.1	28.1	28.1	3.5	33.9
Stanford Area**					
Average				3.69	27.1
Minimum				2.79	24.7
Maximum				5.84	43

*Note: Only cross-sections between the North Fernie Bridge and Maiden Lake were assessed for the Maiden Lake/Northlands Area. There is no dike at Sections 1 and 2.
** Note: This represents the armoured bank in the area.

Thirteen cross-sections of the dike were prepared with each cross-section near to a borehole. The cross-sections, which show the interpreted soil stratigraphy, are found in Appendix V. The cross-section locations are shown on Figures 2-5.

Spot checks along the existing dike indicated no signs of slope instability.

A metal bin wall on a section of Coal Creek between the Park Avenue bridge and the railway bridge to the east serves to provide flood and erosion protection. As noted in Section 3.0 of the report, attempts were made to investigate the bin wall backfill conditions due to concerns of the City of Fernie that some of the backfill may have been eroded by seasonal floodwater. The concrete walkway that covers the backfill does not present any significant distress (i.e., cracking settlement etc.). The metal facing of the bin wall is not significantly damaged. This being the case, no further investigations are recommended at this time. If the bin wall or a concrete walkway present signs of distress in the future, a geotechnical investigation should be initiated.

5.0 GEOTECHNICAL ASSESSMENT

The geotechnical assessment was comprised of assessing dike soils and foundation soils in terms of strength, density and permeability. Seepage characteristics of the dike and underlying materials were also assessed. In addition, bearing capacity of foundation soils was assessed as well as susceptibility to seismic loading.

5.1 Dike and Underlying Materials

The dike fill materials generally consist of compact to dense mixtures of sand and gravel with a trace to some silt. The underlying soils are for the most part, characterized by compact mixtures of sand and gravel with variable minor amounts of silt and cobbles. Boreholes B3, B6, B7 and B9 contain middle zones of mixtures of sand and silt with density that ranged from very loose to compact. Clay soils generally underlay the overlying coarse grain soils. Clay soils were encountered at depths (from the existing top of the dike) ranging from depths of 4.6 m to 7.0 m. The clay soils often consisted of a firm layer overlying a soft layer. hard/dense soils are interpreted to underlie the clay soils; these soils were encountered at depths of 7.9 m to 16.8 m.

No soil conditions, in terms of strength, were encountered that would significantly impact dike design.

5.2 Foundation Soil Bearing Capacity

The ultimate bearing capacity using Terzaghi's method was used to estimate soil bearing capacity for each of the cross-sections using DC-Bearing, a 2 dimension multi soil layer program. The bearing capacity was determined assuming a trapezoid footing with a 4 m wide top and 2.5H:1V side slopes. The top surface of the trapezoid was placed at the Flood Construction Level (FCL) elevation above the existing dike; the elevation was representative of the required fill height for the 200 year flow elevation (plus 0.6 m freeboard). The bottom elevation of the trapezoid, where it encountered the ground surface, was representative of the bottom of the footing. The calculated ultimate soil bear capacity was compared to the estimated pressure that the pseudo footing would impose. The results of the analysis is presented in Table 11:

Table 11
Estimated Soil Bearing Capacity

Cross-section	Pseudo Footing Width (m)	Estimated Ultimate Soil Bearing (kPa)	Estimated Stress at Bottom of Pseudo Footing (kPa)	Factor of Safety	Comments
XS-1	11	216	25	8.6	No dike present
XS-2	9.8	181	24	7.5	No dike present
XS-3	9.9	153	64	2.4	
XS-4	13.0	1066	43	24.8	
XS-5	20.0	284	118	1.7	
XS-6	6.0	311	9	34.5	
XS-7	14.6	78	21	3.7	
XS-8	5.8	122	13	9.4	
XS-9	9.8	95	21	4.5	
XS-10	16.9	82	16	5.1	
XS-11	20	192	1.4	137	
XS-12	12	85	6.6	12.8	

XS-13	na	na	na	na	FCL lower than ground surface

The analysis indicates the subgrade soils should adequately support a raised dike.

5.3 Seepage Assessment

Preliminary seepage analysis was completed using Rocscience's Slide (2018) software on a typical dike section utilizing the aforementioned average permeability values presented earlier for the dike and foundation soils. The analysis utilized flood stage data from the 2013 flood event. The evaluation indicated the dike material and foundation soils are sufficiently permeable to allow the phreatic surface, within the dike (at and near the water side of the dike), to essentially track the changing surface level of the river (i.e., decreasing and increasing stage elevation). The analysis also indicated that ponding beyond the landside of the dike is probable but depends of the ground surface and head difference between the water and land side of the dike. Of interest, ponding occurred on the land side of the Annex dike during the 1995 flood event. However, one should be aware that regional groundwater that flows into the area from the east (mountain to river) will also elevate local groundwater levels.

The construction of a cutoff trench filled with impermeable soils (i.e., clay) would help mitigate under seepage beneath the dike. However, to be truly effective, the trench would have to be completed into the underlying clay layer. Construction of a cutoff trench may require dewatering during construction and would be challenging due to the depth of the clay layer from the underside of the dike (i.e., average 3.9 m). The cost of a cutoff trench would be significant. There would also be some risk regarding the effectiveness due to the local groundwater regime. Groundtech's experience in the area indicates typical groundwater flows are perched in and above a lower clay layer. Regional groundwater flows are interpreted to be for the most part, in a mountain to river direction. Peak groundwater flows are supported by snowmelt and typically occur during the spring, similar to peak river flows. The timing of these peak river and groundwater flow events may not exactly coincide. In any event, elevated groundwater levels and surface ponding would be supported by both underseepage beneath the dike and throughseepage through the dike as well as groundwater flows toward the dike from opposite direction. As such, the effectiveness of a cutoff trench to limit ponding/flooding on the landward side of the dike could be compromised. As such, the cost/benefit of construction of a cutoff may not be less than satisfactory. Further detailed hydrogeological study should be undertaken to confirm the benefits of a cutoff trench. A cutoff trench could be added at a later time.

The use of lower permeability soils in the dike upgrade should be considered as a cost effective method to reduce throughseepage.

5.4 Preliminary Slope Stability Analysis

Slope stability analysis of the proposed dike upgrade was not part of the work scope. However, Groundtech completed some preliminary analysis on a typical cross-section to develop preliminary dike side slope recommendations. Rocscience's Slide (2018) program was used to complete the analysis.

Typically, three conditions are evaluated for slope stability analysis for dike design:

1. End of construction using undrained conditions for impervious dike and foundation soils. Water and land sides are evaluated. The typical acceptance threshold Factor of Safety (FOS) values range from 1.2 to 1.3.

   The existing dike and upper layers of the underlying soils are pervious, coarse grained, free draining

materials. The only impermeable soils are the clay soils that are located, on average, 3.9 m below the base of the existing dike. Preliminary analysis indicated the failure surfaces with the lowest factor occur within the dike itself. As such, assessment of end of construction may not be warranted.

2. Rapid Draw Down is a condition where prolonged seepage saturates a major part of the water side of the dike. For the rapid draw down condition to occur, the soils in the dike drain slower than the fall of the river surface. This condition applies to the water side of the dike. Typical acceptance threshold FOS values are 1.2 to 1.3.

   Based on estimated permeabilities for the dike and foundation soils, these soils are considered free draining and will provide good drainage. The fall of the river stage is interpreted to be slow enough to allow the soils to drain and not develop elevated pore pressures and/or saturated soils above the stage elevation. All things considered, the probability of a rapid draw down condition occurring is low.

3. Steady State Seepage from full flood stage. The analysis assumes the duration of the full flood stage being long enough to fully saturate the dike. The condition may lead to the land side of the dike becoming unstable. The typical FOS acceptance value for this condition is 1.5.

   Preliminary analysis indicates a side slope of 2.5H:1V should provide suitable stability if the head difference between the land side and river side of the dike is 3.5 m or less and the landside of the dike is at least 1 m higher than the river side of the dike. Detailed stability analysis on a section by section basis would be required to provide a final determination of recommended side slopes. Common side slopes for dikes are 3H:1V.

5.5 Liquefaction Assessment

Using Bray et al (2004) criteria, which utilizes Atterberg Limit data, the susceptibility of the underlying clay soils ranges from non-susceptible to susceptible.

Novo Tech's software NovoLIQ was used to complete the liquefaction assessment. The stratigraphy and SPT data from B7 were used in the assessment as B7 presented representative, if not worst case, conditions. Earthquake data was acquired from the Earthquake Canada website for Fernie for the analysis. Key input parameter earthquake data included Peak Ground Acceration (0.107) and Magnitude (5.4). The analysis indicated the FOS against liquefaction ranged from 5.32 for the upper gravel layers to 1.04 for the lower clay zone. The probability of liquefaction ranged from 1.4 % for the upper gravels to 15.4 % for the lower clay layer. Given the FOS values and the relatively low probability of liquefaction, no mitigation works are recommended at this time.

5.6 Settlement Assessment

The two types of settlement that are typically assessed include immediate and consolidation settlement. It is assumed that immediate settlements would occur during construction as the loads from the fills occur. Consolidation settlement would occur over a longer duration as the underlying clay responds to the surface loading. Rocscience's Settle 3D software was used to estimate settlement. Based on a review of FCL and cross-section data, the dike will be raised between 0.06 m and 1.07 m. Data for B4 was used in the assessment as this represents the worst case in terms of fill thickness and depth to the clay layer. The analysis indicates consolidation settlement could be in the order of 25 mm.

5.7 Follow-Up Groundwater Monitoring

Groundwater measurements will be acquired from the piezometers twice a month for April through June of 2019. The data will be forwarded to NWH and COF.

6.0 CLOSURE

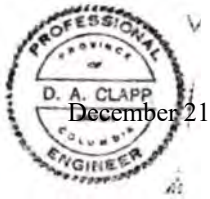
This report has been prepared for the exclusive use of Northwest Hydraulic Consultants and the City of Fernie.

This report is based on subsurface information obtained during the site investigation, which was conducted with accepted geotechnical engineering principles and practices. It should be noted that natural soil and groundwater conditions can be variable. No other warranty, expressed or implied, is made. Groundtech should be contacted if subsurface conditions encountered during construction differ from those anticipated and/or interpreted from the site investigation.

Individual recommendations presented in this report should not be used out of context with the entire report. Interpretation of any part of this report should be made in consultation with Groundtech. Any use or reliance of this report by a third party is the responsibility of said party and Groundtech accepts no responsibility for any damages suffered by said party as a result of decisions made or actions taken based on this report.

If there are any questions or concerns regarding the foregoing information please call Douglas Clapp, P. Eng., at (250) 423-4829.

Respectfully submitted,



December 21, 2018

Douglas A. Clapp, P. Eng.
DAC

7.0 REVIEW OF EXISTING INFORMATION

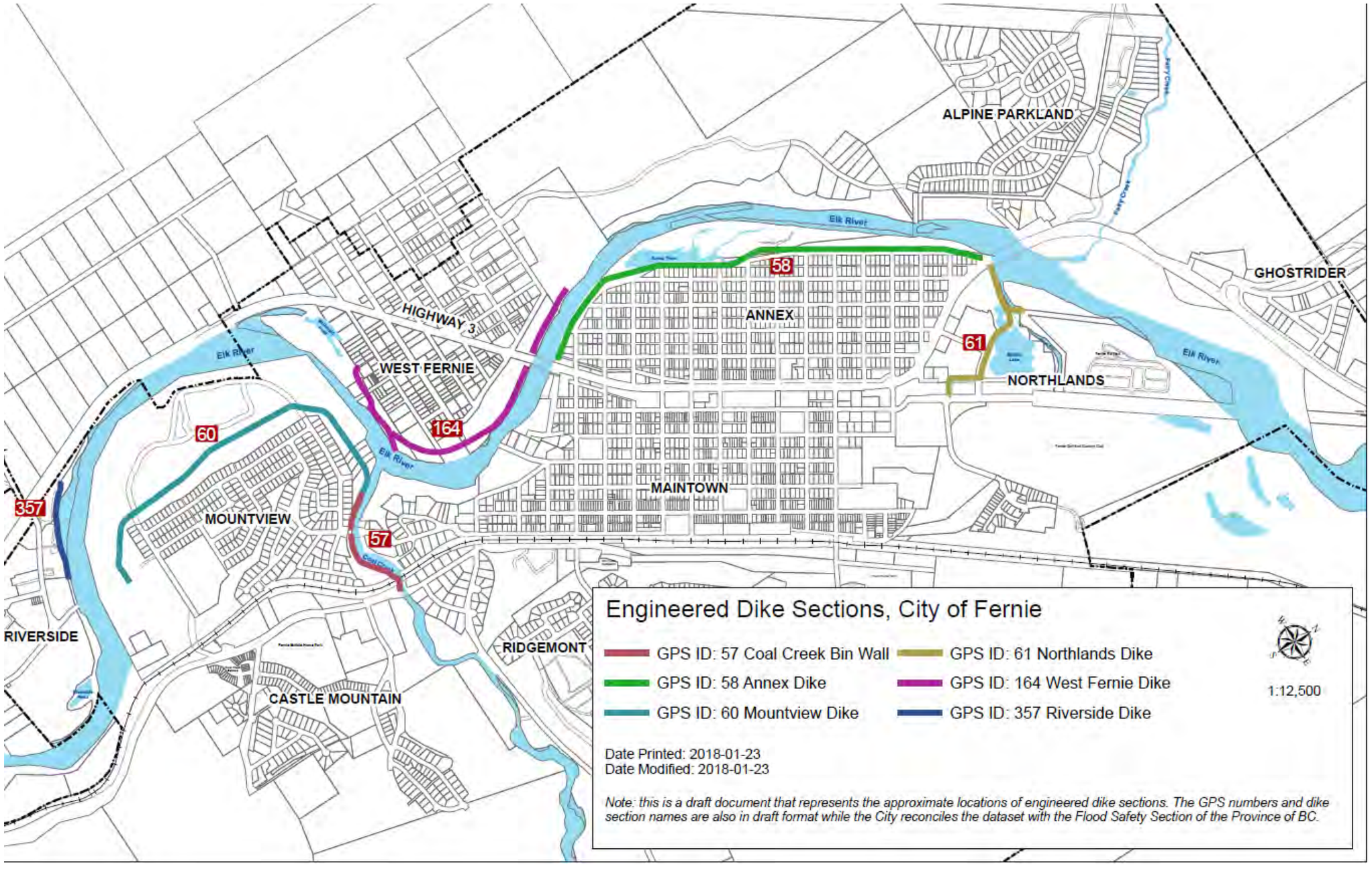
1. Dike Design and Construction Guide, Best Management Practises for British Columbia prepared by the Flood Hazard Management Section, Environmental Protections Division, Province of British Columbia, Ministry of Water, Land and Air Protection, dated July 3, 2003.
2. Seismic Design Guidelines for Dikes 2nd Edition, Ministry of Lands and Natural Resource Operations, Flood Safety Section, dated June 2014.
3. Geotechnical Site Review – Existing Dike Conditions, West Fernie Dike Improvement Phases 3-4, West Bank of the Elk River, Regional District of the East Kootenay, prepared by McElhaney, dated May, 2013.
4. Geotechnical Site Investigation Project, West Fernie Dike Improvement Project – Phase 2
5. Fernie, BC, Groundtech Engineering Ltd. dated July, 2012.
6. Elk River Floodplain Map, Northwest Hydraulic Consultants, dated March 2017.
7. Cross-section survey data acquired by Align Surveys for this project.

APPENDIX I

Figures

Figure 1

Location Map



Project:

Geotechnical Site Investigation
Fernie Dike
Flood Mitigation Plan

Scale: NTS

File: 18m15fg

Groundtech Engineering Ltd.



Figure 2

Site Map

Project:

Geotechnical Site Investigation
Fernie Dike
Flood Mitigation Plan

Legend:

Borehole Locations: B1

Cross Section Locations: XS3

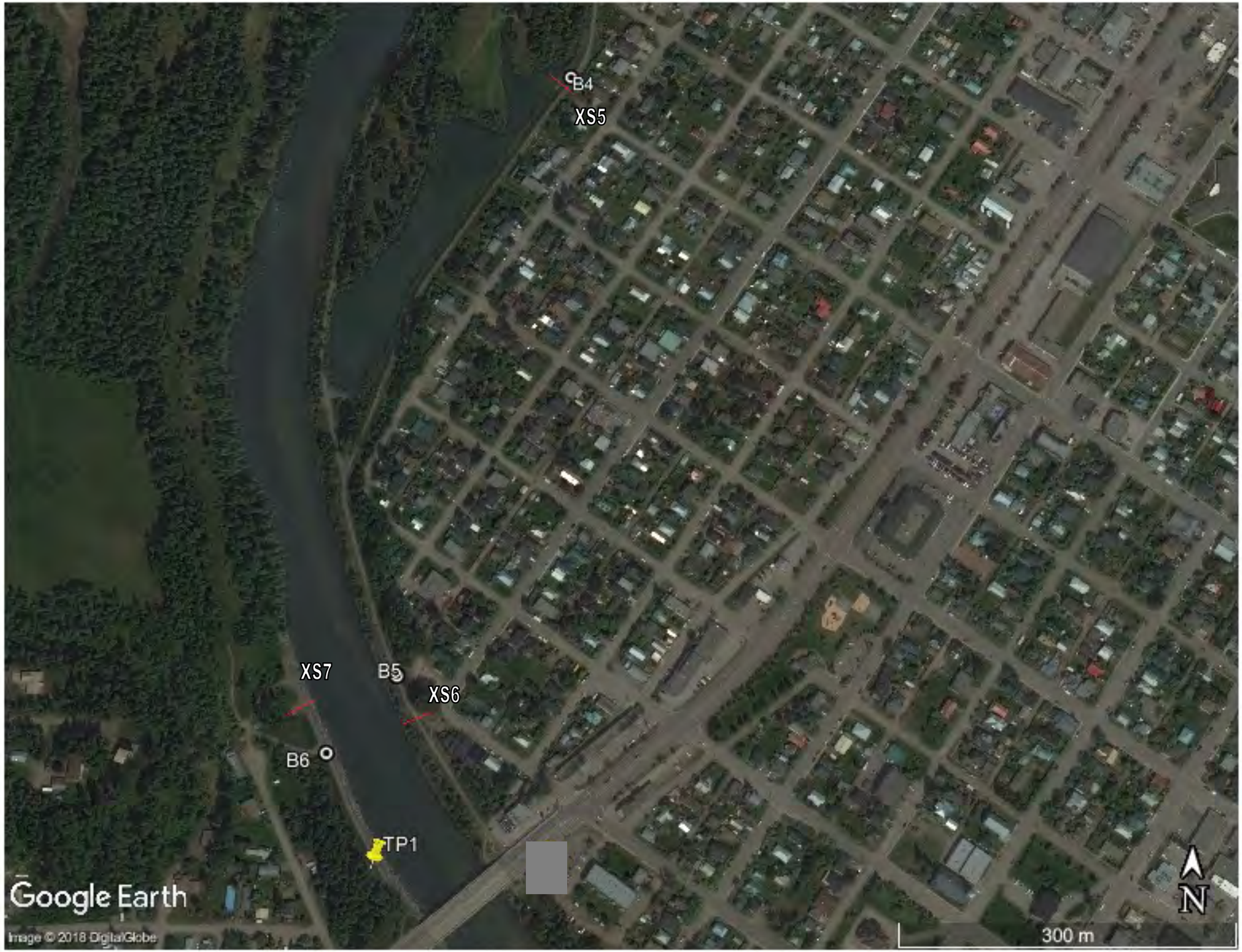
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File: 18m15fg

Groundtech Engineering Ltd.

Figure 3

Site Map



Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Legend:

Borehole Locations: B1

Cross Section Locations: XS3

Test Pit Locations: TP1

Scale: 1:300

File: 18m15fg

Groundtech Engineering Ltd.

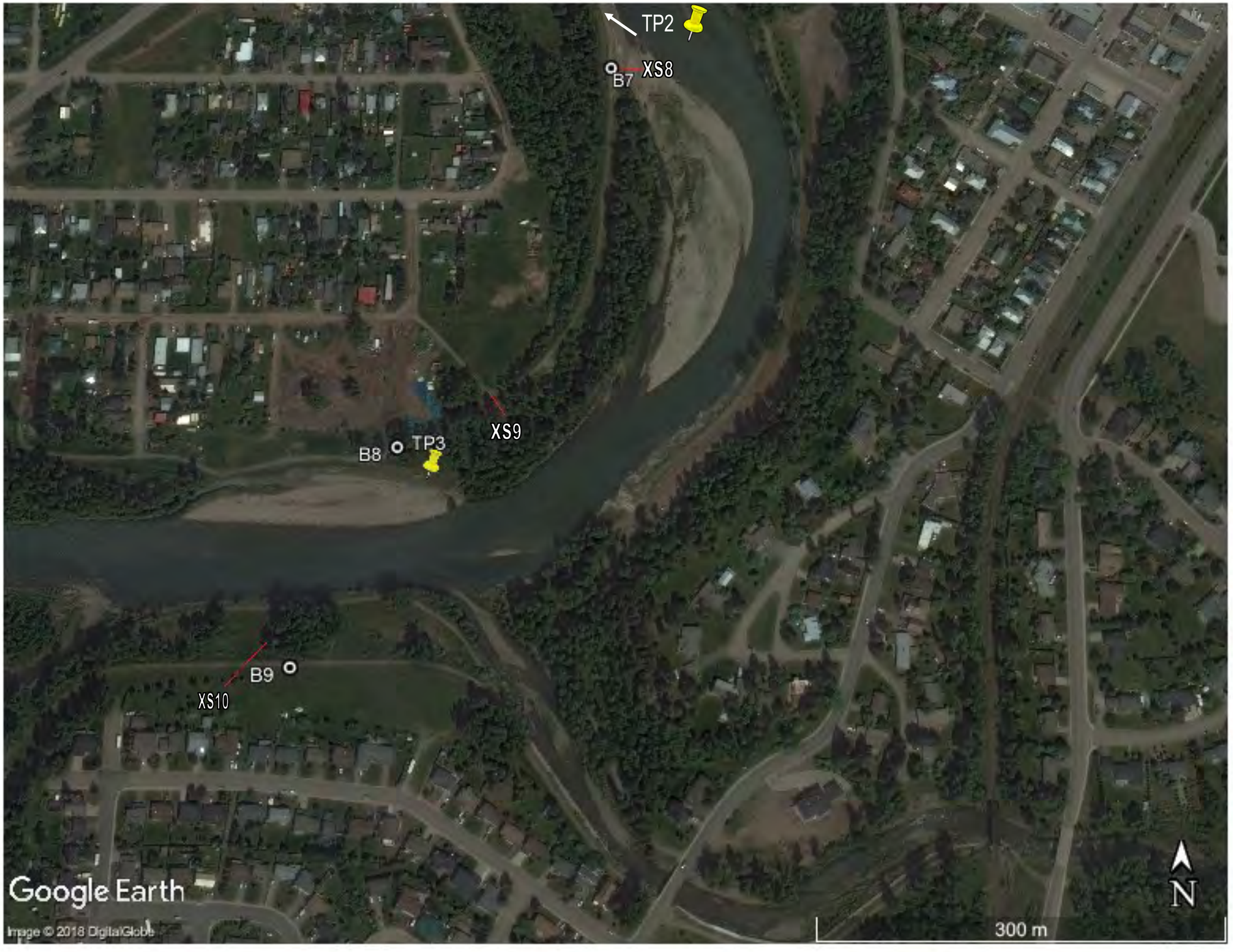


Figure 4

Site Map

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Legend:

Borehole Locations: B1

Cross Section Locations: XS3

Test Pit Locations: TP1

Scale: 1:300

File: 18m15fg

Groundtech Engineering Ltd.



Figure 5

Site Map

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Legend:

Borehole Locations: B1

Cross Section Locations: XS3

Test Pit Locations: TP1

Scale: 1:300

File: 18m15fg

Groundtech Engineering Ltd.

APPENDIX II

Photos



Photo 1

Borehole 1 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.



Photo 2

Borehole 2 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.



Photo 3

Borehole 3 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.



Photo 4

Borehole 4 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.



Photo 5

Borehole 5 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.



Photo 6

Borehole 6 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.



Photo 7

Borehole 7 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.



Photo 8

Borehole 8 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.



Photo 9

Borehole 12 Location

Project:

Geotechnical Site Investigation
Fernie Dike
City of Fernie
Flood Mitigation Plan

Scale: NTS

File: 18m15ph

Groundtech Engineering Ltd.

APPENDIX III

Test Pit and Borehole Logs

Project No: 18m15

Project: Fernie Dike

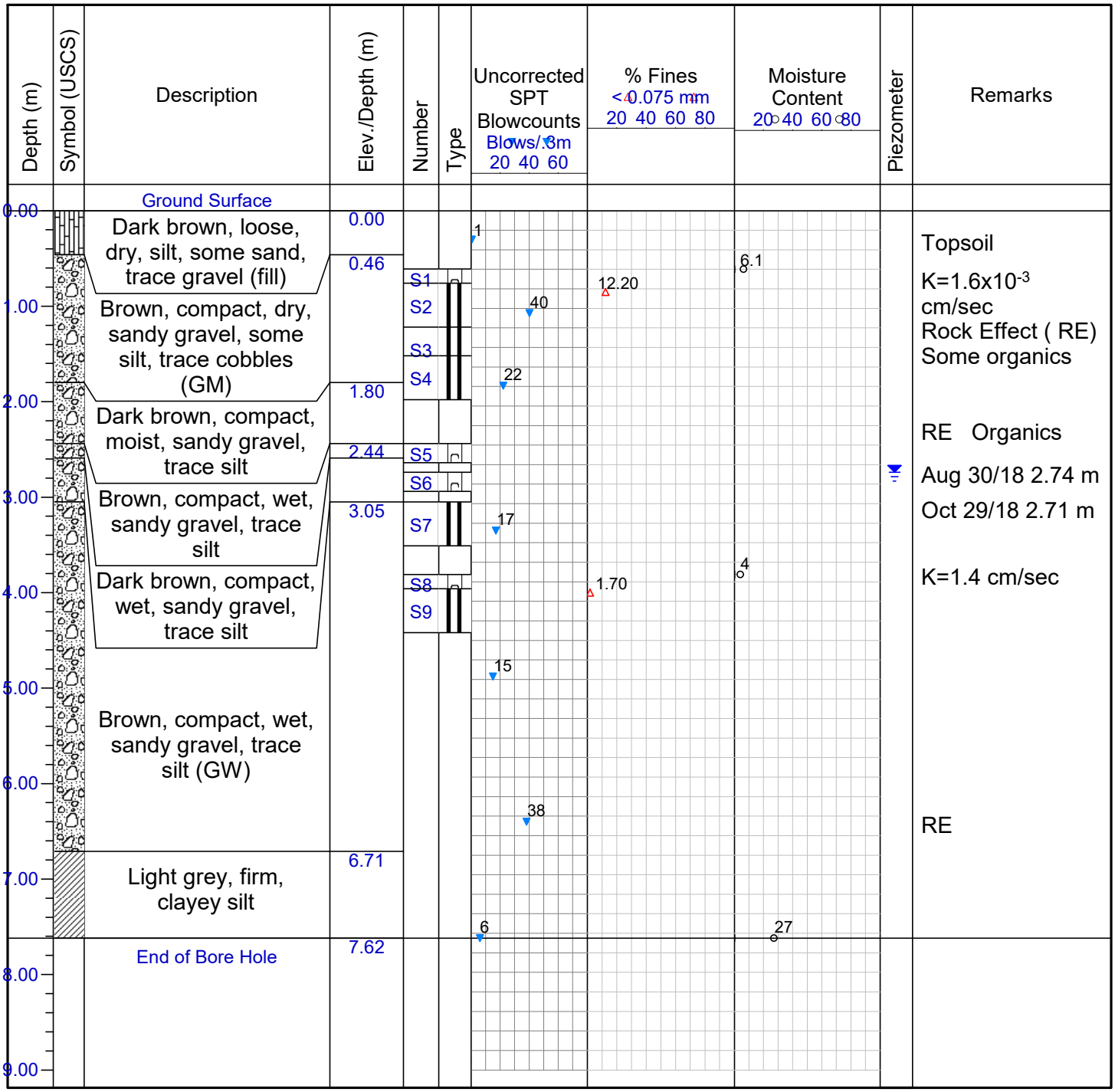
Client: NHC

Location: Maiden Lake - Elevation = 1003.0 m

Bore Hole: B1

Date: August 7 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic Drill

Logged By: IF

Groundtech Engineering Ltd.
PO Box 688
Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

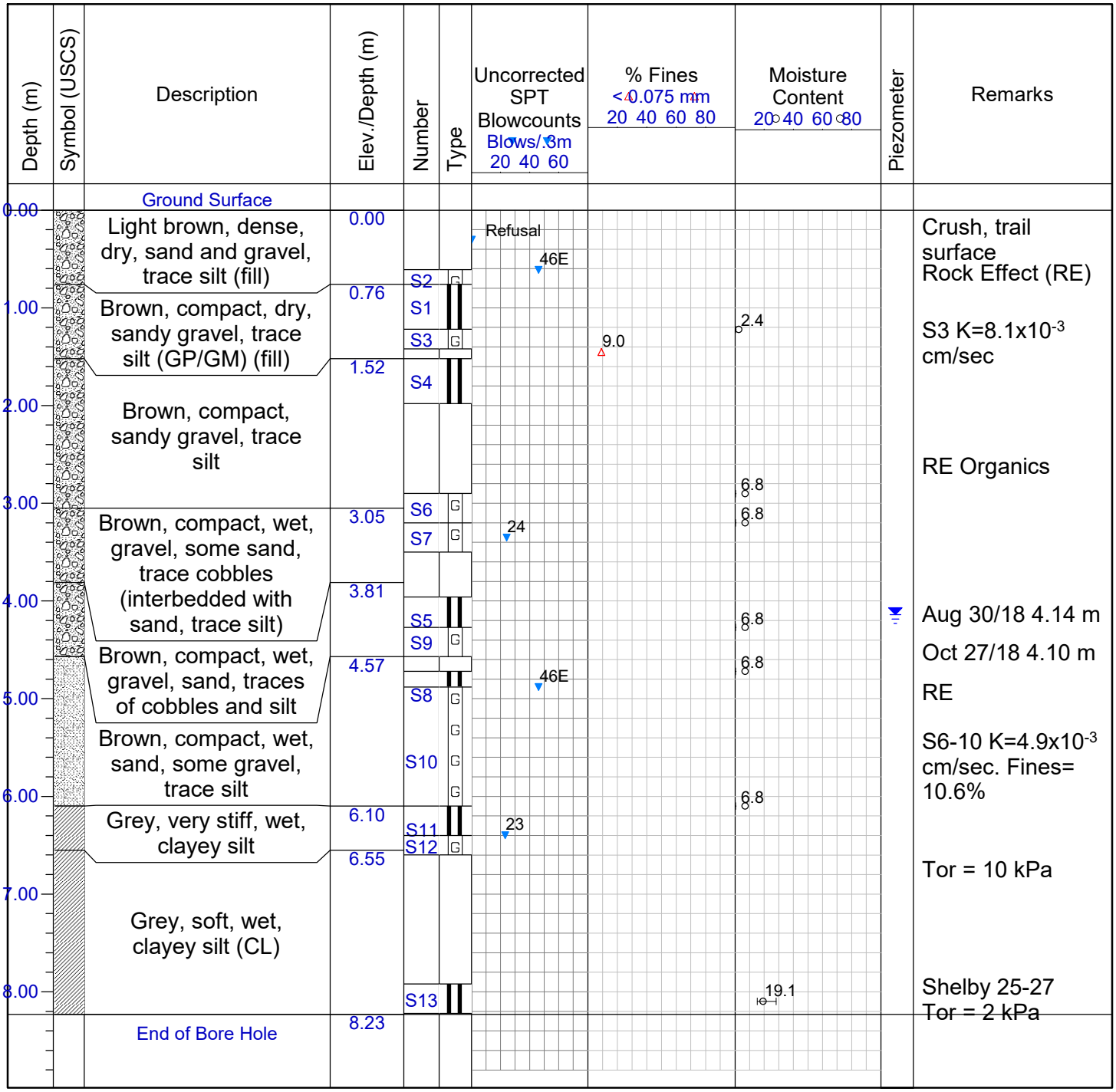
Client: NHC

Location: West of Canadian Tire - Elevation = 1003.3 m

Bore Hole: B2

Date: August 7, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: IF

Groundtech Engineering Ltd.
PO Box 688
Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

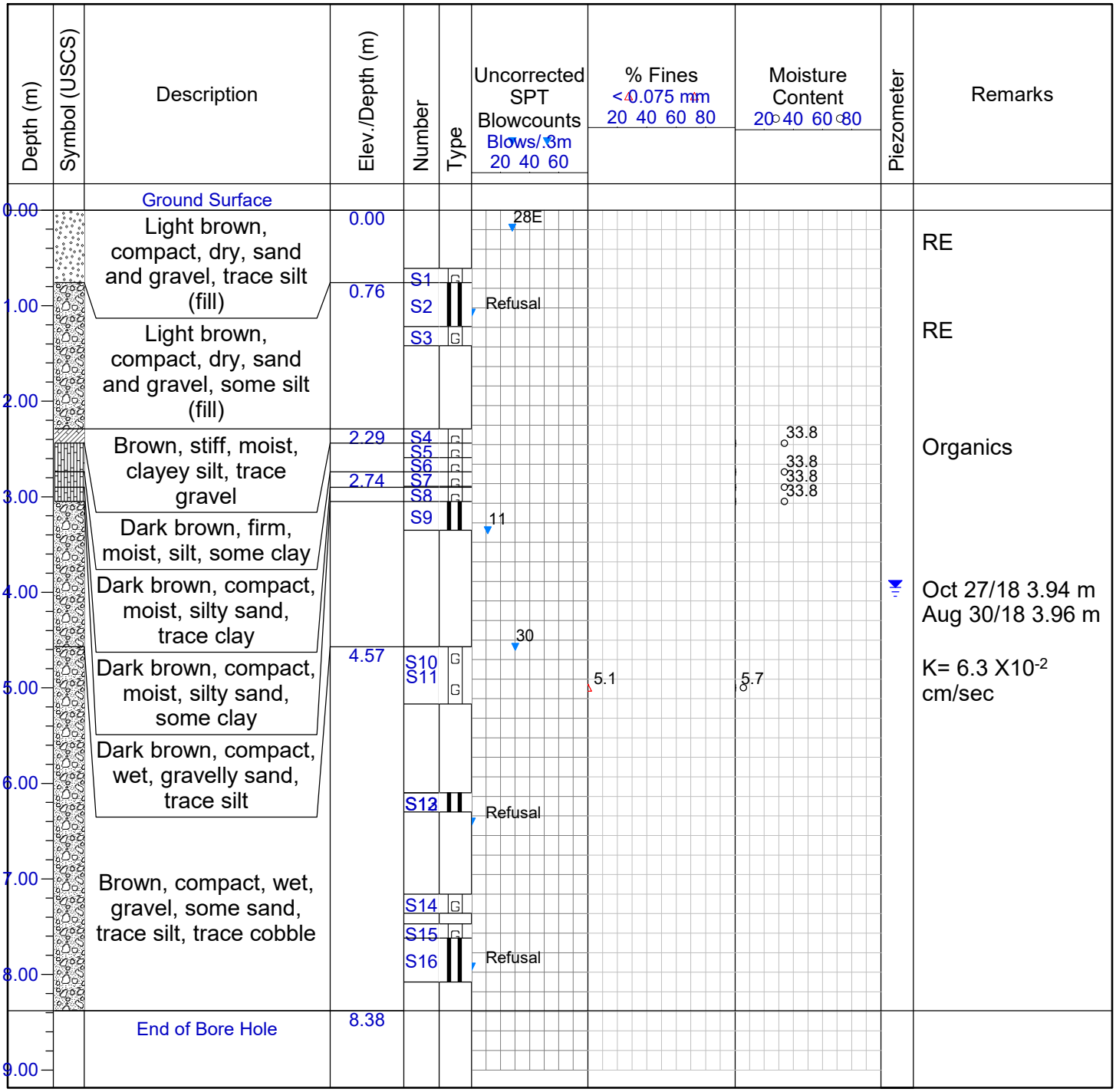
Client: NHC

Location: 16th Street and 12th Ave - Elevation = 1001.8 m

Bore Hole: B3

Date: August 8, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: IF

Groundtech Engineering Ltd.
PO Box 688
Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

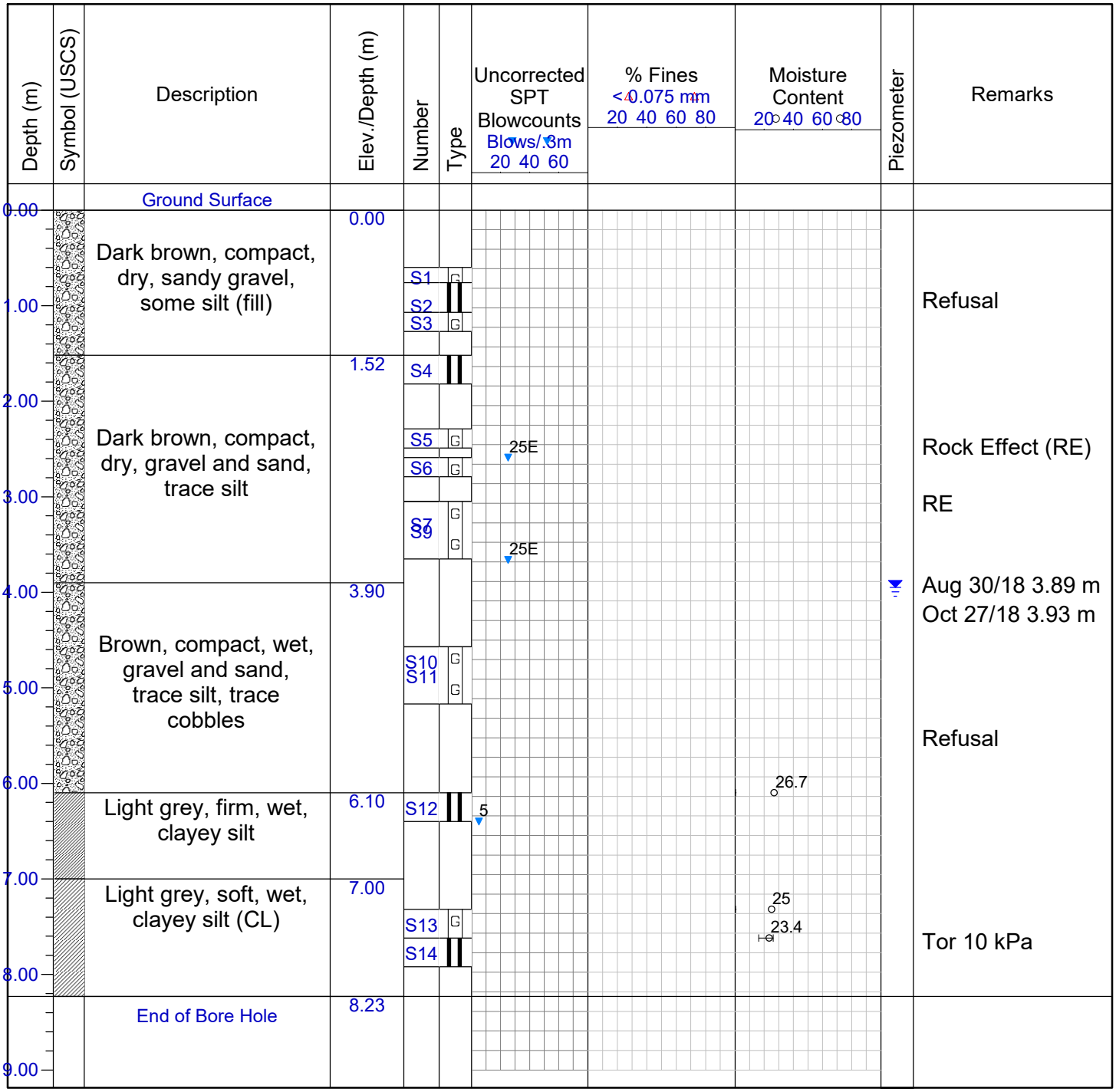
Client: NHC

Location: West end of 9th Street - Elevation = 999.76 m

Bore Hole: B4

Date: August 8, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: IF

Groundtech Engineering Ltd.
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Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

Client: NHC

Location: 4th Street and 9th Ave - Elevation = 998.08 m

Bore Hole: B5

Date: August 8, 2018

Engineer: DAC

Depth (m)	Symbol (USCS)	Description	Elev./Depth (m)	Number	Type	Uncorrected SPT Blowcounts Blows/0.3m 20 40 60	% Fines <0.075 mm 20 40 60 80	Moisture Content 20 40 60 80	Piezometer	Remarks
		Ground Surface								
0.00		Dark brown, dense, sand and gravel, trace silt (fill)	0.00	S1	G	Refusal				Refusal
0.76				S2						
1.00				S3	G		6.9	1.8		K=0.04 cm/sec
		Dark brown, compact, dry, sandy gravel, trace silt (GP/GM)		S4		19				
2.00				S5	G		8.9	5.1		S_{s+6} K=0.01 cm/sec
3.00		Brown, compact, moist, sandy gravel, trace silt, trace cobble	3.05	S6	G G	20	8.9	5.1		Large organics
4.00			3.90							Aug 30/18 3.93 m Oct 27/18 3.99 m
5.00		Brown, compact, wet, gravelly sand, trace silt, trace cobble		S7		15				
				S8						
6.00				S9		68 RE		6.6		RE Tor@6.4=10kPa
			6.40							
7.00		Light grey, soft, wet, clayey silt, trace gravel (CL)		S10	G			25.4		Tor@7.3=13 kPa
8.00										
		End of Bore Hole	8.38							
9.00										

Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: IF

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Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

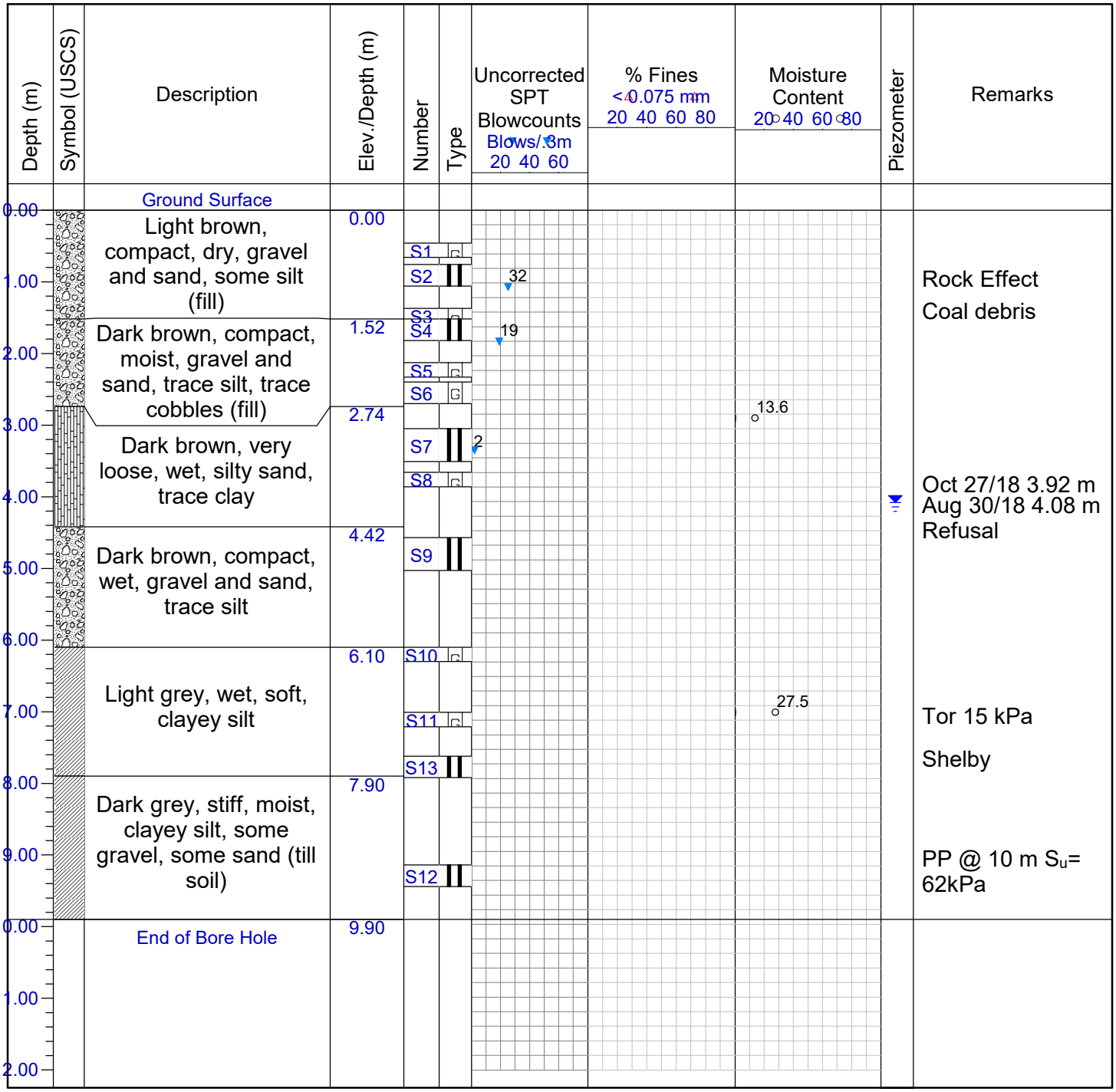
Client: NHC

Location: Riverside - Elevation = 998.05 m

Bore Hole: B6

Date: August 9, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: IF

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Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

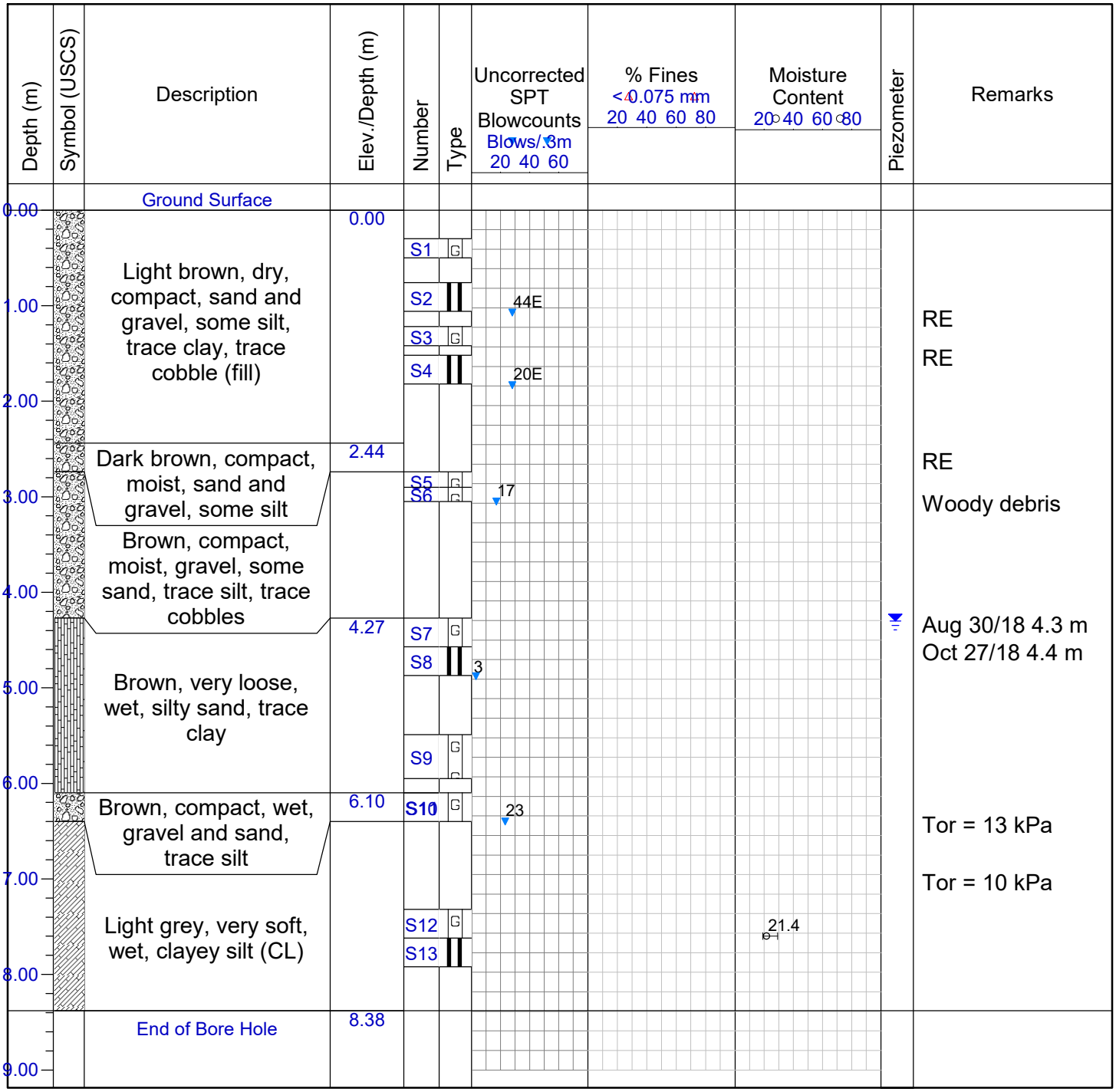
Client: NHC

Location: West Fernie- East of Hand Ave - Elevation = 997.69 m

Bore Hole: B7

Date: August 9, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: IF

Groundtech Engineering Ltd.
PO Box 688
Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

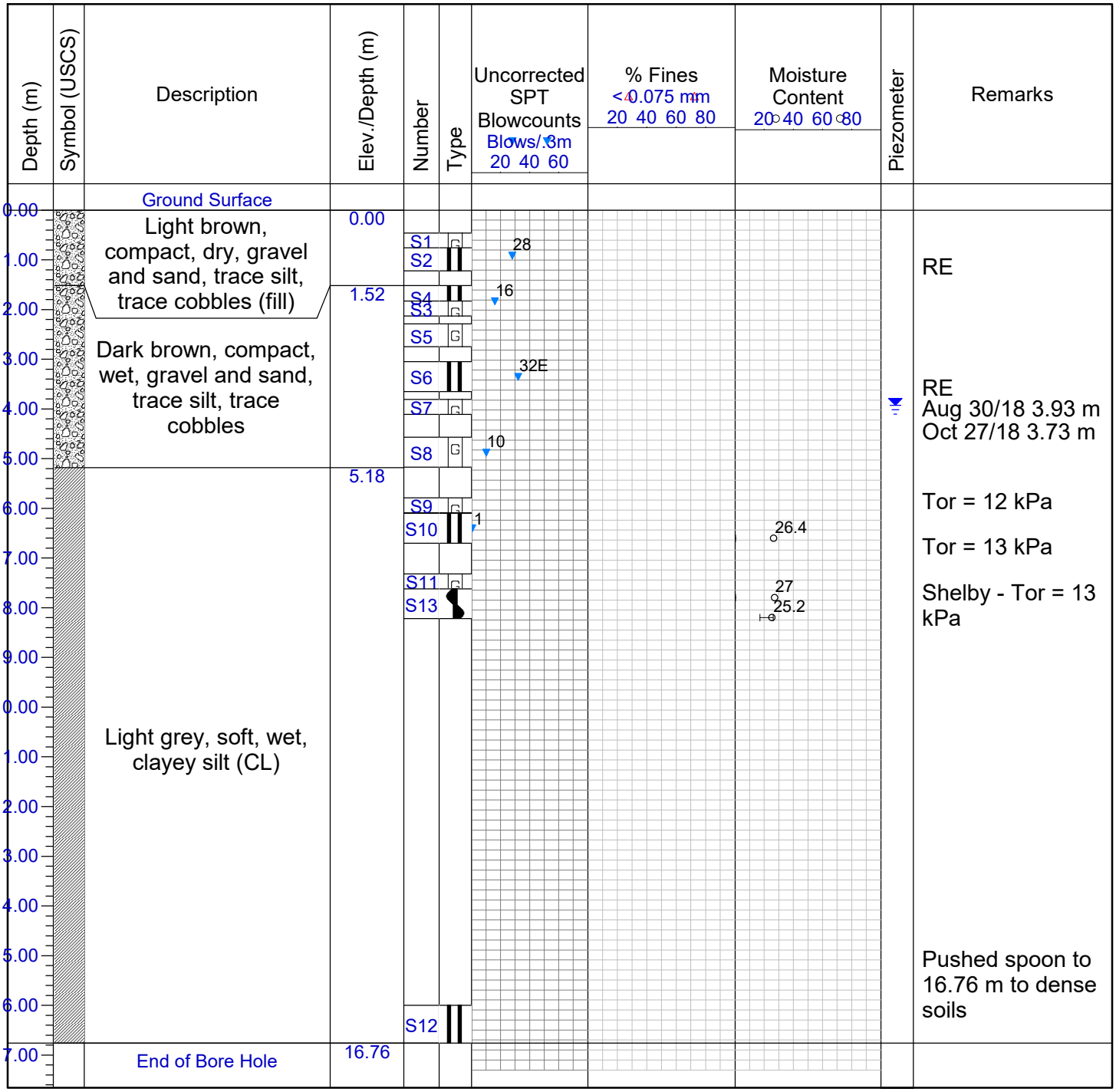
Client: NHC

Location: West Fernie- SE Ekersley Ave - Elevation = 994.14 m

Bore Hole: B8

Date: August 9, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: IF

Groundtech Engineering Ltd.
PO Box 688
Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

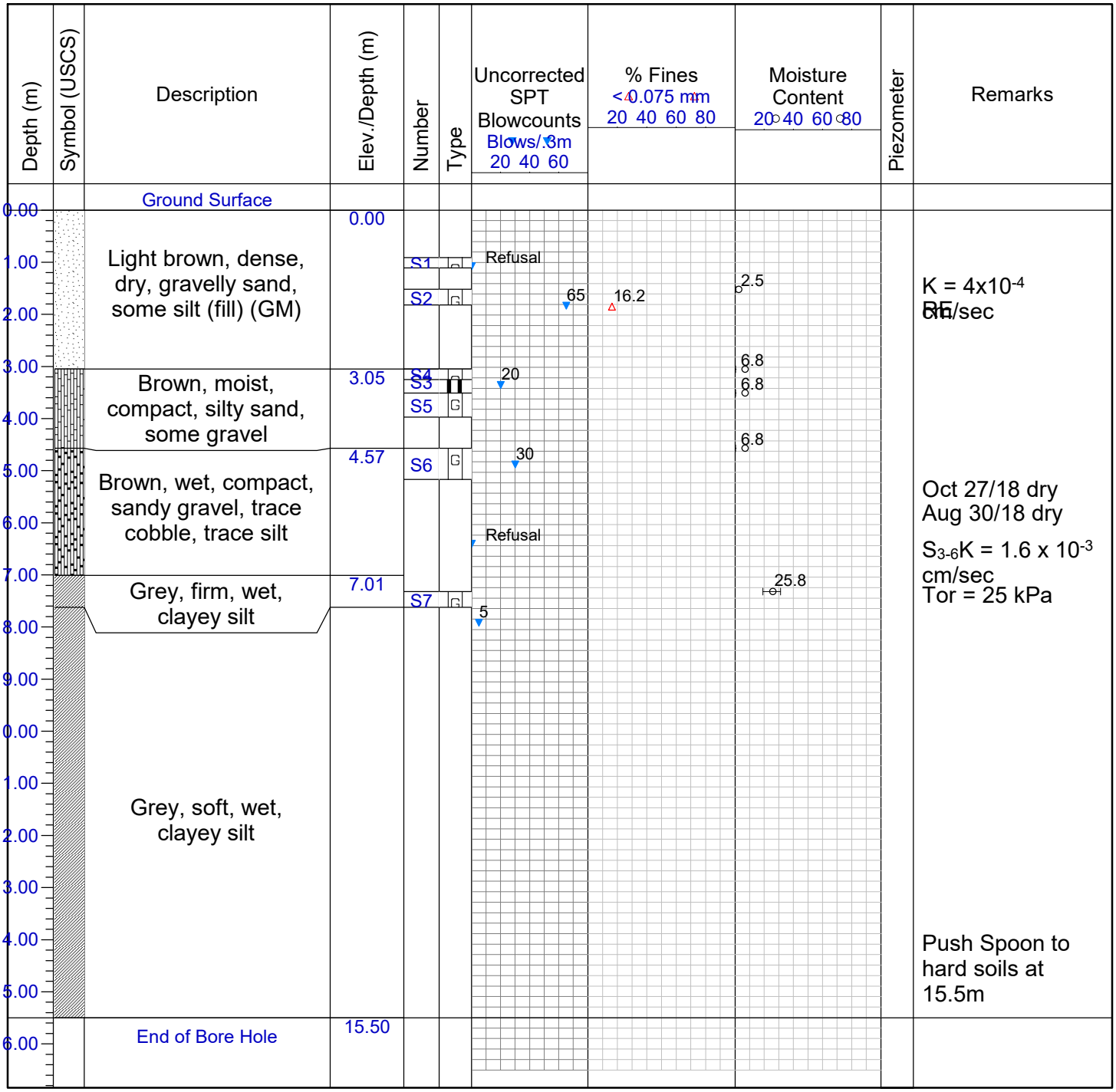
Client: NHC

Location: James White Park - Elevation = 994.46 m

Bore Hole: B9

Date: August 10, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: DAC

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Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

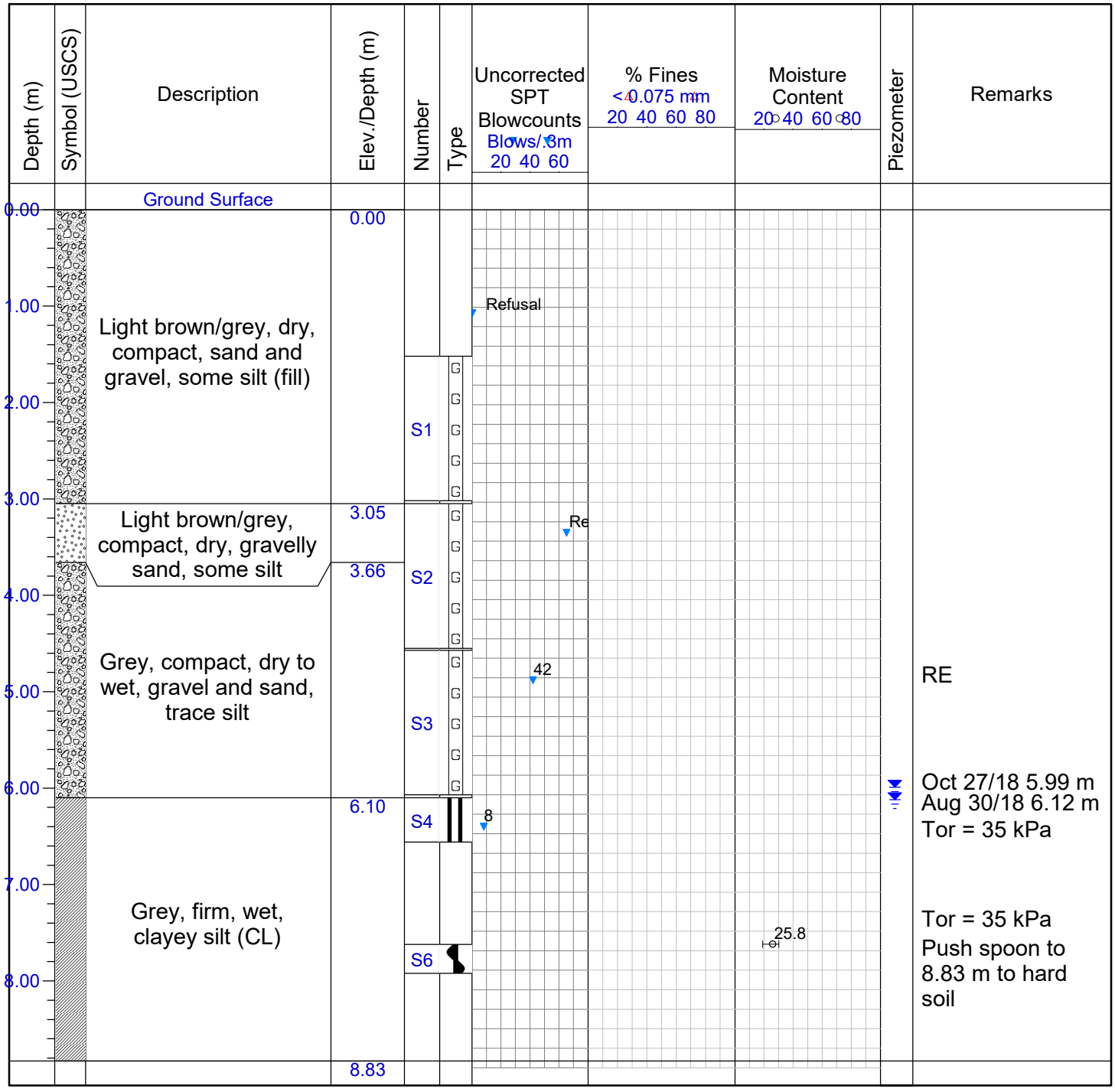
Client: NHC

Location: James White Park - Elevation = 992.85 m

Bore Hole: B10

Date: August 10, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: DAC

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Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

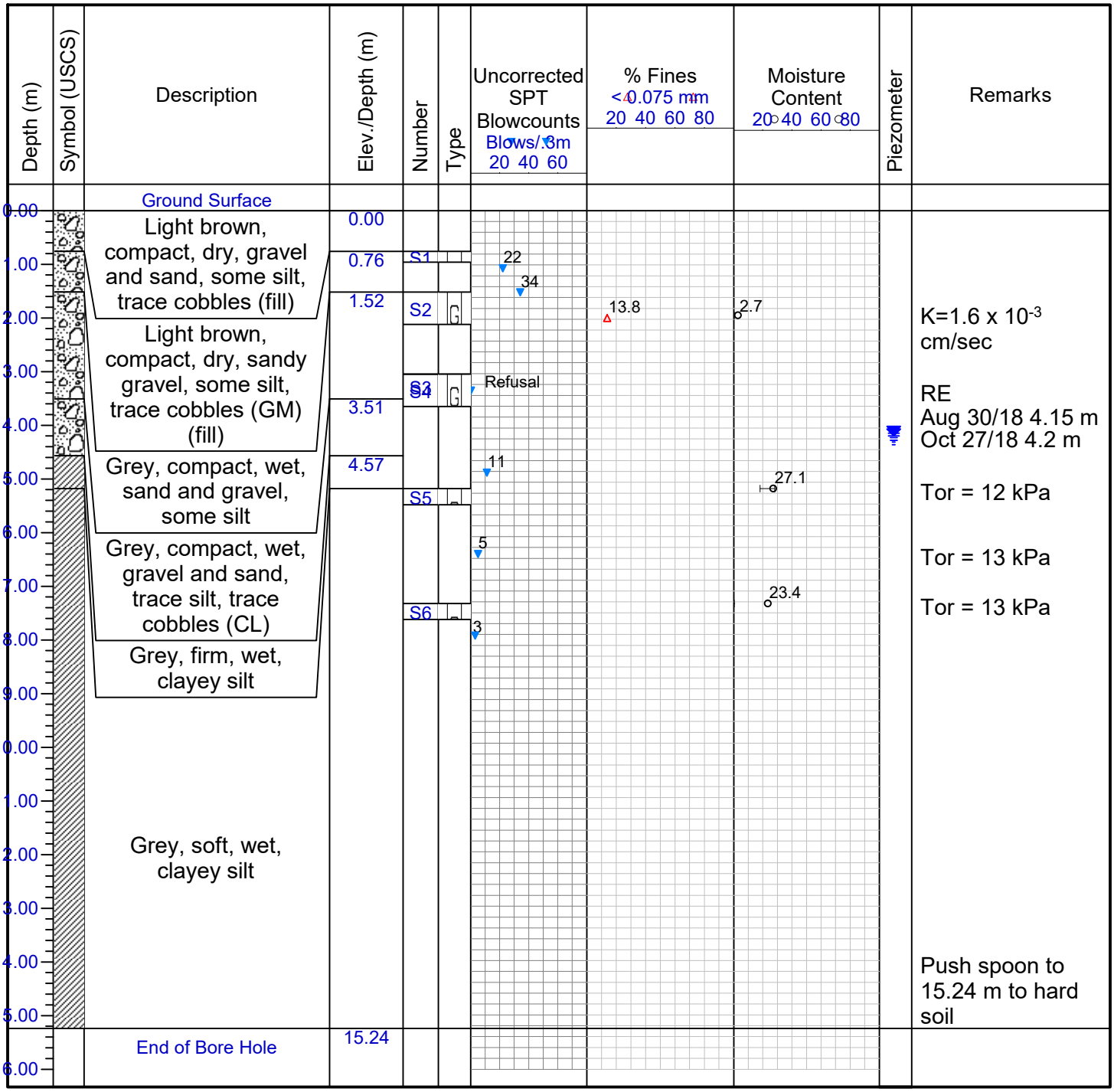
Client: NHC

Location: James White Park - Elevation = 990.38 m

Bore Hole: B11

Date: August 10, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By:

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Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

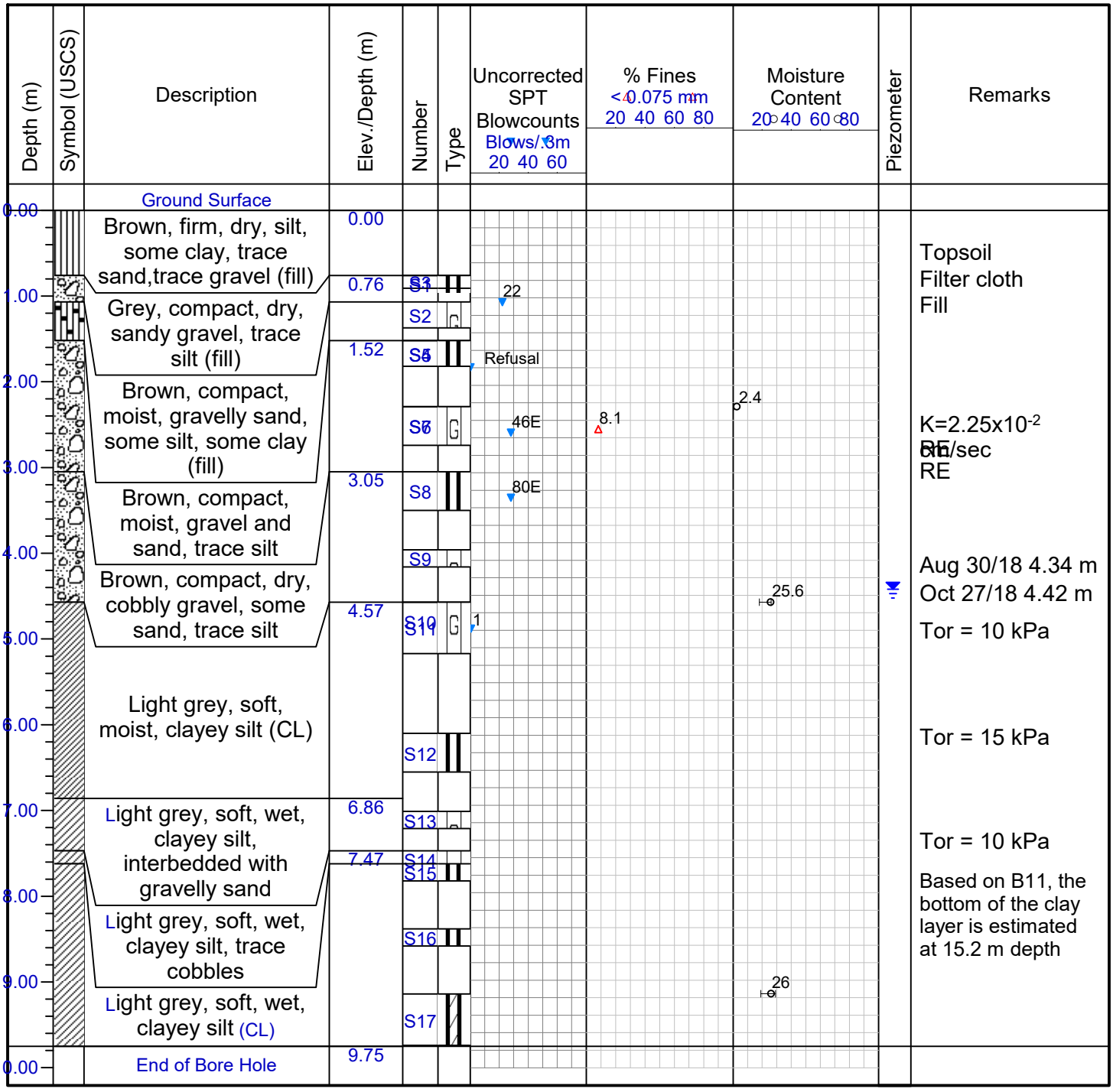
Client: NHC

Location: Stanford Inn - Elevation = 992.13 m

Bore Hole: B12

Date: August 7, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: IF

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Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

Project No: 18m15

Project: Fernie Dike

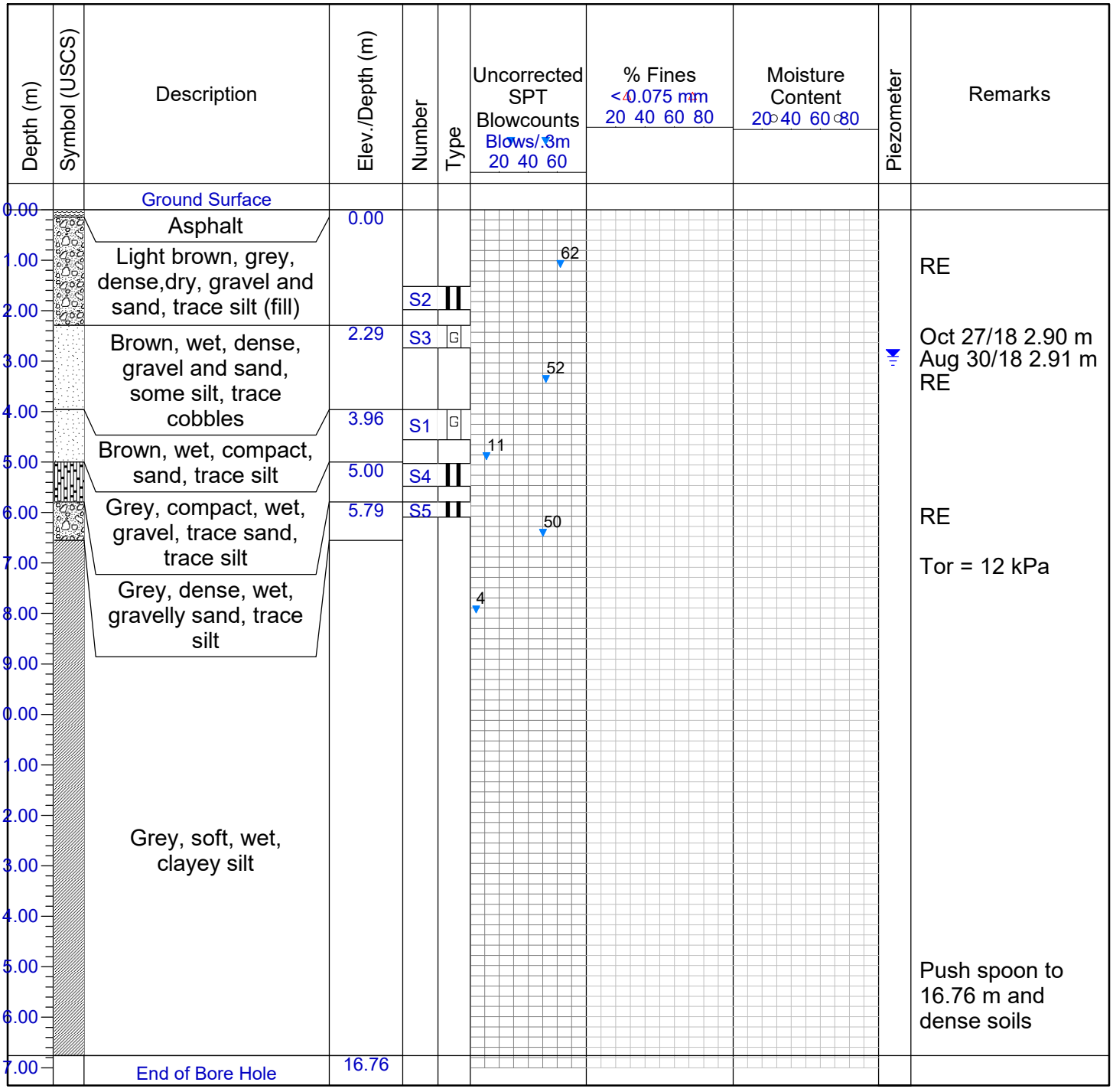
Client: NHC

Location: Near Right of Way- Maiden Lake - Elevation = 1003.0 m

Bore Hole: B13

Date: August 10, 2018

Engineer: DAC



Excavated By: Earth Drilling

Equipment: Sonic drill

Logged By: DAC

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Fernie, BC, V0B 1M0

Datum:

Sheet: 1 of 1

McElhanney
McElhanney Consulting Services Ltd.
Suite 200, 42 - 8th Ave S
Cranbrook BC, V1C 2K3
PH (250) 489 3013
FAX (250) 489 4522

TEST HOLE LOG

TEST PIT No: 01

McElhanney # 2441-00187-0 TEST LOCATION: N 49.5043° 115.07123° W DATE: MARCH 26, 2013

PROJECT: WEST FERNIE DIKE - PHASE 3-4 ELEVATION DATUM: FROM TOP OF DIKE

REGION: WEST FERNIE, B.C. INVESTIGATION METHOD: HITACHI 200LC EXCAVATOR (MERCIER)

DEPTH (m)	SOIL PROFILE	SOIL DESCRIPTION	TEST SAMPLES	FIELD TEST DATA
0.00				
		SANDY GRAVEL (PIT RUN) Trace to some fines, dark brown, compact to dense, damp. Occasional cobbles observed. Older sandy gravel fill from 0.5m – 2.6m Small organics / topsoil from 0.5m – 0.8m Brown, compact, damp. Organic layer observed on backslope approximately 0.5m below surface.	SA #1 @ 0.5m – 1.5m	DCP @ 1.3–1.5m → CBR = 20 Permeameter @ 1.3–1.6m → K(fs) = 500 cm/day
2.60		**FINE – MEDIUM SAND** Some fines.	SA #2 @ 2.8m – 3.0m	
3.00		**MEDIUM – FINE SAND** Some silt, medium brown, compact, wet to moist. Groundwater table @ 3.1m.	Gwt @ 3.1m SA #3 @ 3.2m	DCP @ 3–3.3m → CBR = 5 Permeameter @ 3–3.3m → K(fs) = 180 cm/day
3.50		**FINE SAND AND SILT** Trace Clay, brown / blue, moist, stiff, non-plastic.	SA #4 @ 4.0m	
4.20				

McElhanney
McElhanney Consulting Services Ltd.
Suite 200, 42 - 8th Ave S
Cranbrook BC, V1C 2K3
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TEST HOLE LOG

TEST PIT No: 02

McElhanney # 2441-00187-0 TEST LOCATION: N 49.5043° 115.0691° W DATE: MARCH 26, 2013

PROJECT: WEST FERNIE DIKE – PHASE 3-4 ELEVATION DATUM: FROM TOP OF DIKE

REGION: WEST FERNIE, B.C. INVESTIGATION METHOD: HITACHI 200LC EXCAVATOR (MERCIER)

DEPTH (m)	SOIL PROFILE	SOIL DESCRIPTION	TEST SAMPLES	FIELD TEST DATA
0.00				
		SANDY GRAVEL FILL Trace fines, medium brown, compact, damp. Sub-angular to sub-rounded gravels. Cobbles to 0.35m diameter.	SA #1 @ 0.5m – 1.0m	DCP @ 0.9–1.1m → CBR = 20
1.60			SA #2 @ 1.6m	
		FINE SAND AND SILT FILL Trace Clay, iight brown, compact, damp.		DCP @ 1.6–1.9m → CBR = 6
			SA #3 @ 2.2m	Permeameter @ 2.2–2.5m → K(fs) = 40 cm/day
				DCP @ 2.2–2.7m → CBR = 3.6
2.70		**ORGANICS** Roots, rootlets, topsoil and sand.		
3.00		**GRAVEL** Some sand, trace to some fines, grey, compact to dense, wet. Groundwater table @ 3.1m. Trace occasional small organics. Cobbles observed to 0.25m diameter.	SA #4 @ 3.2m	
4.00				

McElhanney
McElhanney Consulting Services Ltd.
Suite 200, 42 - 8th Ave S
Cranbrook BC, V1C 2K3
PH (250) 489 3013
FAX (250) 489 4522

TEST HOLE LOG

TEST PIT No: 03

McElhanney # 2441-00187-0 TEST LOCATION: N 49.4983° 115.07065° W DATE: MARCH 26, 2013

PROJECT: WEST FERNIE DIKE - PHASE 3-4 ELEVATION DATUM: FROM TOP OF DIKE

REGION: WEST FERNIE, B.C. INVESTIGATION METHOD: HITACHI 200LC EXCAVATOR (MERCIER)

DEPTH (m)	SOIL PROFILE	SOIL DESCRIPTION	TEST SAMPLES	FIELD TEST DATA
0.00		**SANDY GRAVEL FILL** Trace to some fines, compact to dense, brown, damp to moist. Gravel is sub-rounded to sub-angular. Occasional cobble to maximum 0.3m diameter.	SA #1 @ 0.5m	DCP @ 0.5m → Refusal
1.60		**ORGANIC DEBRIS** Logs, roots, organic sand and fines, topsoil.		
1.90		**MEDIUM TO FINE SAND** Trace to some fines, brown, compact, damp.		
2.10		**SANDY GRAVEL** Trace fines, light grey / brown, damp, compact. Fluvial deposition, layering evident throughout. Cobbles evident @ 2.8m.	SA #2 @ 2.3m	DCP @ 2.5-2.7m → CBR = 10 Permeameter test inconclusive, as soil is rapidly draining → K(fs) estimated @ 10,000 cm/day
		Groundwater table @ 3.6m	SA #3 @ 3.5m	
3.60				

APPENDIX IV

Lab Test Reports

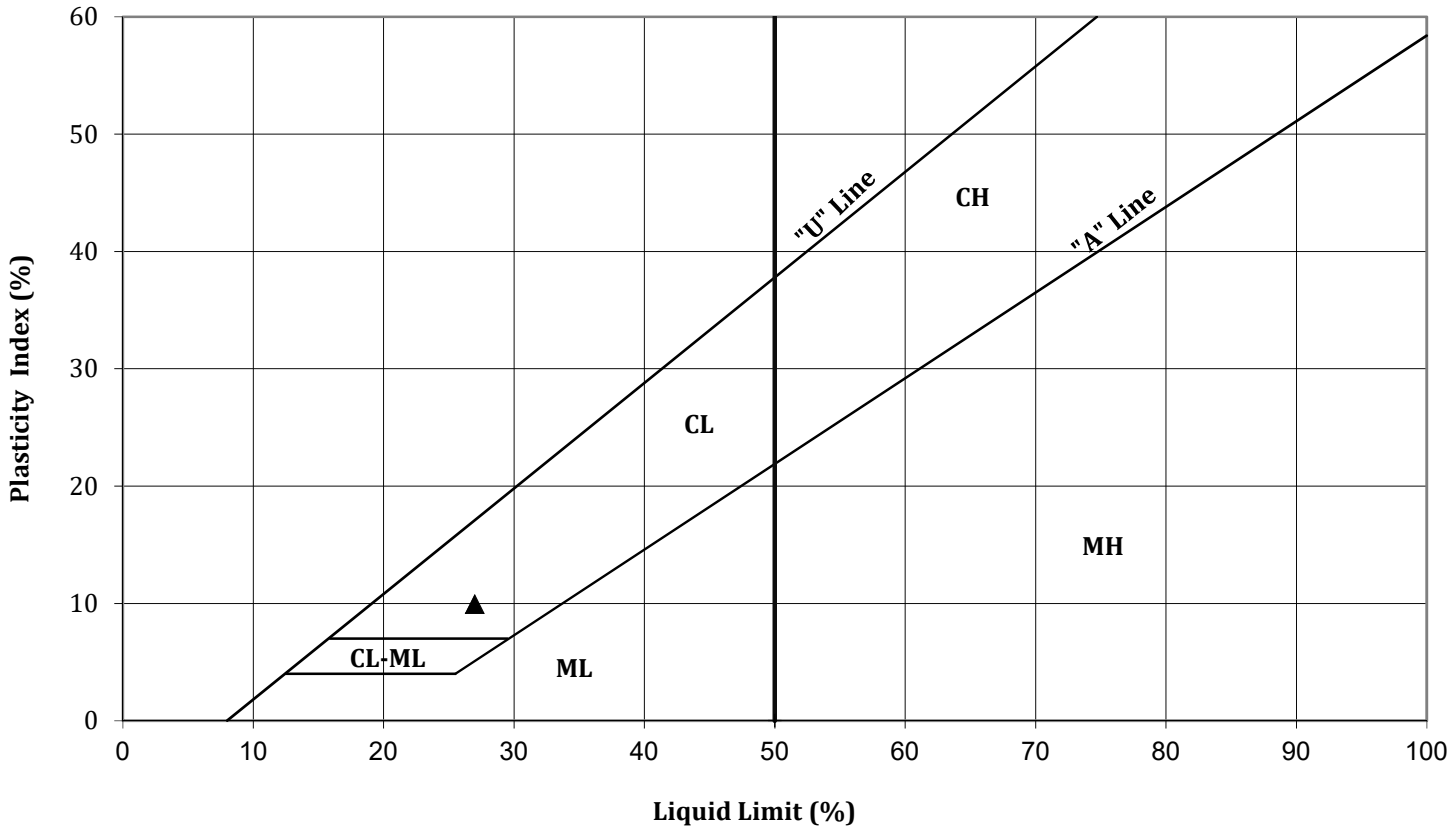
PHONE: 250-489-1940 FAX: 250-489-1667 EMAIL: info@artechconsulting.ca
229 Industrial Rd F, Cranbrook, BC V1C 6N4 www.artechconsulting.ca

ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18474
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B1 S13	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	27.0%	27	17	10



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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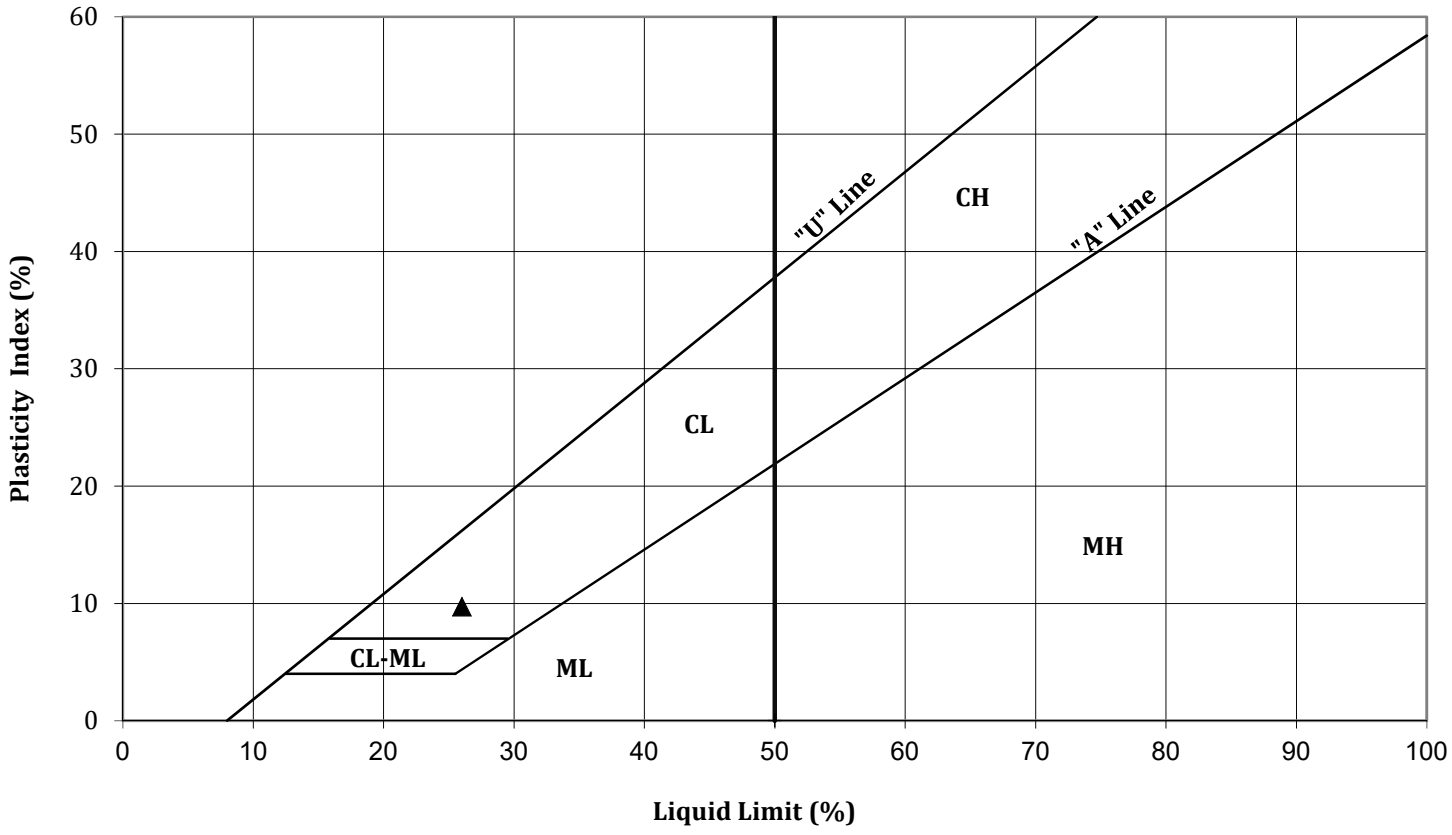
ARTECH CONSULTING LTD.

ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18481
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B4 S14	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	23.4%	26	16	10



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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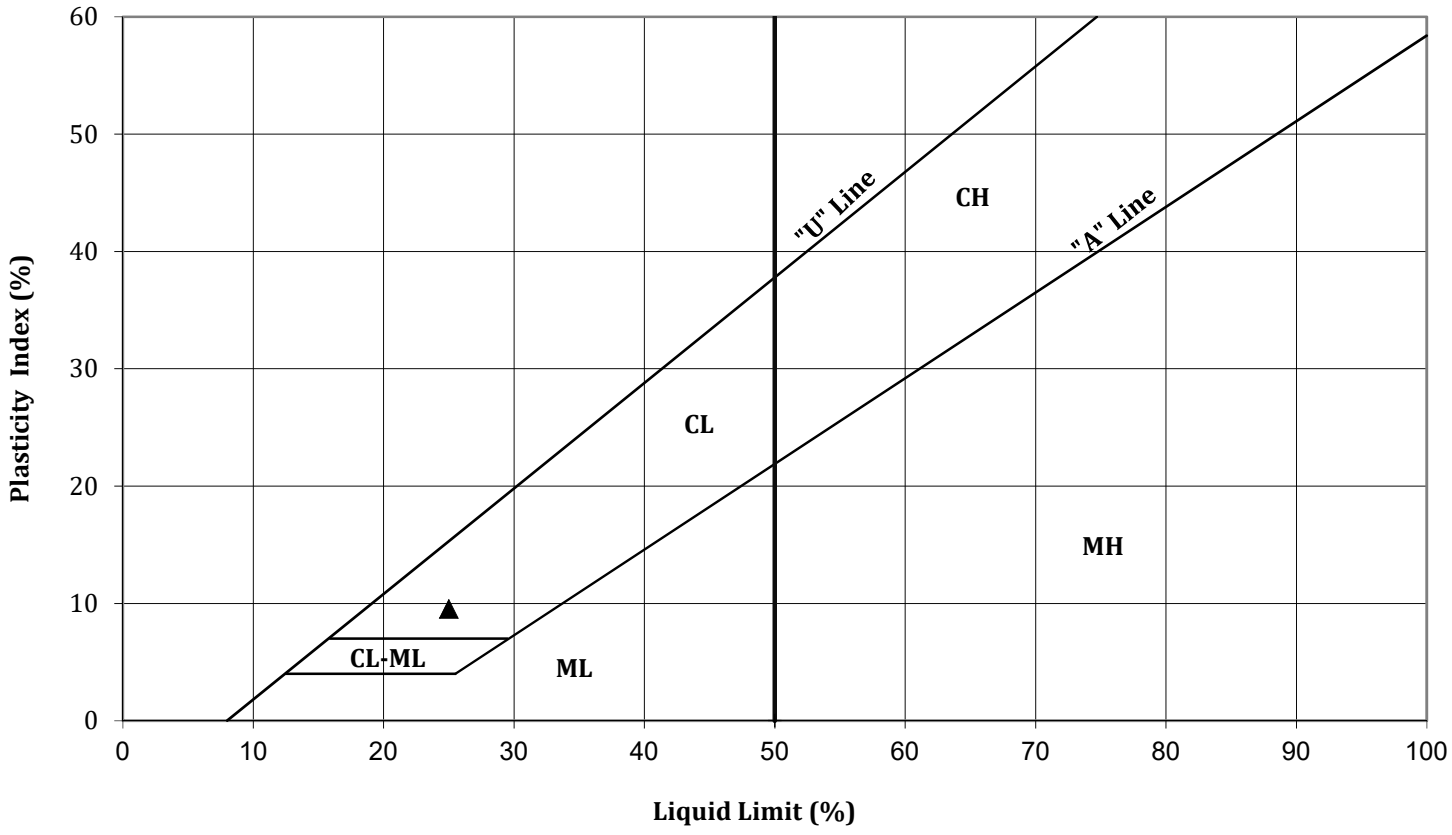
ARTECH CONSULTING LTD.

ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18485
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B5 S10	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	25.4%	25	15	10



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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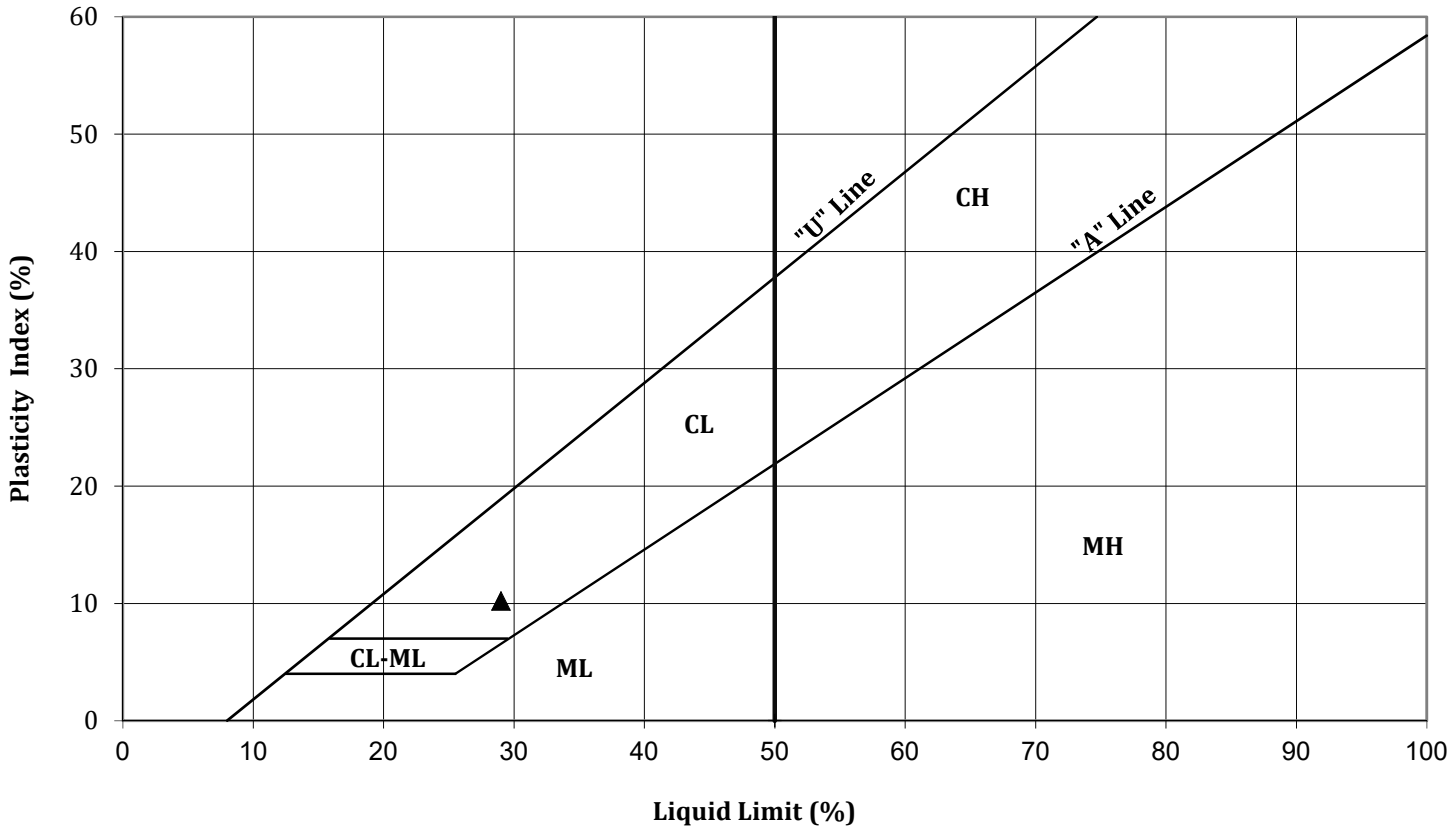
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ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18488
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B7 S12	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	21.4%	29	19	10



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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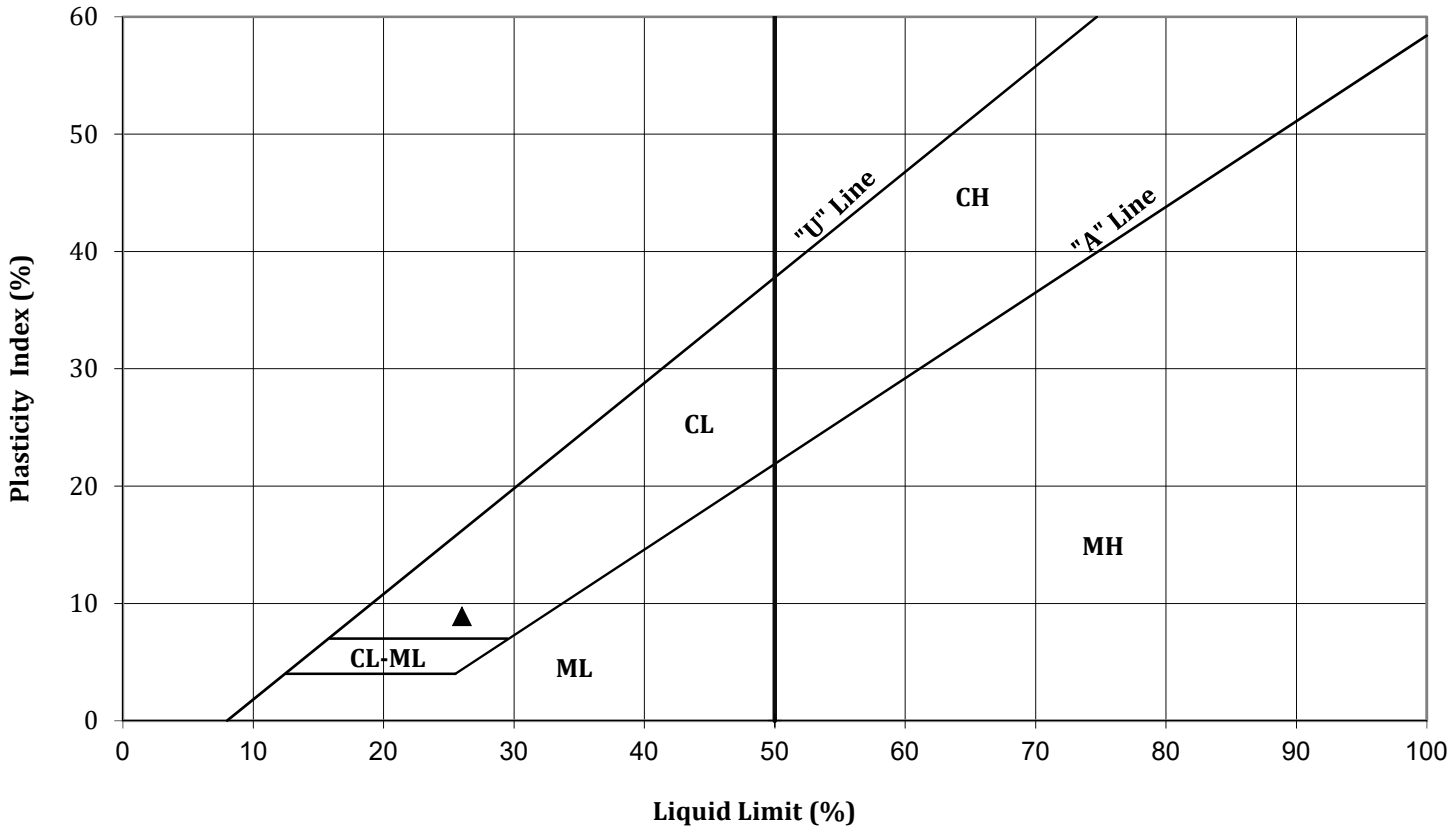
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ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18491
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B8 S13	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	25.2%	26	17	9



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

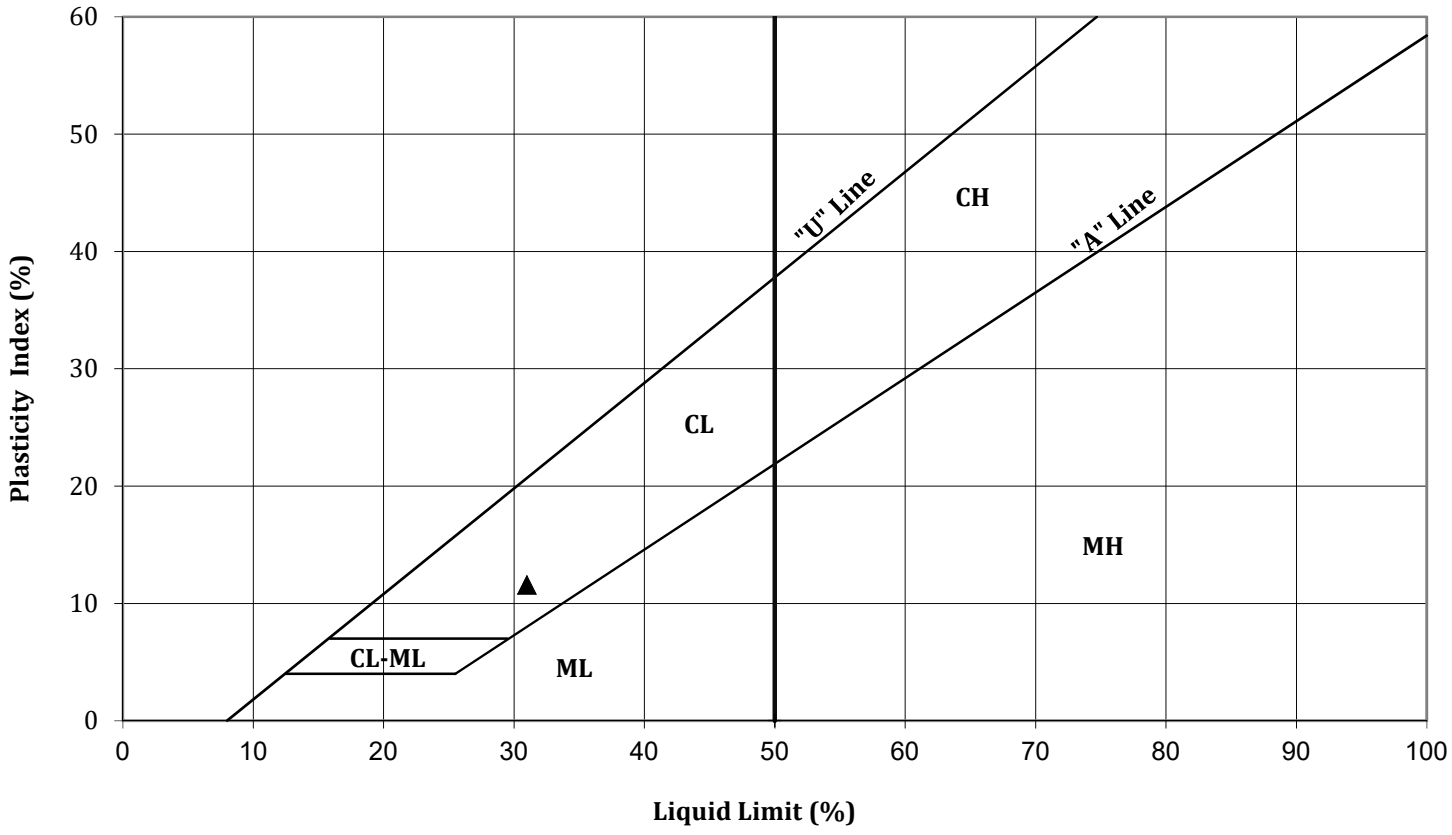
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ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18494
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B9 S7	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	25.8%	31	19	12



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

PHONE: 250-489-1940 FAX: 250-489-1667 EMAIL: info@artechconsulting.ca
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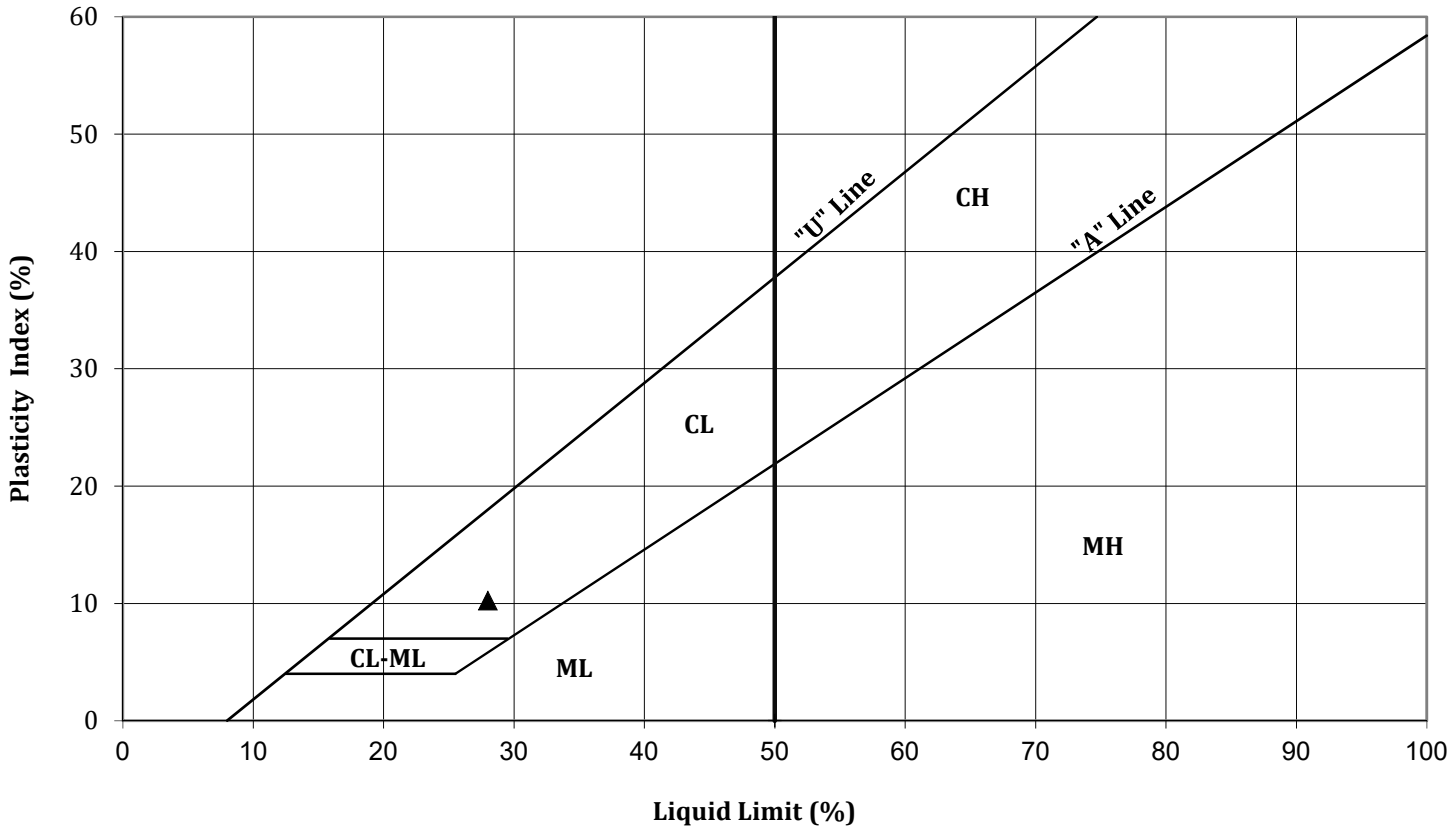
ARTECH CONSULTING LTD.

ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18496
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B11 S5	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	27.1%	28	18	10



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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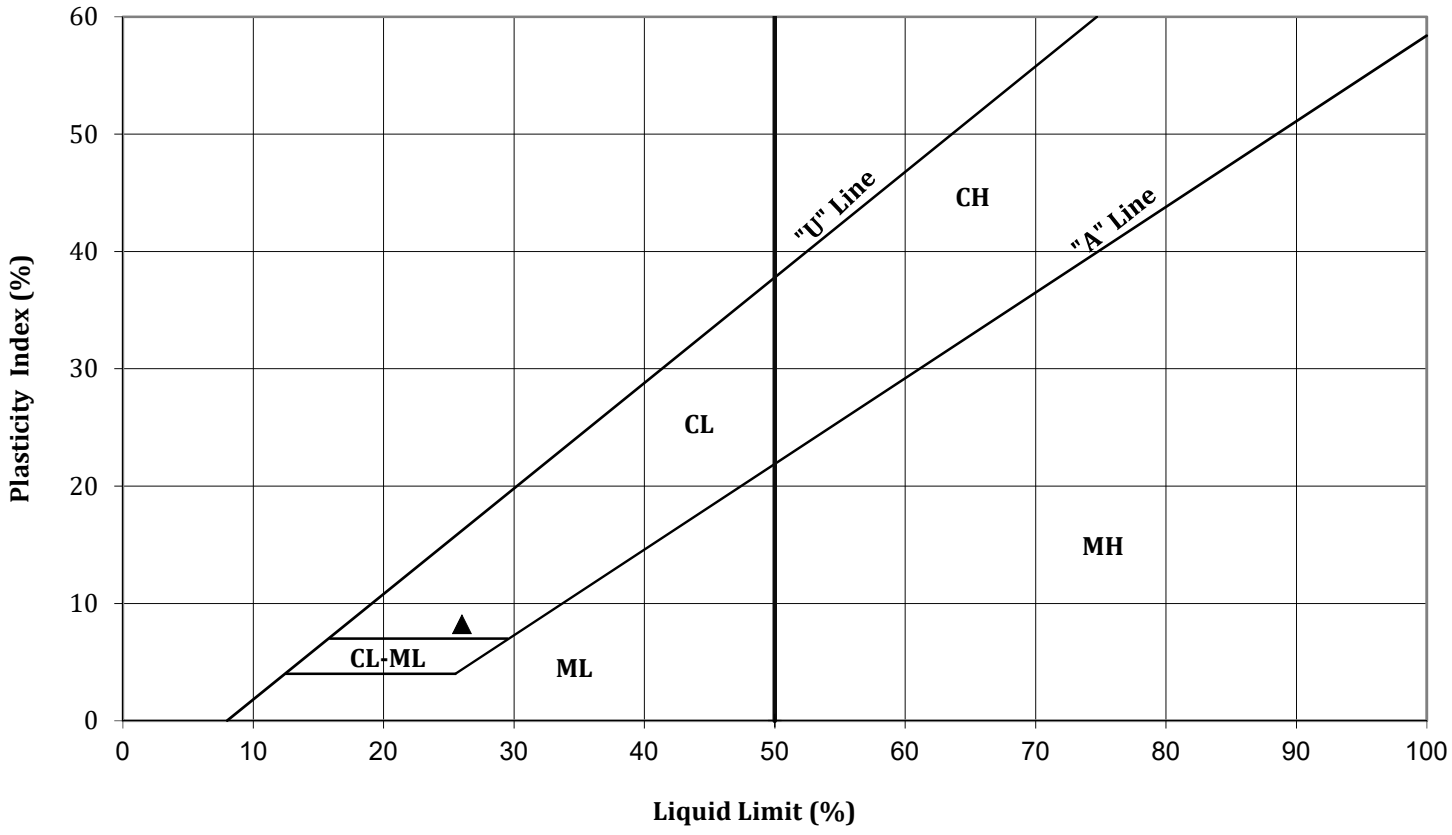
ARTECH CONSULTING LTD.

ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18499
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B12 S11	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	25.6%	26	18	8



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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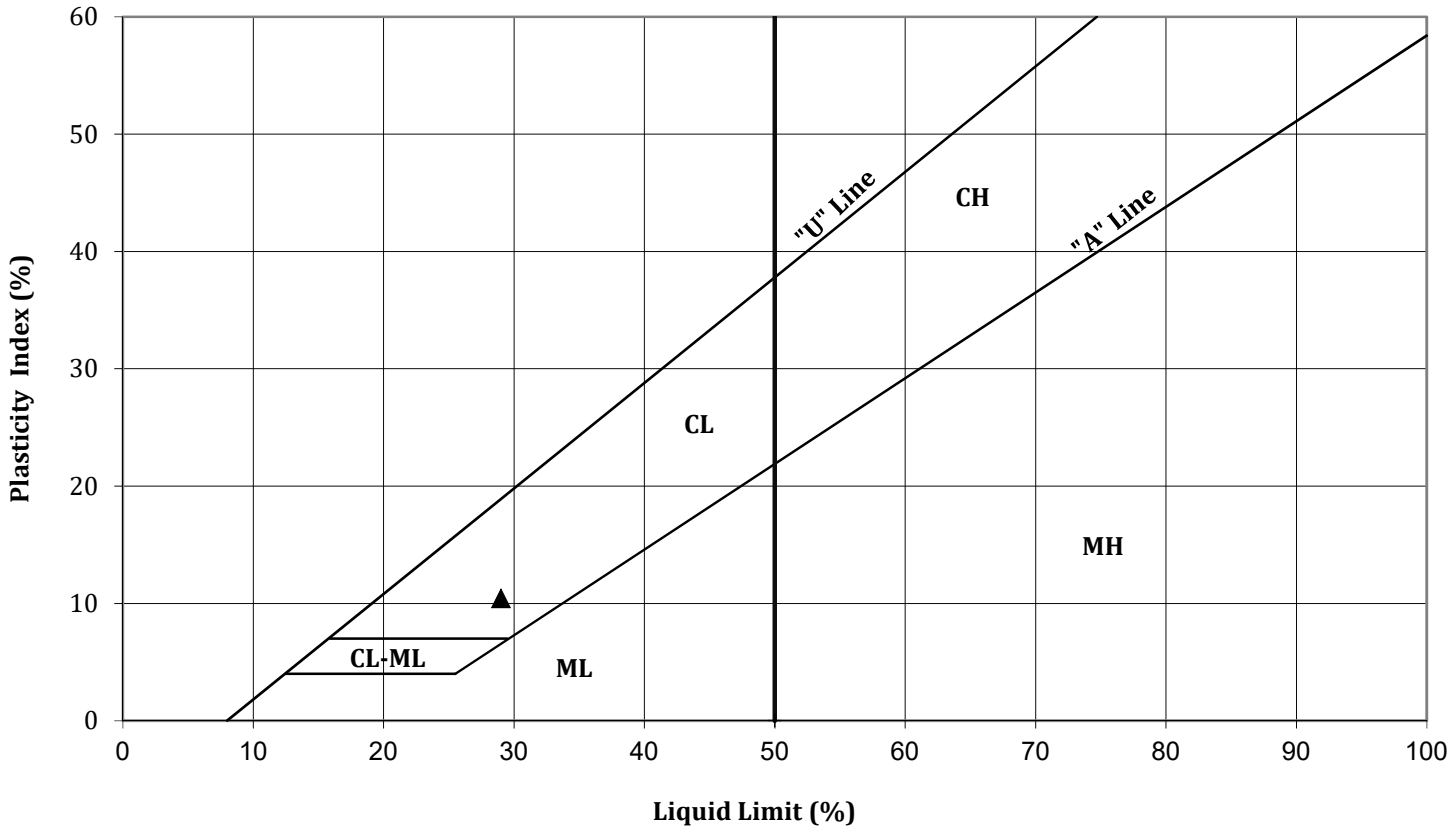
ARTECH CONSULTING LTD.

ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18500
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 17, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B12 S17	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	26.0%	29	19	10



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

PHONE: 250-489-1940 FAX: 250-489-1667 EMAIL: info@artechconsulting.ca
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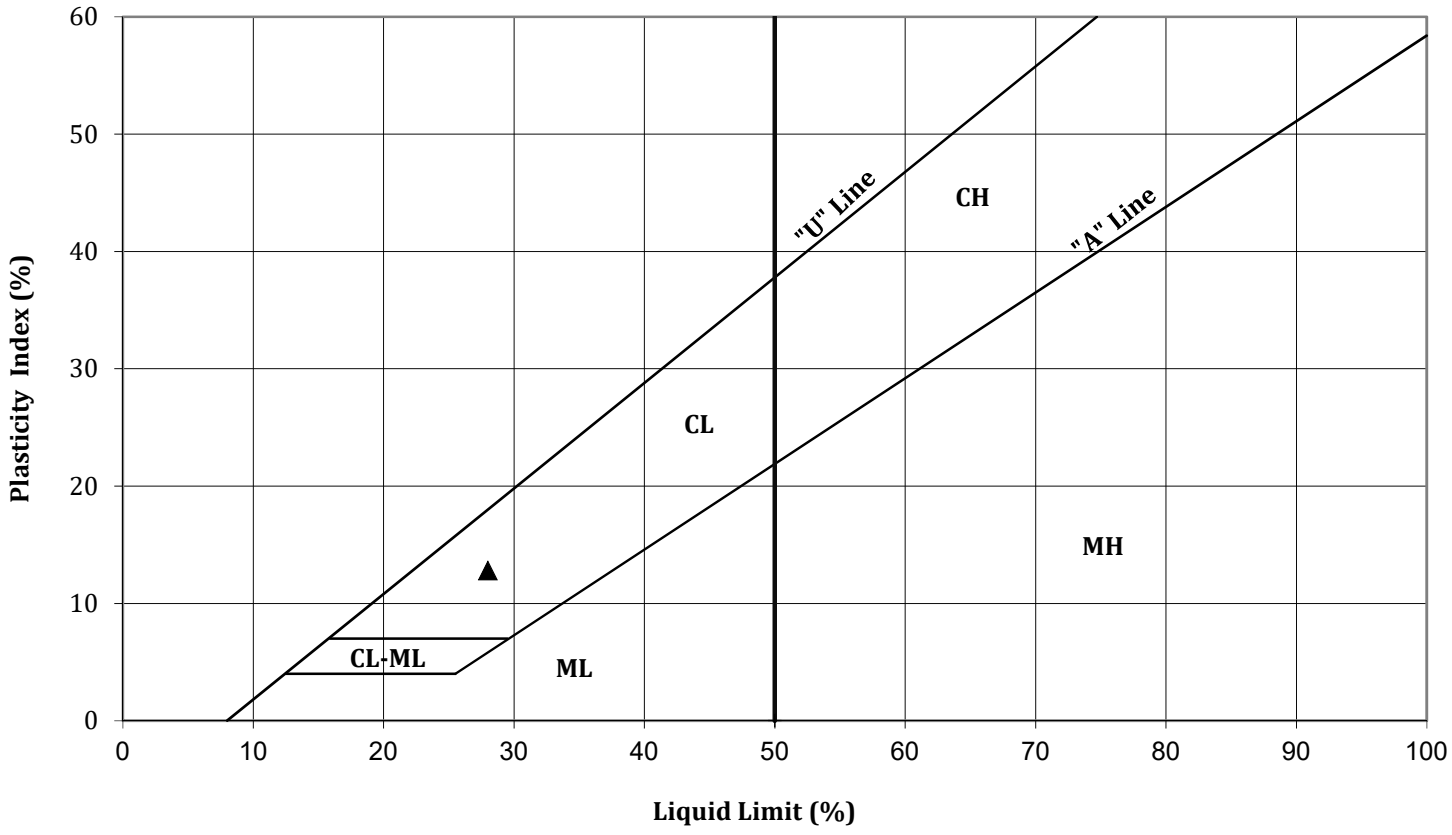
ARTECH CONSULTING LTD.

ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18512
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 21, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B2 S13	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Dry Preparation (air-dried)

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	19.1%	28	15	13



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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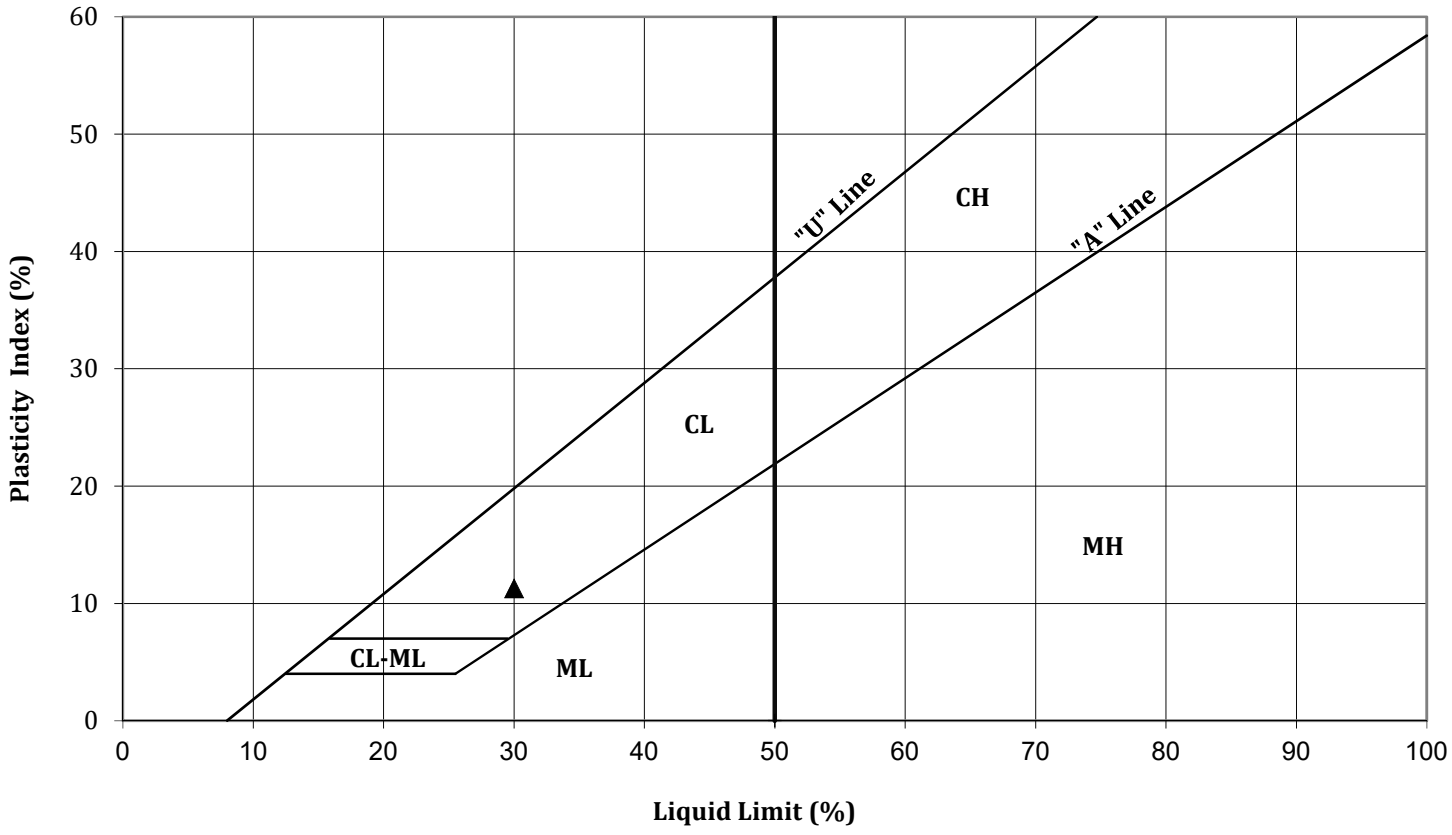
ARTECH CONSULTING LTD.

ATTERBERG LIMITS REPORT

Project No:	18.0005.AR	**Lab ID:**	S18512
Project:	Groundtech General		
Client:	Groundtech Engineering Ltd.	**Client Project:**	Fernie Dike
Attn:	Doug Clapp	**Date Received:**	August 21, 2018
CC:	-		
Sample Description:	-	**Sample Date:**	-
Sample ID:	B10 S6	**Sample Time:**	-
Sample Source:	Geotechnical Investigation	**Sampled By:**	Client

Method: Wet Preparation

Soil Classification (USCS)	Moisture Content	Liquid Limit %	Plastic Limit %	Plasticity Index
CL	25.8%	30	19	11



Comments:

Tested in accordance with ASTM D4318-10 Liquid Limit, Plastic Limit, and Plasticity Index of Soils

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Sample Description: Sandy GRAVEL, some silt/clay
Sample ID: B1 S1
Sample Source: Geotechnical Investigation

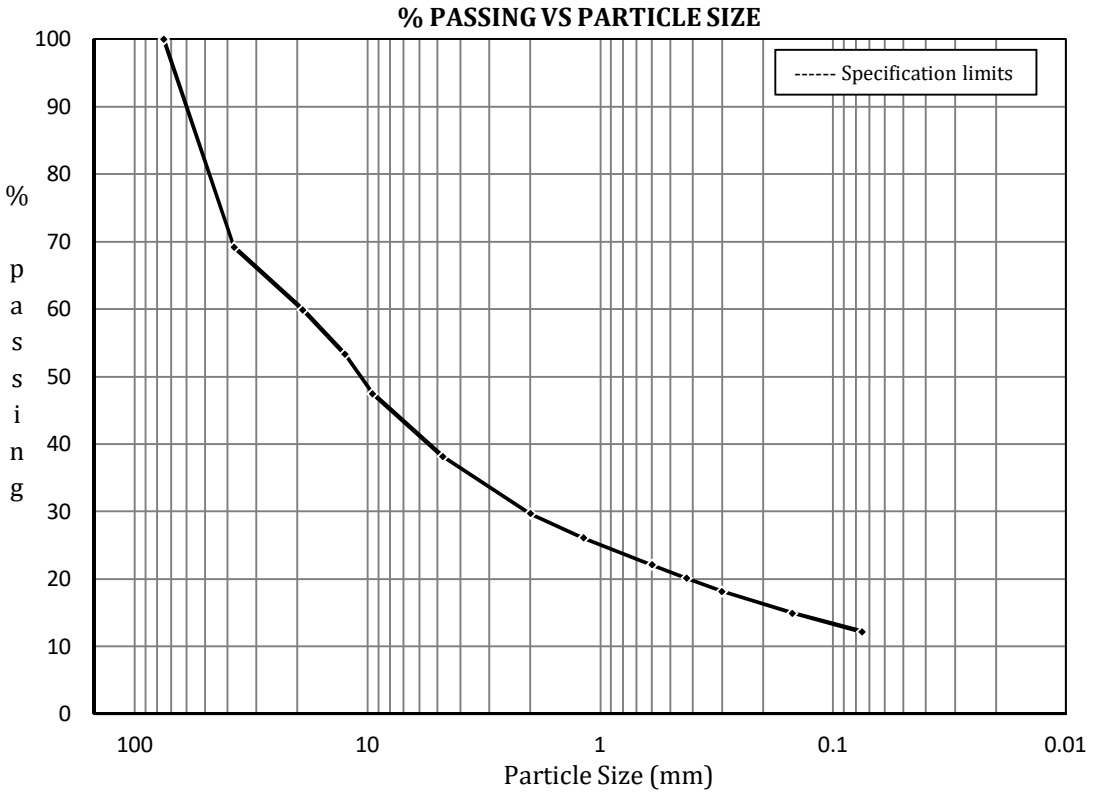
Lab ID: S18472
Client Project: Fernie Dike

Date Received: August 17, 2018

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0		
75.0	100.0	
37.5	69.2	
19.0	59.9	
12.5	53.3	
9.5	47.5	
4.75	38.2	
2.00	29.7	
1.18	26.1	
0.600	22.1	
0.425	20.1	
0.300	18.2	
0.150	15.0	
0.075	12.2	



Summary

Cobble :	>75mm		%
Gravel :	< 75mm and > 4.75mm	61.8	%
Sand :	< 4.75mm and > 0.075mm	26.0	%
Silt/Clay :	< 0.075mm	12.2	%

Moisture Content: 6.1 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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ARTECH CONSULTING LTD.

PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Sample Description: Sandy GRAVEL, trace silt/clay
Sample ID: B1 S8
Sample Source: Geotechnical Investigation

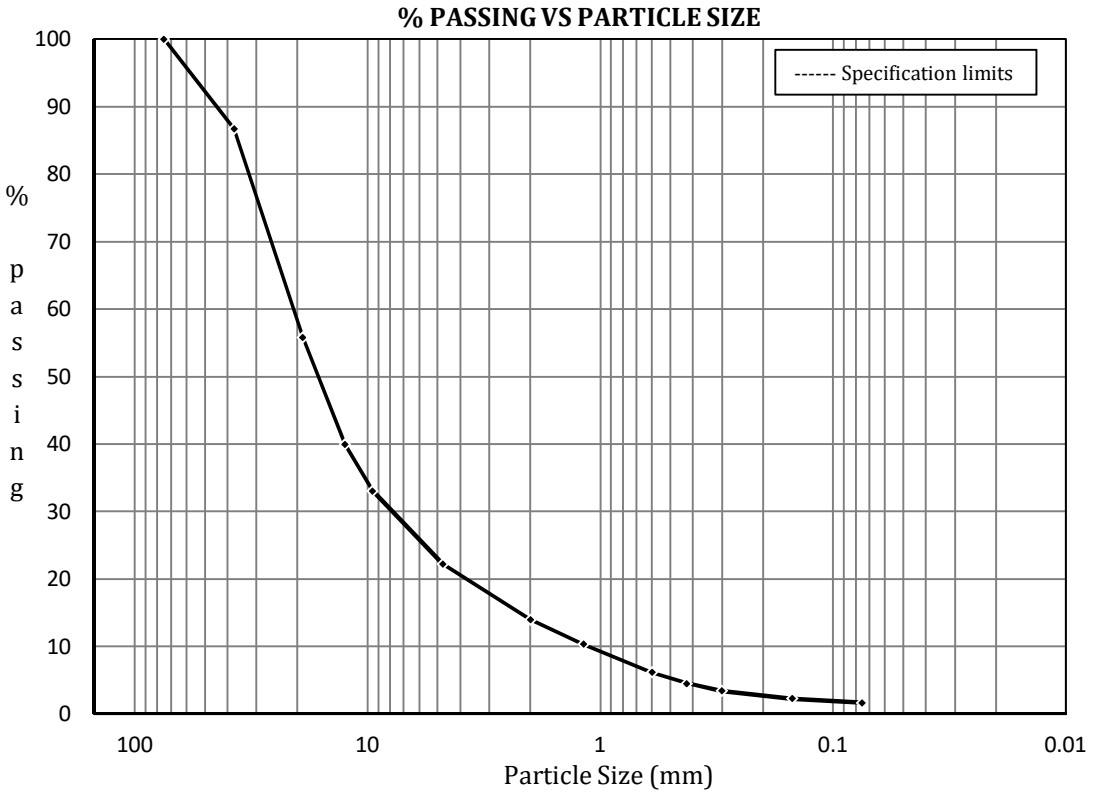
Lab ID: S18473
Client Project: Fernie Dike

Date Received: August 17, 2018

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0		
75.0	100.0	
37.5	86.7	
19.0	55.8	
12.5	39.9	
9.5	33.1	
4.75	22.3	
2.00	14.0	
1.18	10.3	
0.600	6.2	
0.425	4.5	
0.300	3.4	
0.150	2.3	
0.075	1.7	



Summary

Cobble :	>75mm		%
Gravel :	< 75mm and > 4.75mm	77.7	%
Sand :	< 4.75mm and > 0.075mm	20.6	%
Silt/Clay :	< 0.075mm	1.7	%

Moisture Content: 4.0 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By:
Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Sample Description: Sandy GRAVEL, trace silt/clay
Sample ID: B2 S3
Sample Source: Geotechnical Investigation

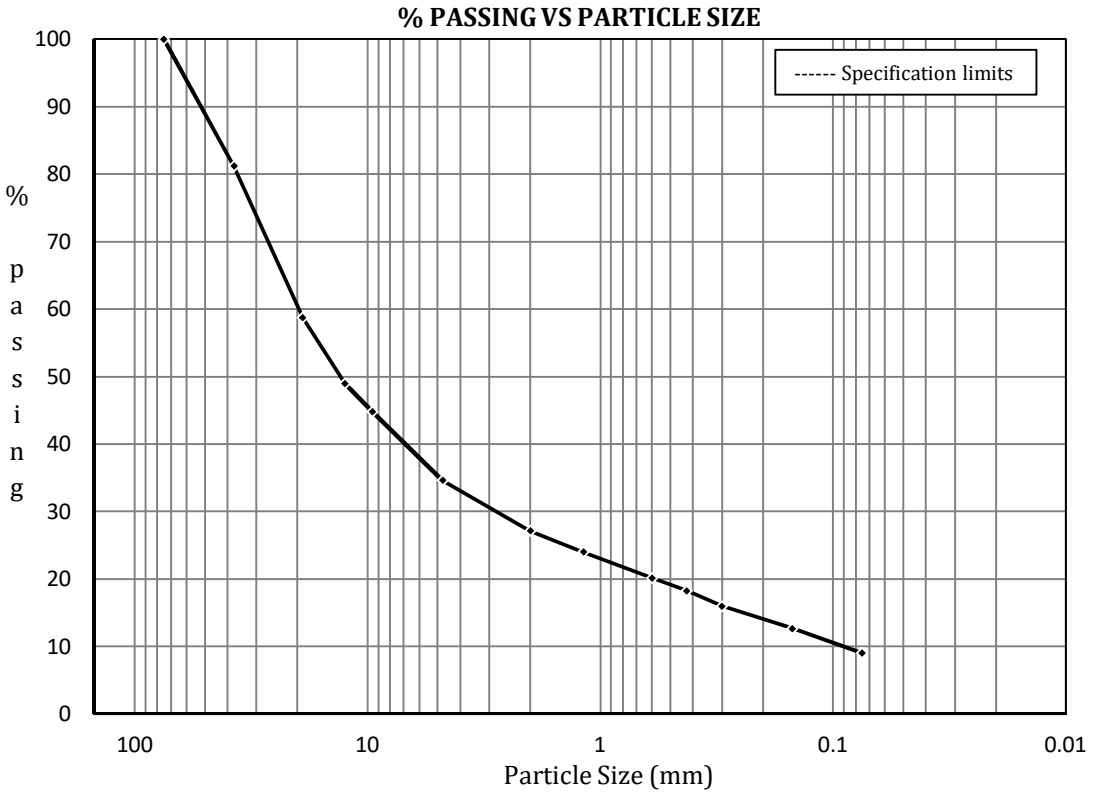
Lab ID: S18475
Client Project: Fernie Dike

Date Received: August 17, 2018

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0		
75.0	100.0	
37.5	81.2	
19.0	58.7	
12.5	48.9	
9.5	44.8	
4.75	34.6	
2.00	27.1	
1.18	24.0	
0.600	20.2	
0.425	18.3	
0.300	16.0	
0.150	12.7	
0.075	9.0	



Summary

Cobble :	>75mm	%
Gravel :	< 75mm and > 4.75mm	65.4 %
Sand :	< 4.75mm and > 0.075mm	25.6 %
Silt/Clay :	< 0.075mm	9.0 %

Moisture Content: 2.4 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18476
Client Project: Fernie Dike

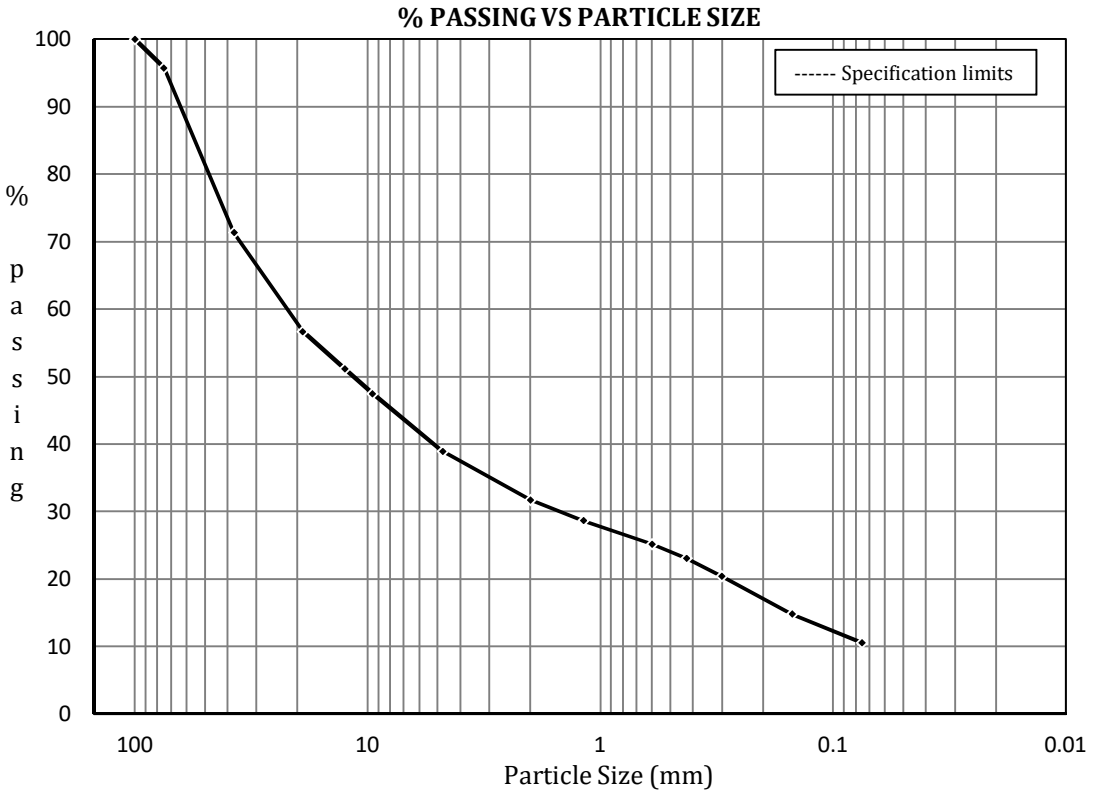
Date Received: August 17, 2018

Sample Description: Sandy GRAVEl, some silt/clay, trace cobble
Sample ID: B2 S6, S7, S8, S9, S10 combined
Sample Source: Geotechnical Investigation

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0	100.0	
75.0	95.7	
37.5	71.3	
19.0	56.7	
12.5	51.1	
9.5	47.4	
4.75	38.9	
2.00	31.7	
1.18	28.7	
0.600	25.2	
0.425	23.1	
0.300	20.4	
0.150	14.8	
0.075	10.6	



Summary

Cobble :	>75mm	4.3 %
Gravel :	< 75mm and > 4.75mm	56.8 %
Sand :	< 4.75mm and > 0.075mm	28.3 %
Silt/Clay :	< 0.075mm	10.6 %

Moisture Content: 6.8 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Sample Description: Sandy SILT/CLAY
Sample ID: B3 S5, S6, S7, S8 combined
Sample Source: Geotechnical Investigation

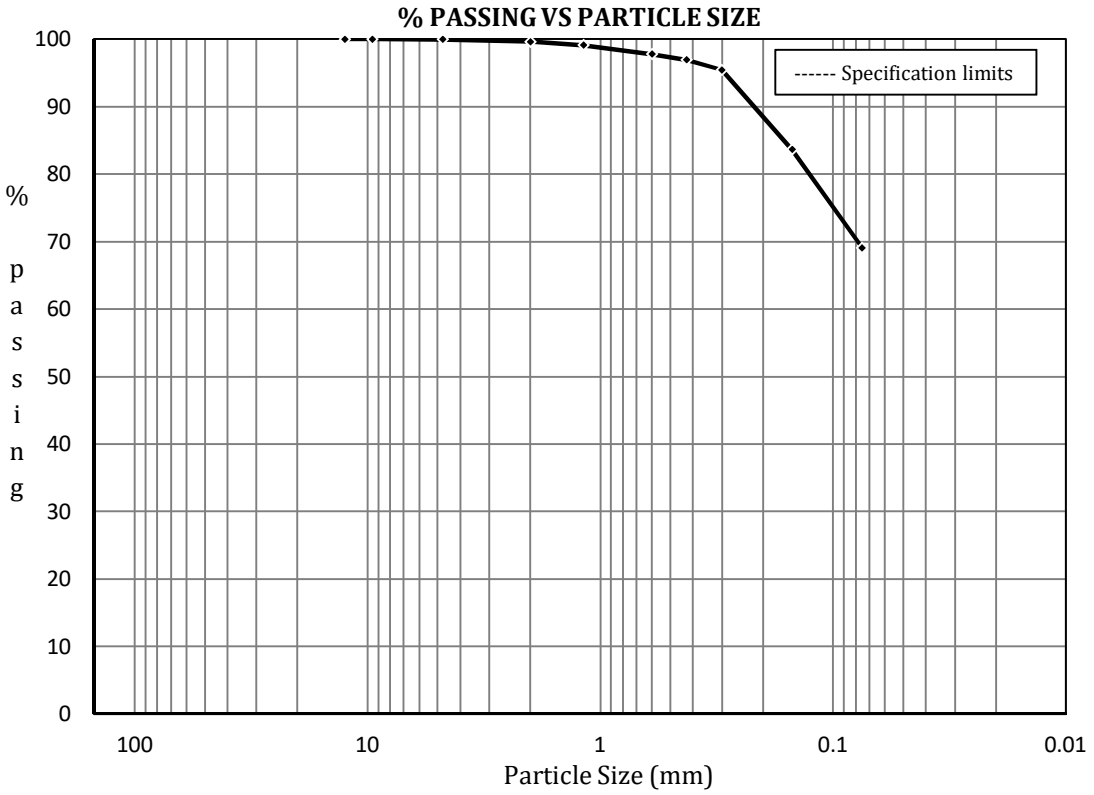
Lab ID: S18477
Client Project: Fernie Dike

Date Received: August 17, 2018

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0		
75.0		
37.5		
19.0		
12.5	100.0	
9.5	100.0	
4.75	99.9	
2.00	99.6	
1.18	99.1	
0.600	97.8	
0.425	96.9	
0.300	95.4	
0.150	83.6	
0.075	69.0	



Summary

Cobble :	>75mm		%
Gravel :	< 75mm and > 4.75mm	0.1	%
Sand :	< 4.75mm and > 0.075mm	30.9	%
Silt/Clay :	< 0.075mm	69.0	%

Moisture Content: 33.8 %

Comments: Sample contained significant organic matter

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18478
Client Project: Fernie Dike

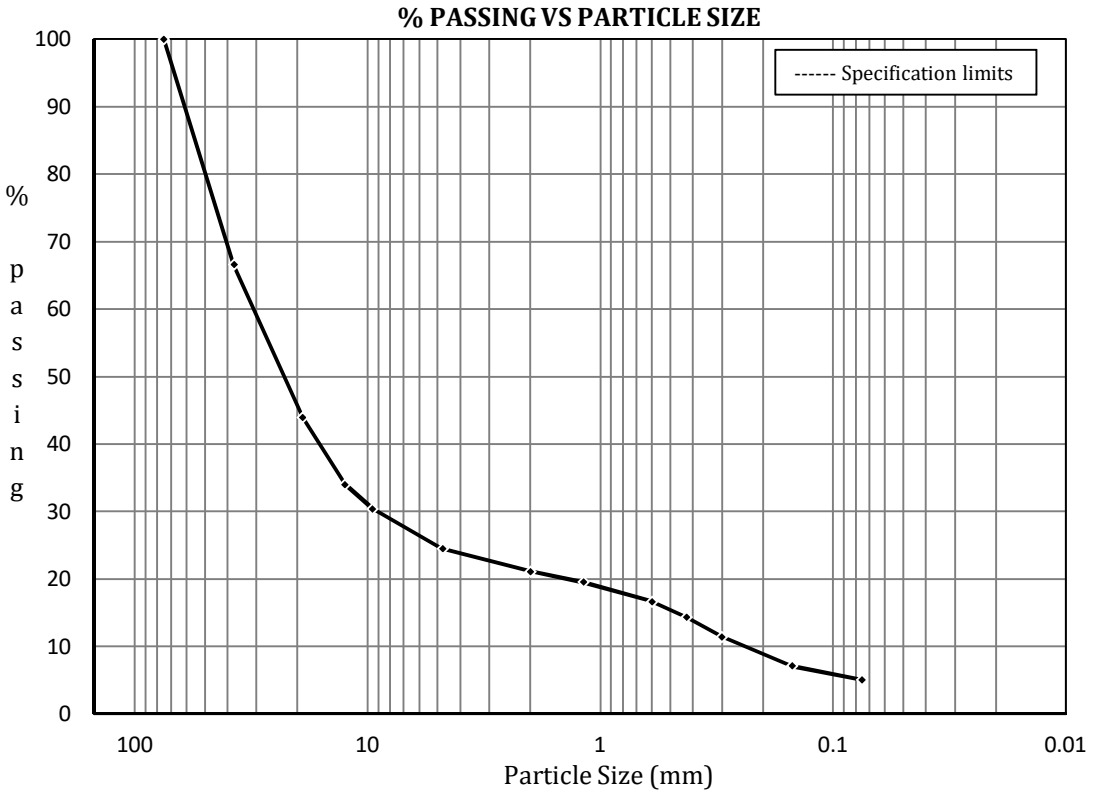
Date Received: August 17, 2018

Sample Description: GRAVEL, some sand, trace silt/clay
Sample ID: B3 S11
Sample Source: Geotechnical Investigation

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0		
75.0	100.0	
37.5	66.6	
19.0	43.9	
12.5	34.0	
9.5	30.4	
4.75	24.5	
2.00	21.1	
1.18	19.5	
0.600	16.7	
0.425	14.3	
0.300	11.4	
0.150	7.1	
0.075	5.1	



Summary

Cobble :	>75mm	0.0 %
Gravel :	< 75mm and > 4.75mm	75.5 %
Sand :	< 4.75mm and > 0.075mm	19.4 %
Silt/Clay :	< 0.075mm	5.1 %

Moisture Content: 5.7 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By:
Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Sample Description: Sandy GRAVEL, trace silt/clay
Sample ID: B5 S3
Sample Source: Geotechnical Investigation

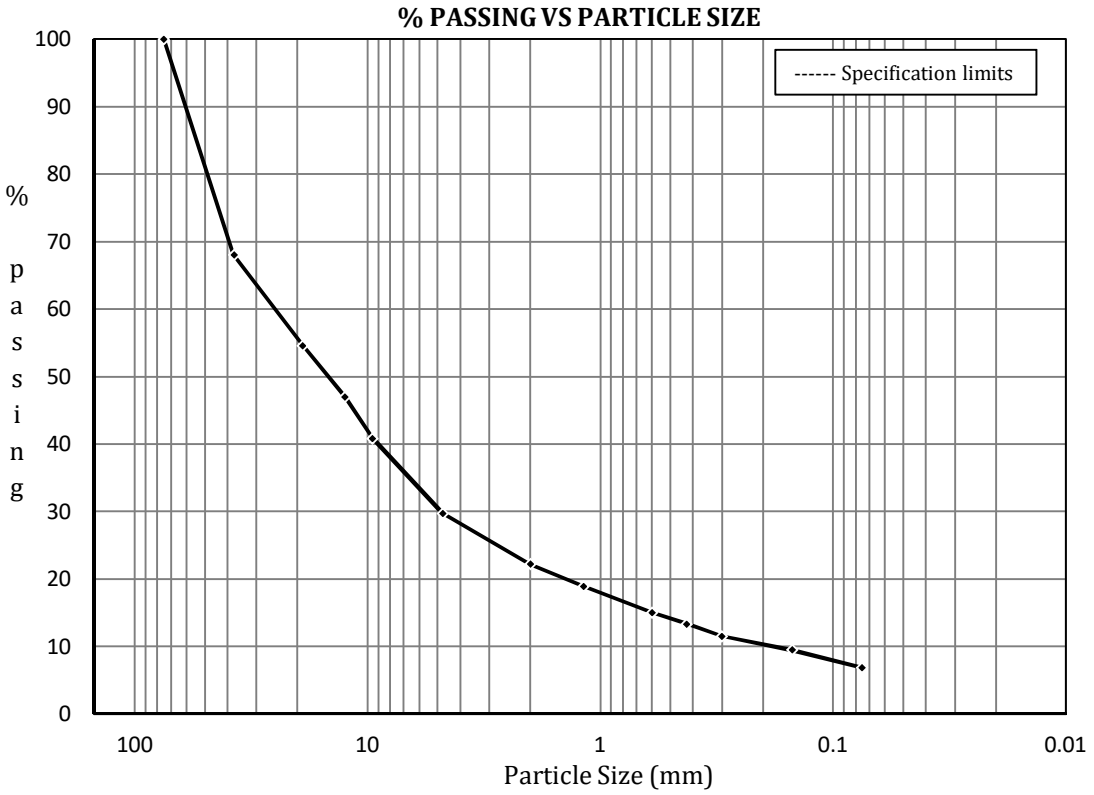
Lab ID: S18482
Client Project: Fernie Dike

Date Received: August 17, 2018

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0		
75.0	100.0	
37.5	68.0	
19.0	54.6	
12.5	47.0	
9.5	40.9	
4.75	29.7	
2.00	22.2	
1.18	18.9	
0.600	15.0	
0.425	13.3	
0.300	11.5	
0.150	9.5	
0.075	6.9	



Summary

Cobble :	>75mm		%
Gravel :	< 75mm and > 4.75mm	70.3	%
Sand :	< 4.75mm and > 0.075mm	22.9	%
Silt/Clay :	< 0.075mm	6.9	%

Moisture Content: 1.8 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By:
Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18483
Client Project: Fernie Dike

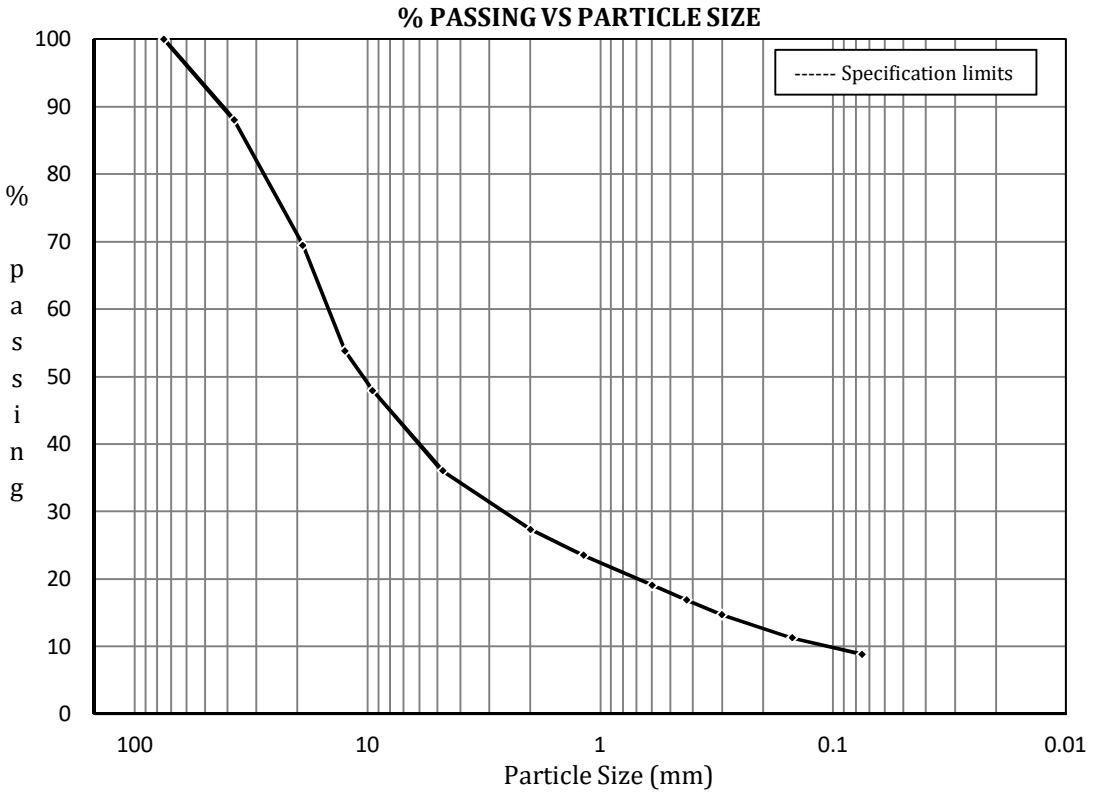
Date Received: August 17, 2018

Sample Description: Sandy GRAVEL, trace silt/clay
Sample ID: B5 S5, S6 combined
Sample Source: Geotechnical Investigation

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0		
75.0	100.0	
37.5	88.0	
19.0	69.4	
12.5	53.8	
9.5	47.9	
4.75	36.0	
2.00	27.4	
1.18	23.6	
0.600	19.1	
0.425	16.9	
0.300	14.7	
0.150	11.3	
0.075	8.9	



Summary

Cobble :	>75mm		%
Gravel :	< 75mm and > 4.75mm	64.0	%
Sand :	< 4.75mm and > 0.075mm	27.2	%
Silt/Clay :	< 0.075mm	8.9	%

Moisture Content: 5.1 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18492
Client Project: Fernie Dike

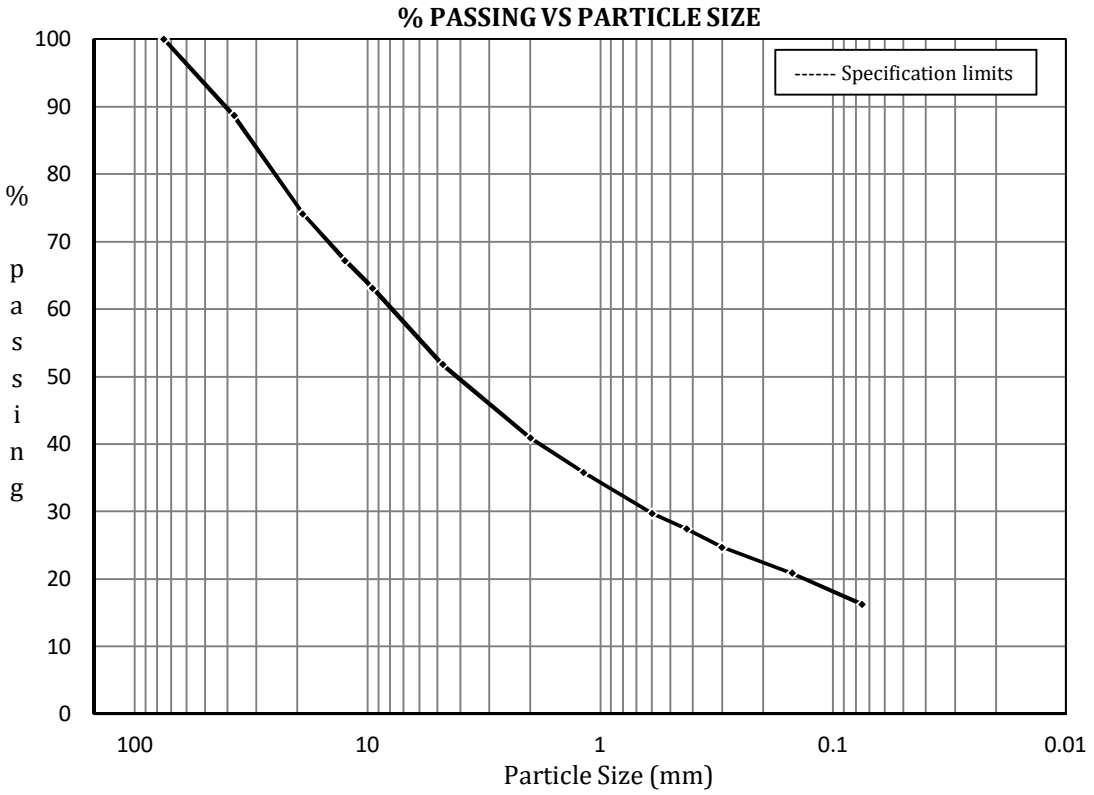
Date Received: August 17, 2018

Sample Description: GRAVEL and SAND, some silt/clay
Sample ID: B9 S2
Sample Source: Geotechnical Investigation

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0		
75.0	100.0	
37.5	88.6	
19.0	74.1	
12.5	67.2	
9.5	63.1	
4.75	51.8	
2.00	40.9	
1.18	35.8	
0.600	29.7	
0.425	27.4	
0.300	24.7	
0.150	20.9	
0.075	16.2	



Summary

Cobble :	>75mm	0.0 %
Gravel :	< 75mm and > 4.75mm	48.2 %
Sand :	< 4.75mm and > 0.075mm	35.5 %
Silt/Clay :	< 0.075mm	16.2 %

Moisture Content: 2.5 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By:
Bryan Morrison, BSc.

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PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18493
Client Project: Fernie Dike

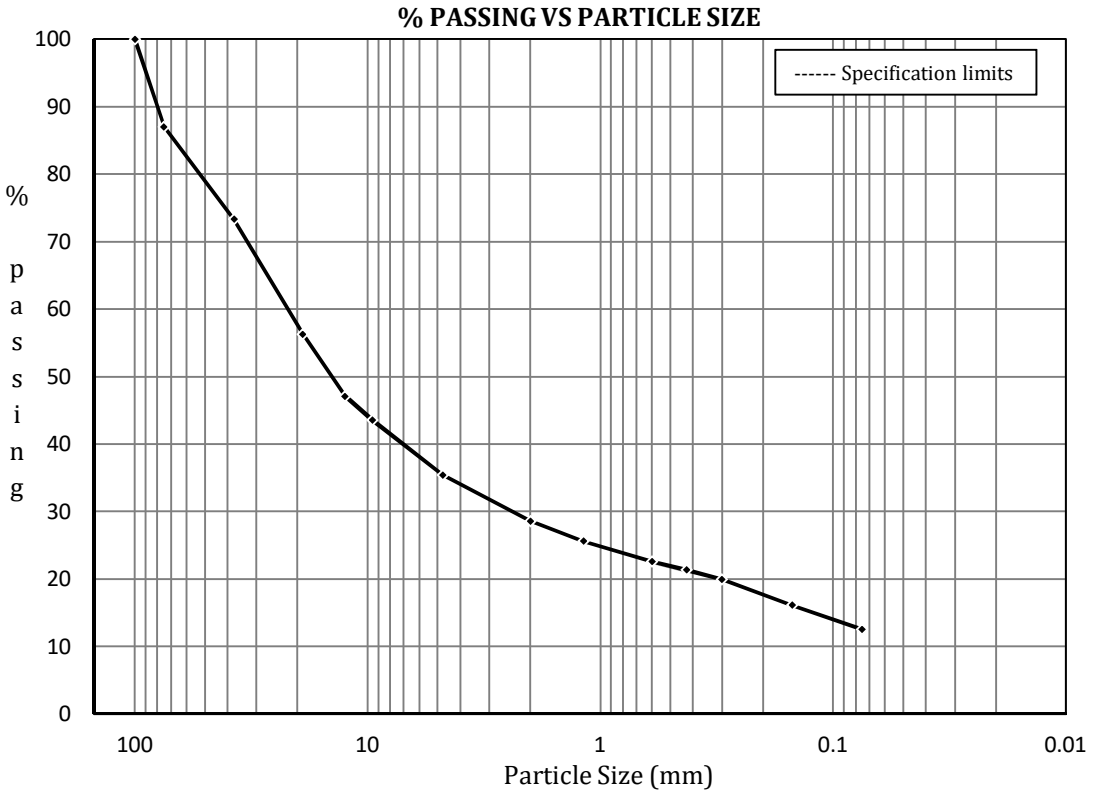
Date Received: August 17, 2018

Sample Description: Sandy GRAVEL, some cobble, some silt/clay
Sample ID: B9 S3, S4, S5, S6 combined
Sample Source: Geotechnical Investigation

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0	100.0	
75.0	87.0	
37.5	73.3	
19.0	56.3	
12.5	47.1	
9.5	43.5	
4.75	35.4	
2.00	28.6	
1.18	25.6	
0.600	22.6	
0.425	21.3	
0.300	19.9	
0.150	16.1	
0.075	12.5	



Summary

Cobble :	>75mm	13.0 %
Gravel :	< 75mm and > 4.75mm	51.5 %
Sand :	< 4.75mm and > 0.075mm	22.9 %
Silt/Clay :	< 0.075mm	12.5 %

Moisture Content: 6.8 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By:
Bryan Morrison, BSc.

ARTECH CONSULTING LTD.
PHONE: 250-489-1940 FAX: 250-489-1667 EMAIL: info@artechconsulting.ca
229 Industrial Rd F, Cranbrook, BC V1C 6N4 www.artechconsulting.ca

PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18495
Client Project: Fernie Dike

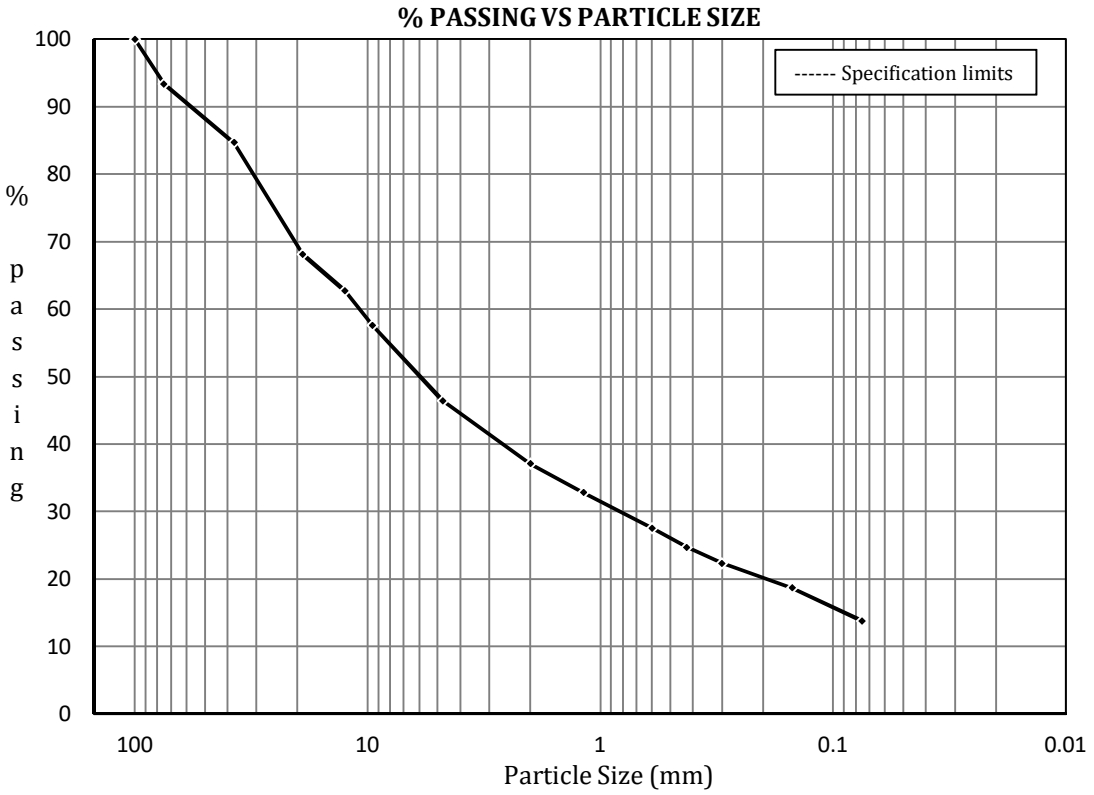
Date Received: August 17, 2018

Sample Description: Sandy GRAVEL, some silt/clay, trace cobble
Sample ID: B11 S2
Sample Source: Geotechnical Investigation

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0	100.0	
75.0	93.3	
37.5	84.7	
19.0	68.1	
12.5	62.7	
9.5	57.6	
4.75	46.4	
2.00	37.1	
1.18	32.8	
0.600	27.5	
0.425	24.7	
0.300	22.3	
0.150	18.7	
0.075	13.8	



Summary

Cobble :	>75mm	6.7 %
Gravel :	< 75mm and > 4.75mm	46.9 %
Sand :	< 4.75mm and > 0.075mm	32.6 %
Silt/Clay :	< 0.075mm	13.8 %

Moisture Content: 2.7 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By: Bryan Morrison, BSc.

ARTECH CONSULTING LTD.
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229 Industrial Rd F, Cranbrook, BC V1C 6N4 www.artechconsulting.ca

PARTICLE SIZE ANALYSIS

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18498
Client Project: Fernie Dike

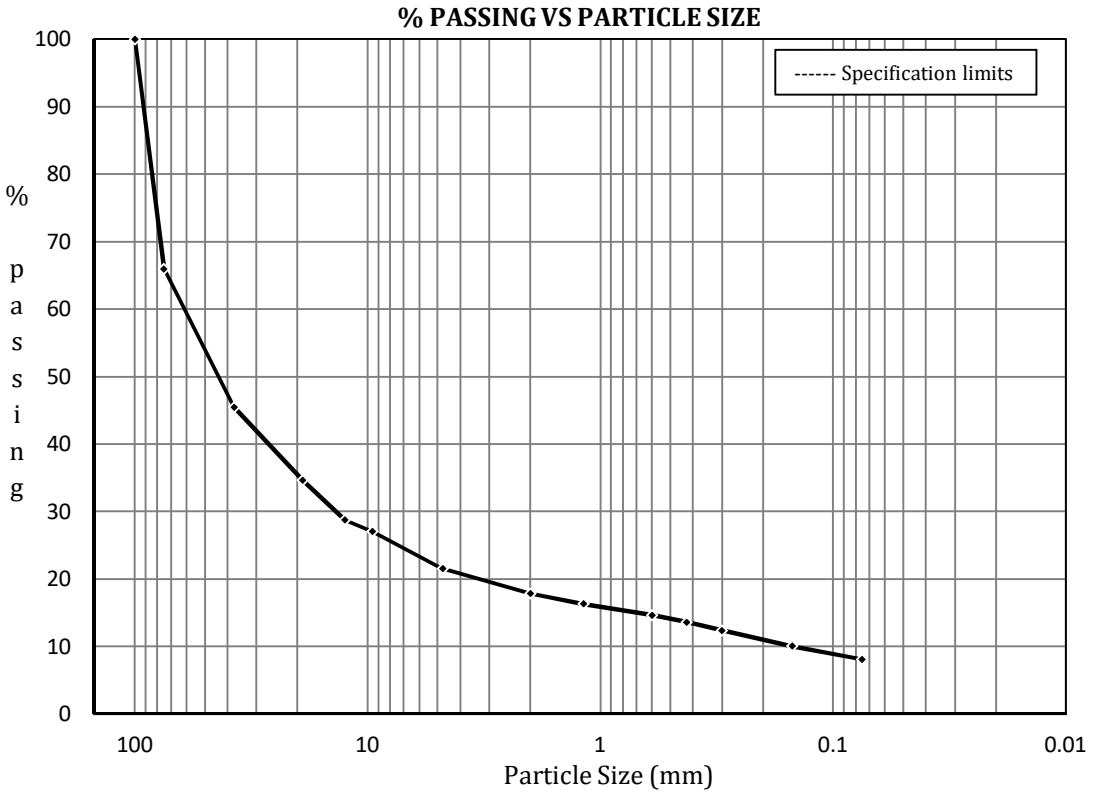
Date Received: August 17, 2018

Sample Description: Cobbly GRAVEL, some sand, trace silt/clay
Sample ID: B12 S7
Sample Source: Geotechnical Investigation

Sample Date: -
Sample Time: -
Sampled By: Client

Specification: NA

Sieve Analysis		
Sieve Size (mm)	% Passing	Specification limits
100.0	100.0	
75.0	65.9	
37.5	45.5	
19.0	34.6	
12.5	28.7	
9.5	27.0	
4.75	21.6	
2.00	17.8	
1.18	16.3	
0.600	14.7	
0.425	13.6	
0.300	12.4	
0.150	10.0	
0.075	8.1	



Summary

Cobble :	>75mm	34.1 %
Gravel :	< 75mm and > 4.75mm	44.4 %
Sand :	< 4.75mm and > 0.075mm	13.5 %
Silt/Clay :	< 0.075mm	8.1 %

Moisture Content: 2.4 %

Comments: -

Tested in accordance with ASTM C136 Sieve Analysis of Fine and Coarse Aggregates /C117 Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

Report Date: August 24, 2018

Reviewed By:
Bryan Morrison, BSc.

ARTECH CONSULTING LTD.
PHONE: 250-489-1940 FAX: 250-489-1667 EMAIL: info@artechconsulting.ca
229 Industrial Rd F, Cranbrook, BC V1C 6N4 www.artechconsulting.ca

MOISTURE CONTENT REPORT

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18472 to S18491
Client Project: Fernie Dike

Date Received: August 17, 2018

Sample Source: Geotechnical Investigation
Sample Date: -
Sample Time: -
Sampled By: Client

Lab ID	Sample ID	Sample Description	% Moisture	Comments
S18472	B1 S1		6.1%	Gradation
S18473	B1 S8		4.0%	Gradation
S18474	B1 S13		27.0%	Limits
S18475	B2 S3		2.4%	Gradation
S18476	B2 S6-S10		6.8%	Gradation
S18477	B3 S5-S8		33.8%	Gradation
S18478	B3 S11		5.7%	Gradation
S18479	B4 S12		26.7%	
S18480	B4 S13		25.0%	
S18481	B4 S14		23.4%	Limits
S18482	B5 S3		1.8%	Gradation
S18483	B5 S5-S6		5.1%	Gradation
S18484	B5 S9		6.6%	
S18485	B5 S10		25.4%	Limits
S18486	B6 S10		13.6%	
S18487	B6 S11		27.5%	
S18488	B7 S12		21.4%	Limits
S18489	B8 S10		26.4%	
S18490	B8 S11		27.0%	
S18491	B8 S13		25.2%	Limits

Tested in accordance with ASTM D2216 Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

Report Date: August 24, 2018

Reviewed By:

PHONE: 250-489-1940 FAX: 250-489-1667 EMAIL: info@artechconsulting.ca
229 Industrial Rd F, Cranbrook, BC V1C 6N4 www.artechconsulting.ca

ARTECH CONSULTING LTD.

MOISTURE CONTENT REPORT

Project No: 18.0005.AR
Project: Groundtech General
Client: Groundtech Engineering Ltd.

Attn: Doug Clapp
CC: -

Lab ID: S18492 to S18500
Client Project: Fernie Dike

Date Received: August 17, 2018

Sample Source: Geotechnical Investigation
Sample Date: -
Sample Time: -
Sampled By: Client

Lab ID	Sample ID	Sample Description	% Moisture	Comments
S18492	B9 S2		2.5%	Gradation
S18493	B9 S3-S6		6.8%	Gradation
S18494	B9 S7		25.8%	Limits
S18495	B11 S2		2.7%	Gradation
S18496	B11 S5		27.1%	Limits
S18497	B11 S6		23.4%	
S18498	B12 S7		2.4%	Gradation
S18499	B12 S11		25.6%	Limits
S18500	B12 S17		26.0%	Limits

Tested in accordance with ASTM D2216 Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

Report Date: August 24, 2018

Reviewed By:

Bryan Morrison, BSc.

GOLDER

PRAIRIES AND NORTH LABORATORIES

ATTN: Douglas A. Clapp, P.Eng. (AB, BC)
Senior Geotechnical Engineer/ Principal
Groundtech Engineering Ltd.

Received: 27-Aug-18
Report Date: 09-Sep-18
Version: Final

Geotechnical Laboratory Testing Report

Client: Groundtech Engineering Ltd.
Client Project Title: Fernie Dike Assessment - 18 M15 Fernie Dike
Golder Billing: 1894867.25.0
Lab No.: C842



Matthew Becker
Geotechnical Laboratory Manager
Calgary Geotechnical Laboratory
Golder Associates Ltd.

Our liability is limited to the cost of the test requested. The test results only relate to the sample as received. No liability in whole or in part is assumed for the collection, handling or transport of the sample, application or interpretation of the test data or results.

GOLDER

ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING

(ASTM D2435_D2435M-11)

Project No.:	1894867.25.0		Initial Water Content:	25.6	%	Initial Wet Density:	2026 kg/m^3
Borehole No.:	Fernie Dike Assessment		Initial Height:	18.87	mm	Inital Dry Density:	1613 kg/m^3
Sample No.:	1		Initial Mass:	147.10	g	Initial Void Ratio:	0.643
Depth:	-		Sample Diameter:	70.00	mm	Initial Saturation:	105.5%
Lab No.:	C842-01		Specific Gravity: (assumed)	2.65		Height of Solids:	11.484 mm
			Final Water Content:	20.6	%	Final Void Ratio: (from height)	0.476
			Final Height: (Measured)	16.95	mm	Area:	0.00385 m^2
Loading Cap:	1.4	kPa	Final Mass:	141.04	g	Initial Dry Mass:	117.12 g

Load No.	H_{sample} (mm)	Stone Correction	$H_{corrected}$ (mm)	Stress (kPa)	Void Ratio	Strain (%)	Incremental Work (kJ/m^3)	Cumulative Work (kJ/m^3)	Stress Point (kPa)
0	18.83	0.00	18.83	1.4	0.639	0.2	0.0	0.0	1.4
1	18.53	0.02	18.55	5.8	0.615	1.7	0.1	0.1	5.8
2	18.34	0.05	18.39	13.8	0.601	2.5	0.1	0.1	13.8
3	18.17	0.08	18.25	26.2	0.589	3.3	0.2	0.3	26.2
4	17.98	0.11	18.10	50.1	0.576	4.1	0.3	0.6	50.1
5	17.69	0.15	17.85	102.3	0.554	5.4	1.1	1.7	102.3
6	17.39	0.19	17.58	197.9	0.531	6.8	2.2	3.9	197.9
7	16.97	0.23	17.21	405.0	0.498	8.8	6.4	10.3	405.0
8	16.58	0.28	16.86	803.3	0.468	10.6	12.2	22.5	803.3
9	16.06	0.36	16.42	1604.4	0.430	13.0	31.6	54.0	1604.4
10	16.26	0.27	16.53	405.0	0.439	12.4			
11	16.47	0.23	16.69	102.3	0.454	11.5			
12	16.69	0.18	16.87	26.2	0.469	10.6			
13	16.94	0.12	17.07	5.8	0.486	9.5			

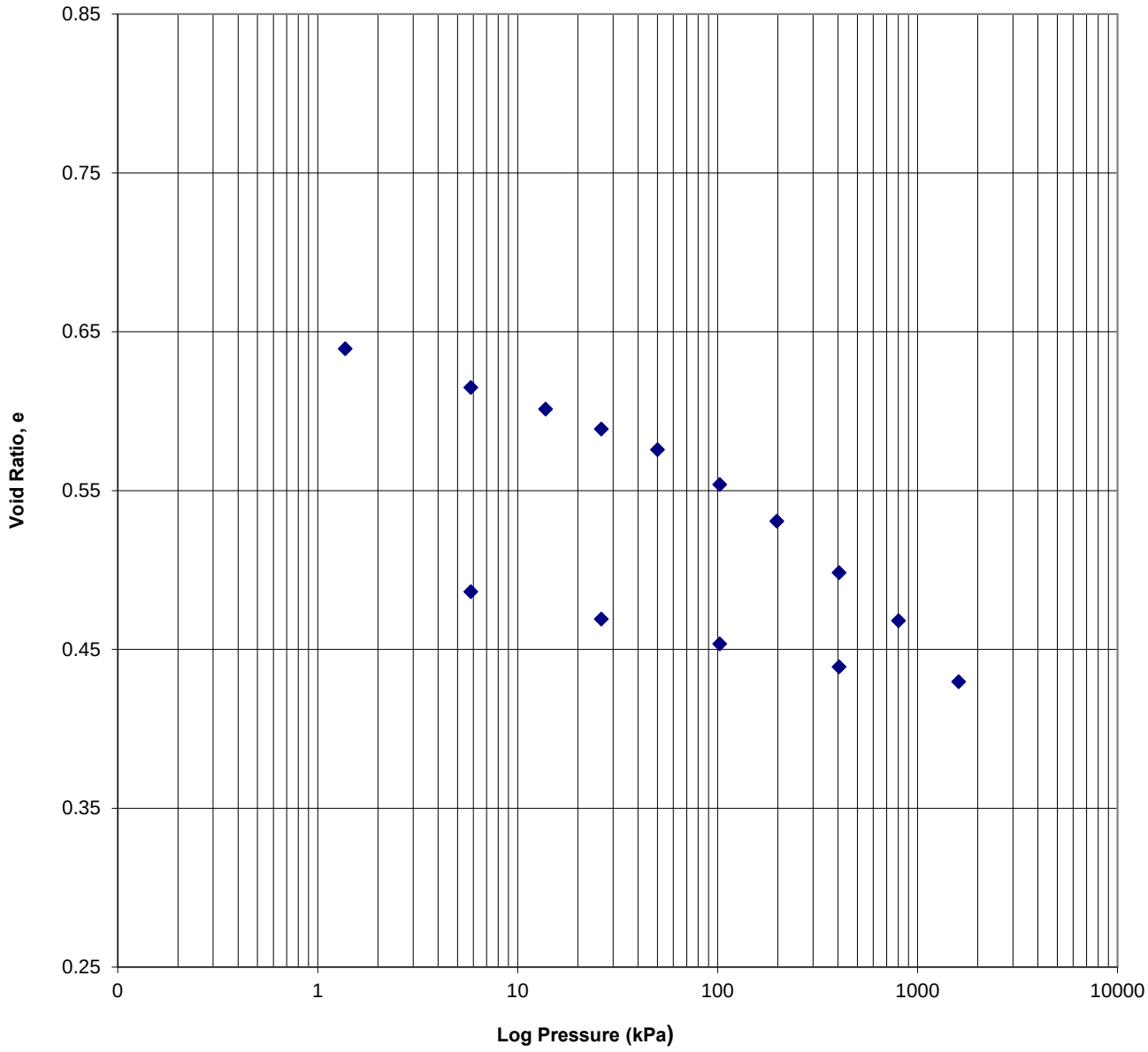
Soil Description: (ML) CLAYEY SILT; light grey; cohesive, w>PL, soft

GOLDER

ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

Void Ratio vs. Log Pressure

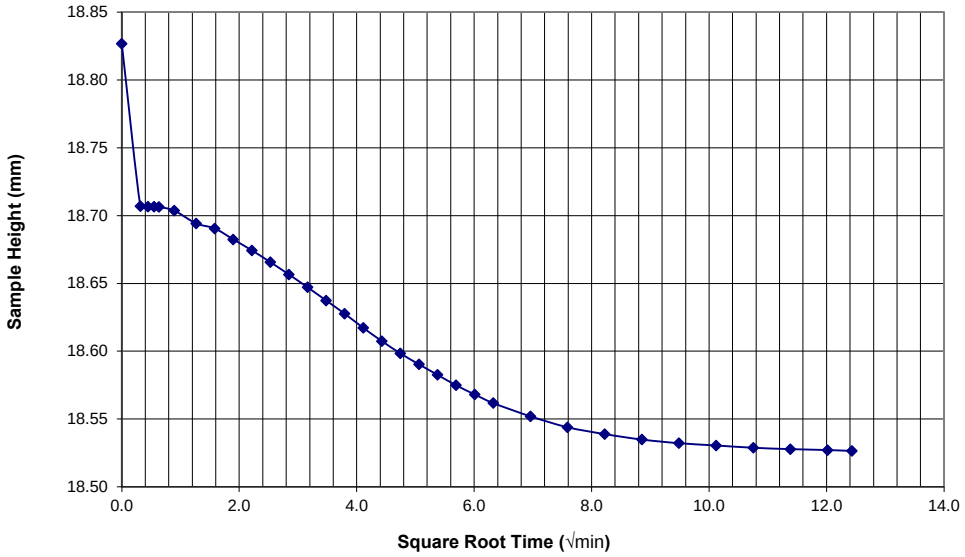


GOLDER

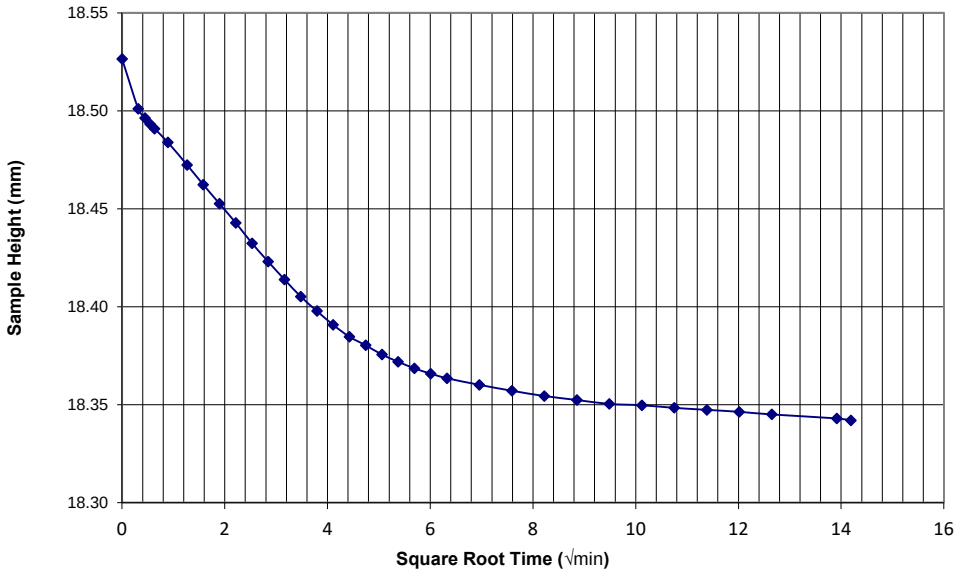
ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

SAMPLE HEIGHT vs. SQUARE ROOT TIME



Total Stress: 5.8 kPa



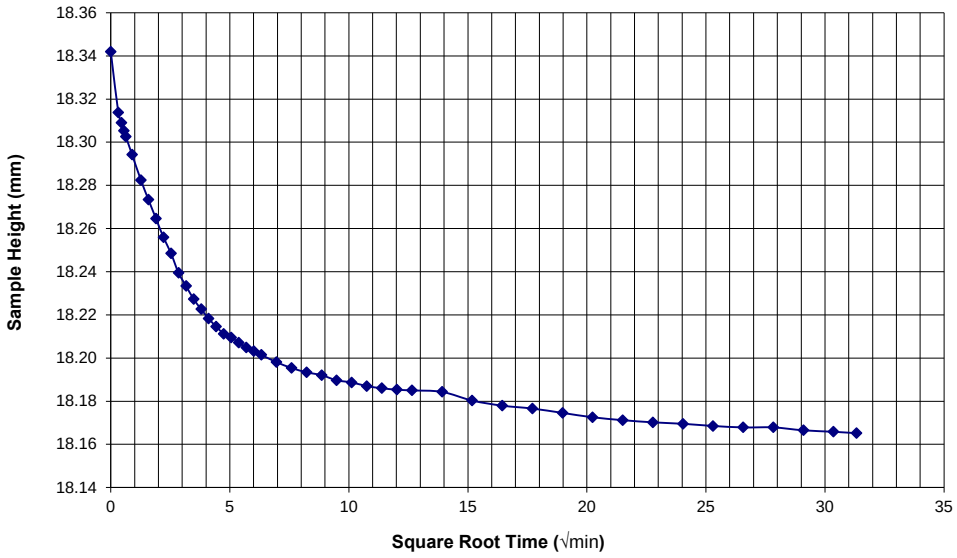
Total Stress: 13.8 kPa

GOLDER

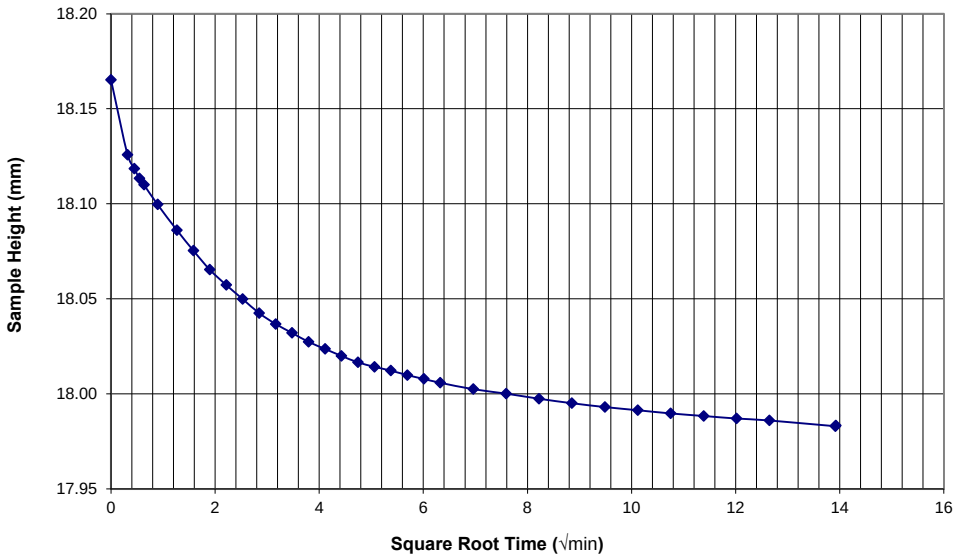
ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

SAMPLE HEIGHT vs. SQUARE ROOT TIME



Total Stress: 26.2 kPa



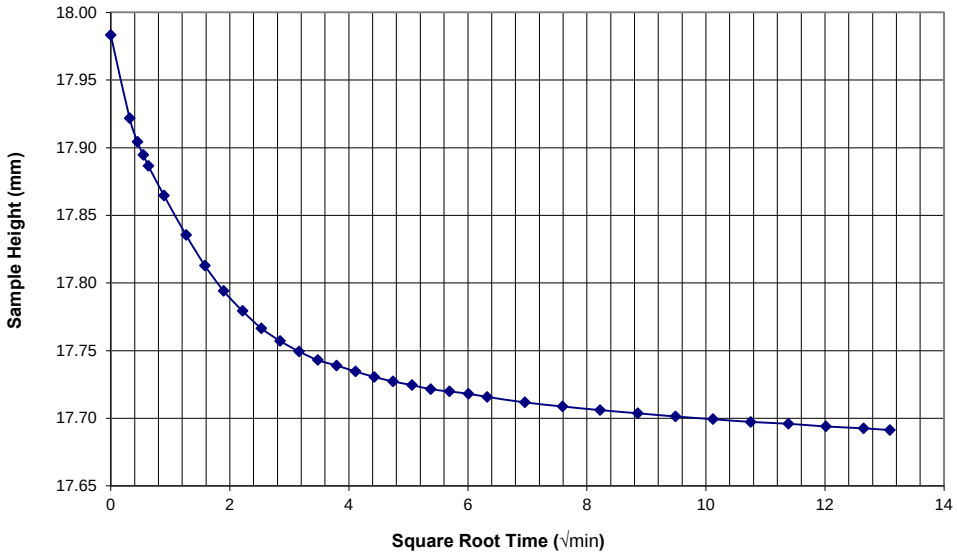
Total Stress: 50.1 kPa

GOLDER

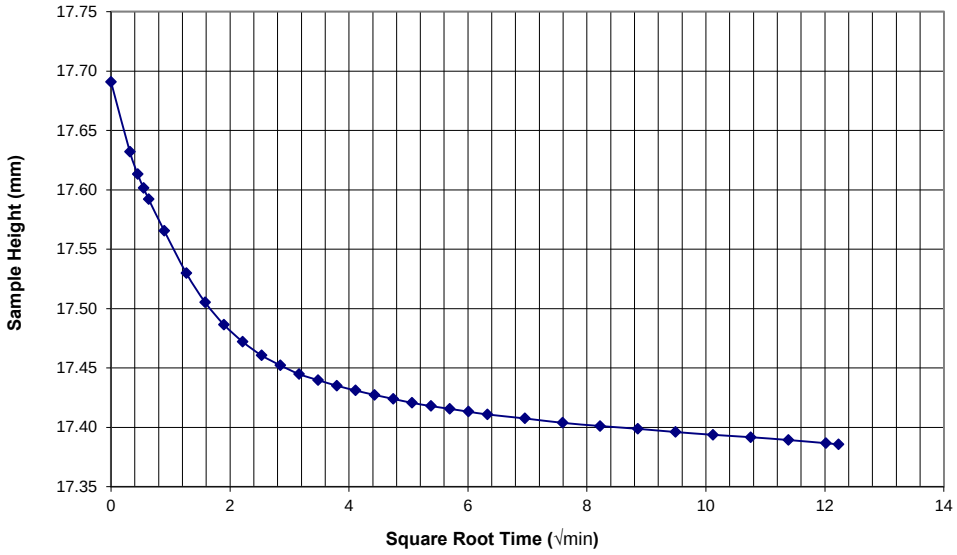
ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

SAMPLE HEIGHT vs. SQUARE ROOT TIME



Total Stress: 102.3 kPa



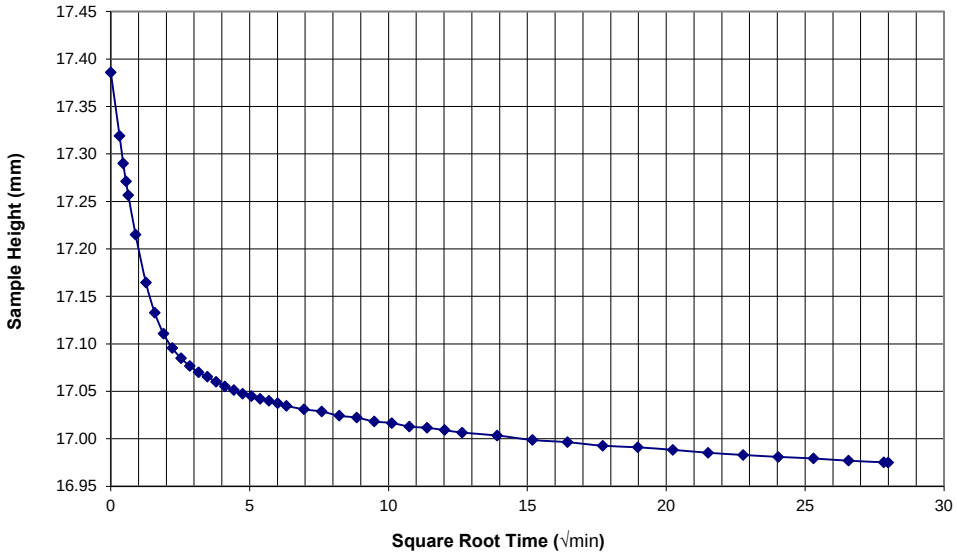
Total Stress: 197.9 kPa

GOLDER

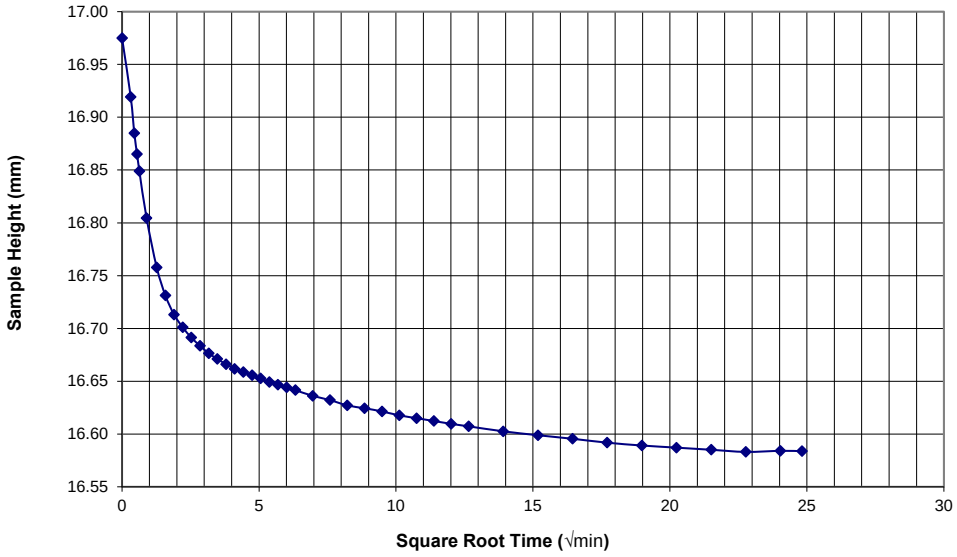
ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

SAMPLE HEIGHT vs. SQUARE ROOT TIME



Total Stress: 405.0 kPa



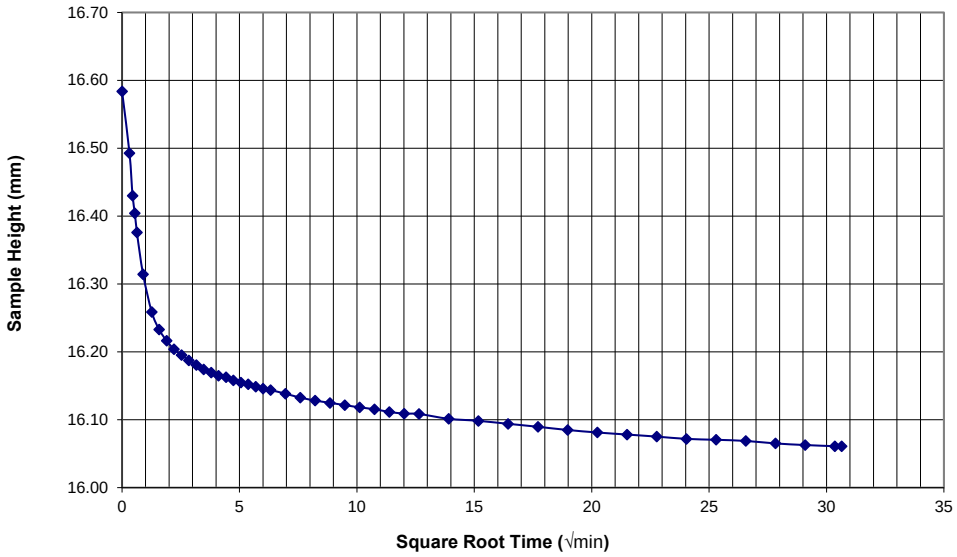
Total Stress: 803.3 kPa

GOLDER

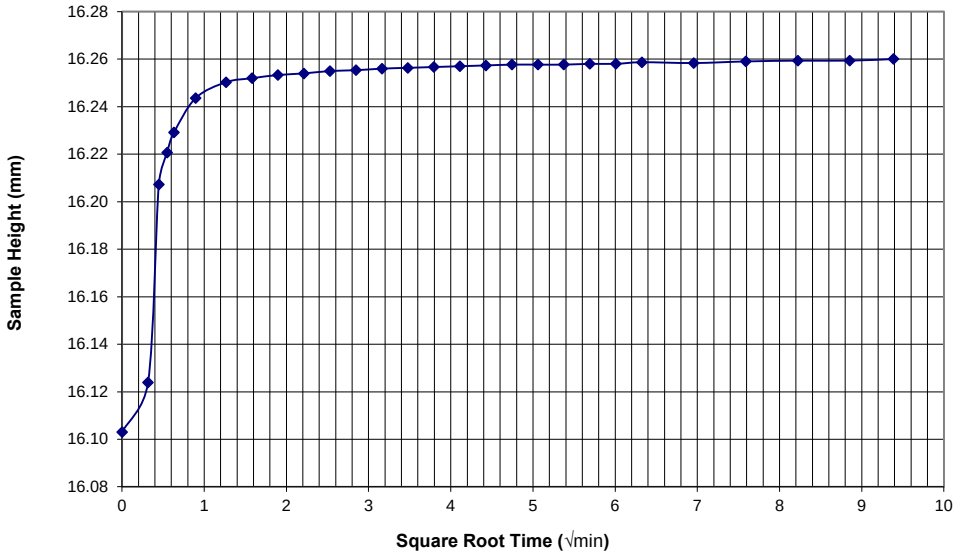
ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

SAMPLE HEIGHT vs. SQUARE ROOT TIME



Total Stress: 1604.4 kPa



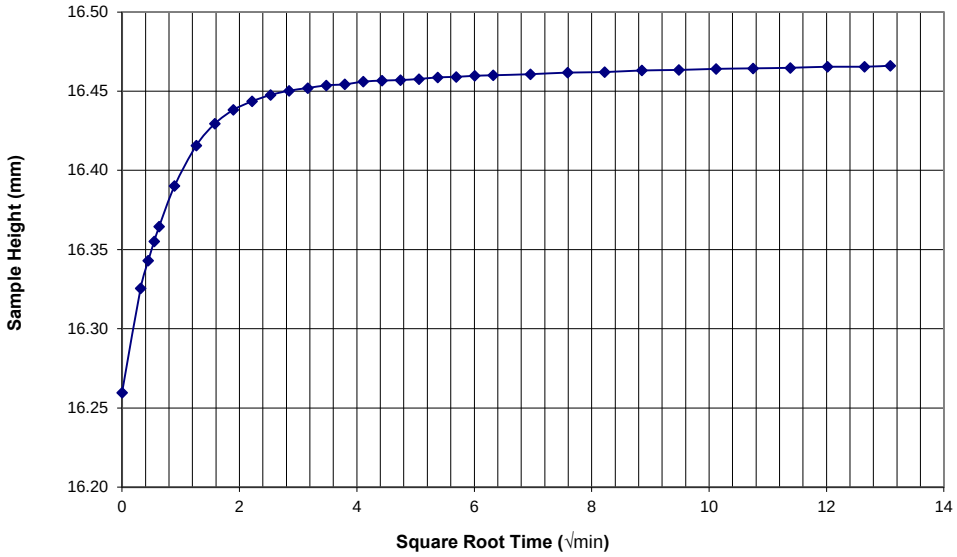
Total Stress: 405.0 kPa

GOLDER

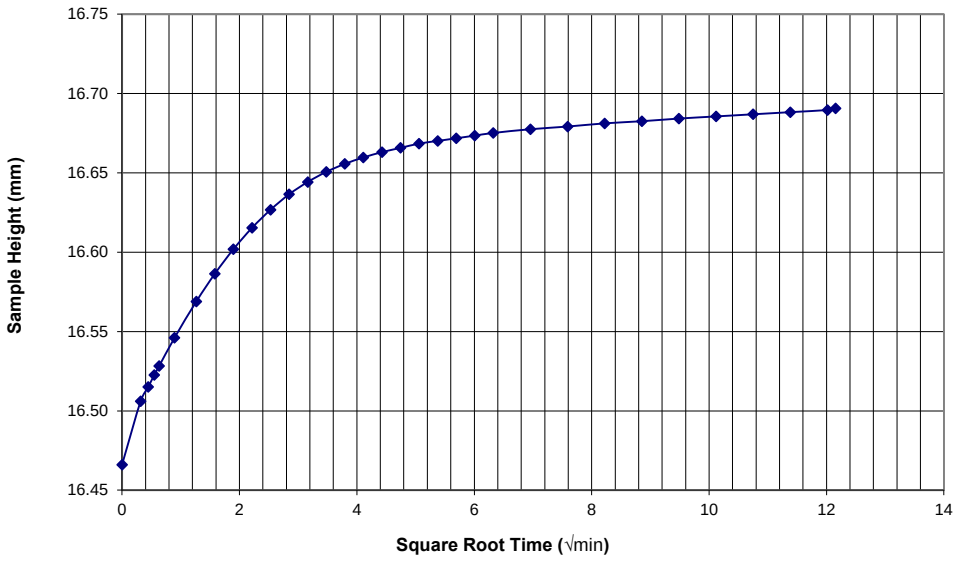
ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

SAMPLE HEIGHT vs. SQUARE ROOT TIME



Total Stress: 102.3 kPa



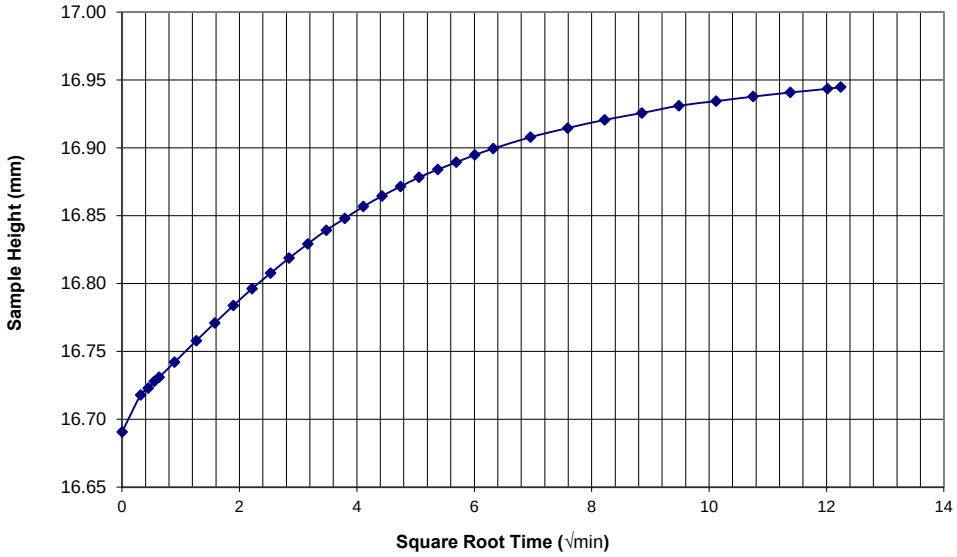
Total Stress: 26.2 kPa

GOLDER

ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

SAMPLE HEIGHT vs. SQUARE ROOT TIME



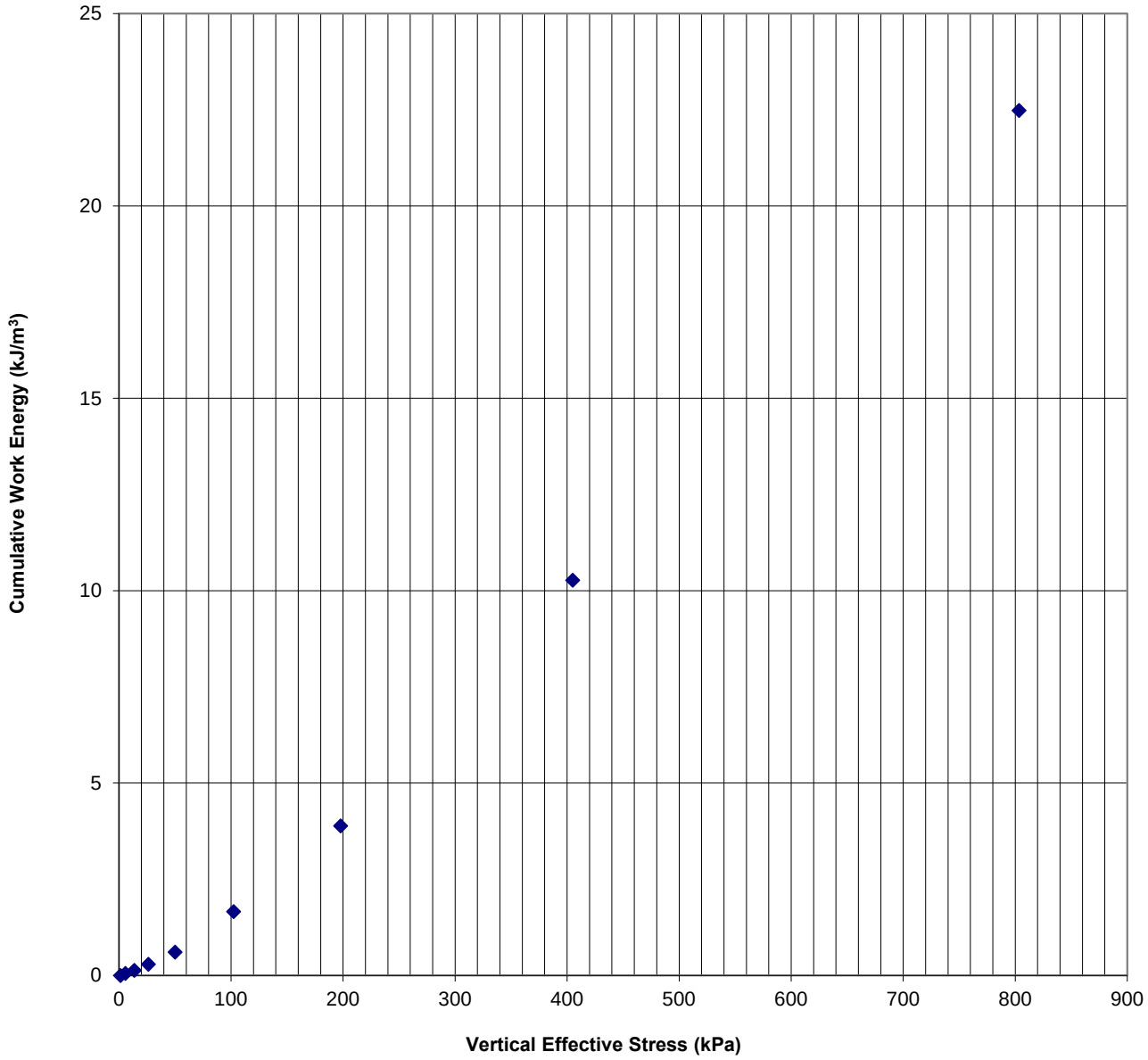
Total Stress: 5.8 kPa

GOLDER

ONE -DIMENSIONAL CONSOLIDATION PROPERTIES OF SOILS USING INCREMENTAL LOADING
(ASTM D2435_D2435M-11)

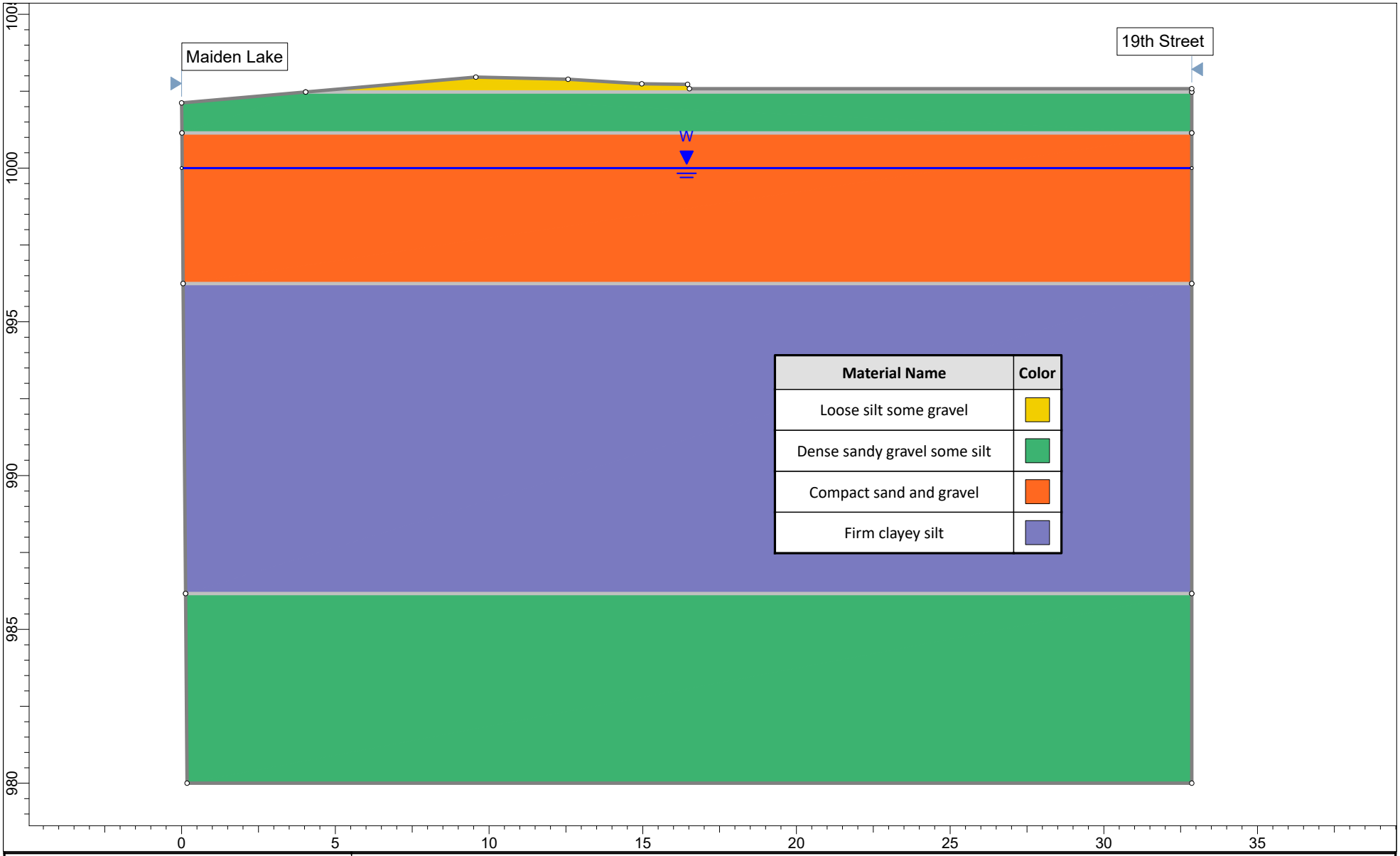
Project No.: 1894867.25.0
Lab No.: C842-01
BH No.: Fernie Dike Assessment
Sample No.: 1
Depth: -

Work Energy Method

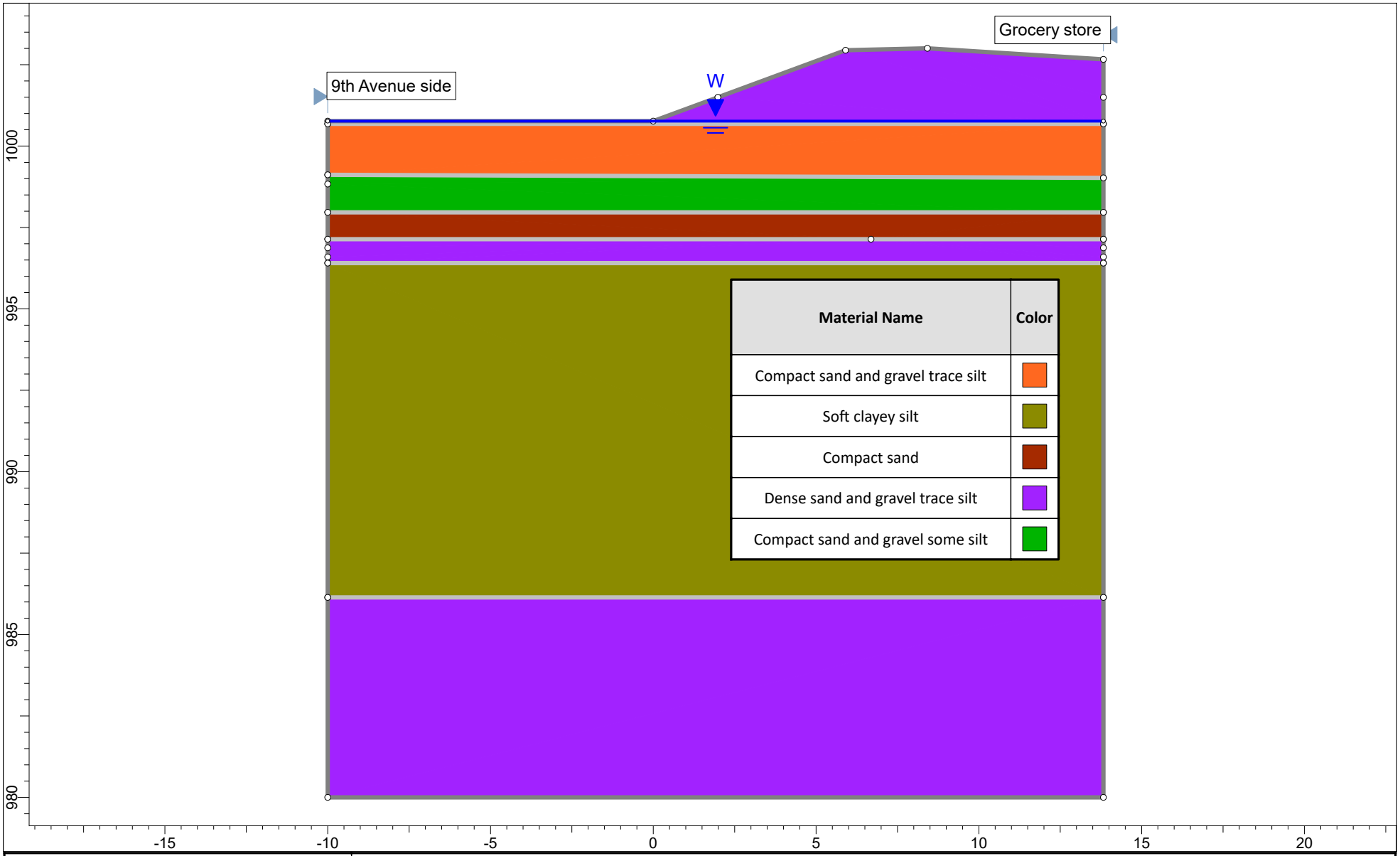


APPENDIX V

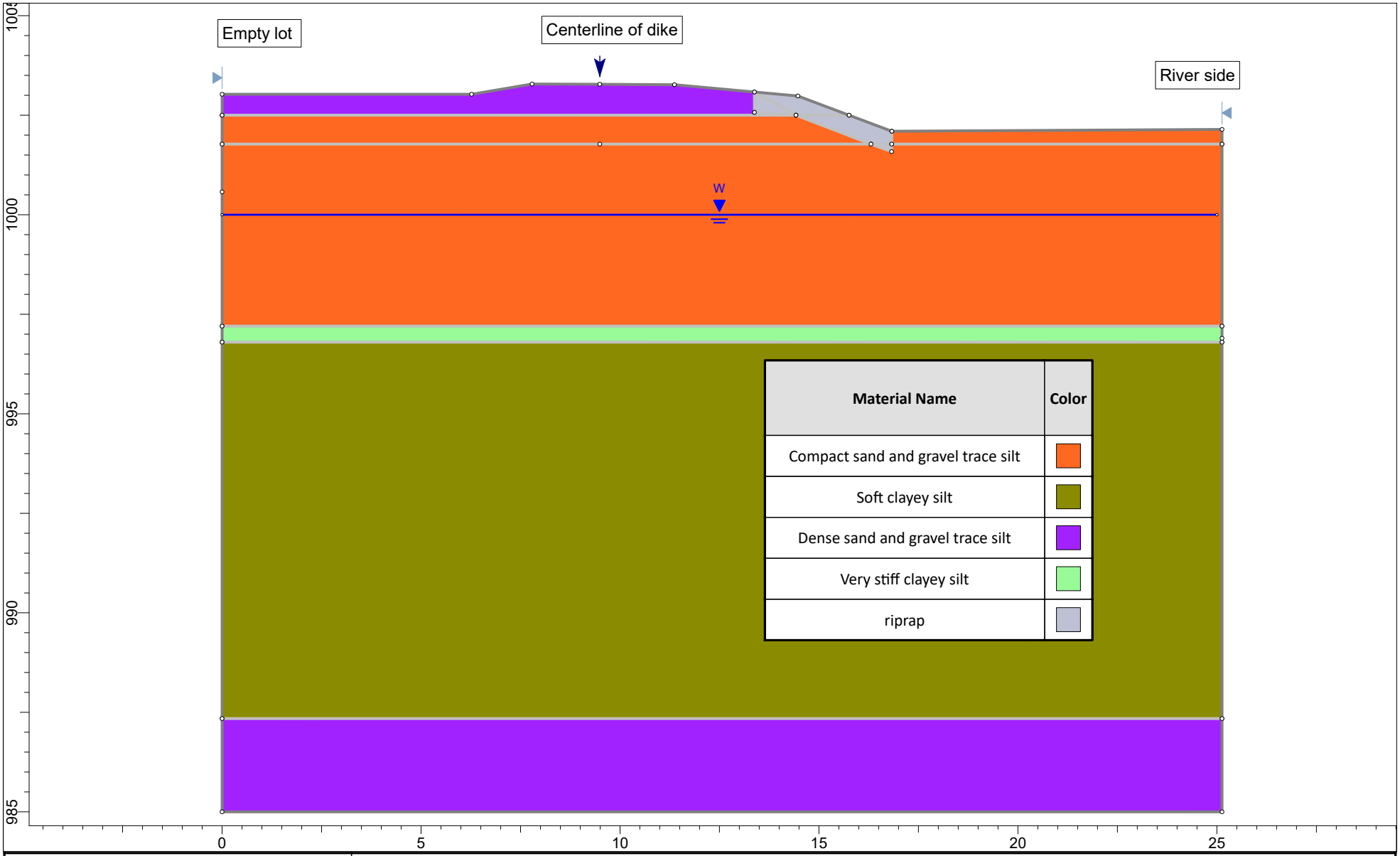
Dike Cross-Sections



rocscience	*Project* SLIDE - An Interactive Slope Stability Program		
	Analysis Description		
	Drawn By	*Scale* 1:175	*Company*
SLIDE 8.018	*Date* 11/5/2018, 4:51:14 PM		*File Name* xs1.slim



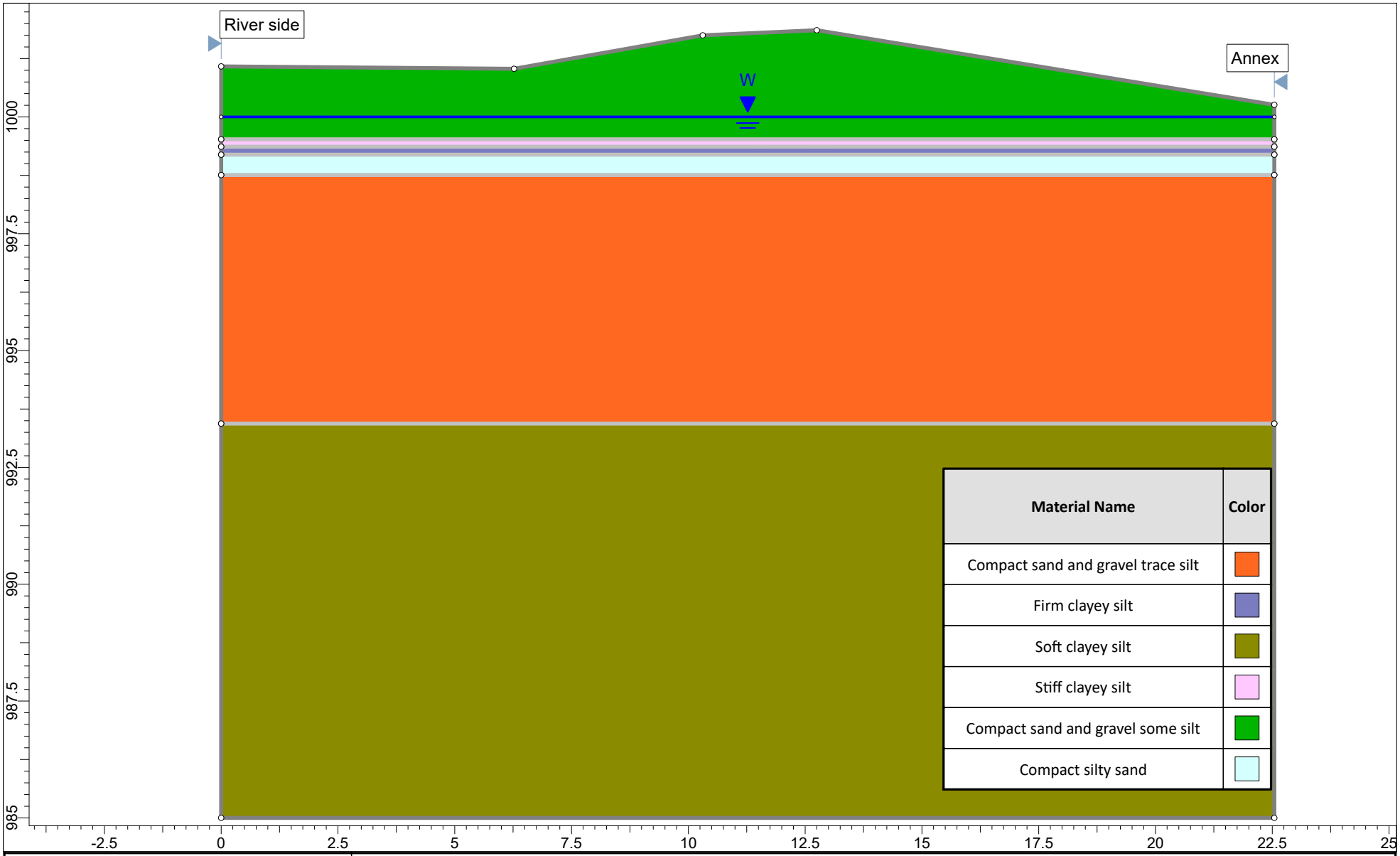
rocscience	Project: SLIDE - An Interactive Slope Stability Program		
	Analysis Description:		
	Drawn By:	Scale: 1:165	Company:
SLIDE 8.018	Date: 11/5/2018, 4:51:14 PM		File Name: xs2.slim



rocscience

SLIDE 8.018

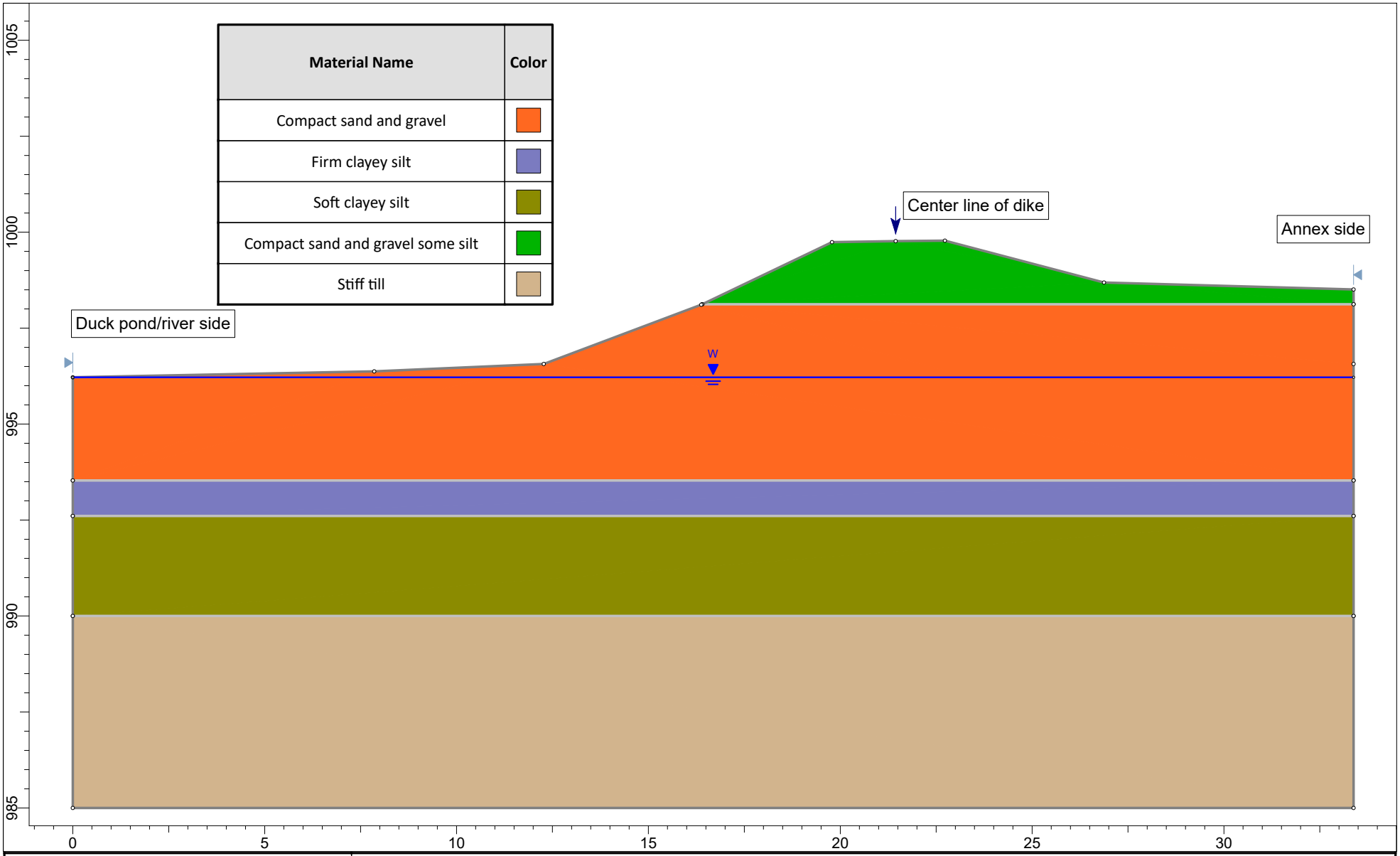
Project	SLIDE - An Interactive Slope Stability Program		
Analysis Description			
Drawn By		*Scale* 1:135	*Company*
Date	11/5/2018, 4:51:14 PM		*File Name* xs3.slim



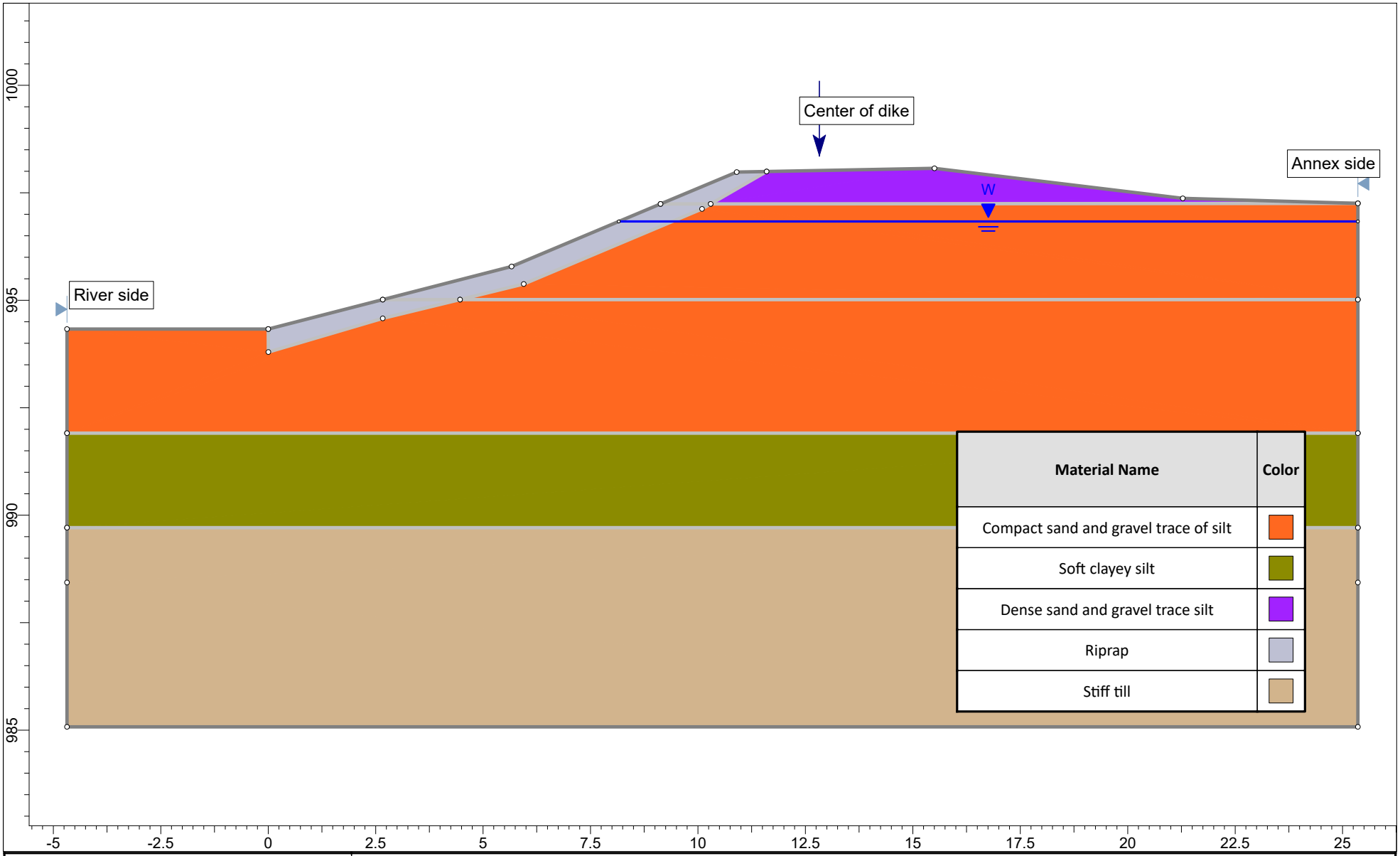
rocscience

SLIDE 8.018

Project	SLIDE - An Interactive Slope Stability Program		
Analysis Description			
Drawn By		*Scale* 1:115	*Company*
Date	11/5/2018, 4:51:14 PM		*File Name* xs4.slim



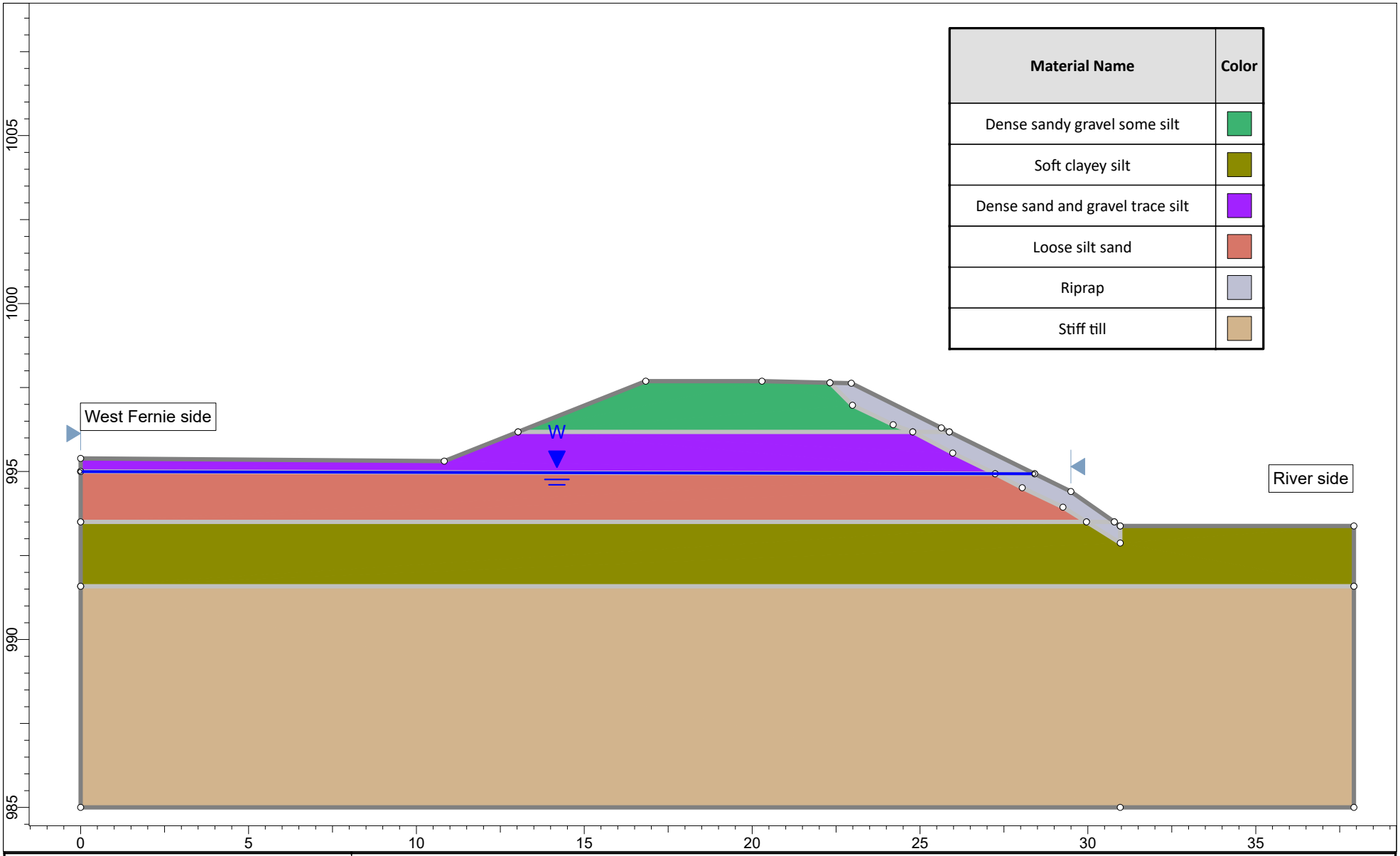
rocscience	*Project*	SLIDE - An Interactive Slope Stability Program	
	Analysis Description		
	Drawn By	*Scale* 1:140	*Company*
SLIDE 8.018	*Date* 11/5/2018, 4:51:14 PM		*File Name* xs5.slim



rocscience

SLIDE 8.018

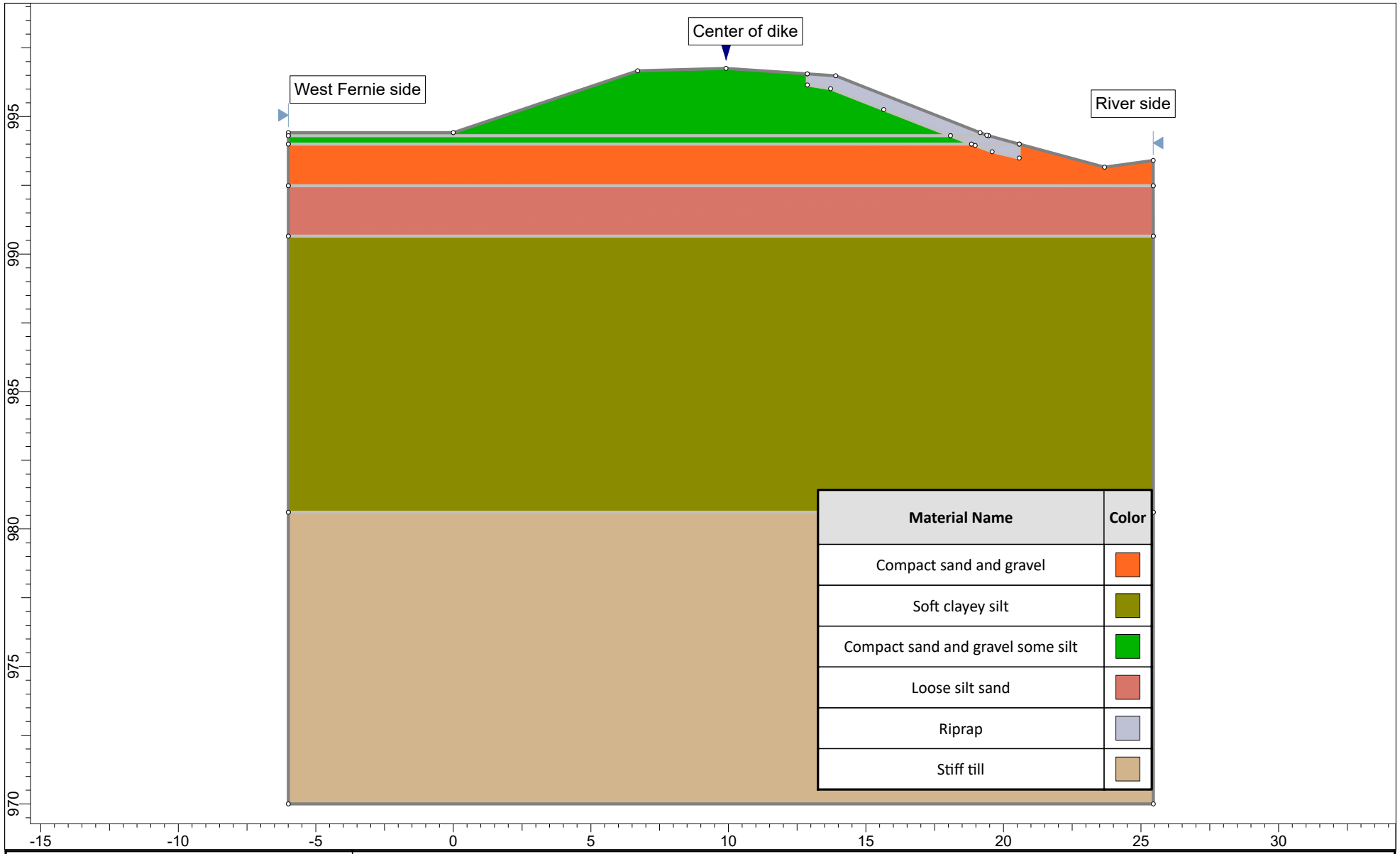
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SLIDE 8.018

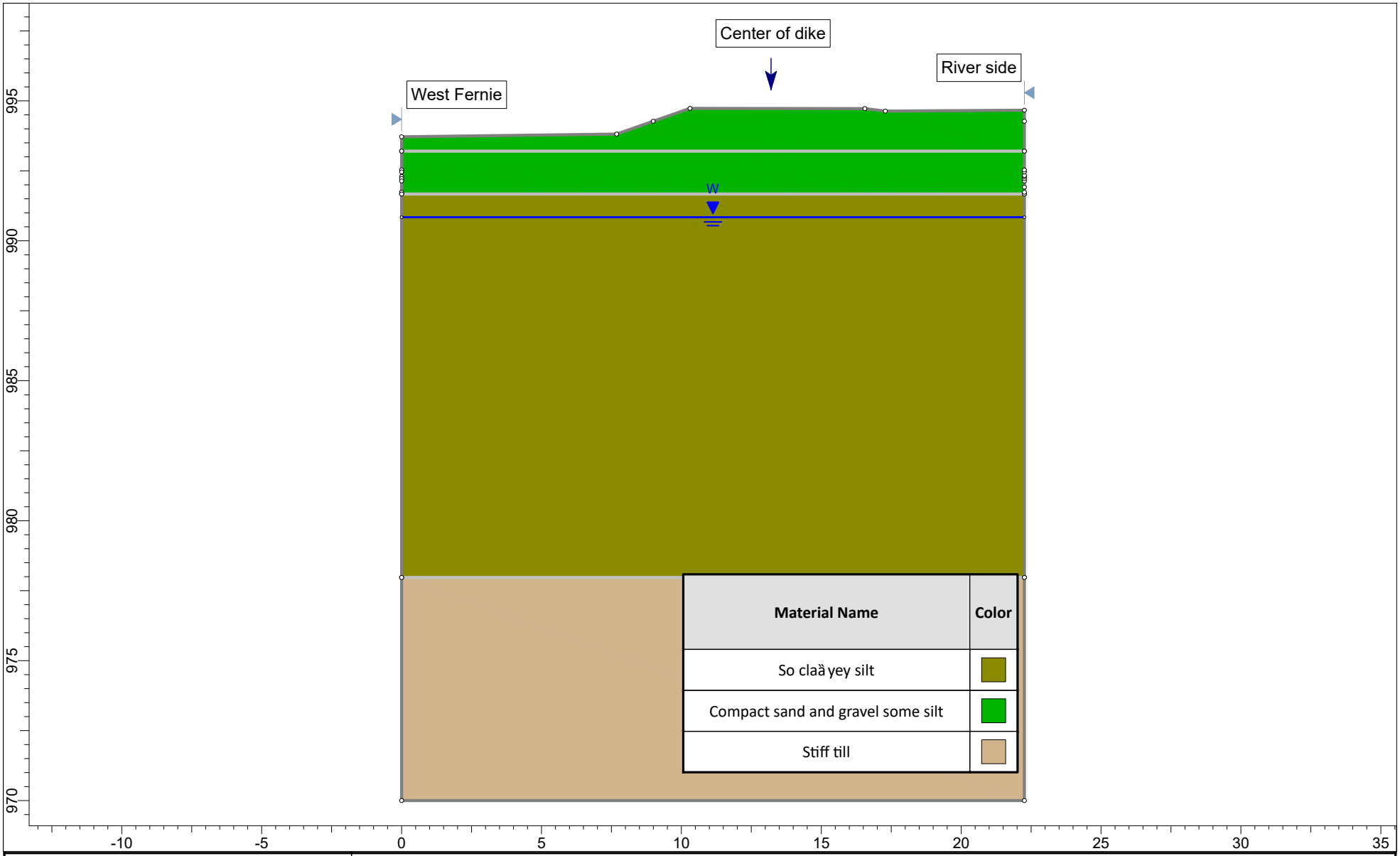
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SLIDE 8.018

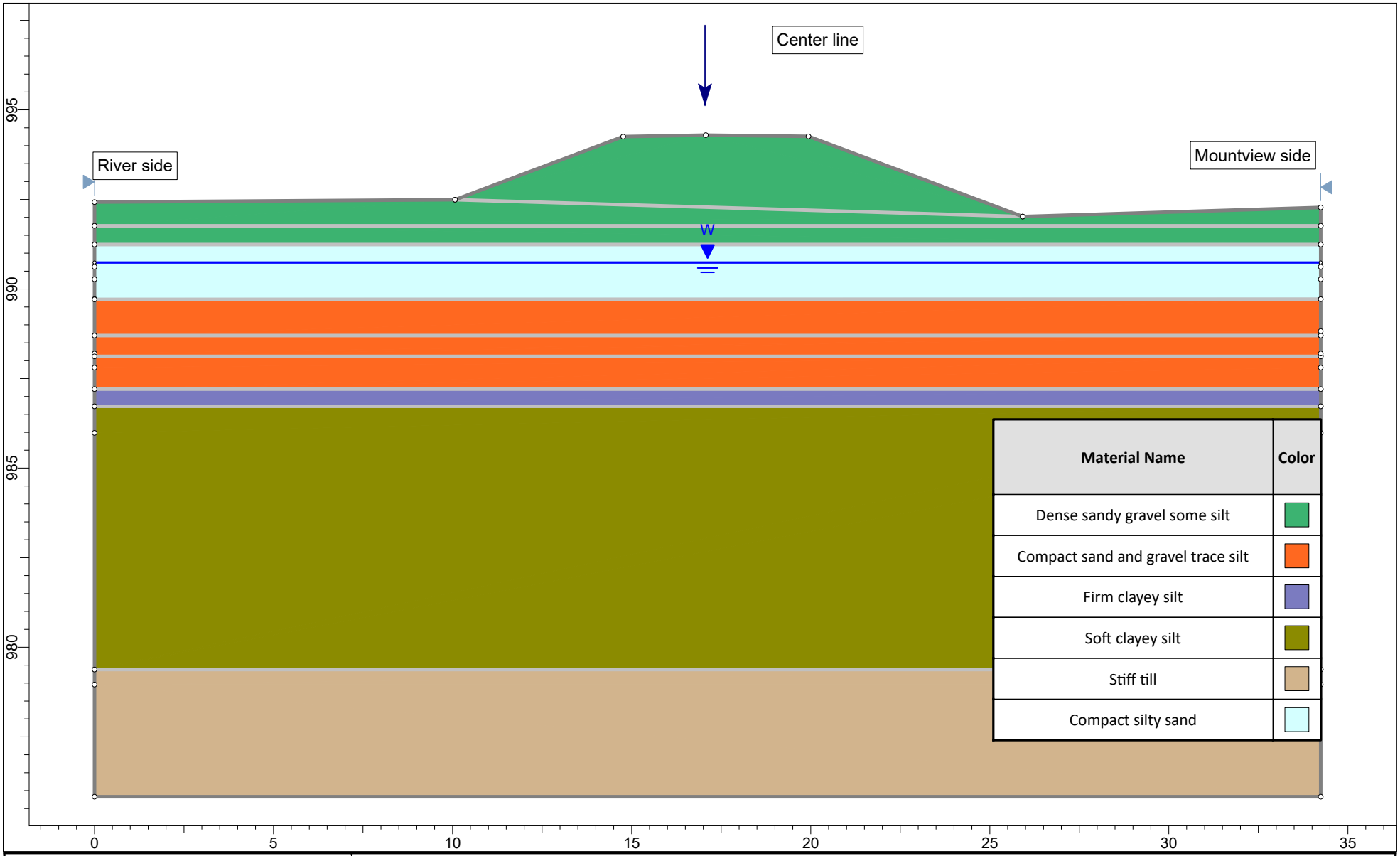
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Analysis Description			
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SLIDE 8.018

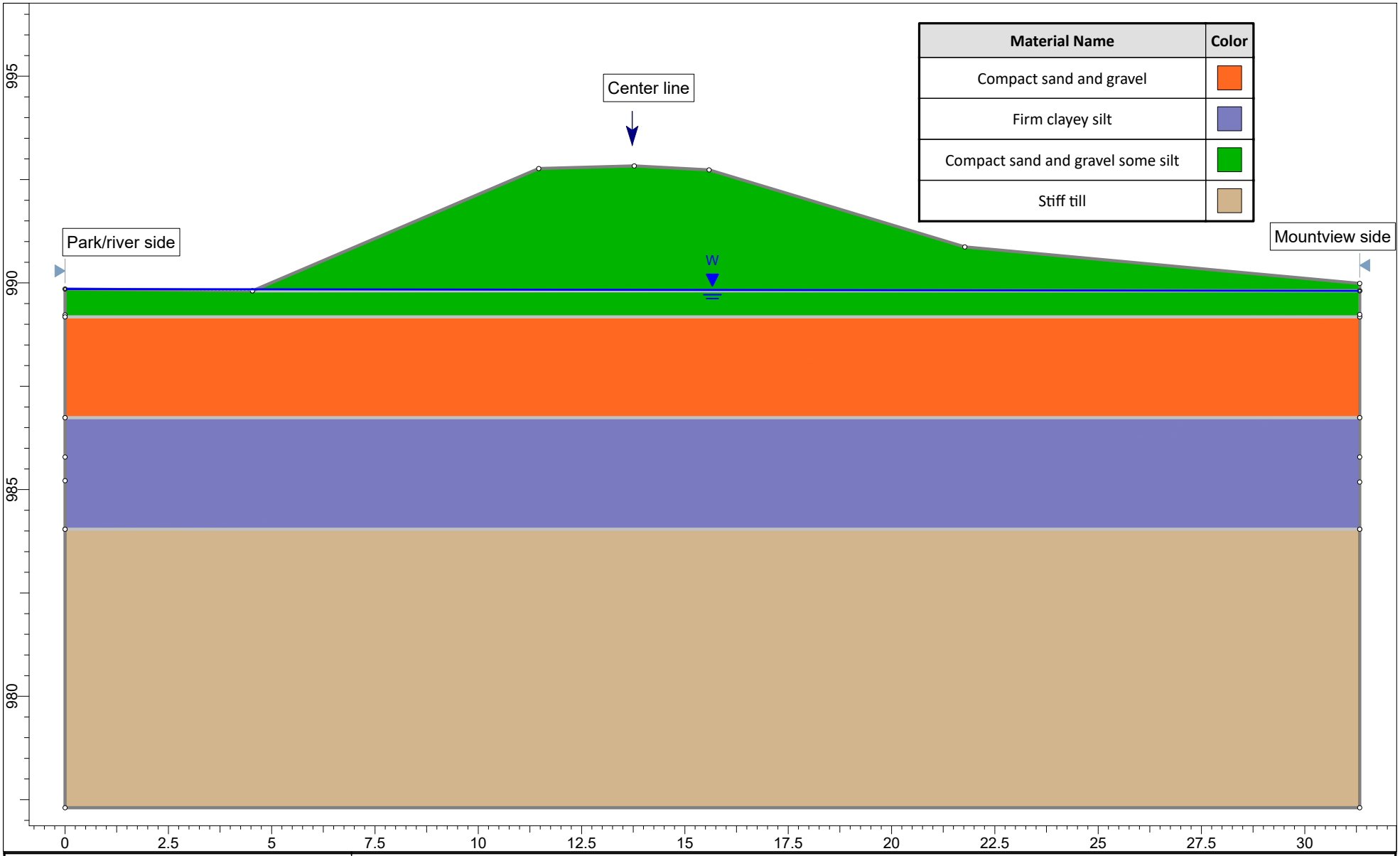
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SLIDE 8.018

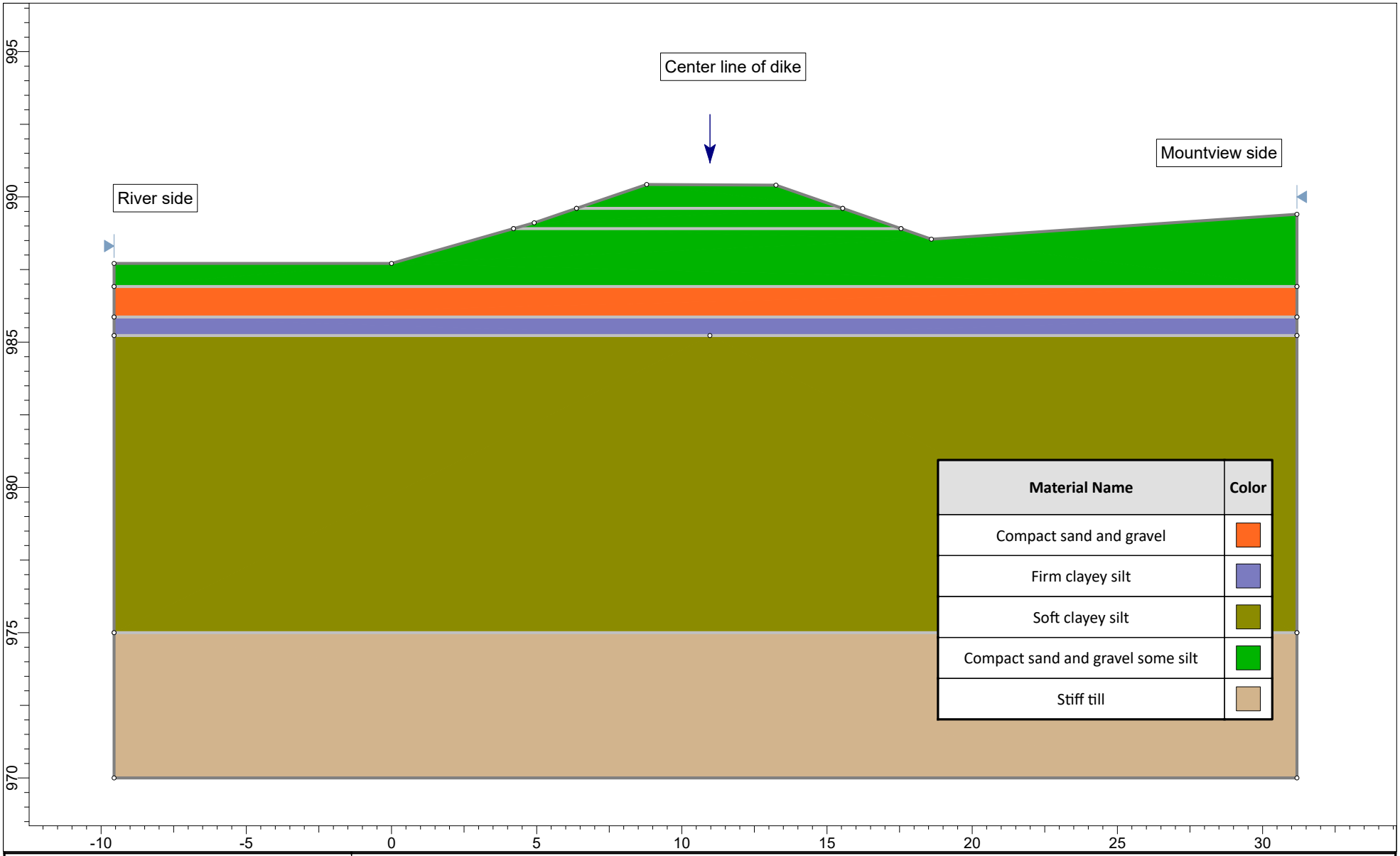
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SLIDE 8.018

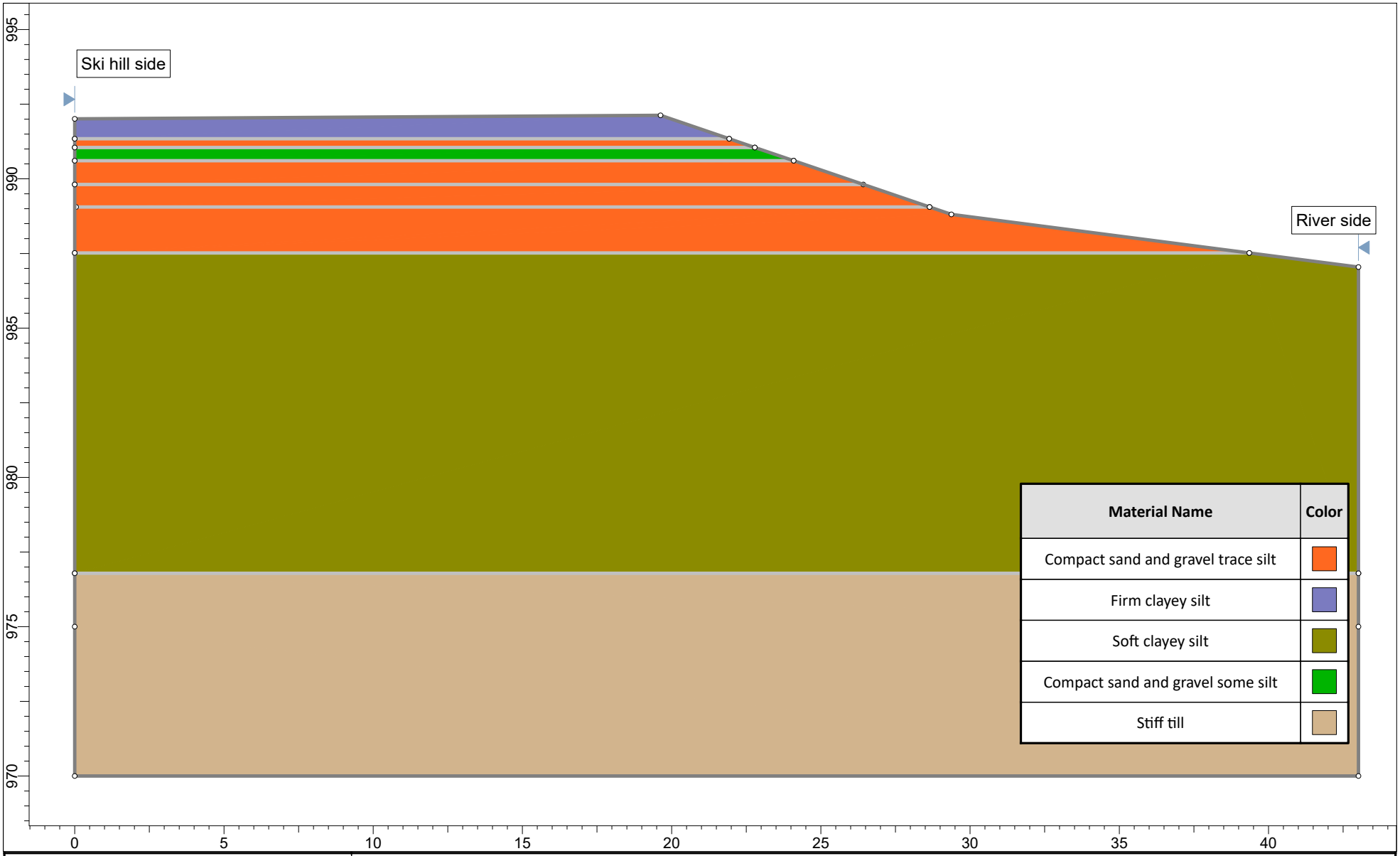
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Analysis Description			
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SLIDE 8.018

Project	SLIDE - An Interactive Slope Stability Program		
Analysis Description			
Drawn By		Scale 1:185	Company
Date	11/5/2018, 4:51:14 PM		File Name xs12.slim



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SLIDE 8.018

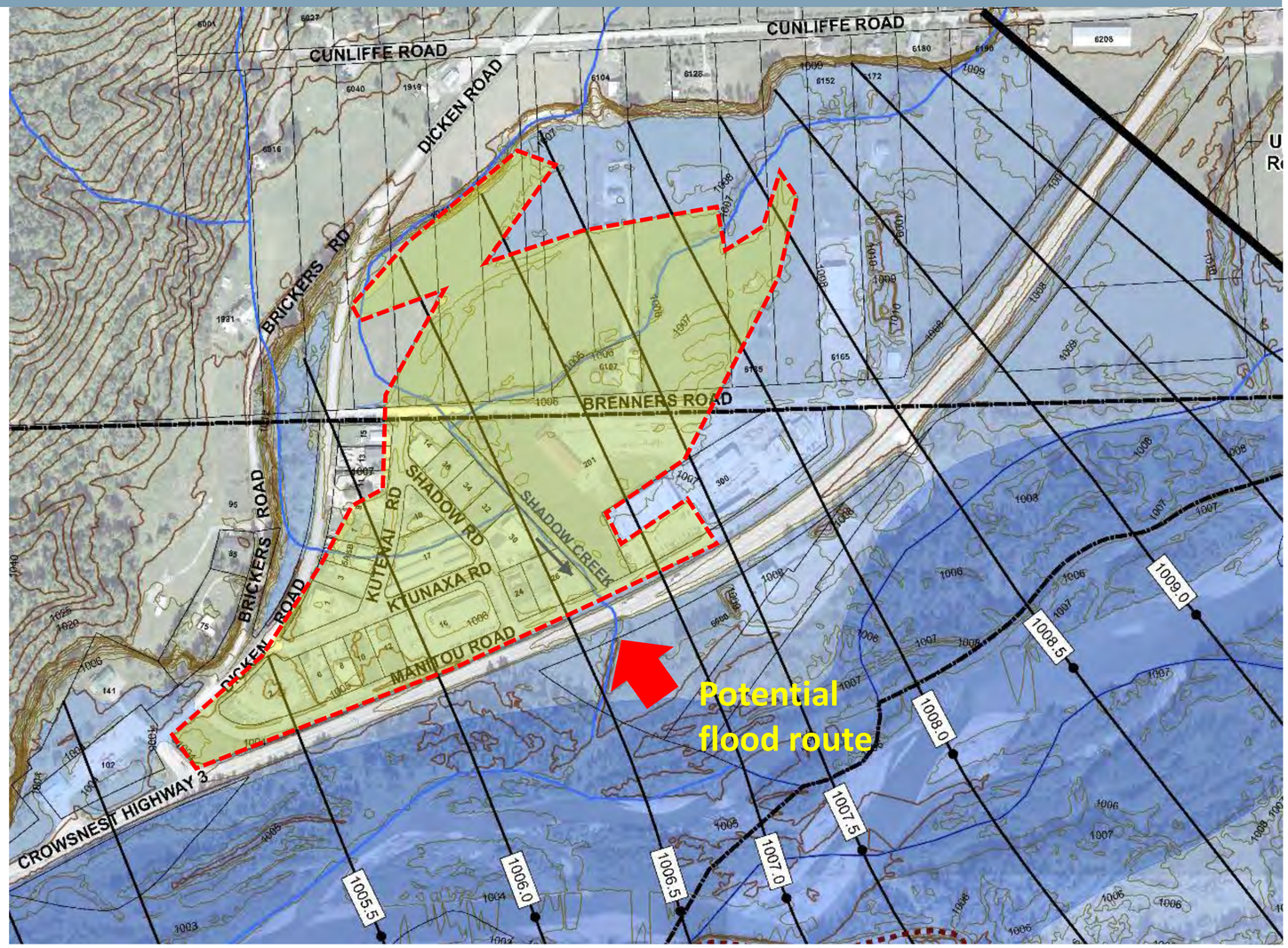
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Analysis Description			
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APPENDIX E
PUBLIC MEETING POSTERS

SHADOW CREEK CULVERT







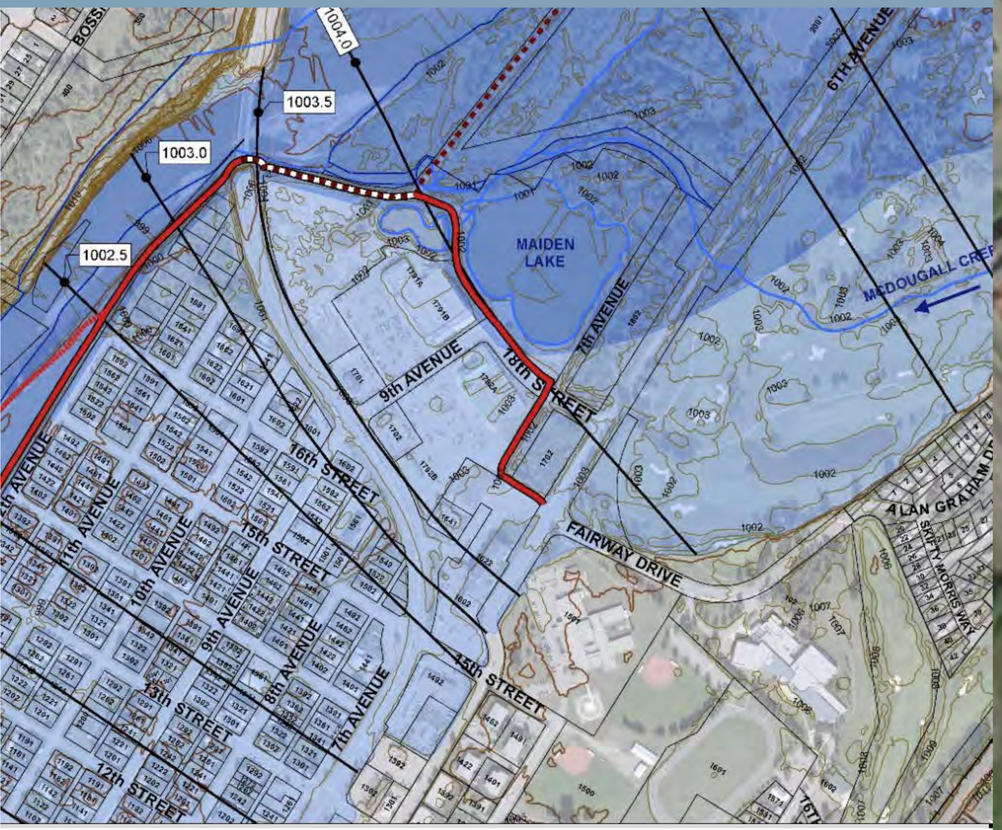
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ASSESSMENT: High Elk River flood levels could backflood Ghostrider Community.

RECOMMENDATION: Add flood gate to culvert outlet

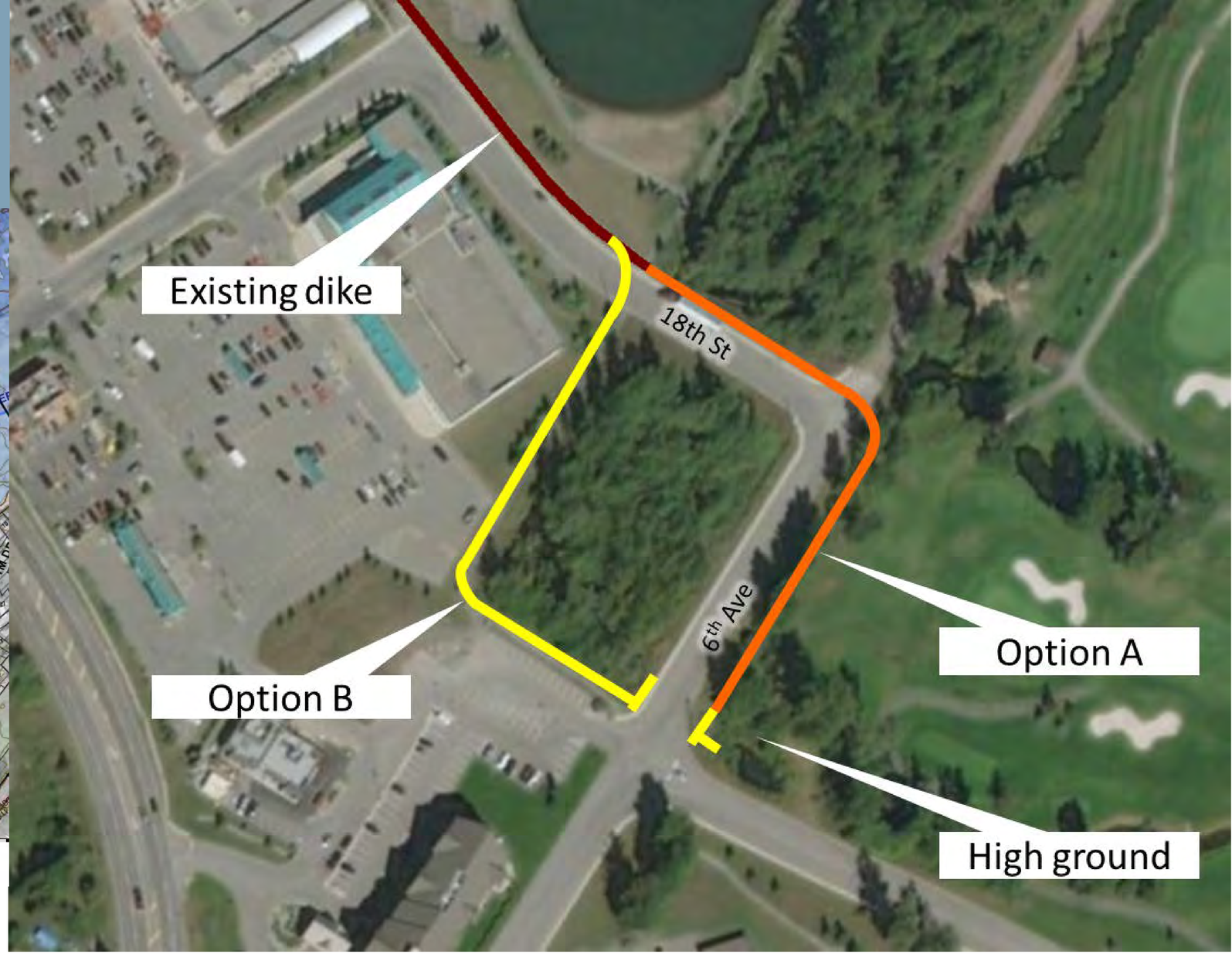
CHALLENGES: Provincial culvert, Shadow Creek inflows, fish passage.

NORTHLANDS DIKE (MAIDEN LAKE)



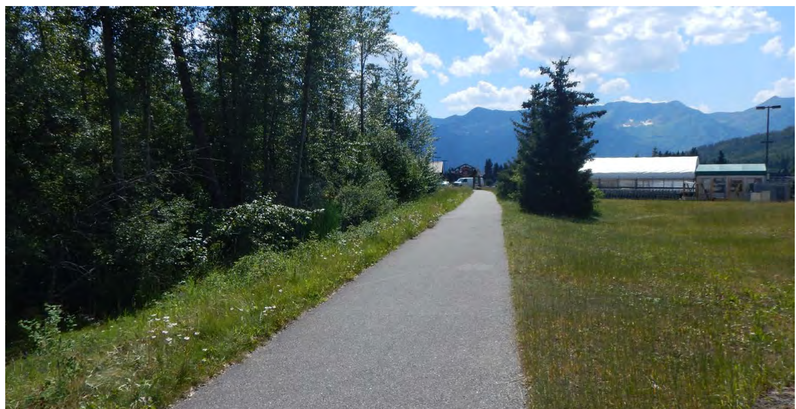
ASSESSMENT: High flood levels can overtop dike or flood around east end of dike.

RECOMMENDATION: Raise dike and extend to high ground.



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ANNEX DIKE

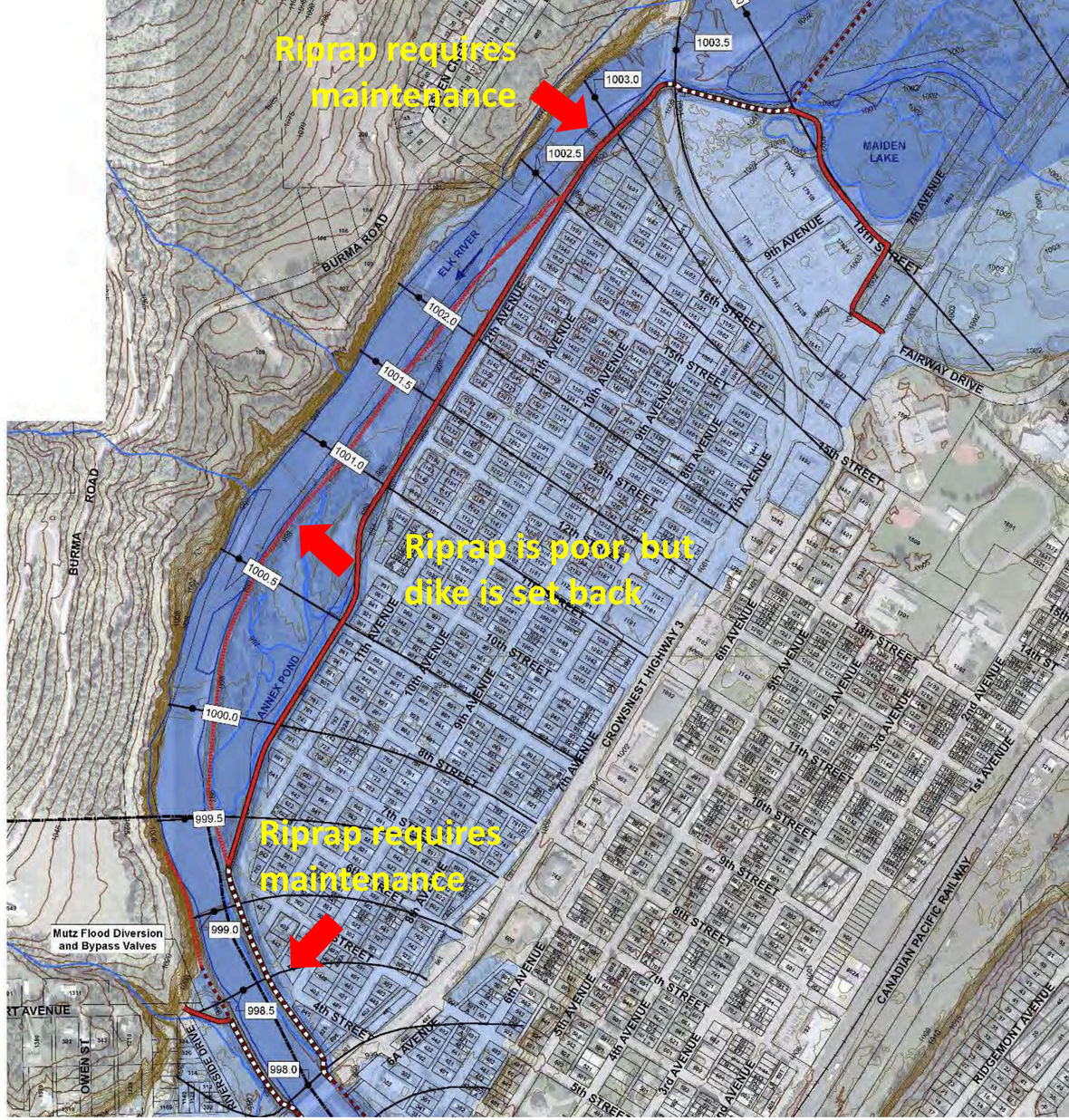


ASSESSMENT: High flood level could overtop. High velocity flow could erode riprap armouring.

RECOMMENDATION: Raise dike and supplement rock riprap at locations where rock appears small (upstream + downstream ends of dike). Monitor locations where dike is set back and armouring is poor

CHALLENGES: right-of-way, increased dike height may impact views, cost

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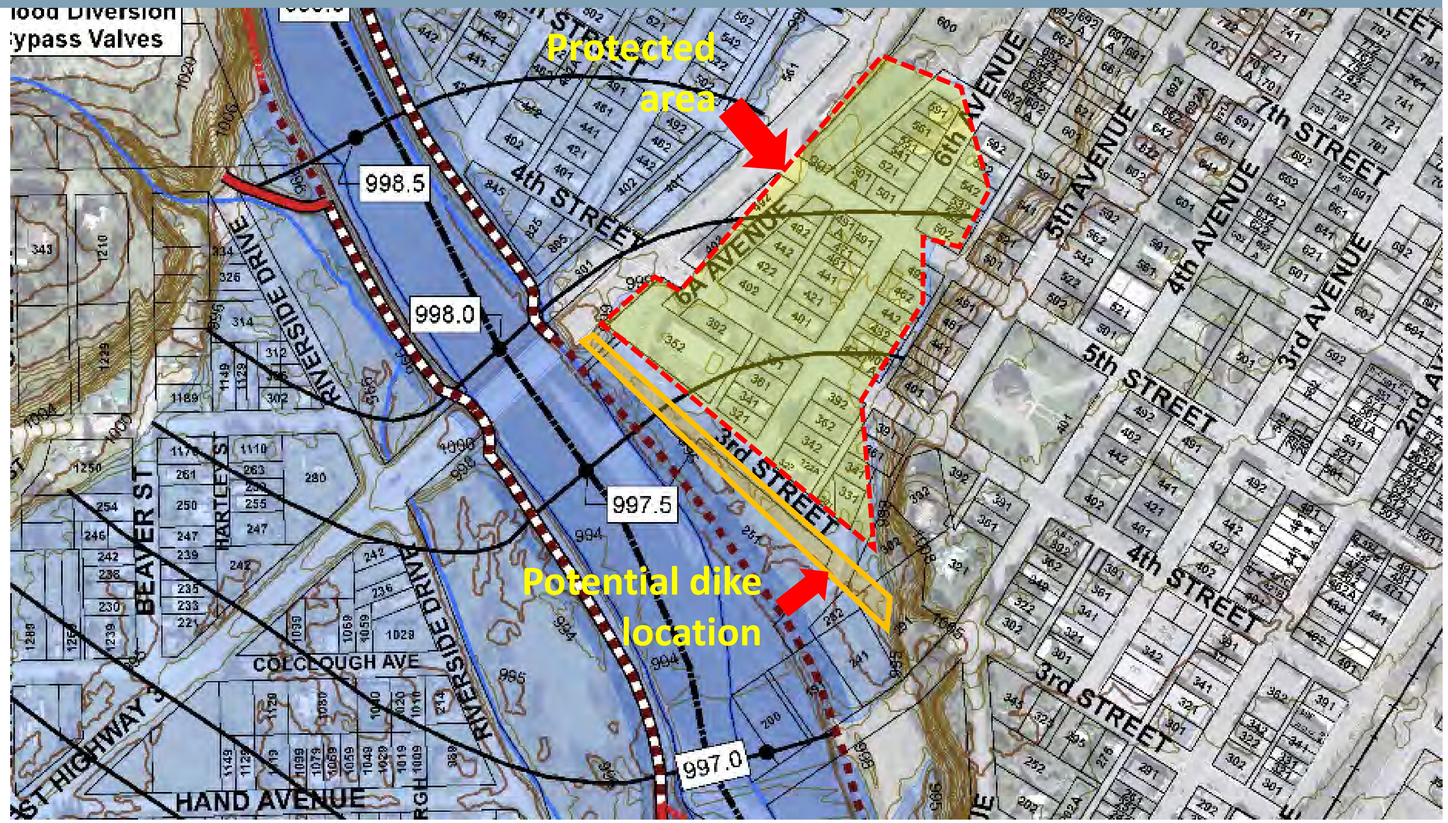






3rd STREET STRUCTURAL FLOOD MITIGATION





ASSESSMENT: Potential for over bank flooding

RECOMMENDATION: Setback dike

CHALLENGES: Existing road, utilities, right-of-way, cost





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WEST FERNIE DIKE EXTENSION

ASSESSMENT: Dike does not tie into high ground downstream

OPTIONS and CHALLENGES:

1. Raise McDonald Avenue with temporary protection for individual homes during floods.

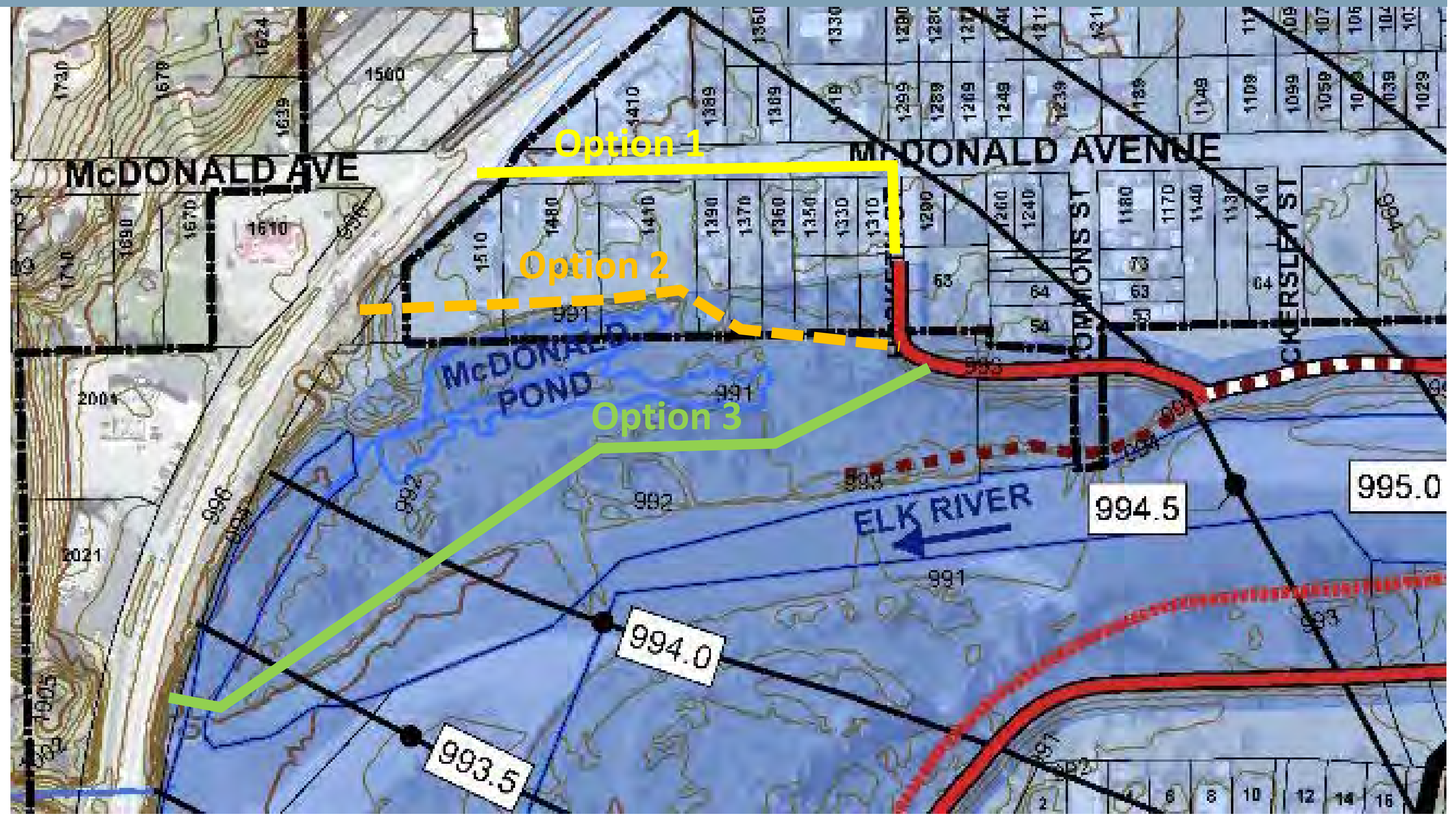
   Homes south of McDonald Ave not protected by dike.
   Road raising impacts property access.

2. Construct a foundation along ridge above McDonald Pond
   Use temporary flood barrier along foundation during floods.

   Requires right-of-way acquisition and emergency works during flood season.

3. Construct dike along ground between Elk River and pond.

   Dike acts as ecological barrier between pond and river.
   Dike susceptible to erosion in active portion of river
   Dike is longer and requires armouring and gated crossing increasing the capital and operational costs.







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MOUNTVIEW DIKE



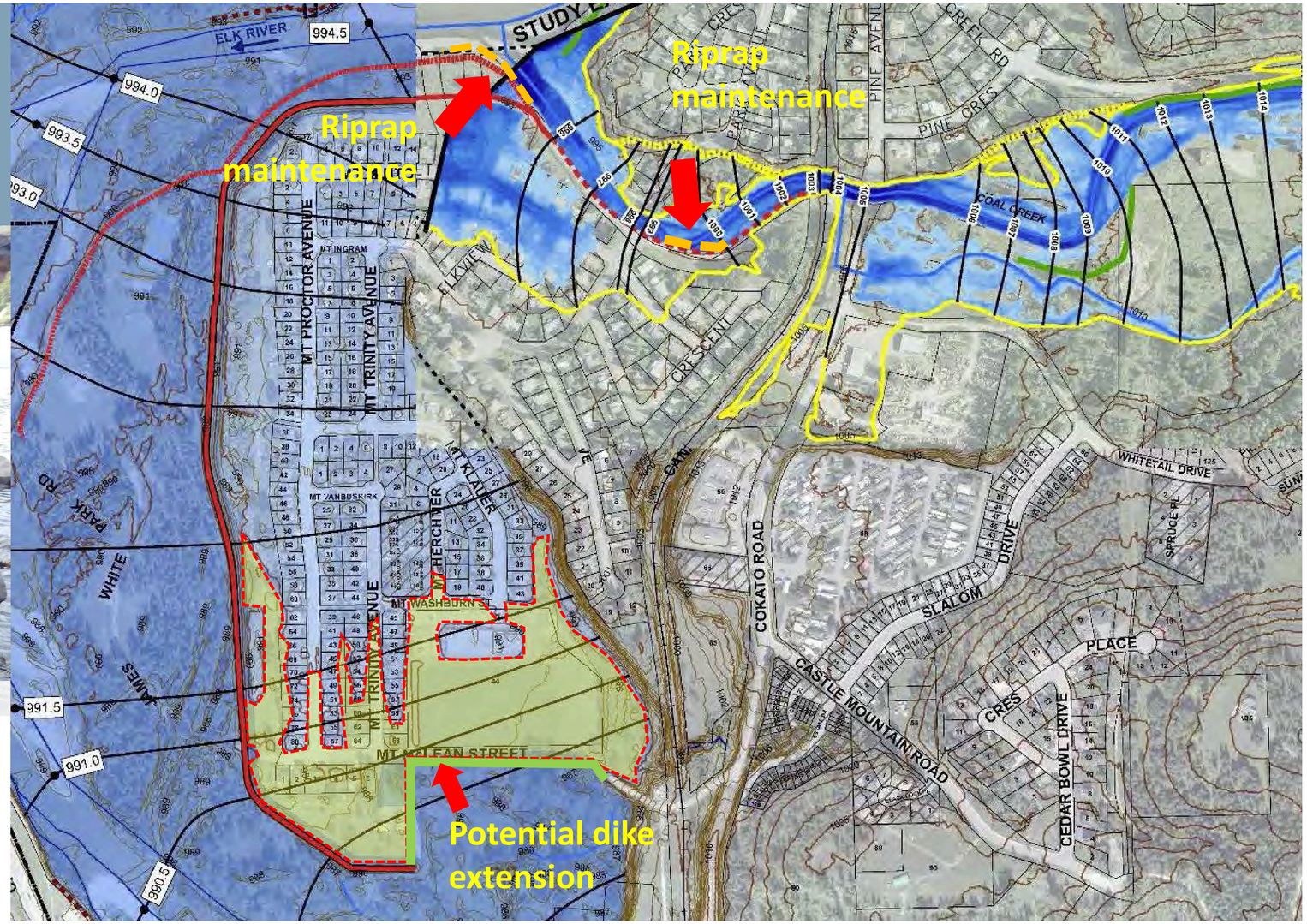
Riprap armouring maintenance at
Elk River – Coal Creek confluence

ASSESSMENT: Armouring requires maintenance and the downstream end of dike does not tie into high ground.

RECOMMENDATION:

1. Repair armouring along Coal Creek bin wall
2. Repair armouring for dike at Elk River Coal Cr. Confluence
3. Consider tie in of downstream end of dike or local flood protection for City infrastructure

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RIVERSIDE STRUCTURAL FLOOD MITIGATION



ASSESSMENT: Erosion protection in need of repair and potential over bank flooding

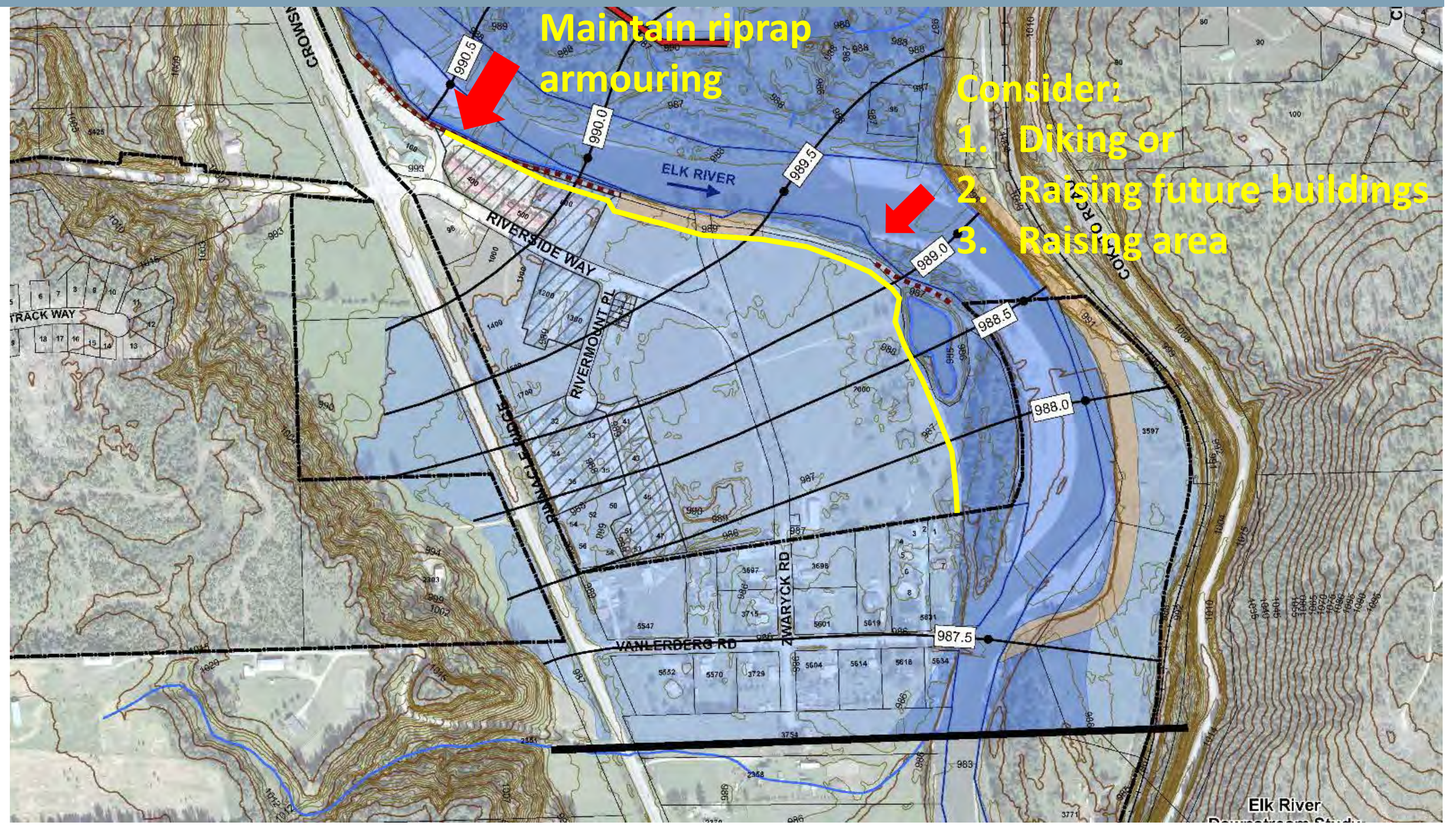
RECOMMENDATION: Maintain riprap (small, loose, sparse)

ADDITIONAL OPTIONS:

1. Diking if development is to be increased, cost to be financed by development

2. Raise buildings and possibly entire area of future development

CHALLENGES: cost, right-of-way, inspection and maintenance, downstream tie-in to high ground, currently level of development does not warrant further diking.







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NON-STRUCTURAL FLOOD MITIGATION

AWARENESS AND EDUCATION: prior, during, and following flood events

1. Public outreach
2. Emergency Management BC (EMBC)
   Flood and emergency preparedness
   https://www2.gov.bc.ca/gov/content/safety/emergency-preparedness-response-recovery
3. City of Fernie
   http://www.fernie.ca/EN/main/residents/emergency-services/emergency-preparedness.html
4. Elk River Alliance
   https://www.elkriveralliance.ca/

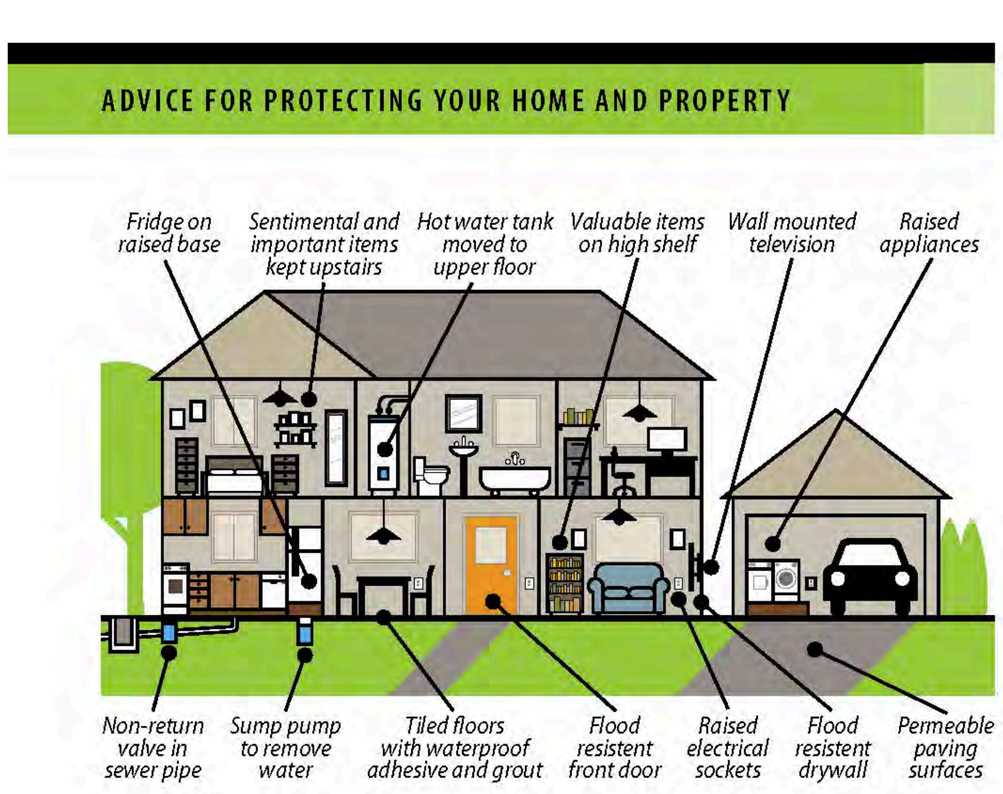
REGULATORY CONTROLS:
City of Fernie Zoning and flood-by laws

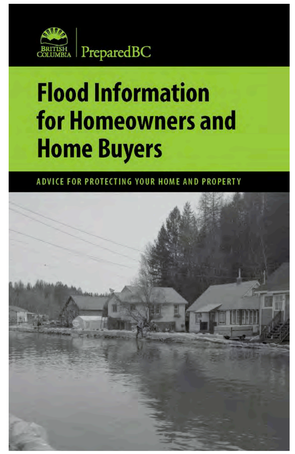
FLOOD WARNING:

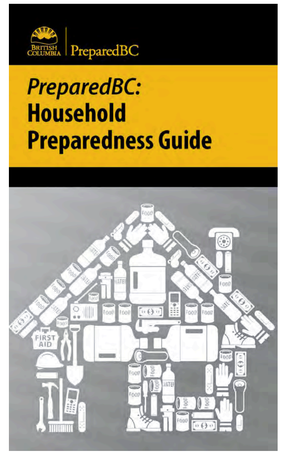
1. BC River Forecast Centre:
   http://bcrfc.env.gov.bc.ca/warnings
2. City of Fernie: www.fernie.ca

FLOOD RESPONSE PLANNING:

1. City of Fernie Emergency and Flood Plans
2. Individuals/residents planning and preparedness
3. Business and institutions planning and preparedness









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