Columbia River Project Water Use Plan

Arrow Reservoir Wildlife Management Plan

CLBWORKS-30A Arrow Lakes Reservoir: Implementation of Wildlife Physical Works – Revelstoke Reach

Reference: CLBWORKS-30A

ARROW LAKE RESERVOIR, SITE 6A ENGINEERING SERVICES

West Arm Headcut Mitigation – Conceptual Design Options

Study Period: 2023

Kerr Wood Leidal

December 12, 2023

KERR WOOD LEIDAL
consulting engineers

Kootenays
302 - 625 Front Street
Nelson, BC V1L 4B6
T 250 352 3404

Technical Memorandum

DATE: December 12, 2023

TO: Trish Joyce, Project Manager & Natural Resources Specialist
BC Hydro

CC: Martin Lawrence, BC Hydro

FROM: Allison Matfin, KWL

RE: **ARROW LAKE RESERVOIR, SITE 6A ENGINEERING SERVICES**
West Arm Headcut Mitigation – Conceptual Design Options
Our File 478.240-300

1. Introduction

1.1 Background

Site 6A is an existing channel with an eroding headcut, located on the east side of the Columbia River near the City of Revelstoke. Site 6A is located approximately 1 km northwest of Airport Marsh, which is an important wetland and wildlife habitat. It is inundated annually with the filling of the Arrow Reservoir (Figure 1). The eroded channel mainstem splits into a "Y" shape, and the two branches are referred to as the East Arm and West Arm (Figure 2). In 2013, BC Hydro completed repair works to stop the progressing erosion in the East Arm and prevent potential impacts to Airport Marsh if the headcut were to progress further. The East Arm was filled with 25 kg riprap placed over geotextile (Golder Associates & Watson Engineering, 2014)[1]. This repair has generally been successful in limiting further erosion of the East Arm. In comparison, the West Arm was left unprotected and has continued to erode towards the north. The site was monitored from 2010 to 2020 by the Okanagan Nation Alliance (ONA) and LGL Limited Environmental Research Associates (LGL) as part of CLBMON-11B4[2]. In addition, drone footage and topographic data was collected May 2022 by ONA.

Based on ongoing site monitoring and 2022 drone footage, the continued progression of the headcut in the West Arm (lengthening, widening, and deepening) was deemed to be a risk to the Airport Marsh system, with the concern that the headcut, if left unaddressed, could eventually reach the valuable marsh habitat and potentially drain or lower the marsh water levels.

[1] Arrow Lakes Reservoir: Implementation of Wildlife Physical Works. Implementation Year 2. Reference: CLBWORKS-30. Site 6A – Airport Overflow – As Built Report. Golder Associates & Watson Engineering, 2014.
[2] Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Implementation Years 1-8. Reference: CLBMON-11B4. Final Comprehensive Report. Okanagan Nation Alliance and LGL Limited Environmental Research Associates, 2021. Study Period: 2010 – 2020.

1.2 Scope

BC Hydro retained Kerr Wood Leidal Associates Ltd. (KWL) to provide engineering services for assessment and design of mitigation works for the headcut in the West Arm channel. The proposed scope of work is broken into two phases, with the expectation that Phase B would be confirmed following completion of the Phase A:

A. Site Assessment, Options Comparison, and Conceptual Design.
B. Detailed Design, Tender Package, Tender Services, and IFC Drawings.

Communication and contact with the Revelstoke Airport is planned to be completed by BC Hydro, to discuss upstream wetlands and drainage infrastructure at the airport which may influence Site 6A. KWL's scope does not include environmental or archaeological services, or associated permitting, which will be provided by BC Hydro or their designate. This scope of work is based on BC Hydro's preferred approach to consider surface water diversion and biotechnical solutions to reduce overland flows reaching the West Arm, which may reduce the rate of headcut progression. As a result, the current project does not consider physical works in the West Arm channel itself or riprap (as was completed for the East Arm), and it does not include any hydrogeological or geotechnical assessment or design input.

The observed headcut progression may be the result of a variety of processes and factors, including surficial erosion of soil from surface water flows, geotechnical instability of site soils (particularly when saturated), erosion at the connection with the Columbia River, and/or piping and erosion of soil as a result of groundwater flows. The proposed type of approach (surface water diversion) does not consider geotechnical or hydrogeological factors that may also contribute to headcut progression within the West Arm, which would likely remain unchanged by surface water diversion. As a result, there is some uncertainty in the outcomes of this type of approach. From previous discussions, BC Hydro is willing to accept the risk of less certainty in understanding headcut processes and associated uncertainty in the effectiveness of solutions, given the headcut channel is not currently close to high value marsh habitat (i.e., some erosion may occur without damage to habitat), and the preference is to implement lower impact and more biotechnical solutions (as opposed to more hard engineering approaches like riprap).

2. Site Investigations

Site investigations completed for this project included:

- Overview site visit with BC Hydro on April 12, 2022 during high flow conditions.
- Engineering site visit on May 11, 2023 to measure flow rates, assess overland flow routes and erosion locations, and excavate shallow test pits for soil sampling.
- Topographic survey of select locations May 23, 2023 by Monashee Surveying.

Figure 2 provides an overview of the site and investigation locations, and this section summarizes the investigation results. Pond and outlet features are labelled following the convention originally established by BC Hydro.

The site was accessed on foot along the pedestrian and cyclist trail and bridge over the Illecillewaet River (approximately 2 km total walking route), which follows the old Arrow Lakes highway (referred to herein as "the old road"). Based on information from BC Hydro, the previous road access along the south (left bank) of the Illecillewaet River has experienced erosion and crosses private property, which in combination did not allow for site access by vehicle. Site access for mitigation works should be determined as the project progresses.

2.1 Engineering Site Visits

The engineering site visit in April 2022 was completed during a high-water period where Ponds B and C had ponding water and were overflowing to the West and East Arm channels below. The same high-water pond conditions were not observed in April or May of 2023 (based on BC Hydro site observations), and while Pond B was partially filled with water, it did not fill sufficiently high to spill over into Pond C. The winter and spring of 2023 were generally drier and warmer than 2022, which may have resulted in less overall water at the site. Flow rates were planned to be measured during the May 2023 site visit, but the majority of channels and ponds were dry. Representative photos from the 2022 and 2023 site visits are attached in Enclosure A – Site Photographs, and a summary of observations is included below. In general, water flows through a series of ponds and shallow outlet channels to either the West or East Arm.

- Vegetation around the site is predominantly grass or sedge, with limited woody shrubs and trees at higher elevations (above 438.3 m).
- The Airport Marsh (Pond A in Figure 2) is separated from the lower ponds by the old road embankment. When on site in 2022 and 2023, water was seen flowing over the old road at a small wooden pedestrian bridge over a depression in the road. The surface of the old road was compact sand with gravel consistent with materials that may be expected for a road base, with limited areas with broken asphalt. No erosion was observed at the overflow.
- Pond B has two overflow/outlet points, labelled B:C-1 and B:C-2 on Figure 2, which are the northern and southern outflows respectively. The pond is impounded by the old CP rail bed on the west side, which cuts across the site and is parallel to the old road.
    - B:C-1 has a wider, shallower grade, and had a much higher volume of flow (during the April 2022 site visit), than B:C-2. This indicates it is the primary outflow from Pond B, which was confirmed based on survey of the outlets. No erosion was observed at B:C-1 and the channel and slopes are completely vegetated.
    - B:C-2 does not have a well defined outflow channel, but a narrow and deep headcut has started to form where flows have overtopped the old rail road embankment and flowed towards the East Arm. The headcut at B:C-2 is up to 0.75 m deep, 0.3 m wide, and the overlying sod is undercut by as much as 0.3 m. The base of this small headcut is silty and gravelly sand. In 2022, sod was excavated by BC Hydro and placed at the upper end of the B:C-2 outlet, starting at the upstream end and progressing for 2 to 3 m downstream, to fill the shallow drainage feature at the outlet that conveys water towards the headcut. Sod placement may have raised the small outlet drainage channel by approximately 10 cm, based on information from BC Hydro.
- Pond C has two outflow routes, one at the south end (referred to as C:E, where E refers to the East Arm) and one along the southwest side (referred to as C:D), which direct water ultimately towards the East and West Arm channels respectively. No erosion was observed in either outflow route, the flow paths are generally shallow gradient very subtle drainage features, and they are only marginally lower than the surrounding ground (by 0.3-0.5 m). Water was flowing along both outflow routes in April 2022.

- The upstream end of the West Arm channel headcut has large blocks of soil and sod that have calved from the surrounding area and fallen into the headcut channel. In May 2023, the West Arm channel was predominantly dry with no surface flow into the channel from upstream, no flow at the base of the channel, nor any observed seepage from the channel walls. In April 2022, the West Arm was largely filled with snow, and the channel was partially backwatered by high water levels on the Columbia River. In April 2022, surface water was flowing into the West Arm at the headcut at two locations from Pond D.
- The East Arm had no observed erosion around the riprap and little to no flow during the May 2023 site visit. In April 2022, surface waters were flowing into the East Arm from upstream and flowing water could be heard percolating through the riprap.
- Where water was flowing in the eroded channel mainstem, the bed of the channel was fine gravel, while the surrounding ground and slopes were predominantly fine-grained material. The sod layer near the top of bank was generally undercut.
- Shallow test pits were hand-dug at six locations (shown on Figure 2), including one in April 2022 (labelled 2022) and five in May 2023 (labelled 1-5):
    - Samples from the test pits were collected on site by hand with a shovel and submitted for geotechnical laboratory testing to gather data on soil types and grain size distribution for an understanding of vulnerability to erosion to inform conceptual design options.
    - The test pit locations are shown in Figure 2. Grain size testing and discussion of findings and observations are summarized in Section 3.

2.2 Site Survey

A topographic site survey was conducted by Monashee Surveying and Geomatics on May 23, 2023. The intent of the survey was to pick up the various overflow points, ponds, and channels (profiles and sections). Low points and vegetation features identified during the site assessment were also surveyed. The survey did not encompass an overall, topographic survey of the area at large beyond the specific features that were requested to be surveyed.

During the time of the survey, the West Arm was backwatered by Arrow Reservoir, and therefore the toe of the channel side slopes and the channel thalweg could not be surveyed. Base plan development based on the 2023 topographic survey is described in Section 3.2.

3. Engineering Assessment

3.1 Previous Assessments

Watson Engineering Ltd. (WEL) and Golder Associates Ltd. (Golder) completed survey, design, construction review, and record drawings of the mitigation works completed in 2013 in the East Arm (Golder Associates & Watson Engineering, 2014). Following construction, Golder prepared monitoring and maintenance recommendations for the works[3]. In their assessments[4], Golder indicated that the primary cause of headcut erosion in the West and East Arm channels is a result of water draining into the channels from spring runoff and reservoir drawdown, adding confidence to the approach of mitigating erosion from surface water as opposed to groundwater seepage or other causes.

The goal of monitoring completed by ONA and LGL[5] was to assess the effectiveness of physical works projects undertaken through CLBWORKS-30A at protecting or enhancing wetland and wildlife habitat in Revelstoke Reach (Arrow Lakes Reservoir). Site 6A (Airport Outflow) monitoring focused on erosion and included visual assessments, survey measurements, Bank Erosion Hazard Index (BEHI) assessments, and air photo imagery assessments of the East and West Arm channels. Between 2008 and 2020, LGL and ONA concluded that the West Arm channel lengthened, widened, and deepened, with the predominant change being the continued lengthening of the channel, while the East Arm channel remained relatively unchanged post-construction of mitigation work in 2013. The eroded channel mainstem was not included in channel erosion monitoring completed by LGL and ONA. This monitoring indicated that the overall rate of headcut erosion and progression in the West Arm increased over time and that it has been episodic rather than continuous, with limited erosion in some years and greater erosion in other years.

3.2 Base Plan Development

The base plan for design is a composite surface including the 2023 topographic survey and LiDAR to supplement areas not included in the survey. The LiDAR was obtained in July 2019 by the Province of British Columbia. Corresponding ortho imagery shows that the site was heavily vegetated with grasses and mostly dry, with the eroded channel mainstem and West Arm backwatered from Arrow Reservoir.

The base plan vertical datum is CGVD28, corresponding to the topographic survey. The LiDAR data is converted from CGVD2013 with a conversion factor obtained from NRCAN's GPS.H tool and verified by comparing elevations picked up from the topographic survey to the same locations on the converted LiDAR surface:

- The areas of highest accuracy (i.e., unvegetated areas, such as the old road) have elevation differences between LiDAR and survey within 10 cm.
- The areas with lowest accuracy (heavily vegetated areas, or areas with water) have elevation differences between LiDAR and survey of up to 1 m.
- The average difference between surveyed elevations and converted LiDAR elevations is approximately 0.5 m.

---

[3] Arrow Lakes Reservoir: Implementation of Wildlife Physical Works. Implementation Year 2. Reference: CLBWORKS-30. Technical Memorandum for Site 6A – Airport Overflow. Completion Report. Golder Associates, 2015.
[4] Ibid.
[5] Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Implementation Years 1-8. Reference: CLBMON-11B4. Final Comprehensive Report. Okanagan Nation Alliance and LGL Limited Environmental Research Associates, 2021. Study Period: 2010 – 2020.

Based on the above analysis, there is a fairly large discrepancy between LiDAR and survey elevations in wetted or vegetated areas. However, vegetation cover is generally consistent across the site and LiDAR data is much more comprehensive, and as a result, it is expected that the LiDAR data generally captures the trends and variability in the terrain, if not the accurate elevations. The survey surface is expected to provide more accurate elevations; however, it is much more limited in extent and density of points. The conceptual design figures are based on the topographic survey primarily; however, the LiDAR data was considered for general topographic trends and in areas where there is limited to no survey coverage.

3.3 Hydrotechnical

While an in-depth hydrological analysis is not part of the project scope, a brief assessment of sub-watershed areas and estimated flow rates through the various channels and flow paths was undertaken to approximate the volume and velocity of water movement throughout the site for input to design.

The Revelstoke airport (operated by the Columbia Shuswap Regional District, CSRD) is located adjacent to the Airport Marsh system to the southeast. The airport has large wetlands located on either side of the runway, and the facility may include water management or conveyance structures (such as culverts) that influence water levels and flow around the airport and the Airport Marsh system which then drains to Site 6A. This assessment does not include any field inspections or communication with the CSRD regarding water management at the airport, and it is recommended that BC Hydro contacts the CSRD to discuss water management facilities. Conveyance structures that are damaged or blocked may contribute to elevated water levels in the wetlands, which could increase flows to Site 6A and influence headcut progression.

The following sub-watershed areas draining to either Pond B or the East or West Arm were delineated based on the LiDAR topography sampled at 0.1 m lateral resolution and are shown in Figure 3:

- Area draining into Pond B east of the old road.
- Area draining into Pond B between the old road and the old CP rail bed.
- Area draining into the east arm, west of the old CP rail bed.
- Area draining into the west arm, west of the old CP rail bed.

Surface water from Airport Marsh (Pond A) flows west over a former road (the old Arrow Lakes highway) into Pond B, which flows over the old CP rail embankment at two locations (B:C-1 and B:C-2 on Figure 2). Water that flows through B:C-1 goes to Pond C, where it either flows south to the East Arm or west to Pond D and the West Arm. Water that discharges at B:C-2 flows along a grassy swale (channel C:E on Figure 2) to the East Arm. Depending on the volume of water inflow to the area, water elevations in the ponds and associated water flow routes and quantities vary. Notably, B:C-1 is the lowest elevation and primary outflow for Pond B, but if water elevations are high enough, water also flows at B:C-2. The Pond C outlets have similar elevations and water flows out at both outlet channels. The spill elevations (elevation at which water begins to flow downstream into a channel or outlet) have been estimated for each outlet based on base plan topography and are shown in Table 1.

Flow measurements were not taken on the May 2023 site assessment since the site was mostly dry or did not have sufficient flows to measure. A range of flow rates, velocities, and unit discharge at the outlets have been estimated corresponding with the April 2022 site conditions based on:

- Water depth ranges estimated from photographs from the 2022 site visit and other photographs provided by BC Hydro.
- Channel geometry and grade obtained from the base plan (survey).
- Manning's equation, with roughness values estimated from vegetation and channel characteristics and simplified channel geometry (assumed trapezoidal channels).
- Delineated catchment areas (Figure 3).

Estimated ranges of flows, velocities, and water surface elevations are provided in Table 1. Flows in the East Arm and West Arm were not estimated given backwater conditions and snow cover during the two site visits. These values are approximate and represent one point in time during relatively high flows, and the site may have experienced (or may yet experience) higher flow rates. Photos included in the Golder (2015)[6] report (date of photos not listed) show what appears to be higher water levels and flow rates than those observed in April 2022.

Table 1: Estimated Hydraulic Parameters for Existing Channels from April 2022 Site Conditions

Location	Channel Grade [a] (%)	Total Flow [b] (m^3/s)	Velocity (m/s) [b]	Shear Stress [b] (N/m^2)	Estimated Spill Elevations [a] (m)
A Pond Outflow (A:B)	4-5%	0.2 to 0.3	0.9 to 1.5	30 to 70	438.1
B Pond Outflows	2% (B:C-1) 3-13% (B:C-2)[b]	0.2 to 0.4 [c]	0.8 to 1.4 (B:C-1) 0.4 to 0.7 (B:C-2)	20 to 50 (B:C-1) 40 to 80 (B:C-2)	437.5 (B:C-1) 437.95 (B:C-2)
C Pond Outflows	1-1.5%	0.1 and 0.3 [d]	0.4 to 0.7	5 to 20	437.45 (C:D) 437.4 (C:E)

a) From 2023 topographic survey
b) Total flow, velocity, and shear stress are estimated based on April 2022 flow conditions. Unit flow for the area estimated as 0.4 to 0.7 $m^3/s/km^2$ based on flow and catchment area.
c) The B:C-2 outlet and overflow has varied grade due to the old CP rail embankment, pre-existing ground, and the headcut that has formed. The embankment grade prior to the headcut is estimated to have been 10% based on current topography.
d) B:C-2 estimated to convey approximately 1/3 of total outflow in April 2022.
e) C:D and C:E estimated to convey a similar proportion of total outflow in April 2022.

Notably, B:C-2 has a relatively steep grade, which is expected to have contributed to headcut progression at this location. Based on April 2022 conditions, the old road overflow (A:B) and B:C-1 channels are estimated to experience flow velocities at between 0.8 m/s and 1.5 m/s; however, they have more shallow grades and appear to be generally stable based on current site conditions.

[6] Golder Associates. (2015). Monitoring and maintenance of wildlife physical works (WPW) 6A – airport outflow. Reference No. 1314340002-003-TM-Rev0-4000, February 13, 2015.

3.4 Geotechnical - Soils

One soil sample was gathered and submitted for grain size testing from each test pit. The locations are shown on Figure 2. Four samples were submitted for sieve analysis only, while two were submitted for sieve and hydrometer analysis (Test pits 2 and 2022). The sieve analysis provides grain size distribution down to 0.075 mm, while the hydrometer analysis includes grain sizes down to 0.002 mm. Soil particles smaller than 0.075 mm are classed as fines (silt and clay), while particles smaller than 0.002 mm are classed as clay particles. The laboratory results are included in Enclosure B – Soil Laboratory Test Results. Test pits were approximately 40-60 cm deep, as the intention was to characterize the soil below the top layer consisting primarily of topsoil and organics, to assess vulnerability to erosion due to runoff and overland flow.

Generally, the test pits exposed a top layer of organics (typically 10-15 cm deep and at most 30 cm deep), with fine sand and silt below. Test pit #5, excavated near the old rail embankment, had more sand and gravel near the bottom of the test pit than others. In general, soils within the old rail embankment were notably denser than the soils encountered in the other test pits, where soils were unconsolidated and soft. The test pit excavated at the back of the West Arm in 2022 consisted primarily of silt, with some clay, fine sand, and organics.

Within the West Arm, there is gravel (approximately 25-50 mm diameter) on the channel bed, with silt in the channel banks. It appears that flowing water generally erodes the fine material, while the fine to medium gravel remains in place as a lag deposit.

A summary of the grain size distribution data is provided in Table 2 below. The grain size ranges for gravel, sand, silt, and clay are based on ASTM D2487-17[7]. For test pits 2 and 2022, the hydrometer test data enabled differentiation between silt and clay particles. For the other samples, these are not differentiated, and so silt and clay are grouped together as fines.

Table 2: Grain Size Distributions from Test Pit Samples

Test Pit ID (location)	% Gravel (>4.75 mm)	% Sand (0.075 mm – 4.75 mm)	% Fines	
			% Silt (0.002 mm – 0.075 mm)	% Clay (<0.002 mm)
2022 (West Arm headcut)	0	2.4	88.4	9.2
1 (B:C-2)	4	30.6	65.4	
2 (C:E)	0	4.2	88.7	7.1
3 (eroded channel mainstem bed)	76.4	20.9	2.7	
4 (C:D)	0.1	7.6	92.3	
5 (B:C-1)	10.5	54.6	34.9	

[7] Unified Soil Classification System is ASTM D2487-17: Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System).

Based on the laboratory data and relative state of compaction observed during the site work, it is expected that soils are more dense along the old rail and road alignments and have a lower proportion of fines, compared to the rest of the site where soils are very soft and predominantly consist of silt. The soil profile under the old rail and road embankments likely consists of embankment fills suitable for road and rail, which would be more granular and hence less erodible than other locations within the project area. Fine grained soils with low cohesion and poor consolidation, like those observed around the rest of the site, have greater risk of erosion and headcut development[8].

3.5 Historical Air Photo and Top of Bank Review

The following section outlines a review of available historical air photos and comparison of the location of the eroding top (edge) of bank at the back of the West Arm channel due to headcut erosion over time, based on previous assessments by others and a recent survey of the head cut erosion feature.

Historical Air Photo Review

To assess progression of the head cut erosion feature over time, a review of recent imagery and historic aerial photos was completed. Historical (hard copy) aerial photos were obtained from the University of British Columbia's Geographic Information Centre (GIC). Recent imagery for the study was taken from Bing Imagery, available from ESRI ArcGIS. A list of imagery and aerial photos obtained for this assessment is provided in Table 3. The aerial photos and imagery obtained for this study cover a period of record between 1945 and 2022. The nominal photo scales are sourced from the BC Base Map Online Store[9] or estimated for photos where the scale is not provided.

Table 3: Summary of Imagery Used for Air Photo Interpretation

Year	Source or Roll/Photo Number	Date of Imagery	Nominal Scale[1]
2022	Bing Imagery	August 29, 2022	N/A
2001	15BCC01026 #87-89	September 16, 2007	1:30,000
1996	30BCB96042 #25-27, 50-52	August 10, 1996	1:15,000
1989	30BCC1050 #1-3, 153,154	September 24, 1989	1:16,000
1984	15BC84014 #152-155, 140, 142	June 13, 1984	1:15,000
1980	15BC80041 #125-129, 104-109	June 13, 1980	1:12,000
1974	BC5599 #217-221, 231-235	June 20, 1974	1:12,000
1970	BC7266 #15-18, 245-248	July 14, 1970	1:16,000
1961	BC4003 # 167-170	August 2, 1961	~1:16,000
1951	BC1393 #89,88	September 17, 1951	~1:32,000
1945	A9423 #66, 63	-[2]	~1:20,000

Notes:
1. Nominal photo scales sourced from BC Base Map Online Store or estimated for photos not provided. Estimated scales denoted by "~".
2. Date (month and day) of photo not found.

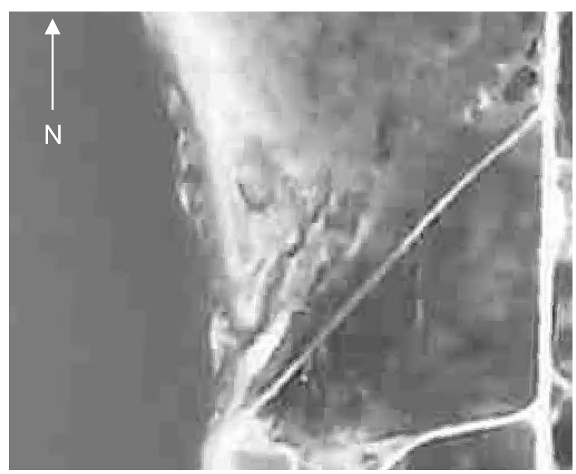
[8] Technical Supplement 14P: Gullies and Their Control. Part 654 National Engineering Handbook. USDA, 2007. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17826.wba
[9] Government of British Columbia. BC Basemap Online Store. URL: https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/base-map-online-store Accessed September 29, 2023.

Due the small size of the headcut feature in relation to the scale and/or the poor resolution of the historical air photos, it was not possible to complete a geo-rectification of the photos to quantitatively assess changes in the size or position of the headcut feature over time. As such, the air photo review is limited to qualitative observations of the headcut erosion feature over time, relating to both size and progression.

The headcut erosion feature is visible in the reviewed historical aerial photos from 1984 to 2022 (Figure 4), but it was not present in any earlier aerial photos (1980 or prior). It appears that at some point between 1980 and 1984, the headcut was first formed.

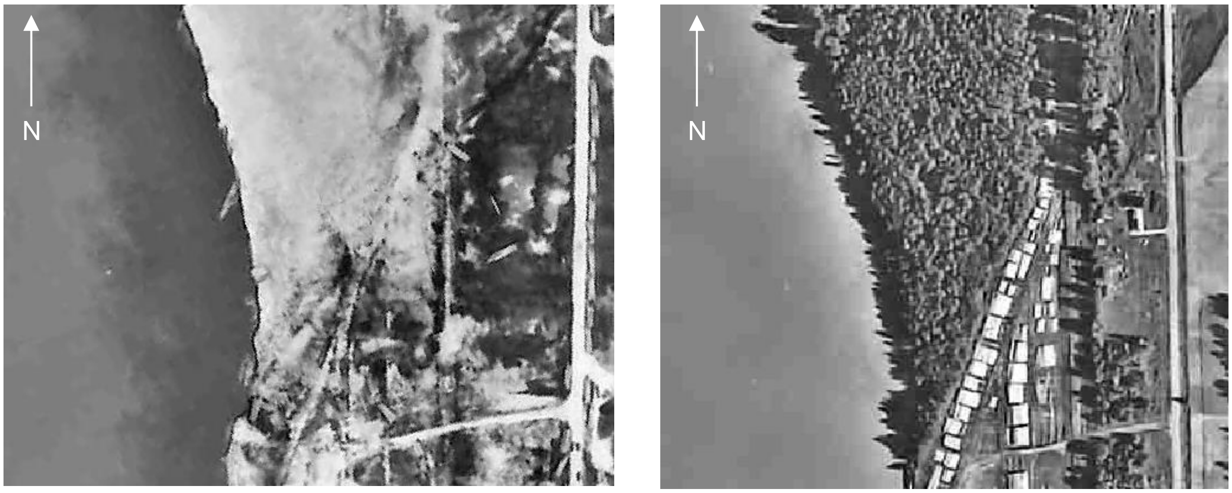
The 1974 and 1961 aerial photos (Figure 5) do not show the headcut feature but do illustrate how the land cover has changed over time, from forest in 1961 to predominantly field in 1974. The Hugh Keenleyside Dam, which impounds water in the Arrow Lakes Reservoir, has been operational since 1968, which impacts the water levels and as a result vegetation in the site area. The site area is forested in all the air photos up until 1974, where the area no longer has any trees present (Figure 5). The site may have been logged prior to inundation in 1968. The air photos in 1951 and 1961 also show a train and barge unloading facility that was present at that time immediately south of the site. This facility was present in an area that currently is at a higher elevation than the adjacent field to the north, which may have the effect of funnelling drainage along the path of the headcut channels and contributing to their formation or progression.

In 1983, the Illecillewaet River, the mouth of which, at its confluence with the Columbia River, is located approximately 1 km upstream of the eroded channel mainstem experienced the largest peak flood event on record (see Figure 6). The record is from 1964-2021 and based on Water Survey of Canada (WSC) Station Illecillewaet River at Greenley (08ND013), located approximately 10 km upstream of the confluence of the Illecillewaet River with the Columbia River. It is suspected that the headcut erosion feature may have formed as a result of the 1983 flood event. This peak flow during the 1983 flood occurred on July 12. Based on reservoir levels recorded at Nakusp (WSC Station 08NE104), the water level in Arrow Reservoir was approximately 438.6 m on that day and had been rising rapidly over the preceding days, suggesting the site may have been partially inundated during the peak flood on the Illicillewaet River. Due to the higher ground located immediately south of the headcut area, high water levels and flows from the Illecillewaet River or other local catchments may have been funnelled along the path where the headcut formed.



2022 **1984**

Figure 4: The head cut erosion feature shown in the 2022 image (left) is visible in the 1984 aerial image (right).



1974 1961

Figure 5: The headcut erosion feature does not appear in the 1974 aerial photo (left) and the 1961 aerial photo (right).

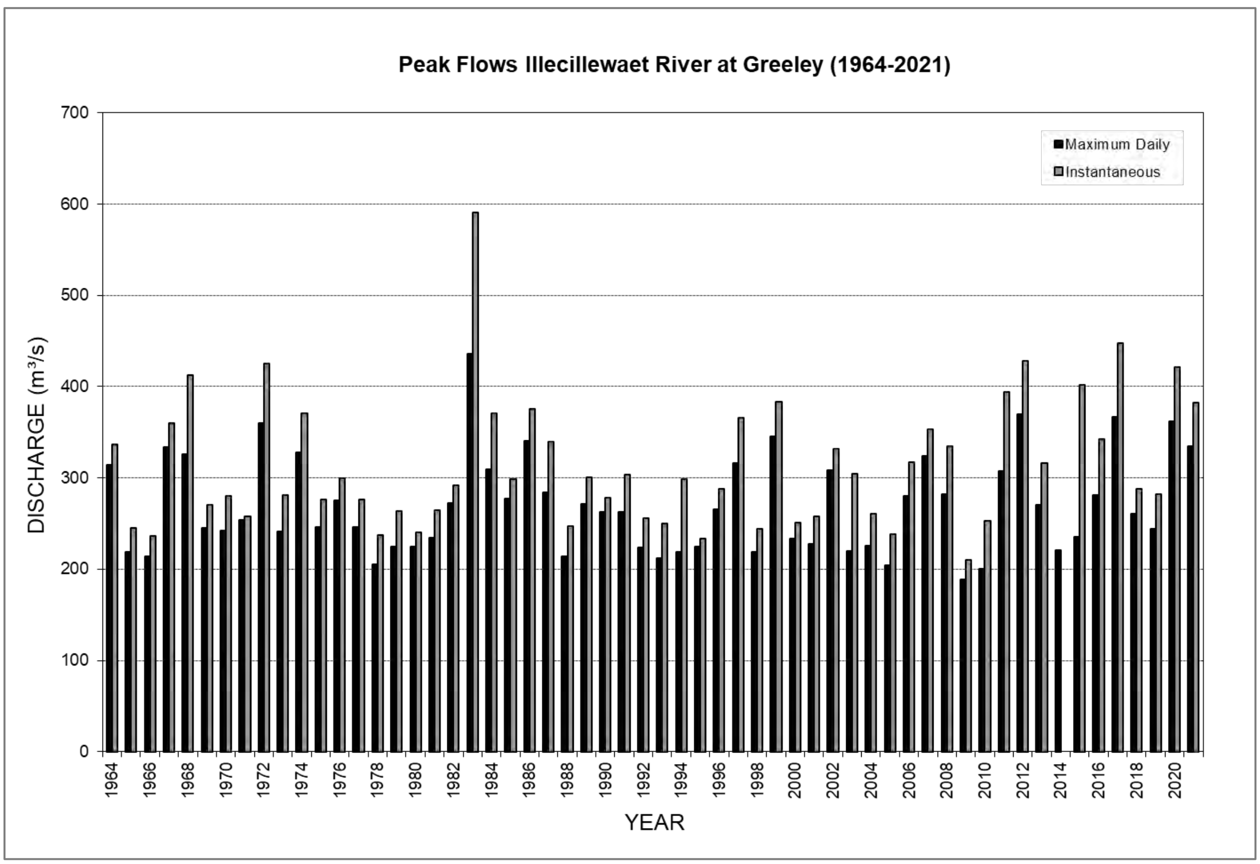


Figure 6: Peak Flows Illecillewaet River at Greeley (WSC Station 08ND013)

Top (Edge) of Bank Review

Erosion within the West and East Arms has been monitored over the last several years and erosion/progression rates estimated[10]. Figure 7 presents the progression of the headcut in each Arm based on the top of bank outlines recorded at each of 8 timelines from 2008 to 2023. The 2023 survey was conducted by Monashee Surveying and Geomatics; all other top of bank edge lines in Figure 7 were collected by others[9], whether by survey or interpretation from air photos or drone photography. The East Arm was protected by riprap in 2013, which has effectively ceased the ongoing erosion that had occurred at this location prior that time[9] (Figure 7).

Erosion along the West Arm has progressed regularly since 2010, though not necessarily by a significant amount every year. Two metrics for quantifying erosion in the erosion features are the annual rate of change as an area (m^2/yr) and length (m/yr).

Table 4 summarises the erosion observed in the west channel over total site monitoring/date period (2008 to 2023). Erosion rates are approximate, and length of erosion varies across the channel width. Prior to 2020, erosion rates were estimated by LGL and ONA, and erosion rates after 2020 are based on KWL comparison of the digitized top (edge) of bank line from LGL and ONA in 2020 and the survey in 2023. The highest erosion rates observed occurred are approximately 2-3 m/year and occurred 2020-2023 and 2010-2012. Notably, based on information from BC Hydro and site observations, the recent erosion occurred primarily in 2022, indicating the erosion has been more episodic, resulting in certain years with higher rates of erosion than the annual average indicates.

Table 4: Erosion rates of West Arm between 2008 and 2023.

Years for Estimate	Source[a]	Annual Average Rate of Area Loss (m^2/yr) [c]	Annual Average Rate of Headcut Progression (m/yr) [c]
2008-2010	LGL and ONA banklines from aerial imagery for each year	10.2	0
2010-2012		12.4	3.0
2012-2014		11.8	1.1
2014-2016		5.5	1.2
2016-2019	2016 LGL and ONA bankline from aerial imagery and 2019 LGL and ONA bankline from drone imagery	14.7	0.2
2019-2020	2019 and 2020 LGL and ONA banklines from drone imagery	6.6	0.2
2020-2023	2020 LGL and ONA bankline from drone imagery and 2023 topographic survey[b]	14.8	2.3

a) LGL and ONA top of bank and rates of change as provided in footnote 10.
b) KWL analysis of topographic data and top of bank from LGL and ONA.
c) Erosion rates were estimated by LGL and ONA from 2008 to 2020, and by KWL after 2020.

[10] Okanagan Nation Alliance and LGL Limited Environmental Research Associates, 2020. Columba River Project Water Use Plan. Kinbasket and Arrow Reservoirs Revegetation Management Plan: Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Implementation Years 1-8. Prepared for BC Hydro, Reference: CLBMON-11B4.

3.6 Headcut Processes

This section discusses erosion processes at the two headcuts located at Site 6A and introduces potential mitigation approaches. Mitigation is discussed further in Sections 4 and 5.

West Arm Headcut

The relative contribution of groundwater processes, geotechnical soil instability, and surface water flow erosion to the headcut progression in the West Arm is uncertain. They are all likely contributing factors, with high groundwater levels and soil saturation likely causing instability due to excess pore pressures during reservoir drawdown on the steep banks resulting in calving and slumping, while continued erosion of fine-grained sediment by surficial water flows at the steep headcut lengthens the channel and causes slope instabilities as the headcut progresses. The surficial flow in the channel also erodes fine grained sediment in the channel, leaving behind coarser material (gravel)as a lag deposit. This continued erosion of the sediment in the lower channel may contribute to channel widening and deepening as soil along the banks is lost and banks are steepened until they are unstable. Since mitigation works were installed in the East Arm, limited changes in East Arm channel depth, width, or length were observed over the course of monitoring by LGL and ONA and has demonstrated the effectiveness of the riprap buttress in stabilising the channel banks and arresting headcut regression.

If unmitigated, the West Arm headcut is expected to continue to erode, most likely following the topography of existing drainage features that convey the site runoff that causes erosion. If multiple flow paths enter the headcut, it may split into multiple channels. Over a very long time period, the headcut in the West Arm may achieve an equilibrium state where it has re-graded itself to a stable slope, but it is uncertain when and if this may be achieved. There is a substantial distance between the current headcut and the more valuable wetland habitat at Pond A (Airport Marsh) and based on past rates of erosion and existing drainage paths, there would be many years before the headcut may reach Pond A. Based on discussions to date with BC Hydro, the other ponds on site are not as valuable for habitat, but this should be confirmed, as the headcut progression over time may impact these other more ephemeral ponds. Erosion is expected to be intermittent, with higher snowmelt and spring rainfall and more rapid reservoir drawdowns contributing to increased erosion rates.

Based on the headcut processes discussed above, mitigation of the headcut erosion could consider the following types of approaches:

- Protecting the headcut itself from further erosion (armoring with riprap and a filter layer, or similar).
- Diverting overland flows away from the West Arm channel.
- Grading and infilling the headcut in the channel.
- Stabilizing with trees and vegetation (likely not feasible in the drawdown zone).
- Construction of small earthen berms or grade control structures in the headcut channel to dissipate energy.

At this stage, BC Hydro's preferred approach is to focus on diverting water away from the West Arm and redirecting it towards the East Arm, where a riprap buttress is already installed. In the long-term armoring or other more intensive options may be considered if water diversion does not sufficiently reduce headcut progression. There is a risk that directing additional flow towards the East Arm (and drainage features that feed it) could cause erosion in new locations, which should be considered in any mitigation design and is discussed further in Section 5.

Small Headcut at B:C-2

The small headcut that has formed in the B:C-2 outlet is located in a low point in the old CP rail embankment where water outflows from Pond B and flows towards the East Arm channel (Figure 3). Based on photos and observations from April 2022, this location has lower flow rates than the main B:C-1 outlet (in some years it may not receive any). However, it appears that the combination of flows, terrain that concentrates water, soft erodible soils (particularly at the base of the embankment), and the relatively steep grade (up to 13%) have resulted in erosion at B:C-2. At present the upstream extent of the headcut is located at a pedestrian trail. Soft erodible silts located near the toe of the old rail embankment are likely most susceptible to erosion.

BC Hydro staff placed sod at the upper end of the channel in 2022 in an effort to reduce overflow and continued erosion in the headcut that remains downstream. This treatment may be effective at mitigating erosion in the headcut if flows no longer overtop the old rail embankment and flow downstream into the headcut. If water overtops the embankment and flows out the B:C-2 outlet, then erosion in the headcut immediately downstream may reinitiate. 2023 was a relatively low water year, and continued monitoring of water levels and flow at this location in future years would inform a better understanding of the risk of continued erosion. This small headcut is located closer to the old road and Pond A where the more valuable habitat is located, and this headcut may pose a risk if it were to reinitiate and continue to progress. Notably, it also has the potential to impact Pond B, which may have associated habitat impacts.

Given the small size and early stage of this secondary headcut, design approaches could consider repairing the headcut to avoid further potential progression if the spot repair is not successful, in conjunction with other potential works. Alternative mitigation approaches to this are described in Section 5.

3.7 Characteristics of Stable and Unstable Channels

The intent of mitigation options is to provide bio-technical solutions that mitigate headcut progression risk and reduce concentrated flows reaching the West Arm. The geometries, flow rates, and grades of existing stable and unstable channels on site were assessed to identify characteristics to emulate stable channel form. A summary is provided below along with reported maximum permissible velocities and shear stresses (from various technical guidance) for various biotechnical erosion control materials.

In general, unstable channels on site (B:C-2 and the West Arm), have the following characteristics: narrow flow paths (concentrated flow), relatively steep grades (10% to vertical), and are located in soft erodible silts. In the two headcuts, fine to mid-sized gravel is observed at the base of the channels, which may indicate the stable grain size threshold for the prevailing hydraulic forces.

Conversely, stable channels on site (all other channels), have the following characteristics: shallower grades (1% to 5%) either wider channels or shallow channels with surrounding grassy areas, and in some cases located in the old rail and road embankments where soils are firmer and coarser (i.e., sand and gravel). Notably, the channels that have been estimated to convey the greatest flows (B:C-1 and A:B) and have the highest velocities (0.8 to 1.5 m/s) are both located in old embankments at modest grades (2% to 5%), are vegetated with grasses, and are currently stable.

Below is a summary of reported stability thresholds for erosion resistant materials, focusing on materials that are in line with the bio-technical approach (limited import or use of non-natural or biodegradable materials), as opposed to products/materials that use synthetic materials (turf-reinforcement mats, synthetic erosion control mats/blankets). Erosion resistance of non-cohesive soils is shown for comparison.

Table 5: Reported[11] Maximum Permissible Shear Stress and Velocity for Natural Materials

Material	Maximum Permissible Velocity (m/s)	Maximum Permissible Shear Stress (N/m²)
Non-cohesive fine-grained soils	0.5 to 0.8	1.5 to 20
Gravel (D_{50} = 25 to 50 mm)	0.8 to 1.8	16 to 32
Established Grass (Classes A through E Turf, native grasses)[a]	0.8 to 2.4	17 to 180
Biodegradable Erosion Control Mat (various materials straw, jute, coir, wood)	1.8 to 4.6	20 to 140
a) Vegetative lining/turf (i.e., grass) classes are organized such that Class A provides the highest erosion resistance and Class E the lowest[12]. The class is dependent on the species of grass. Taller and denser grass species generally have a higher resistance to flow, compared to short flexible grasses. Native grasses and other species not defined within the turf grasses follow the same principles for erosion resistance, but there are fewer standards or performance results.		

Based on the assessment above, the erosion mitigation design should consider:

- Establishing vegetation or erosion protection over all bare soils.
- Limiting velocities and shear stresses below the thresholds noted in Table 5 and those expected to prevail in existing stable channels on site (i.e., target flow velocities < 1.5 m/s).
- Establishing or maintaining wide and shallow channels (disperse flow and energy).
- Establishing or maintaining shallow channel grades, ideally below 2% and potentially up to 5% if located along existing firm compacted fill embankments.

3.8 Assessment Conclusions

Based on previous monitoring at the site by others and the more recent assessments, below is a summary of current conclusions regarding the site and headcut risk.

- There are two active headcuts at Site 6A, which are summarized below.
  - West Arm headcut: west branch of the eroded channel mainstem, which has steep and undercut banks and receives surface flows from Ponds B, C, and D and the surrounding terrain (in addition to groundwater contributions). The headcut channel is several metres deep and across and has been progressing steadily over the last 15 years. This feature poses a long-term risk to the wetlands upstream if left unmitigated.
  - B:C-2 outlet: a secondary (at a higher elevation) outlet of Pond B that flows towards the East Arm and armoured channel. A small headcut has formed downstream of this overflow point and eroded up to 0.75 m of sediment vertically. This drainage channel appears to be visible in the 2019 LGL monitoring data, indicating it may have been present for several years. Though smaller than the headcut in the West Arm, this feature may also pose a risk to the upstream wetland habitat (notably it is closer to valuable habitat).

[11] Design Guidelines for Erosion and Flood Control Projects for Streambank and Riparian Stability Restoration. AMEC Environment & Infrastructure, 2012. Prepared for the City of Calgary.
[12] Hydraulic Engineering Circular No. 15, Third Edition: Design of Roadside Channels with Flexible Linings. US Department of Transportation Federal Highway Administration, 2005.

- The soft non-cohesive silts at the site are particularly vulnerable to erosion. The old road and rail road embankment fills are firmer and somewhat coarser and should be marginally less susceptible to erosion. Headcuts that have formed on the site are expected to continue to progress if left unmitigated and water still reaches these locations.
- Erosion and headcut progression appear to predominantly be driven by processes at the headcut itself, whether as a result of primarily surface water flow or also due to groundwater seepage and excess pore pressure induced bank instability.
- The existing terrain funnels surface water flows towards the West and East Arm channels, which may also have contributed to their original formation. Based on an air photo review, the headcut channel from the Columbia River appears to have formed sometime between 1980 and 1984.
- Erosion and headcut progression are dependent on the amount of surface water and concentration of flows on site and the rate of snowmelt or drawdown. Monitoring has indicated that erosion may not necessarily occur every year, and rates of erosion in years where it occurs may be greater than the annual average estimates (annual averages of headcut erosion range from 0 to 3 m/yr and associated areal loss due to erosion in the range of 5.5 to 14.8 m^2/yr).
- The East Arm headcut has been successfully stabilized based on riprap and filter placement in 2013.
- The spill elevation at outflow channel B:C-1 is 0.4 m lower than outflow channel B:C-2. Therefore, Pond B flows out at B:C-1 before B:C-2. Total outflow from Pond B in April 2022 is estimated at between 0.2 and 0.4 m^3/s.
- Though observations from the April 2022 site assessment and the LiDAR DEM suggest that Pond C primarily outflows at channel C:D, outflow channels C:D and C:E have similar spill elevations, and a similar volume of water flows into both channels based on flow estimates and observations on site. Total outflow from Pond C in April 2022 is estimated at between 0.1 and 0.3 m^3/s.
- A mitigation design should consider maintaining or establishing shallow and wide channels with grades no steeper than 5% and ideally less than 2% and with design flow velocities generally less than 1.5 m/s for stability while using a local grass cover.

4. Design Basis

4.1 Applicable Design Guidance

The following guidelines have been considered in the design basis and conceptual design.

- Hydraulic Engineering Circular No. 15, Third Edition: Design of Roadside Channels with Flexible Linings. US Department of Transportation Federal Highway Administration, 2005.
- Design Guidelines for Erosion and Flood Control Projects for Streambank and Riparian Stability Restoration. AMEC Environment & Infrastructure, 2012. Prepared for the City of Calgary.
- Part 654 National Engineering Handbook Technical Supplements. United States Department of Agriculture, 2007.
  - Technical Supplement 14G: Grade Stabilization Techniques
  - Technical Supplement 14P: Gullies and Their Control
- Erosion Control Treatment Selection Guide. United States Department of Agriculture, 2007.

4.2 Design Basis

This section summarizes the proposed design basis for the Site 6A headcut mitigation works. It considers the results from site observations and investigations, background information provided, and results of the engineering assessments. The design basis outlines the criteria and constraints that guide the design. The design basis is summarised in Table 6.

Table 6: Site 6A Headcut Mitigation Design Basis

Item	Design Criteria or Constraint
Objective	• Mitigate the risk that existing headcuts pose to the Airport Marsh wetland system. • Specifically, slow or halt the rate of headcut progression in the West Arm channel and limit further erosion, halt or repair the small headcut at the B:C-2 outlet.
Preferred Mitigation Approach	• Surface water re-direction/diversion away from the headcut in the West Arm channel, to reduce flow reaching the channel and resulting ongoing erosion. • Monitor and/or repair the B:C-2 outlet to remediate the headcut and reduce the potential for it to progress. • The preferred approach is to consider bio-technical solutions that use natural materials, as far as possible, and minimize the use of riprap and/or manufactured materials (such as concrete). • Smaller scale biotechnical works with monitoring are generally preferred by BC Hydro, due to the expectation that there is some time to evaluate performance of these approaches and take other actions if needed.
Site Access	• Construction access to the site will be confirmed by BC Hydro. • At present, the only access to the site is along the existing pedestrian trail along the old Arrow Lake highway embankment and narrow footbridge across the

Item	Design Criteria or Constraint
	Illecillewaet River. The bridge is height and width limited and would likely restrict access to small equipment. • BC Hydro should contact the authority responsible for maintaining and operating the existing trail and bridge to confirm equipment/load restrictions and possibility of the bridge use for construction access, in addition to considering other access routes used for previous construction projects.
Existing Soils	• There is a 0.15-0.3 m thick topsoil/organic layer at the surface with a dense root matrix. • Coarser-grained soils (sand and gravel) and compact fills were observed at test pits in the old railway embankment and at the surface on the old road than the rest of the site. • Elsewhere on site (including the eroded West Arm), the native soil is an unconsolidated soft erodible silt with some clay and fine sand content. There is gravel exposed in the channel bed in the West Arm.
Site Vegetation and Elevations	• Low growing grasses and sedges are located across the site, with the primary vegetation cover being Reed Canary Grass. Woody vegetation and shrubs are located above 438.3 m elevation.
Channel Flow Rates	Estimated flow rates in April 2022 for use in design: • Pond B outflow is estimated to be between 0.2 and 0.4 m^3/s (total of B:C-1 & B:C-2) • Pond C outflow is estimated to be between 0.1 and 0.3 m^3/s (total of C:D & C:E) • Unit discharge across the site is estimated between 0.4 to 0.7 m^3/s /km^2 These flows are based on flows observed in April 2022 and represent a point in time. Erosion in spring 2022 was one of the higher estimated rates over the history of site monitoring, suggesting relatively high flows compared to typical conditions. The flows do not include an additional factor of safety or allowance for higher flow events, which may be considered based on BC Hydro's input and risk tolerance.
Pond Spill Points	• Water from Pond B flows into B:C-1 before B:C-2 based on an elevation difference of 0.4 m. • Water from Pond C flows into C:D (towards the West Arm) and C:E (towards the East Arm) in roughly equal amounts. The two outlet channels from Pond C have similar spill elevations. • Refer to Table 1 for spill point elevations.
Maximum Velocities and Geometry	Emulate natural stable channels on site and design guidance for bio-technical erosion control materials (grass, gravel, biodegradable erosion control mats – see Table 5). • Channel Grade: ideally < 2%, or potentially up to 5% if located in compact embankment fills (may require some additional stabilization). • Channel Geometry: wide with shallow side slopes to encourage dispersed flow. • Berm Geometry: minimum 0.5 m top width with maximum 5H:1V slopes to mitigate erosion if/when overtopped. • Target maximum channel velocity of 1.5 m/s where modifying channels and/or flows, which is in the tolerable range for vegetated long grasses.

Item	Design Criteria or Constraint
Flow Concentration and Re-Direction	• **Where flows are to be concentrated or increased**: consider a monitoring plan, channel widening, erosion control, grade control, increasing roughness, and/or shallowing grade to either reduce erosive forces or increase resistance to erosion. Assess expected velocities for re-directed flows to existing channels to determine the potential need for these actions. • **Where flows are to be diverted/re-directed away**: plug or berm low points to divert flows, avoid creating features steeper than existing natural terrain, and provide temporary and long-term erosion protection for exposed soils.
Exposed Soils & Revegetation	• Limit the extent and duration of soil exposure and establish vegetation or surficial erosion protection. Include temporary erosion protection measures during vegetation establishment period.

5. Conceptual Design Options

5.1 Summary

The following subsections provide a description of the objective of each of the conceptual mitigation options and the proposed associated works, with Class D cost estimates.

In general, the objective of each option is to direct runoff towards the armored East Arm and away from the West Arm to reduce potential erosion and headcutting. In addition, the options include either monitoring or constructed works to mitigate erosion risk at the headcut that has formed at the B:C-2 outlet. Proposed works were developed based on the design basis and providing erosion protection using natural materials.

Fill (where required) is proposed to be local borrow soil sources (silty sand or sandy silt). On-site borrow should consider sediment salvage in areas with low potential for erosion, such as within dry pond beds or other flat field areas near the existing access road. Borrow sites should have sod stripped and replaced for revegetation and to protect underlying soils from erosion. On-site borrow is accompanied by the risk of causing unintended erosion near borrow sites, given the susceptibility of the existing soils to erosion. Borrow sites would need to be planned and managed accordingly to limit this risk, or suitable soil/fill could be imported from off-site for fill.

Many of the options have interchangeable features or arrangements that could be combined into different arrangements other than the three options provided. **The options share common design details, construction techniques and materials as follows.**

- Strip sod from work footprints for reuse.
- If included, excavate channels or outlets where and as shown in the conceptual design figures. Not included in all options.
- Excavate and place local borrow soils as fill to plug outlets and/or construct shallow berms where and as shown in design figures. A compatible imported soil could be considered instead of local borrow soil.
- Provide erosion protection in the form of re-use of stripped grass sod and biodegradable erosion matting (while sod and vegetation re-establishes) in all cut and fill areas.

Given the fine-grained and unconsolidated soils on site, any disturbance by excavation or equipment trafficking has the potential for unintended consequences from soil compaction or disturbance that may alter drainage routes on site or possibly create new erosion areas, which may require further management and/or ongoing monitoring. This includes the works areas themselves as well as heavy equipment access routes. Commentary on unintended consequences and associated risk is provided with each option below.

Detailed design may consider:

- Importing fill, depending on site borrow constraints, and/or alternative fill or plug materials.
- The need for import of additional sod and grass seeding or planting.
- Additional erosion control or grade control materials (such as gravel) in select locations.
- Refinement of the selected option.

5.2 Conceptual Options

Option 1 – Pond B Outlet Modifications

Option 1 consists of plugging the channel at B:C-1 and directing the majority of flow from Pond B through B:C-2 to the East Arm. The intention is to mitigate the risk of continued erosion at the headcut at B:C-2 and significantly reduce the runoff into the West Arm and the resulting headcut erosion. Option 1 is shown in Figures 8 and 9. As noted above, some options share common construction techniques and materials, which are summarized in Section 5.1. The features included with Option 1 are as follows.

- Infilling the existing headcut at outlet B:C-2 and lowering and regrading the outlet to convey the majority of flow from Pond B to the East Arm. The conceptual outlet dimensions and elevations were developed to approximately match those of the existing B:C-1 outlet, to convey similar volumes of water and maintain similar water elevations in Pond B. The need for armoring (beyond grass cover as outlined above) along the new outlet would be assessed in detailed design.
- Low plug (20-30 cm high) at outlet B:C-1 to reduce flows to Pond C that lead to the West Arm. Some flow would still be anticipated at B:C-1 during high runoff and pond levels, unless the plug was higher. Water levels in Pond B may be marginally reduced as the plug is 20 cm lower than the current secondary outflow at B:C-2.

This option would reduce flow reaching the West Arm and the associated headcut erosion at that location. However, it would not prevent all flow from reaching the West Arm, because flow from the fields west of Pond B and shallow subsurface flows may still reach this area. The plug at B:C-1 may be overtopped in particularly high flow events. Overall, this is expected to decrease the rate of headcut erosion in the West Arm, but monitoring would be required to determine if it is able to halt the headcut erosion.

The proposed work at the B:C-2 outlet re-directs flow towards the East Arm and mitigates the risk of the headcut at B:C-2 by regrading the site, infilling the headcut, and providing vegetation for erosion protection and temporary biodegradable erosion protection while vegetation establishes. However, it does have risks associated with significantly increasing flow to an area that presently receives limited flow. The concepts have been developed with shallow grades that mirror stable conditions elsewhere on site (notably at the B:C-1 outlet), but differences in conditions or vegetation establishment periods may result in some uncertainty in the outcome. This may necessitate ongoing monitoring and potential remedial actions if issues arise.

As noted previously, unintended consequences (such as soil compaction, damage, and erosion) are possible as a result of equipment access to the sites. This option would be completed most effectively with heavy equipment, which would require access routes to two locations along Pond B.

Option 2 – Pond C Low Berm and Repair and Raise Pond B Headcut

The objectives of Option 2 are to divert water from Pond C away from the West Arm and to raise the B:C-2 outlet to prevent or significantly limit overflows that could contribute to continued erosion at the headcut immediately downstream in B:C-2. This involves raising and regrading the B:C-2 channel outlet to the elevation of the old rail embankment, and diverting water away from the West Arm by constructing a low berm along Pond C to direct the outflow from Pond C toward the East Arm. The mitigation works completed by BC Hydro at B:C-2 may effectively prevent water from flowing over this outlet to the headcut, but additional monitoring would be required to confirm, which may indicate whether additional work is needed. Option 2 is shown in Figures 10 and 11. As noted above, some of the options share common construction techniques and materials, which are summarized in in Section 5.1. The features included with Option 2 are as follows.

- Filling and raising outlet B:C-2 to an elevation similar to the rest of the old rail embankment to prevent channelized overflows at this location (i.e. flows would overtop the entire length of embankment rather than one low spot). This includes filling the headcut and reducing the grade of the downstream side of the outlet/embankment at the outlet. The need for armoring (beyond grass cover as outlined above) would be assessed in detailed design. Raising the outlet may allow for planting of woody vegetation that could improve soil stability. This would prevent or significantly reduce the flow through this outlet and the downstream headcut and direct the Pond B outflow through B:C-1 (currently the primary outlet of Pond B). No modifications are proposed at B:C-1.
- Diverting water away from Pond D and the West Arm by constructing an earthen plug in the C:D outlet and a low vegetated berm along the western side of Pond C. The low berm (10 to 30 cm height) is proposed to reduce the likelihood of outflow to Pond D in other low areas along the western side of Pond C, as the terrain is generally low between the ponds. This may require a continuous berm, or a series of discontinuous berms each at a specific low area. A continuous berm would provide more confidence that water would not overtop Pond C and flow to Pond D, but it would require more substantial work. The relative height of the berm would also impact how fully it prevents flow from reaching Pond D, where a very low berm may be sufficient for most years but may not be sufficient for high runoff years.
- Given the increased flows in C:E relative to present conditions, this channel would be monitored after construction to assess stability and erosion. Alternatively, the channel could be widened and/or armored as part of the works, depending on BC Hydro's risk tolerance. This could be considered, and associated risks further assessed in detailed design.

This option would reduce flow reaching the West Arm and associated headcut erosion. However, it may not prevent all flow from reaching the West Arm, because flow from the fields west of Pond C and shallow subsurface flows may still reach the area. Depending on the height of the berm, it may be overtopped in high flow years, but that is expected to be limited to extreme events. Overall, this is expected to decrease the rate of headcut erosion in the West Arm (likely more than Option 1), but monitoring would be required to determine if it is able to halt the headcut erosion. The berm has the risk of unintended consequences associated with equipment access to the site and work around the berm (i.e., soil compaction, damage, and erosion), with greater risk than Option 1 and similar to Option 3. The berm also has risk associated with potential greater impoundment of water along Pond C (potential water licensing implications) and potential for fish stranding. The berm is low (0.2 m) and would not meet the criteria to be classified as a regulated dam[13] (not regulated if less than 7.5 m in height and impounds less than 10,000 m^3). A fish stranding assessment is not within the current scope and should be considered by BC Hydro in option selection. There is some uncertainty on the required extent and height of the berm, as topographic survey pick-up in the area was limited and available LiDAR shows large discrepancies in vegetated or wet areas. This could be addressed by additional targeted survey or field confirmation of proposed berm locations during high runoff periods.

The proposed work at the B:C-2 outlet mitigates the risk of the headcut at B:C-2 by raising the outlet to prevent overtopping, infilling the headcut, re-grading the outlet to reduce the potential for erosion if overtopping were to occur, and providing vegetation for erosion protection and temporary biodegradable erosion protection while vegetation establishes. Risks associated with this component of the work are primarily related to unintended consequences associated with equipment access to the site (i.e. soil compaction, damage, erosion), similar to Option 1. It may slightly increase flows at B:C-1, which could increase flow rates and velocities downstream of that outlet and potential for erosion, but this is expected to be a relatively minor increase. As noted above, the mitigation works completed by BC Hydro in 2022 may be adequate to prevent overflow at the B:C-2 outlet, but monitoring would be needed to confirm.

Option 3 – Pond D Low Berm and Diversion Channel & Repair and Widen B:C-2 Outlet

The objectives of Option 3 are to divert water from the West Arm at Pond D and to retain the B:C-2 outlet at its current elevation but modify the geometry and grade to reduce the potential for erosion at B:C-2. Flows are diverted away from the West Arm at Pond D with construction of a low berm and shallow diversion channel. The outlet at B:C-2 is maintained close to its current elevation but widened to dissipate energy and disperse flow, and the existing headcut backfilled with local borrow. No modifications are proposed at B:C-1 or C:D. The mitigation works completed by BC Hydro at B:C-2 may effectively prevent water from flowing over this outlet to the headcut, but additional monitoring would be required to confirm, which may indicate whether additional work is needed. Option 3 is shown in Figures 12 and 13. As noted above, all options share common construction techniques and materials, which are summarized in in Section 5.1. The features included with Option 2 are as follows.

- Filling the headcut, and widening and re-grading outlet B:C-2 to dissipate potential flow and reduce shear stress (while maintaining the current spill elevation). The outlet may be expected to experience overflows at a similar frequency and magnitude as present conditions, but with a reconfigured geometry that is less susceptible to erosion (as noted above, BC Hydro's modifications may reduce or prevent overflows in the future). The need for armoring (beyond grass cover as outlined above) would be assessed in detailed design.
- Diverting water away from the West Arm by constructing the following:
  - A low (15 to 35 cm) vegetated berm across Pond D and the adjacent low areas.
  - A low gradient vegetated diversion channel to divert flow from Pond D to channel C:E. Detailed design may consider the need for armoring (beyond grass cover) and refinement to channel dimensions.
- Given the increased flows in C:E relative to present conditions, this channel would be monitored after construction to assess stability and erosion. Alternatively, the channel could be widened and/or armored as part of the works, depending on BC Hydro's risk tolerance. This could be further considered along with associated risks in detailed design.

[13] https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/40_2016

Compared to the other options, Option 3 diverts flows away from the West Arm at the furthest possible point, which may divert the most flow of all the options, but it has the risk of being undermined by the headcut if it does not fully address headcut progression. The berm and diversion channel also have the risk of being insufficient to fully divert water from the West Arm, as the diversion channel is limited by grade, which may require a wider channel than shown in the concept to adequately divert water. The berm also has risk associated with potential greater impoundment of water in Pond D (potential water licensing implications) and potential for fish stranding. The berm is low (0.25 m on average) and would not meet the criteria to be classified as a regulated dam (not regulated if less than 7.5 m in height and impounds less than 10,000 m^3). It likely has the greatest potential for unintended consequences associated with construction equipment of any option, as it has a relatively large footprint and would require some of the longest equipment access routes.

The proposed work at the B:C-2 outlet mitigates the risk of the headcut at B:C-2 by infilling the headcut, re-grading and widening the outlet to reduce the potential for erosion if overtopping were to occur, and providing vegetation for erosion protection and temporary biodegradable erosion protection while vegetation establishes. Risks associated with this component of the work are primarily related to unintended consequences associated with equipment access to the site (i.e., soil compaction, damage, erosion), similar to Option 1 and 2. An additional risk associated with this work is the conveyance of water down a relatively steep grade to the C:E channel; though the outlet would be graded significantly shallower than the existing and pre-headcut condition, the proposed grade of 3% is relatively steep for the site and additional armoring may be required.

Option 4 – Site Monitoring and C:D Channel Plug

The objective of Option 4 is to take very small scale actions to mitigate the risk of West Arm headcut progression and monitor the work completed by BC Hydro at the B:C-2 outlet. This includes one small channel plug at the C:D outlet and monitoring of all pond outlets and headcuts. Additional small scale actions are summarized below that could be considered based on the results of monitoring. Option 4 is shown in Figures 14 and 15. The features included with Option 4 are as follows.

- Plugging the C:D outlet with a low channel plug constructed with locally salvaged borrow and sod for revegetation and erosion protection, along with biodegradable erosion control matting. The low plug would focus on filling the small outlet and has the potential to be overtopped or outflanked by overtopping elsewhere along Pond C.
- Monitoring the pond outlets and existing headcuts as discussed below. Monitoring timing should focus on spring high water and rapid reservoir drawdown in late summer/fall when the outlets and ponds are most likely to be relatively high and actively conveying water downstream.
  - Monitor outflow conditions at the B:C-1 and B:C-2 outlets. Specific monitoring at B:C-2 should focus on whether flows overtop the embankment and flow out the B:C-2 outlet towards the headcut, which could contribute to continued erosion at the headcut. Monitoring at B:C-2 should also include measurements of the existing headcut depth, length, and width at a pre-determined location established with survey stakes or similar on an annual basis. If continued overtopping and headcut progression are observed, this may trigger further mitigation actions, such as raising the existing plug with local sod or imported material and planting.
  - Monitor the C:D plug performance, including whether flows overtop the plug itself or bypass the plug and overtop Pond C's western bank towards Pond D and the West Arm. Overtopping and continued overflow towards the West Arm may trigger the need for additional mitigation actions, which could include raising the plug or constructing similar small plugs at other targeted outflow points. In conjunction with this monitoring, simultaneously assess the flows that are continuing to

reach the West Arm (is water from the field west of Pond C or subsurface flow a significant source of water to the West Arm).

- Monitor the C:E channel for any erosion or damage associated with increased flows from plugging the C:D outlet.
- Continue to monitor condition of the East Arm and condition and erosion rates of the West Arm. The West Arm headcut monitoring should include measurements of change to headcut length and area, which could be facilitated by regular survey of the top of headcut, drone orthophotography and digital delineation, or establishing a series of control stakes from which to measure erosion. The latter would be the lowest cost but likely the least accurate, particularly as the headcut may erode in a non-linear fashion and widen and split over time.

This option differs from the others in that it would be easily implemented by hand (without the need for any heavy equipment), while Options 1-3 would be completed more efficiently by machine. This significantly reduces the risk of unintended consequences, such as unwanted ground disturbance associated with heavy equipment use on the site and unforeseen outcomes, such as impounded water associated with larger earthworks. It is possible that erosion may occur on the downstream side of the C:D plug if it is overtopped, however, the plug could be built to have a gentle backslope and be well vegetated to reduce this risk.

The primary risk of Option 4 is that it may not effectively limit headcut progression, as the proposed plug at C:D and the existing plug at B:C-2 are relatively small features that may not fully prevent overflows at those locations. The consequence of this occurring could be continued headcut progression in one or both of the existing headcuts. If the West Arm headcut continued to progress, it does not imminently pose a threat to important wetland habitat. If the B:C-2 outlet headcut continued to progress, it may quickly impact Pond B and any associated habitat benefits. In both potential headcut progression scenarios, based on observed headcut rates, there would likely be time to monitor, assess the effectiveness of the small plug approach, and implement further mitigation works if needed, so the risk of the solution not being effective could be effectively mitigated with carefully timed monitoring.

5.3 Class D Cost Estimate

The "Budget Guidelines for Consulting Engineering Services" (EGBC, 2009)[14] defines a Class D cost estimate as the following:

> "A preliminary estimate which, due to little or no site information, indicates the approximate magnitude of cost of the proposed project, based on the client's broad requirements. This overall cost estimate may be derived from lump sum or unit costs for a similar project. It may be used in developing long term capital plans and for preliminary discussion of proposed capital projects."

A contingency of 40% is incorporated into the cost estimates for each conceptual option, which is typical for Class D estimates.

[14] Engineers and Geoscientists British Columbia. (2009). Budget Guidelines for Consulting Engineering Services.

The Class D estimate unit rates were developed in 2023 dollars. They do not include any escalation for future conditions. The estimates are based on the following assumptions:

- Site access is assumed to be from the north, using the pedestrian bridge over the Illecillewaet River and the old highway. Depending on the conceptual options constructed, swamp mats may be required for access, although these are not explicitly included at this stage. The need for additional access considerations will be assessed in detailed design.
- For Options 1-3, equipment is assumed to include a small excavator, a small skid steer, and small pick-up trucks due to the anticipated loading and size restrictions of the bridge. Large dump trucks are not expected to be permissible. Actual equipment that could be used will be dependent on actual bridge loading restrictions, which should be confirmed by BC Hydro. For Option 4, all work is expected to be completed with hand tools and manual labour.
- At this conceptual stage, the need for additional armoring beyond biodegradable erosion control matting and replacement of stripped sod over filled and excavated areas has not been assessed in detail. For the Class D estimates, it has been assumed that the B:C-2 outlet in Options 1 and 3 may require some form of gravel or cobble armoring and that similar armoring may be required for the diversion channel in Option 3. The need for this would be further assessed in detailed design.
- It is assumed that all backfill materials will be sourced from local borrow site(s), either from excavations from other modified areas as part of the works, from the ponds, or from outside the project area (further north in the field, for example). However, for options requiring construction of berms (Option 2 and 3), the volume of fill required may be greater than acceptable borrow volumes near the site, and imported fill may be required. The cost estimate is based on use of on-site borrow only, with an estimated unit rate provided for imported fill if required (assumed to be locally imported 75 mm pit run for costing). Limitations and potential for on-site borrow (permitting and land constraints) should be further assessed at detailed design and confirmed by BC Hydro.
- In Options 2 and 3, the approach for channel C:E is to monitor in the short term to see if the existing channel is adequate to handle additional flow without causing erosion or instability, with the alternative being to proactively widen and armor the channel in anticipation of increased flows relative to present conditions. This will depend on BC Hydro's risk tolerance and preference for monitoring versus initial action. At this stage, modifications to C:E have not been included in the conceptual design or accounted for in the cost estimates. This can be considered in detailed design.
- The cost estimates include an allowance for engineering and environmental fees for construction as a percentage (25%) of construction cost based on similar past projects. Actual costs for this item, which would include construction monitoring and completion documentation, will be assessed during detailed design based on the option chosen and on-site presence required during construction. For Option 4, the 25% allowance is expected to be only sufficient for limited environmental mitigation and monitoring input and limited engineering input (no engineer of record, engineering field review/site visits, or completion documentation).

Due to the relatively small size of the proposed works, unit rates are anticipated to be higher than for larger jobs where there is typically an efficiency of scale, and similar is expected to be true for mobilization and demobilization. Option 4, which could be completed by hand and potentially by BC Hydro staff, has lower mobilization and demobilization, due to the limited equipment and personnel needed to complete the work (hand tools and labour only).

Tables showing the breakdown of the cost estimate for each conceptual option are provided in Enclosure D – Class D Cost Estimates. The Class D Estimates for each option are summarized in Table 6 below. The cost estimates exclude all applicable taxes.

Table 7: Class D Cost Estimates for Site 6A Conceptual Mitigation Options

Conceptual Mitigation Option	Subtotal Construction	Contingency (40%)	Construction Engineering & Environmental Allowance (25%)	Total
Option 1	$139,000	$55,600	$34,750	$230,000
Option 2	$123,000	$49,200	$30,750	$203,000
Option 3	$153,000	$61,200	$38,250	$253,000
Option 4	$16,000	$6,400	$4,000	$27,000

5.4 Option Comparison

A comparison of the conceptual mitigation options based on various criteria is shown in Table 8. The options are compared in terms of disturbance, effectiveness, risk, monitoring and maintenance requirements, and cost.

The preferred option should be selected based on input from BC Hydro considering the comparison presented, and it could consider combinations of the options or a staged approach, where limited works are undertaken and their effectiveness would be monitored to evaluate the need for additional works. A staged approach may have greater long-term costs if small works are ineffective, as mobilization, preparation of site access, and demobilization, are a large portion of the overall cost for a small project of this size.

Environmental permitting, archaeological impact assessments, and fish stranding assessments are not included in the scope, but it is recommended that these items be further considered and evaluated by BC Hydro as part of option selection. Overall, smaller footprint options are expected to be most beneficial for all of these items, and limiting berms or water retention structures may have lower fish stranding risks (though all options include some amount of plug or berm to divert water).

Options that avoid large access route footprints and extensive ground and vegetation disturbance are expected to be preferred, as the soft soils are very susceptible to erosion, compaction, softening, and rutting, if disturbed. Limiting the number, length, and width of travel routes is preferred. However, this has trade-offs with the amount of water diverted from the West Arm, as diversion closer to the West Arm is expected to capture a greater volume of the water that is contributing to the headcut progression.

In addition, unintended consequences as a result of unforeseen conditions are possible with any option due to the ground conditions and subtle and complex drainage features. A related consideration is management responsibility, where any works would likely become the responsibility of BC Hydro to manage and maintain if damaged or there are unforeseen issues that occur. For larger works, this added management effort may be more significant.

Given the large distance between the headcuts and the important habitat (> 100 m) relative to the rate or erosion (several metres per year in the West Arm), there may be time to implement smaller scale trial works and monitoring, such as Option 4, to better inform the potential need for more significant works. This would require some acceptance of risk that the headcuts may continue to progress if small-scale works are insufficient. Based on discussion, this is in line with BC Hydro's preferred approach.

Based on the option comparison presented and the discussion above, Option 4 is recommended for consideration as a prudent first step, since it has the lowest risk of unintended consequences, lowest cost, lowest footprint, and could be easy to implement by BC Hydro personnel or a contractor. There is the risk of continued headcut progression, as the changes are small-scale and could be insufficient for future high runoff events that are similar to or higher than those observed in 2022. Ongoing monitoring would require dedicated resources to monitor performance and risk. During this period, BC Hydro should advance further discussions with the CSRD regarding the airport drainage system and its potential influence on conditions at Site 6A. By comparison, Options 1-3 are higher cost and have a greater risk of unintended consequences and more ongoing management, though that is accompanied by more robust physical works to divert water and protect areas from erosion.

The description of Option 4 in Section 5.2 includes additional small actions that could be taken if monitoring indicates the initial works are inadequate. If the work is not adequately meeting the project objectives, monitoring outcomes could also inform next steps. Below is a list of potential staging approaches, if monitoring indicates the Option 4 works are not adequately addressing headcut erosion.

- If water is overtopping the C:D plug and/or the western bank of Pond C, BC Hydro could consider raising the plug followed by implementing targeted small plugs at specific overflow areas between ponds C and D or perhaps the Option 2 berm.
- If water is overtopping the B:C-2 outlet and the headcut erosion is progressing, the plug could initially be raised with small scale works (sod, soil with planting and erosion control, or coir logs) and if that is insufficient one of the approaches shown in Options 1 to 3 could be considered. Option 2 is expected to have the lowest risk of continued erosion and unforeseen consequences, as it raises and re-grades the outlet to both prevent overflow and reduce the risk of erosion if it occurs.
- If the C:D plug is effective at preventing flow from Pond C but erosion in the West Arm continues, BC Hydro could consider additional water diversion locations further downstream at Pond D (such as Option 3) or riprap armour and granular filter in the headcut channel, similar to what was completed in the East Arm, which has been effective at mitigating headcut progression there.
- If erosion starts to occur elsewhere around the site, alternative mitigation options at specific locations may be considered based on risk.

Table 8: Comparison of Conceptual Mitigation Options

Criteria	Option 1 Pond B Outlet Modifications	Option 2 Pond C Low Berm and Repair and Raise Pond B Headcut	Option 3 Pond D Low Berm and Diversion Channel & Repair and Widen B:C-2 Outlet	Option 4 Site Monitoring and C:D Channel Plug
Description	**Plug Channel B:C-1:** • Strip and stockpile existing topsoil and sod from plug footprint. • Construct plug with fill sourced from local borrow. • Cover fill with biodegradable erosion control mat and sod. **Widen and Lower B:C-2:** • Strip and stockpile existing topsoil and sod from footprint. • Fill in head cut with fill sourced from local borrow. • Excavate channel to lower spill point elevation, wider channel, and shallower grade. • Place erosion control matting and sod over disturbed area.	**Raise and Regrade B:C-2 Outlet to Match Railbed:** • Strip and stockpile existing topsoil and sod from footprint. • Fill in headcut and raise channel with fill sourced from local borrow to the elevation of the old rail embankment on either side and grade to match surrounding embankment (uniform overtopping along the embankment). • Cover fill with biodegradable erosion control mat and sod. **Low Berm between Ponds C and D:** • Strip and stockpile existing topsoil and sod from footprint. • Construct berm using fill sourced from local borrow. • Place erosion control matting and sod over berm. **C:E Options:** • Monitor, consider widening or armoring	**Widen and Regrade B:C-2 Outlet:** • Strip and stockpile existing topsoil and sod from footprint. • Fill in headcut with fill sourced from local borrow and widen and re-grade outlet to shallower grade at similar spill point elevation. • Cover fill with biodegradable erosion control mat and sod. **Low Berm across Pond D and construct diversion channel:** • Strip and stockpile existing topsoil and sod from berm and channel footprints. • Construct berm using fill sourced from local borrow. • Excavate diversion channel north of berm to divert drainage from Pond D to C:E. • Cover berm and channel with biodegradable erosion control mat and sod. **C:E Options:** • Monitor, consider widening or armoring	**Monitoring:** • Monitor all outlets of Ponds B and C and the existing headcuts. **Plug Channel C:D:** • Strip and stockpile existing topsoil and sod from plug footprint. • Construct plug with fill sourced from local borrow. • Cover fill with biodegradable erosion control mat and sod.
Disturbance	• Low disturbance, more than Option 4 • Least difficult access requirements, since work areas are close to old road used to access site. Limits potential adverse impacts from access. • Least amount of fill required from local borrow. • Total disturbance footprint = 110 m^2 (not considering access)	• Most amount of disturbance of all options. • Similar access requirements to Option 3, less than Option 1. • Most amount of fill required from local borrow. • Total disturbance footprint = 250 m^2 (not considering access)	• Moderate disturbance; more than Option 1, much more than Option 4, but less than Option 2. • Similar access requirements to Option 2, less than Option 1 or 4. • Between Options 1 and 2 in terms of fill required from local borrow • Total disturbance footprint = 180 m^2 (not considering access)	• Low disturbance, much less than all other others • Low amount of fill required from local borrow • Total disturbance footprint 30 m^2 or less depending on final design approach (not considering access)
Effectiveness	• This option may be the least effective at diverting flow from the West Arm, as it only addresses outflows from Pond B, and not the other areas contributing runoff to Pond C and West Arm. • Under high runoff/flow conditions, some overflow is still anticipated at B:C-1, which may reach the West Arm and contribute to headcutting.	• This option is likely more effective at diverting flow from the West Arm than Option 1 and Option 4, but less than Option 3. • This option still allows runoff west of the berm to reach the West Arm.	• This option may be the most effective at diverting flow from the West Arm, but has greater risk of uncertainty. • This option has the risk of being undermined by the headcut if it continues to progress due to other factors. • Under high flow conditions, runoff may exceed the diversion channel capacity and overtop the berm across Pond D (depending on berm height).	• This option is likely more effective than Option 1 at diverting flow from the West Arm, but less than Options 2 and 3. • By plugging C:D, water may still be able to travel from Pond C to Pond D by the next lowest point (suspected to be north of C:D) given the subtle topography. • Under high runoff/flow conditions, some flow may overtop the C:D plug, which would reach the West Arm and contribute to headcutting. The same is true for the B:C-2 outlet and associated headcut. • If successful could be the most efficient option.
Risk	• Highest risk of runoff still reaching the West Arm. • There is risk of erosion and instability at B:C-2, since flow to this currently unstable channel is increased; however grade is significantly reduced. • This option poses some risk to the lower part of C:E due to increased flows. • There is a risk of unintended consequences associated with heavy equipment use at the site, less than Options 2 and 3 but much greater than Option 4.	• Low-Moderate risk of runoff still reaching the West Arm. • There is less risk of erosion at B:C-2 due to the raised ground elevation. • Flow over the berm prior to reservoir filling is less likely than Option 2B. • This option poses some risk to C:E due to increased flows. • There is a risk of unintended consequences associated with heavy equipment use at the site, greater than Option 1, much greater than Option 4, and slightly less than Option 3.	• Low risk of runoff still reaching the West Arm but may contribute more subsurface flow associated with Pond D water levels. • There is more risk of erosion at B:C-2 than Option 2 as flows still would overtop, but improved relative to current condition and less risk than Option 1. • This option poses some risk to C:E due to increased flows. • There is a risk of unintended consequences associated with heavy equipment use at the site, greater than Option 1, much greater than Option 4, and slightly more than Option 2.	• Moderate risk that enough runoff may still reach the West Arm for headcut progression to continue. • There is a risk that B:C-2 could still overtop and result in renewed head cutting at B:C-2. • This option poses some risk to C:E due to increased flows. • The monitoring program, and additional mitigation if needed, could moderate the potential risks above. • There is less risk of unintended consequences than the other options.
Monitoring and Maintenance Requirements	• Lower overall size and extent of works may result in lower maintenance. • Monitoring at B:C-1, B:C-2, C:E, East Arm, and West Arm recommended.	• Higher overall size and extent of works may result in higher maintenance (higher than or similar to Option 3), but lower likelihood of maintenance at B:C-2 compared to Options 1 and 3. • Monitoring at C:D berm, B:C-2, C:E, East Arm, and West Arm recommended.	• Higher overall size and extent of works may result in higher maintenance (lower than or similar to Option 2). • Monitoring at D berm, diversion channel, B:C-2, C:E, East Arm, and West Arm recommended.	• Lowest overall size and extent of works may result in lower maintenance. • Monitoring at C:D, B:C-2, B:C-1, C:E, East Arm, and West Arm recommended.
Costs	• High cost, between option 2 and option 3	• High cost, slightly lower than options 1 and 3	• Highest cost, slightly higher than options 1 and 2	• Lowest cost (by significant amount)

6. Summary & Recommendations

Site 6A is a gently sloping natural field and wetland complex that is seasonally inundated by the Arrow Lakes reservoir and has two eroding headcuts (at the West Arm and at outlet B:C-2). This memorandum documents an engineering assessment of the existing headcuts, site drainage patterns, and erosion risks as well as conceptual mitigation options for consideration. Key items from the assessment are summarized below.

- The area is generally susceptible to continued headcut erosion and erosion generally due to the soft non-cohesive silts. The old road and rail embankments fills are firmer and somewhat coarser and should be marginally less susceptible to erosion. Headcuts that have formed on the site are expected to continue to progress if left unmitigated and water continues to reach these sites.
- BC Hydro constructed a small plug at the B:C-2 outlet to reduce the potential for water overflow. Monitoring during high runoff and pond levels will allow for the assessment of its effectiveness.
- Erosion and headcut progression appear to predominantly be driven by processes at the headcut itself, whether as a result of primarily surface water flow or also due to groundwater seepage and excess pore pressure induced bank instability.
- Erosion and headcut progression are dependent on the amount of surface water and concentration of flows on site and the rate of snowmelt and/or drawdown. Monitoring has indicated that erosion may not necessarily occur every year, and rates of erosion in years where it occurs may be greater than the annual average estimates (annual averages of headcut erosion in the West Arm range from 0 to 3 m/yr). The B:C-2 headcut is newer and erosion rates have not been assessed.
- The East Arm headcut has been successfully stabilized based on riprap and filter placement in 2013.
- Mitigation should consider maintaining or establishing gentle grade and wide channels with low design flow velocities for stability considering local soils and grass cover.
- Conceptual mitigation options were developed for review and input by BC Hydro, which are summarized below.
  - Option 1 Pond B Outlet Modifications: The objective is to direct the majority of flow from Pond B away from the West Arm, and to the armoured East Arm by plugging the channel at B:C-1 and lowering and regrading B:C-2.
  - Option 2 Pond C Low Berm and Repair and Raise Pond B Headcut: The objectives are to divert water from Pond C away from the West Arm with a low berm and to raise and repair the B:C-2 outlet to prevent or significantly limit overflows that could contribute to continued erosion at the headcut immediately downstream.
  - Option 3 Pond D Low Berm and Diversion Channel & Repair and Widen B:C-2 Outlet: The objectives are to divert water from the West Arm at Pond D with a low berm and diversion channel and to retain the B:C-2 outlet at its current elevation but modify the geometry and grade to reduce the potential for erosion.
  - Option 4 Site Monitoring and Channel C:D Plug: The objective is to take very small scale actions to mitigate the risk of West Arm headcut progression (plug the C:D channel) and monitor the work previously completed by BC Hydro at the B:C-2 outlet.

- Class D cost estimates were completed for each option and all four options were compared across multiple categories considering cost, footprint, construction impacts, effectiveness, and risk. Option 4 is recommended for further consideration by BC Hydro for the reasons noted below:
    - It has the lowest cost and is easiest to implement (costs may increase if fill is imported).
    - It has the lowest risk of unintended consequences associated with construction equipment access and significant changes in water management on site, as this option can be completed by manual labour.
    - Risks of this option are related to it potentially being ineffective at mitigating the headcut (i.e., maintain status quo), which is understood to be acceptable to BC Hydro given the current long distance from the headcuts to the important wetland habitat.
    - It is most aligned with BC Hydro's preferred approach for small initial steps rather than larger works, which minimizes site disturbance and future management efforts, if effective.
    - It can be scaled up in the future if needed and monitoring would better inform future works if required.
- It is recommended that BC Hydro consider the following in confirming a preferred option:
    - Advancing discussions with the operators of the Revelstoke Airport to understand if upstream drainage structures are impacting drainage to Site 6A and the headcut risk.
    - Exploring environmental permitting, archaeological impact assessments, and fish stranding assessments to inform risks of implementation and any additional requirements.
    - Investigating access routes for construction staff and vehicles, specifically confirming if access along the existing trail and pedestrian bridge across the Illecillewaet River is feasible.

Closing

This memorandum documents the site assessments, design basis, and conceptual design options with estimated costs for the Site 6A headcut mitigation. This memorandum was provided for BC Hydro review and input in draft form and has been revised and finalized following review.

KERR WOOD LEIDAL ASSOCIATES LTD.

Prepared by:

Permit to Practice #1000696
PROFESSIONAL PROVINCE OF A. R. MATFIN # 51066 BRITISH COLUMBIA ENGINEER
2024-03-12

Kalie Siemens, P.Eng
Junior Engineer

Allison Matfin, P.Eng.
Project Engineer

Prepared by:

Chad Davey, M.Sc., R.P.Bio.
Fluvial Geomorphologist

Reviewed by:

Stefan Joyce, P.Eng.
Technical Reviewer

KS/ARM/SFJ

Encl.: Figure 1: Site 6A Location
Figure 2: Site 6A Drainage Features
Figure 3: Site 6A Estimated Catchment Areas
Figure 7: Survey of East and West Channels of Headcut Erosion Features Delineated by Year
Figure 8: Option 1 – Pond B Outlet Modifications - Plan
Figure 9: Option 1 – Pond B Outlet Modifications – Profile and Cross Sections
Figure 10: Options 2 - Pond C Low Berm and Repair and Raise Pond B Headcut – Plan
Figure 11: Options 2 - Pond C Low Berm and Repair and Raise Pond B Headcut – Profiles and Cross Sections
Figure 12: Option 3 - Pond D Low Berm and Diversion Channel and Repair and Widen B:C-2 Outlet – Plan
Figure 13: Option 3 - Pond D Berm and Diversion Channel and Repair and Widen B:C-2 Outlet – Profile and Cross Sections
Figure 14: Option 4 – Site Monitoring and C:D Channel Plug – Plan
Figure 15: Option 4 – Site Monitoring and C:D Channel Plug – Profiles and Cross Sections
Enclosure A – Site Photographs
Enclosure B – Soil Laboratory Test Results
Enclosure C – Class D Cost Estimates

Statement of Limitations

This document has been prepared by Kerr Wood Leidal Associates Ltd. (KWL) for the exclusive use and benefit of the intended recipient. No other party is entitled to rely on any of the conclusions, data, opinions, or any other information contained in this document.

This document represents KWL's best professional judgement based on the information available at the time of its completion and as appropriate for the project scope of work. Services performed in developing the content of this document have been conducted in a manner consistent with that level and skill ordinarily exercised by members of the engineering profession currently practising under similar conditions. No warranty, express or implied, is made.

Copyright Notice

Revision History

Revision #	Date	Status	Revision Description	Author
0	December 12, 2023	Final	Final Conceptual Design	KMS/ARM/SFJ

BC Hydro

Site 6A Headcut Mitigation Conceptual Design

KERR WOOD LEIDAL
consulting engineers

Service Layer Credits: World Imagery: Maxar

Coordinate System: NAD 1983 UTM Zone 11N

Scale Disclaimer: The map scale of 1:20,000 is only valid on a 11"x17" print.

Project No.	478.240
Date	December 2023
Scale	1:20,000

0 100 200 400 m

Site 6A Location

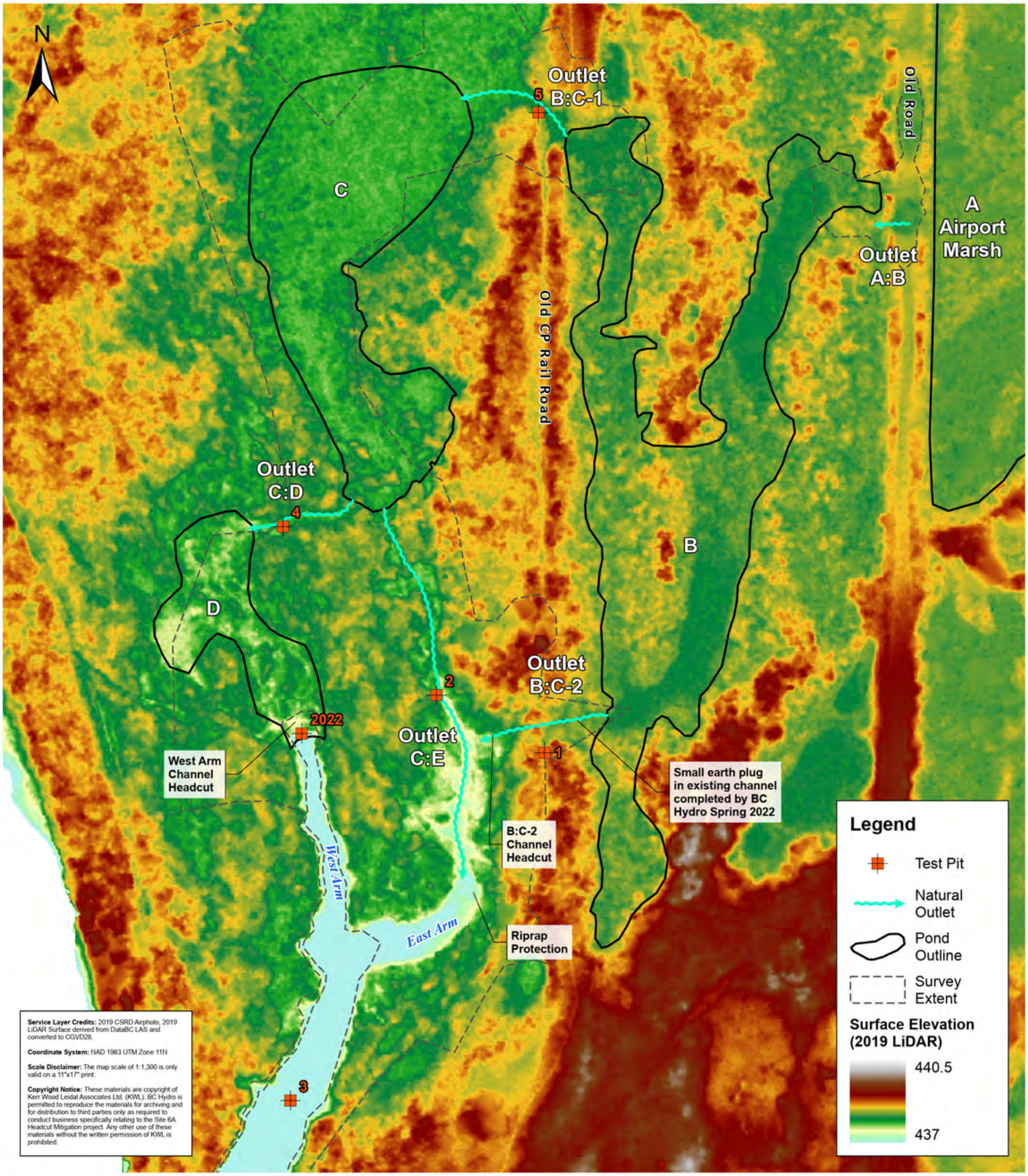
Figure 1

Path: P:\0400-0499\478-240\430-GIS\Pro Projects\0478240_Rp_Figures\0478240_Rp_Figures.aprx\0478240_Figure_2_SiteOverview | Date Saved: 12/8/2023 9:25 PM | Author: TRomans

BC Hydro

Site 6A Headcut Mitigation

KWL KERR WOOD LEIDAL consulting engineers



Project No. 478.240

Date December 2023

Scale 1:1,300

0 5 10 20 Metres

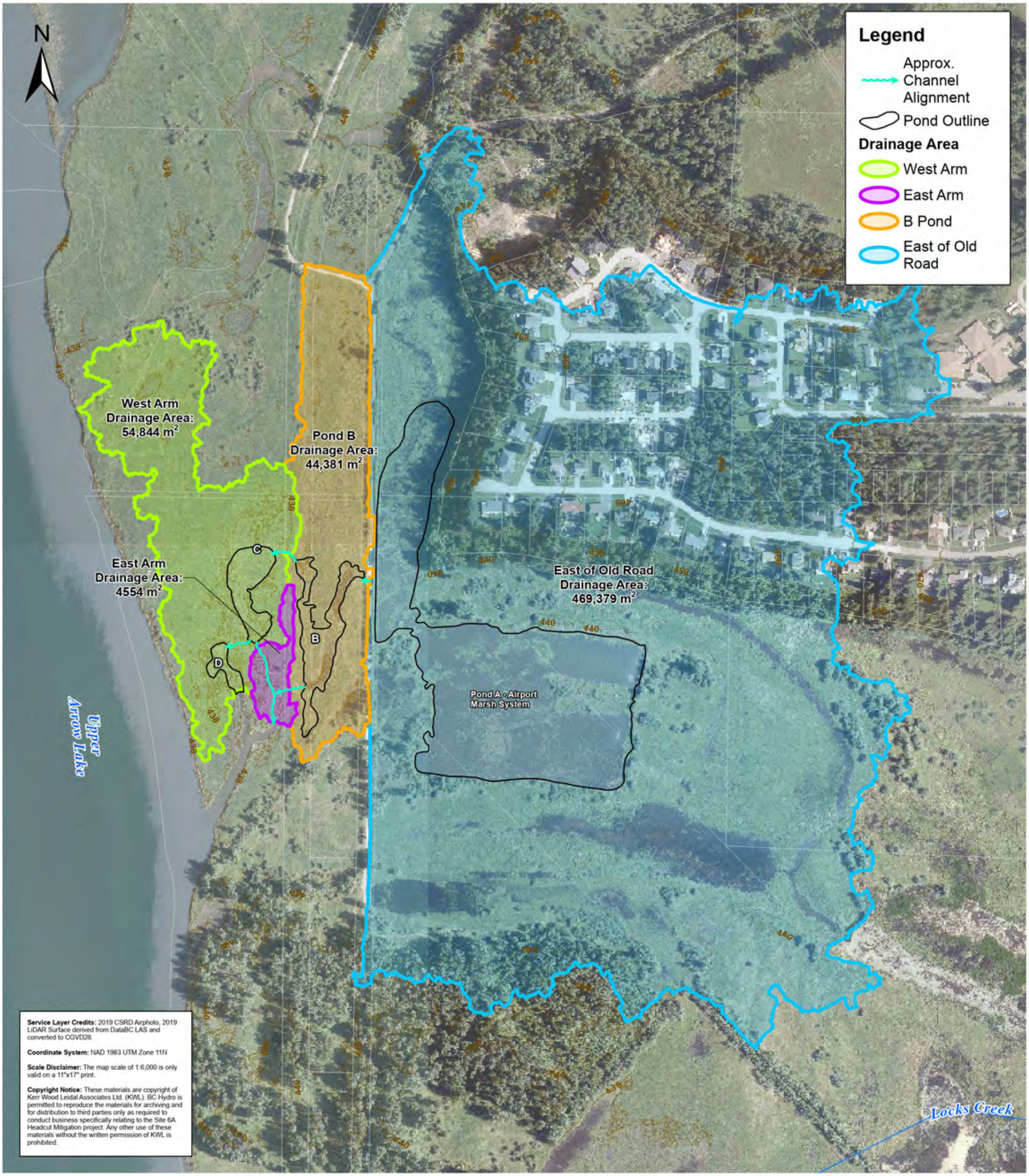
Site 6A Overview and Investigations

Figure 2

BC Hydro

Site 6A Headcut Mitigation

KERR WOOD LEIDAL
consulting engineers



Service Layer Credits: 2019 CSRD Airphoto, 2019 LiDAR Surface derived from DataBC LAS and converted to CGVD28.

Coordinate System: NAD 1983 UTM Zone 11N

Scale Disclaimer: The map scale of 1:6,000 is only valid on a 11"x17" print.

Project No.	478.240
Date	December 2023
Scale	1:6,000

0 50 100 200 Metres

Site 6A Drainage Area Estimates

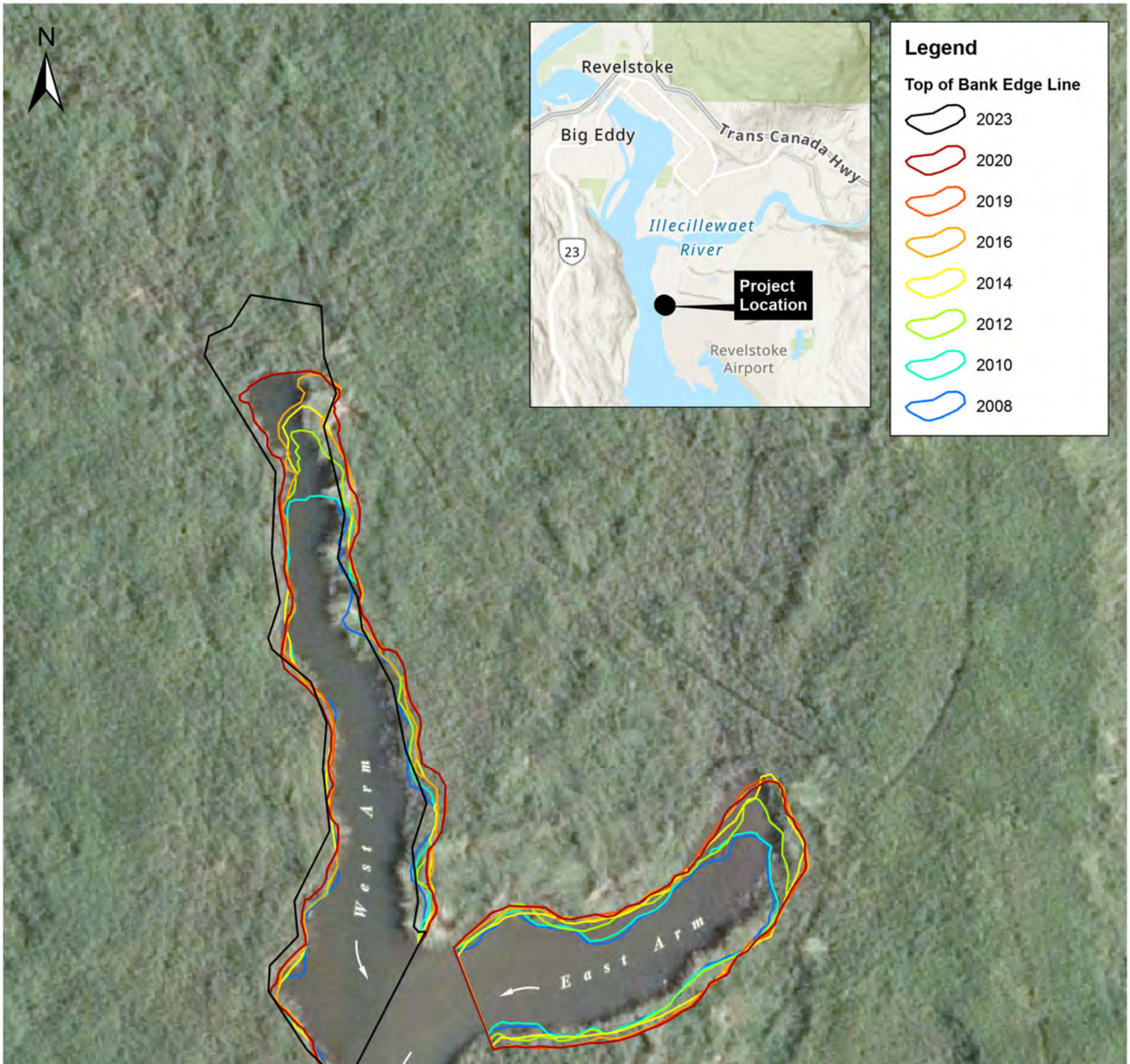
Figure 3

Path: P:\0400-0499\478-240\430-GIS\Pro Projects\0478240_Rp_Figures\0478240_Rp_Figures.aprx\0478240_Figure_7_Erosion | Date Saved: 12/8/2023 9:25 PM | Author: TRomans

BC Hydro

Site 6A Headcut Mitigation Conceptual Design

KERR WOOD LEIDAL
consulting engineers



Service Layer Credits: World Topographic Map: Esri Canada, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, USDA, NRCan, Parks Canada
World Hillshade: Esri, NASA, NGA, USGS, FEMA
2019 imagery shown from the Columbia Shuswap Regional District Open Data

Coordinate System: NAD 1983 UTM Zone 11N

Scale Disclaimer: The map scale of 1:500 is only valid on a 8.5"x11" print.

Note:
1. 2023 bankline from BC Hydro May 23, 2023 topographic survey.

2. 2008 - 2020 banklines from the following document: *Okanagan Nation Alliance and LGL Limited Environmental Research Associates, 2020. Columba River Project Water Use Plan. Kinbasket and Arrow Reservoirs Revegetation Management Plan: Monitoring Wetland and Riparian Habitat in Revelstoke Reach in Response to Wildlife Physical Works. Implementation Years 1-8. Prepared for BC Hydro, Reference: CLBMON-11B4.*

Project No.	478.240
Date	December 2023
Scale	1:500

0 2.5 5 10 m

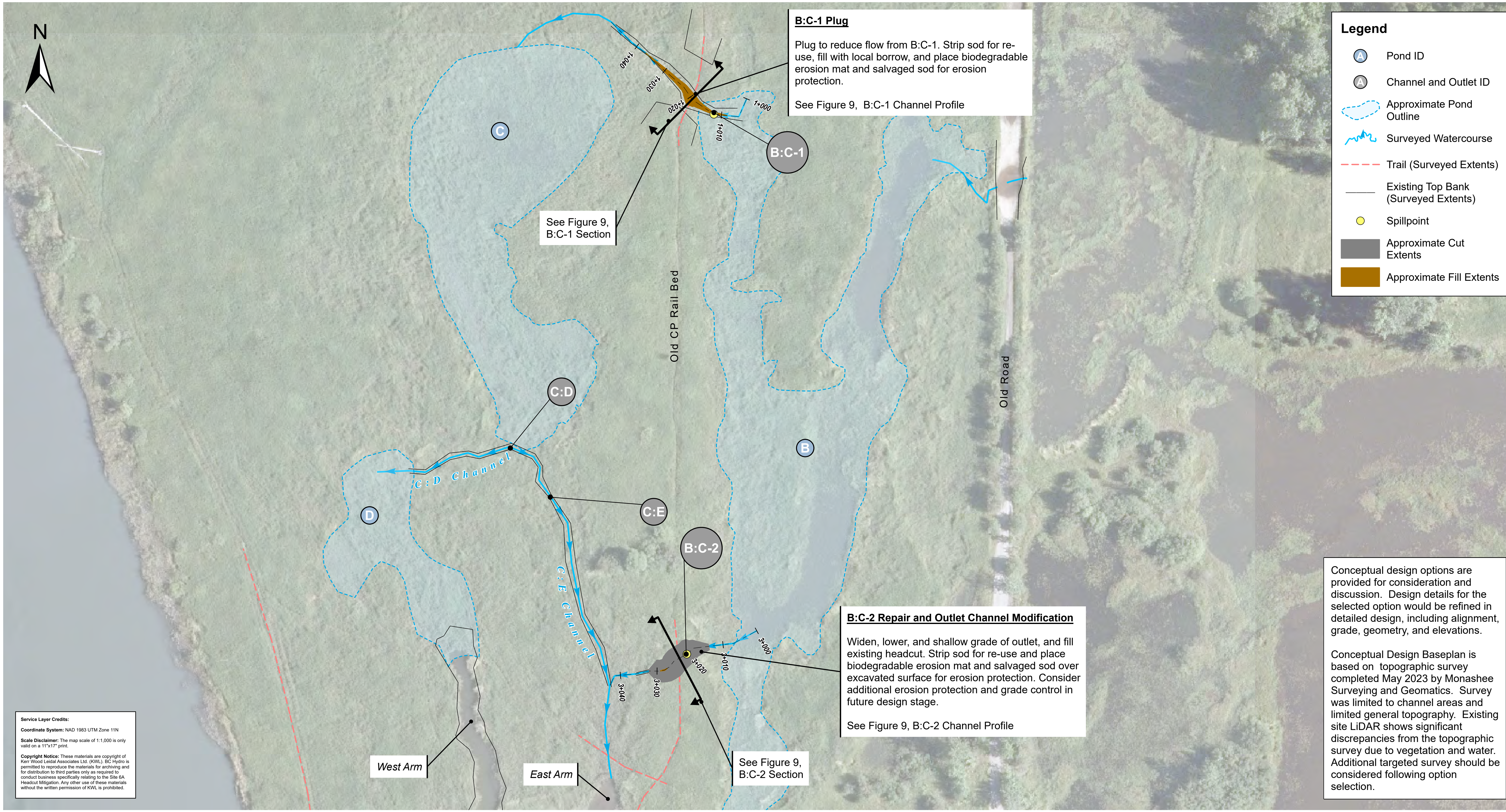
Survey of East and West Channels of Headcut Erosion Features Delineated by Year

Figure 7

Path: \\kwl.ca\projects\0400-0499\478-240\430-GIS\Pro Projects\0478240_Rp_Figures\0478240_Rp_Figures.aprx\0478240_Figure_8_Option 1 | Date Saved: 2023-10-17 9:58 AM | Author: JLau

BC Hydro
Site 6A Headcut Mitigation Conceptual Design

KERR WOOD LEIDAL
consulting engineers



Project No. 478.240
Date December 2023
Scale 1:1,000
0 5 10 20 m

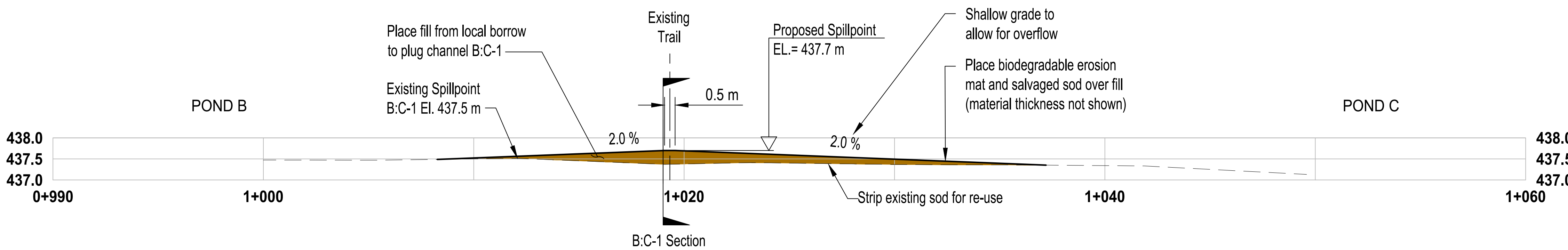
Option 1 - Pond B Outlet Modifications - Plan

Figure 8

BC Hydro

Site 6A Headcut Mitigation Conceptual Design

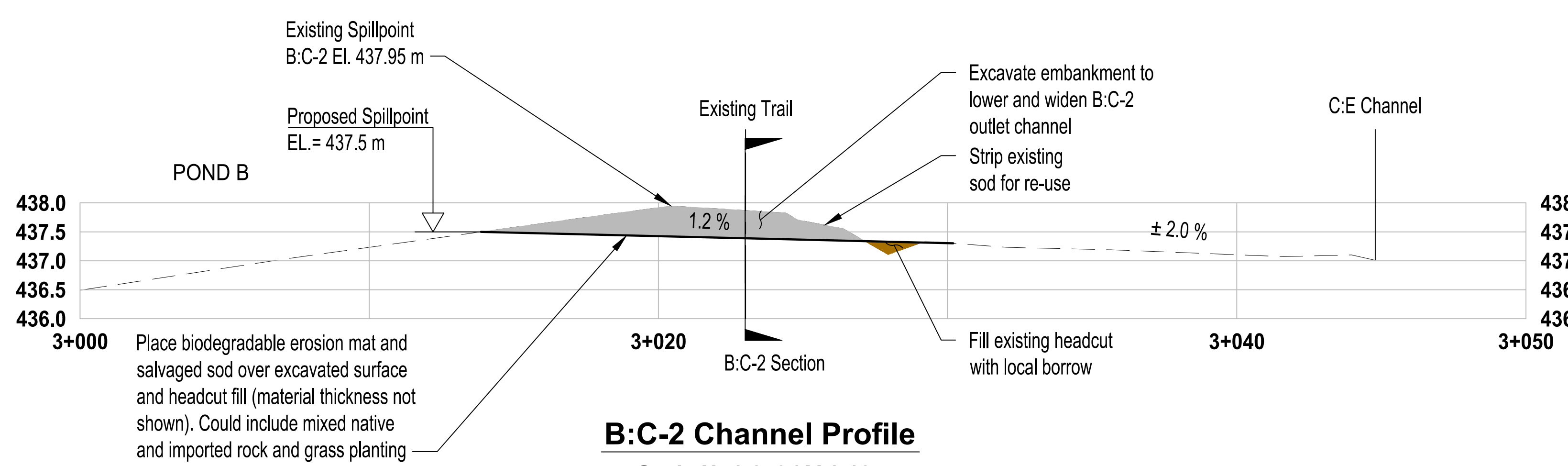
KERR WOOD LEIDAL
consulting engineers



B:C-1 Channel Profile

Scale H: 1:250 | V 1:125

Profile vertically exaggerated by 2 times



B:C-2 Channel Profile

Scale H: 1:250 | V 1:125

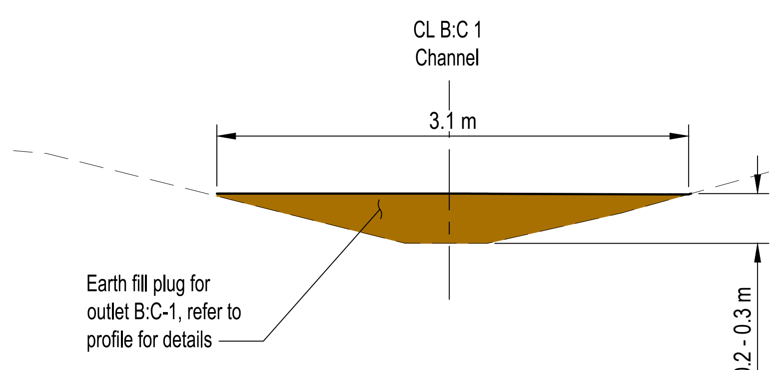
Profile vertically exaggerated by 2 times

Legend

- - - - Existing ground from May 23, 2023 BC Hydro survey. CGVD28
— Concept Design grade
Concept Cut Area
Concept Fill Area

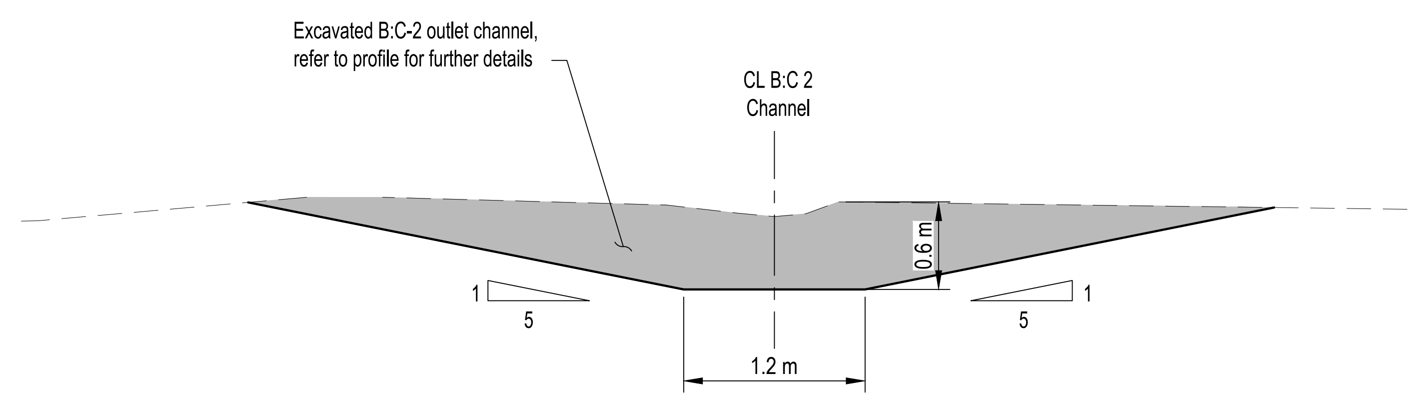
Note:
Proposed spill elevations are based on making outlet B:C-2 the primary outflow point from Pond B. However, this may not divert all flow away from outlet B:C-1, which may have some outflow during high flow periods.

Conceptual design options are provided for consideration and discussion. Design details for the selected option would be refined in detailed design, including alignment, grade, geometry, and elevations.



B:C-1 Section

Scale 1:50



B:C-2 Section

Scale 1:50

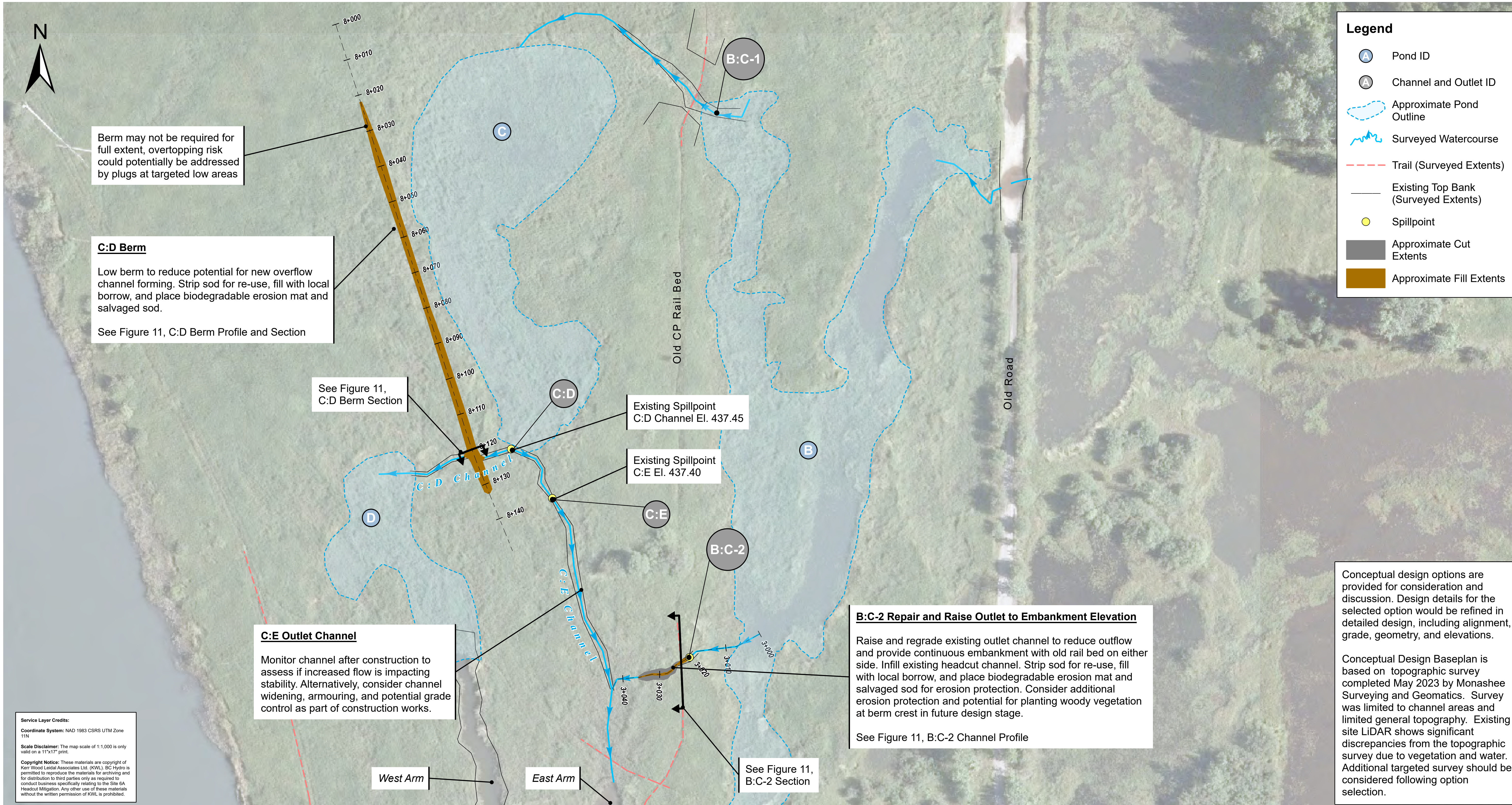
Option 1 - Pond B Outlet Modifications - Profile and Cross Sections

Path: \\kwl.ca\projects\0400-0499\478-240\430-GIS\Pro Projects\0478240_Rp_Figures\0478240_Rp_Figures.aprx\0478240_Figure_10_Option 2 | Date Saved: 2023-10-17 9:58 AM | Author: JLau

BC Hydro

Site 6A Headcut Mitigation Conceptual Design

KERR WOOD LEIDAL
consulting engineers



Project No. 478.240

Date December 2023

Scale 1:1,000

0 5 10 20 m

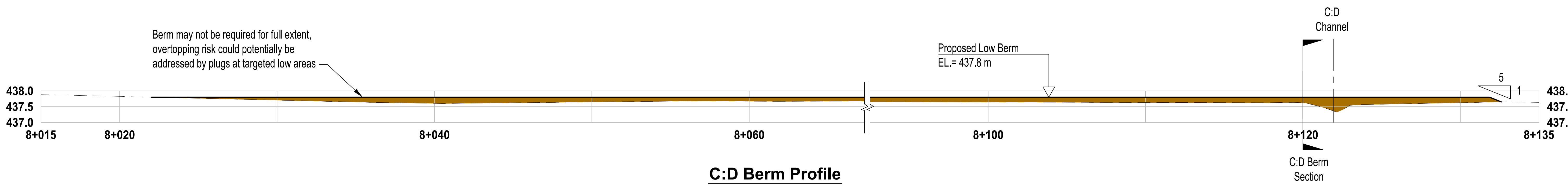
Option 2 - Pond C Low Berm and Repair and Raise Pond B Headcut - Plan

Figure 10

BC Hydro

Site 6A Headcut Mitigation Conceptual Design

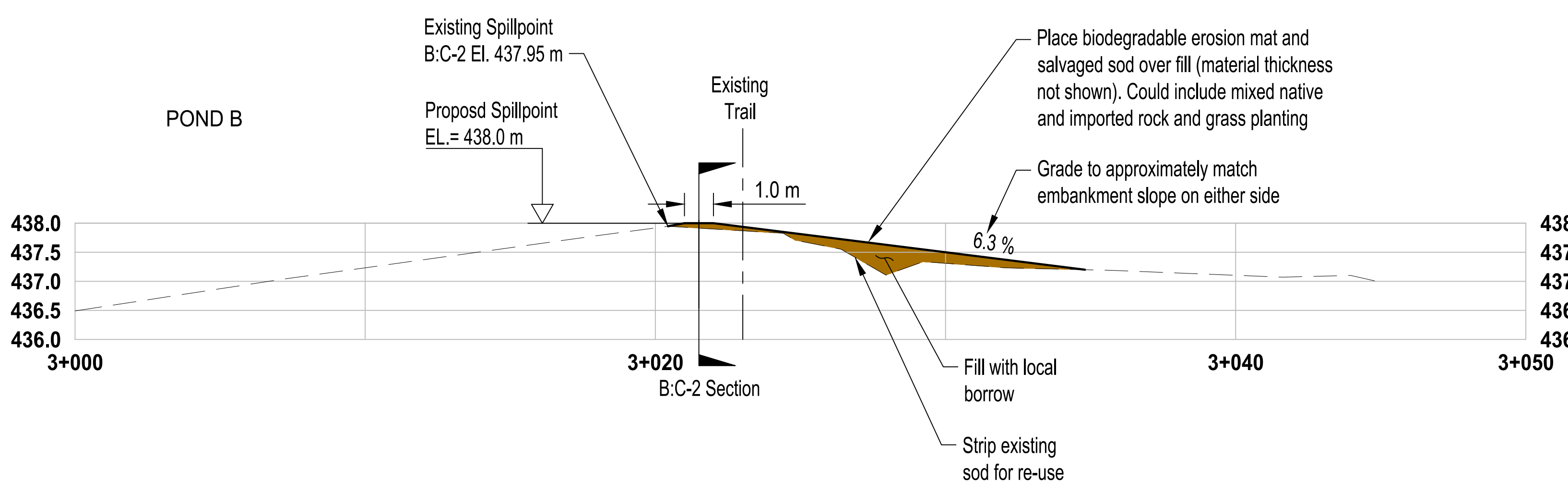
KERR WOOD LEIDAL
consulting engineers



C:D Berm Profile

Scale H: 1:250 | V 1:125

Profile vertically exaggerated by 2 times



B:C-2 Channel Profile

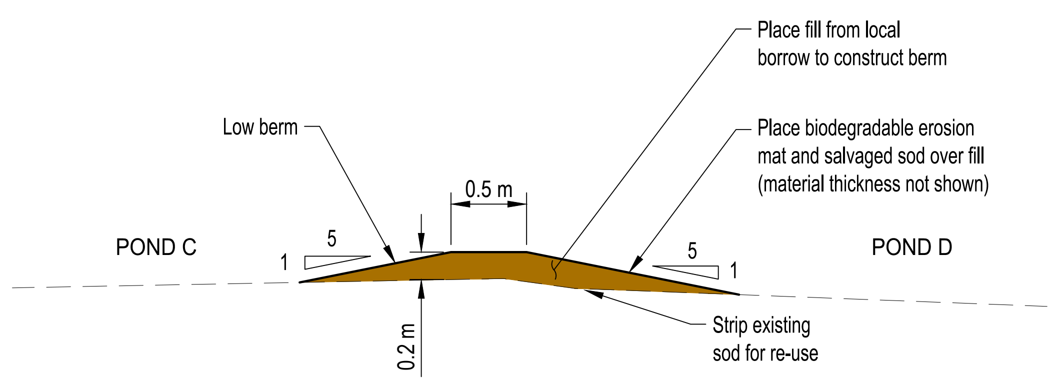
Scale H: 1:250 | V 1:125

Profile vertically exaggerated by 2 times

Legend

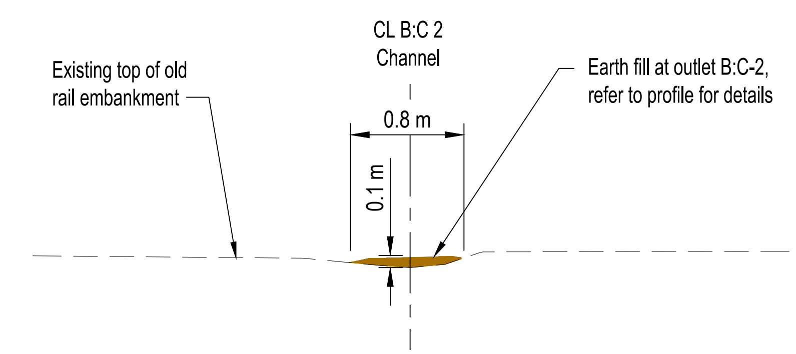
- - - - Existing ground from May 23, 2023 BC Hydro survey. CGVD28
—— Concept Design grade
Concept Cut Area
Concept Fill Area

Note:
Conceptual design options are provided for consideration and discussion. Design details for the selected option would be refined in detailed design, including alignment, grade, geometry, and elevations.



C:D Berm Cross-Section

Scale 1:50



B:C-2 Section

Scale 1:50

Project No. 478.240
Date December 2023
Scale As shown

Option 2 - Pond C Low Berm and Repair and Raise Pond B Headcut - Profiles and Cross Sections

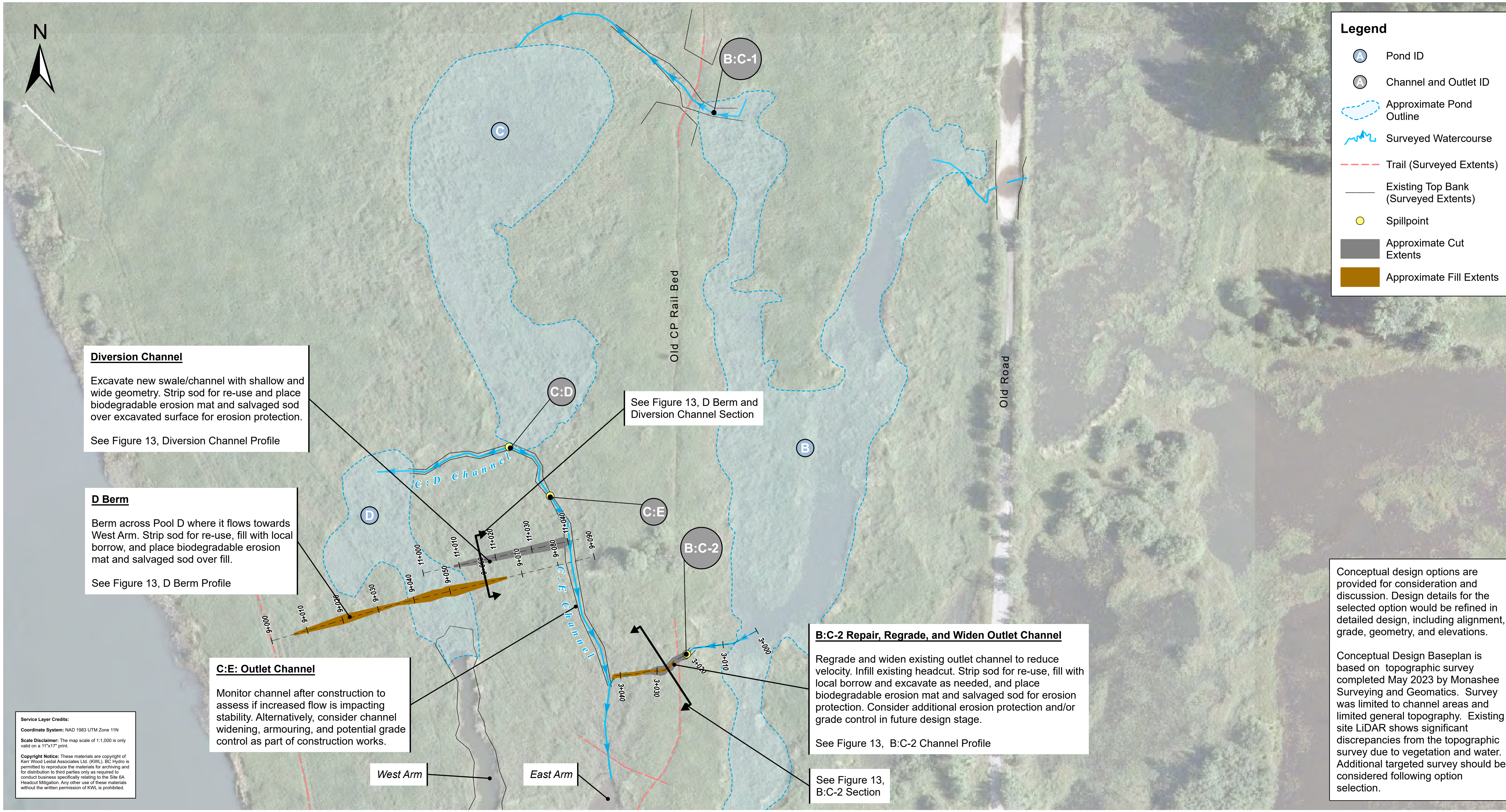
Figure 11

Path: \\kwl.ca\projects\0400-0499\478-240\430-GIS\Pro Projects\0478240_Rp_Figures\0478240_Rp_Figures.aprx\0478240_Figure_12_Option 3 | Date Saved: 2023-10-17 9:58 AM | Author: JLau

BC Hydro

Site 6A Headcut Mitigation Conceptual Design

KERR WOOD LEIDAL consulting engineers



Project No. 478.240

Date December 2023

Scale 1:1,000

0 5 10 20 m

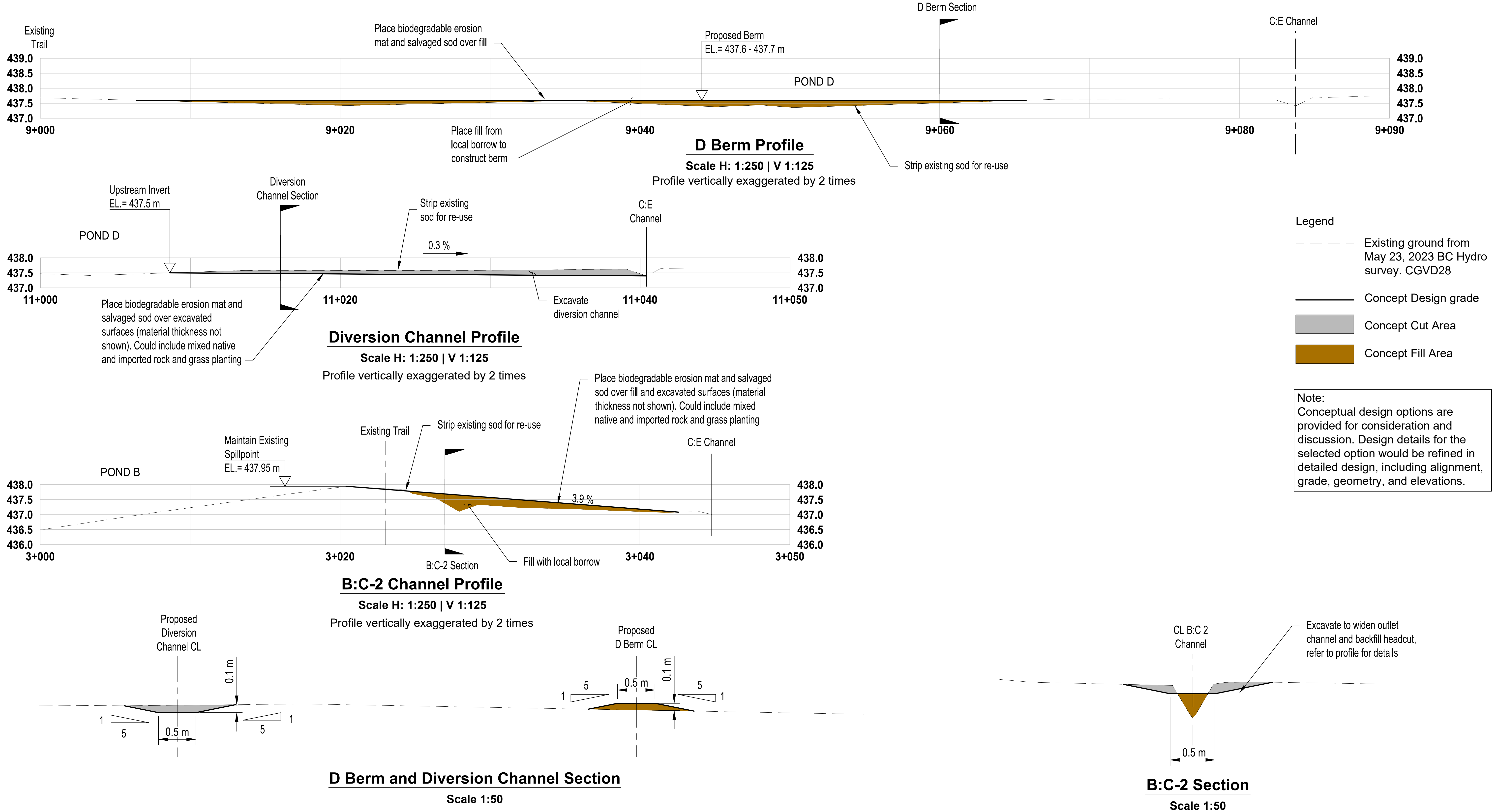
Option 3 - Pond D Low Berm and Diversion Channel and Repair and Widen B:C-2 Outlet - Plan

Figure 12

BC Hydro

Site 6A Headcut Mitigation Conceptual Design

KERR WOOD LEIDAL consulting engineers



Note:
Conceptual design options are provided for consideration and discussion. Design details for the selected option would be refined in detailed design, including alignment, grade, geometry, and elevations.

Project No. 478.240
Date December 2023
Scale As shown

Option 3 - Pond D Low Berm and Diversion Channel and Repair and Widen B:C-2 Outlet - Profile and Cross Sections

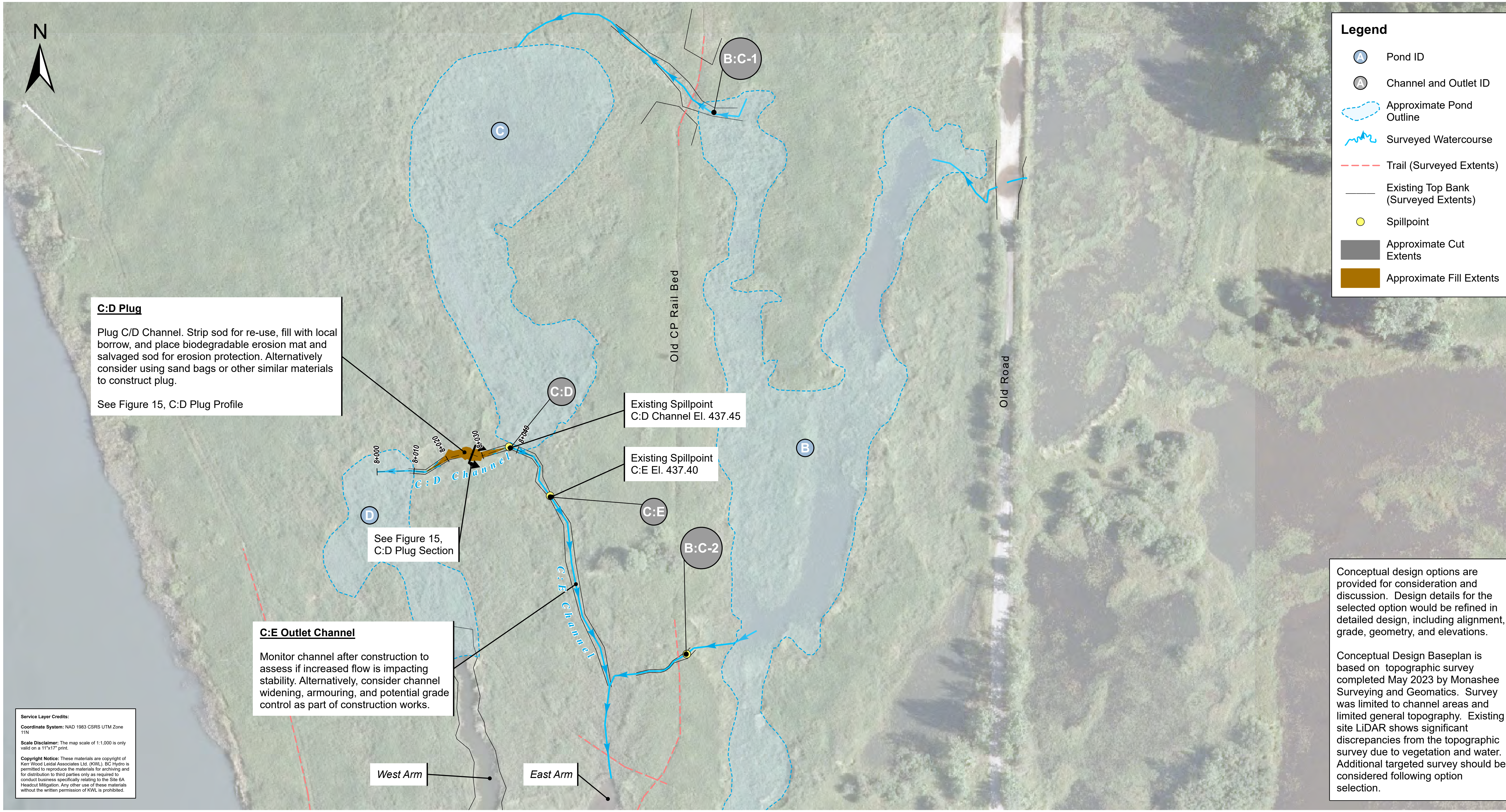
Figure 13

Path: \\kwl.ca\projects\0400-0499\478-240\430-GIS\Pro Projects\0478240_Rp_Figures\0478240_Rp_Figures.aprx\0478240_Figure_14_Option 4 | Date Saved: 2023-10-17 9:58 AM | Author: JLau

BC Hydro

Site 6A Headcut Mitigation Conceptual Design

KERR WOOD LEIDAL consulting engineers



Project No. 478.240

Date December 2023

Scale 1:1,000

0 5 10 20 m

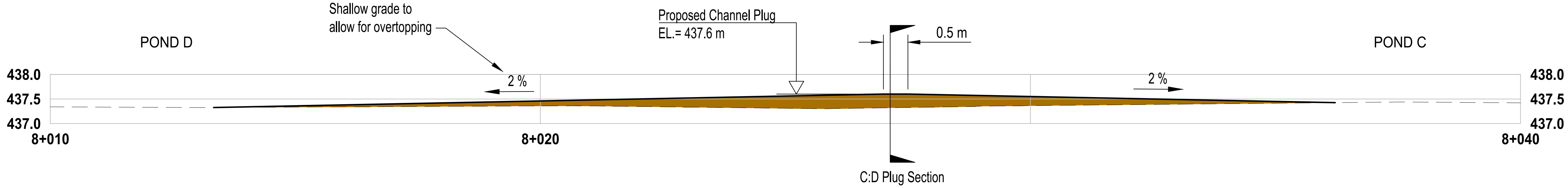
Option 4 - Site Monitoring and C:D Channel Plug - Plan

Figure 14

BC Hydro

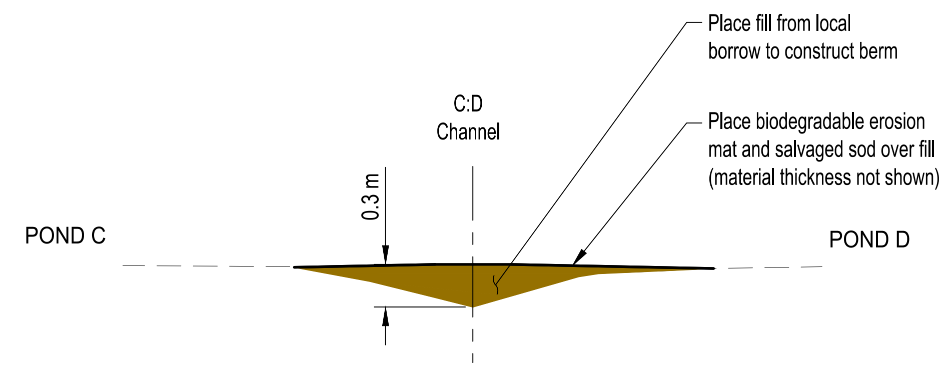
Site 6A Headcut Mitigation Conceptual Design

KERR WOOD LEIDAL consulting engineers



C:D Plug Profile along C:D Channel

Scale 1:100



C:D Plug Cross-Section

Scale 1:50

Legend

- Existing ground from May 23, 2023 BC Hydro survey. CGVD28
- Concept Design grade
- Concept Cut Area
- Concept Fill Area

Note:
Conceptual design options are provided for consideration and discussion. Design details for the selected option would be refined in detailed design, including alignment, grade, geometry, and elevations.

Project No. 478.240
Date December 2023
Scale As shown

Option 4 - Pond C Channel Plug and Pond B Headcut - Profile and Cross Section

Figure 15

Enclosure A

Site Photographs

Enclosure A – Site Photographs

Photo 1: Location of head cut at the end of the West Arm of the eroded channel, looking down the channel. April 12, 2022.

Photo 2: Existing riprap in the East Arm of the eroded channel, looking down the channel. April 12, 2022.

Photo 3: Confluence of the East and West Arms into the eroded channel mainstem, backwatered by Arrow Reservoir. Looking toward the reservoir. April 12, 2022.

Photo 4: Water flowing over the old road (outflow A:B) into Pond B. Looking North. April 12, 2022.

Enclosure A – Site Photographs

Photo 5: Water flowing from Pond B into B-C:2 channel. Looking northeast toward Pond B. April 12, 2022.

Photo 6: Water flowing through the old rail road from Pond B into B-C:1 channel. Looking northwest toward Pond C. April 12, 2022.

Photo 7: Water flowing from Pond C to Pond D through C:D channel. Looking west toward Pond D. April 12, 2022.

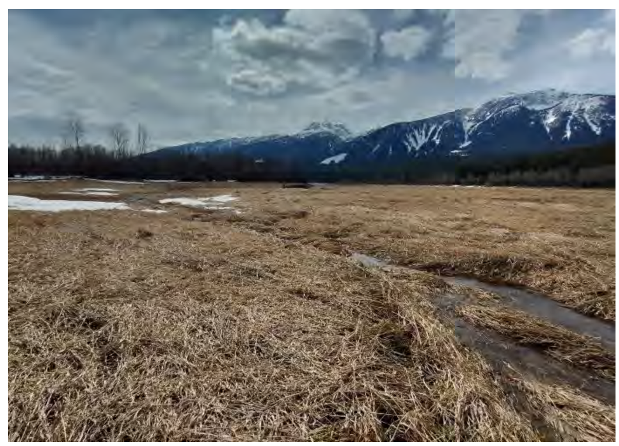


Photo 8: Water flowing from C pond to East Arm, looking southwest towards East Arm. April 12, 2022.

Enclosure A – Site Photographs

Photo 9: Water flowing over the old road (A:B) towards Pond B at 7 cm deep. Looking west, May 11, 2023.

Photo 10: Water starting to pool in Pond B, but not yet spilling at B-C:1 or B-C:2. Looking southwest, May 11, 2023.

Photo 11: Previous attempt by BC Hydro to stop erosion at B-C:2 by digging out adjacent soil and placing it in the channel at the spill point. May 11, 2023.

Photo 12: Typical silty clay test pit soils below the organic layer. May 11, 2023.

Enclosure A – Site Photographs

Photo 13: Gravels on channel bed in eroded channel mainstem, with erodible silt on side slopes and undercut banks. May 11, 2023.

Photo 14: Looking down West Arm from the channel head cut. May 11, 2023.

Photo 15: Confluence of East and West Arms to main eroded channel. Looking northeast, May 11, 2023.

Photo 16: Looking southwest down the main eroded channel from the confluence of the East and West Arms. May 11, 2023.

Enclosure B

Soil Laboratory Test Results

FPA Fletcher Paine Associates Ltd.

Consulting Geotechnical and Materials Engineers

GRAIN-SIZE DISTRIBUTION

ASTM C136 & C117

Project: KWL Grain Size Distribution Testing **Client:** Kerr Wood Leidal Associates Ltd. **Project No.:** 6946 **Location:** Revelstoke, B.C.

Sample Label: BC Hydro Site 6A West Channel **Source:** Unknown **Sampled By:** Client **Received:** 19-May-2023

Gradation Specifications: No Specification

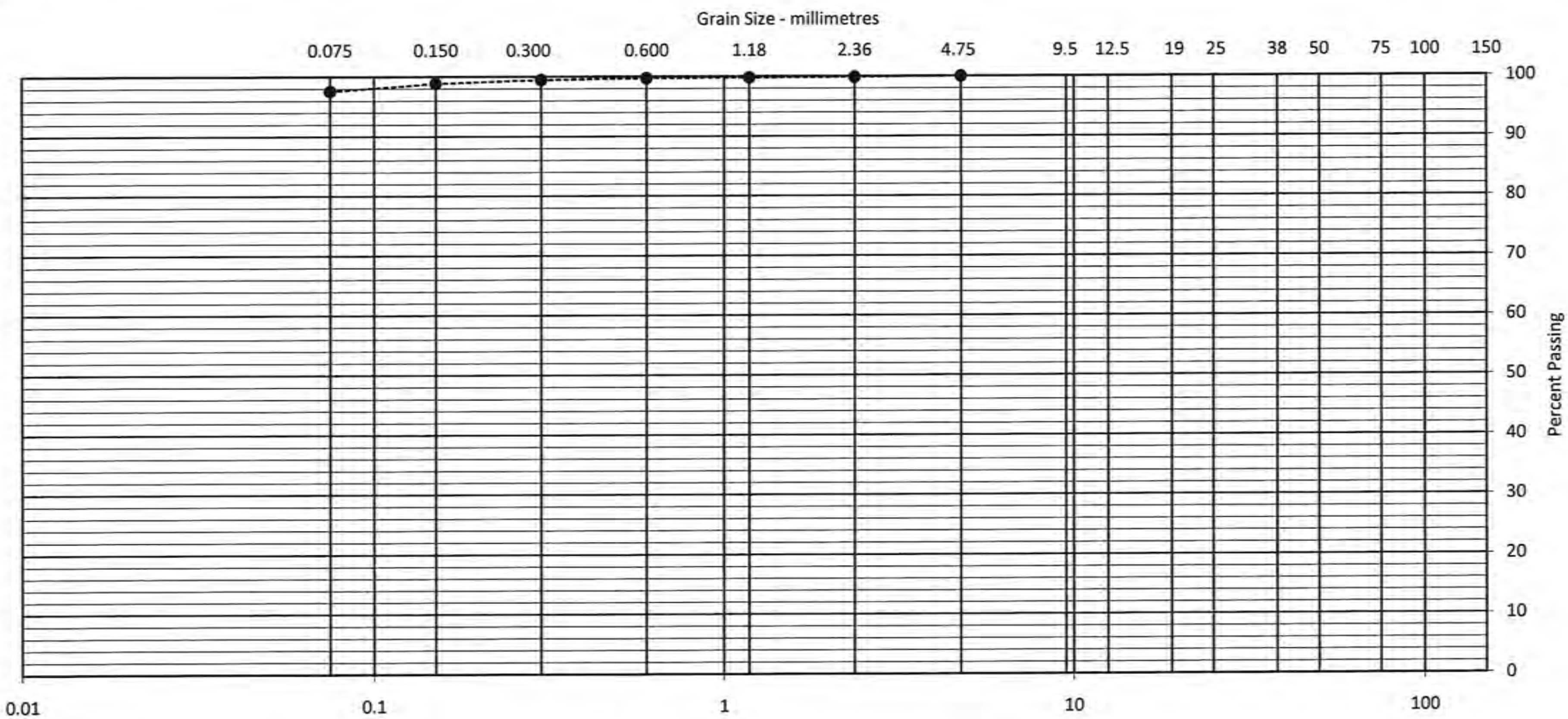
Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %
150			
100			
75			
50			
38			
25			
19			
12.5			

Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %
9.50			
4.75	100		
2.36	99.9		
1.18	99.8		
0.600	99.7		
0.300	99.5		
0.150	98.9		
0.075	97.6		

Remarks:

CCIL

Sample labelled:
April 12/22
BC Hydro Site 6A
West Channel



Reporting of this test result constitutes testing services only. Engineering interpretation or evaluation of the test result is provided only upon written request.
Data presented in this report is for the exclusive use of the Client listed above. F.P.A. will not take any responsibility for any unauthorized use.

FPA Fletcher Paine Associates Ltd.

Consulting Geotechnical and Materials Engineers

GRAIN-SIZE DISTRIBUTION

ASTM C136 & C117

Project: KWL Grain Size Distribution Testing **Client:** Kerr Wood Leidal Associates Ltd. **Project No.:** 6946 **Location:** Revelstoke, B.C.

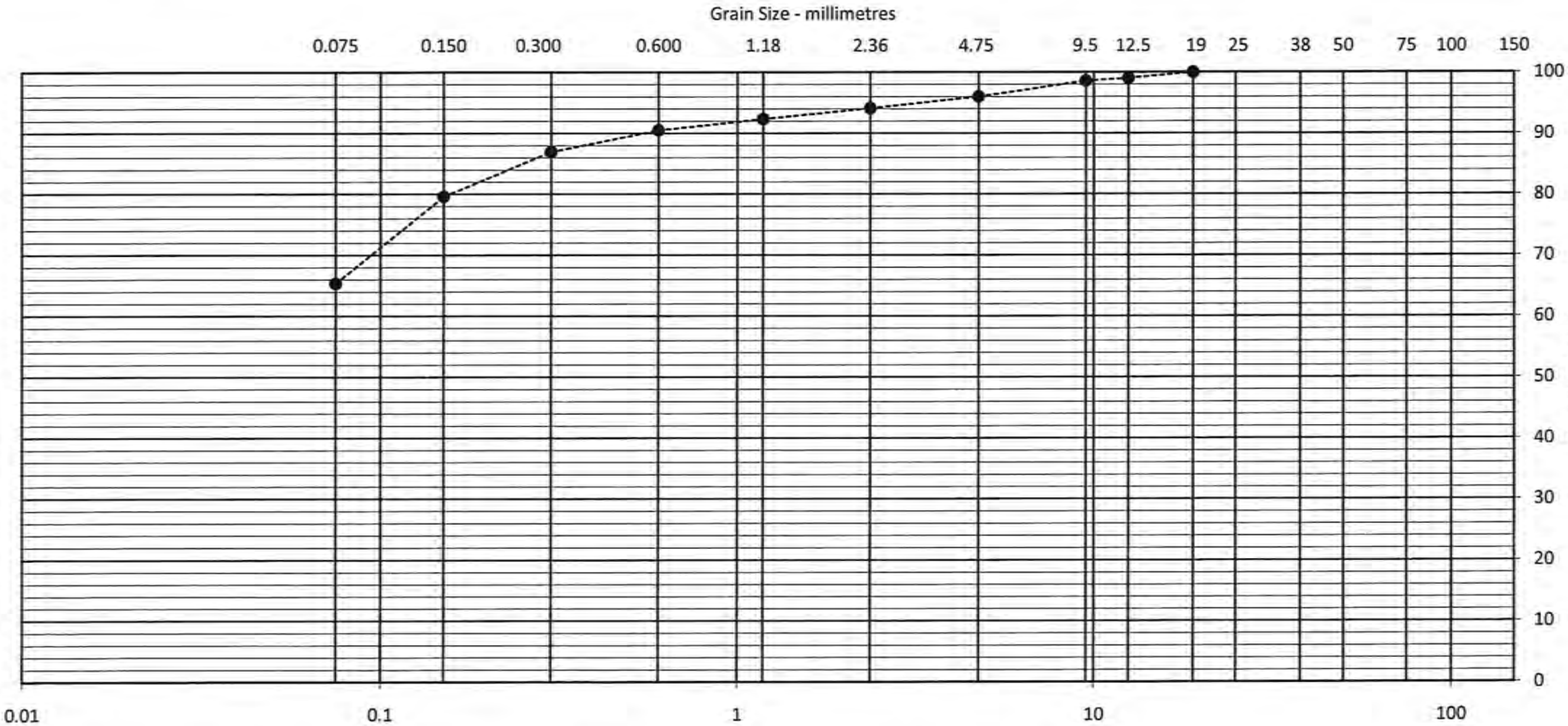
Sample Label: Test Pit 1, BC-2 (478-240) **Source:** Unknown **Sampled By:** Client **Received:** 19-May-2023

Gradation Specifications: No Specification

Wash Analysis		Limits		Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %	Sieve (mm)	% Passing	Min. %	Max. %
150				9.50	98.6		
100				4.75	96.0		
75				2.36	94.1		
50				1.18	92.4		
38				0.600	90.5		
25				0.300	87.0		
19	100			0.150	79.6		
12.5	99.0			0.075	65.4		

Remarks:

Sample labelled:
478-240
TP #1
BC-2
May 11/23



Reporting of this test result constitutes testing services only. Engineering interpretation or evaluation of the test result is provided only upon written request.
Data presented in this report is for the exclusive use of the Client listed above. F.P.A. will not take any responsibility for any unauthorized use.

FPA Fletcher Paine Associates Ltd.

Consulting Geotechnical and Materials Engineers

GRAIN-SIZE DISTRIBUTION

ASTM C136 & C117

Project: KWL Grain Size Distribution Testing **Client:** Kerr Wood Leidal Associates Ltd. **Project No.:** 6946 **Location:** Revelstoke, B.C.

Sample Label: Test Pit 2, Sample (478-240) **Source:** Unknown **Sampled By:** Client **Received:** 19-May-2023

Gradation Specifications: No Specification

Wash Analysis		Limits		Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %	Sieve (mm)	% Passing	Min. %	Max. %
150				9.50			
100				4.75			
75				2.36	100		
50				1.18	99.9		
38				0.600	99.9		
25				0.300	99.4		
19				0.150	98.9		
12.5				0.075	95.8		

Remarks:

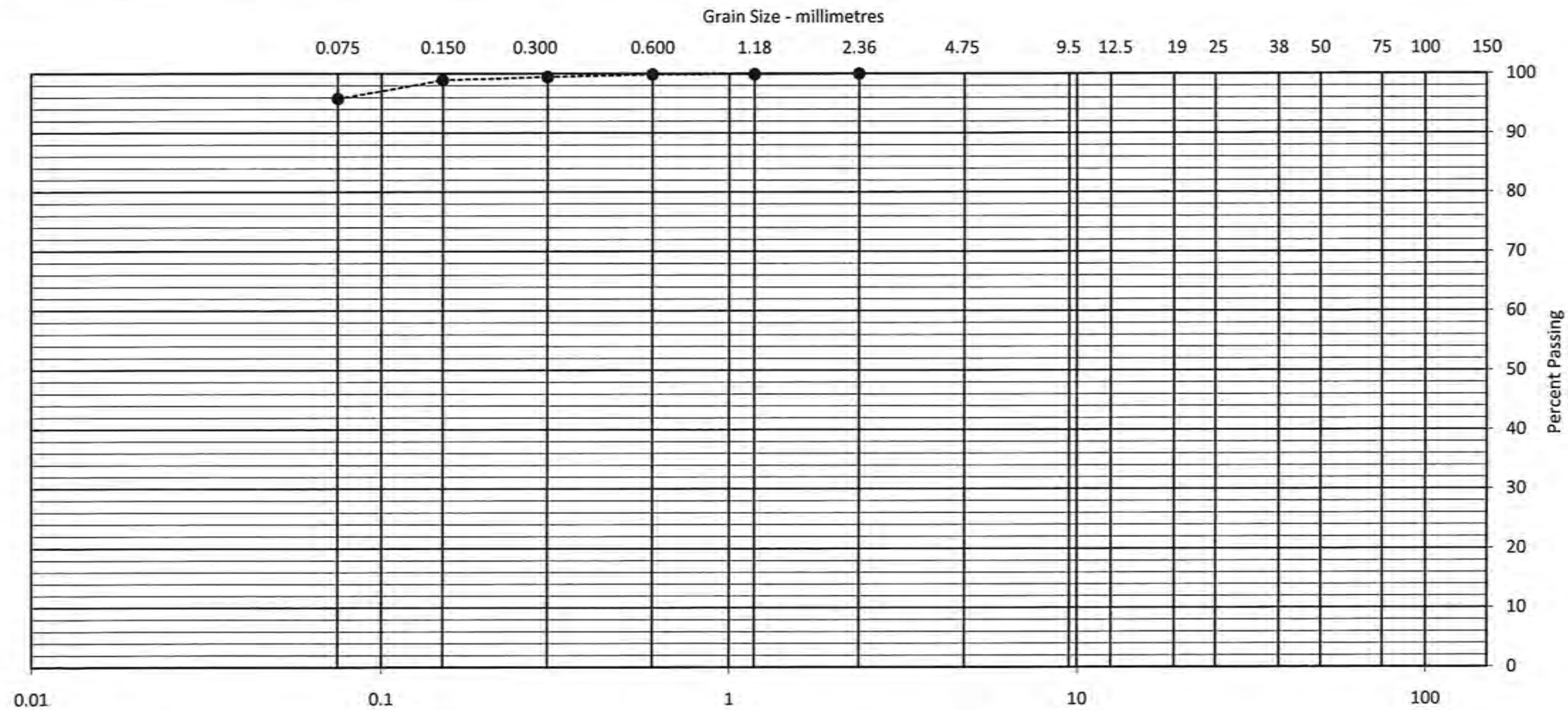
CCIL

Sample labelled:

478-240

TP #2

May 11/23



Reporting of this test result constitutes testing services only. Engineering interpretation or evaluation of the test result is provided only upon written request.

Data presented in this report is for the exclusive use of the Client listed above. F.P.A. will not take any responsibility for any unauthorized use.

FPA Fletcher Paine Associates Ltd.

Consulting Geotechnical and Materials Engineers

GRAIN-SIZE DISTRIBUTION

ASTM C136 & C117

Project: KWL Grain Size Distribution Testing **Client:** Kerr Wood Leidal Associates Ltd. **Project No.:** 6946 **Location:** Revelstoke, B.C.

Sample Label: Test Pit 3, Sample (478-240) **Source:** Unknown **Sampled By:** Client **Received:** 19-May-2023

Gradation Specifications: No Specification

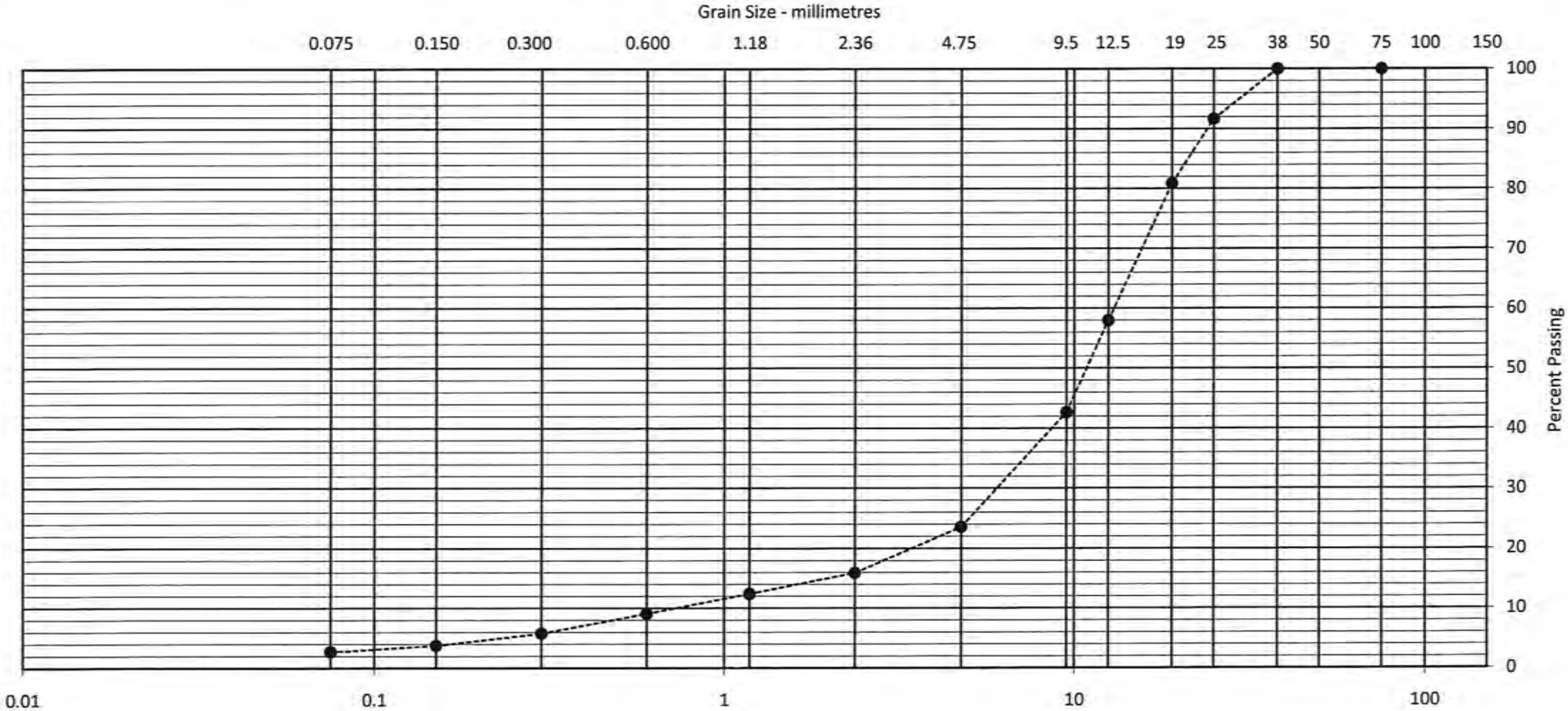
Wash Analysis		Limits		Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %	Sieve (mm)	% Passing	Min. %	Max. %
150				9.50	42.7		
100				4.75	23.6		
75	100			2.36	15.9		
50				1.18	12.4		
38	100			0.600	9.1		
25	91.7			0.300	5.8		
19	80.9			0.150	3.8		
12.5	58.0			0.075	2.7		

Remarks:

Sample labelled:

478-240

TP #3



Reporting of this test result constitutes testing services only. Engineering interpretation or evaluation of the test result is provided only upon written request.

Data presented in this report is for the exclusive use of the Client listed above. F.P.A. will not take any responsibility for any unauthorized use.

FPA Fletcher Paine Associates Ltd.

Consulting Geotechnical and Materials Engineers

GRAIN-SIZE DISTRIBUTION

ASTM C136 & C117

Project: KWL Grain Size Distribution Testing **Client:** Kerr Wood Leidal Associates Ltd. **Project No.:** 6946 **Location:** Revelstoke, B.C.

Sample Label: Test Pit 4, Sample C:D (478-240) **Source:** Unknown **Sampled By:** Client **Received:** 19-May-2023

Gradation Specifications: No Specification

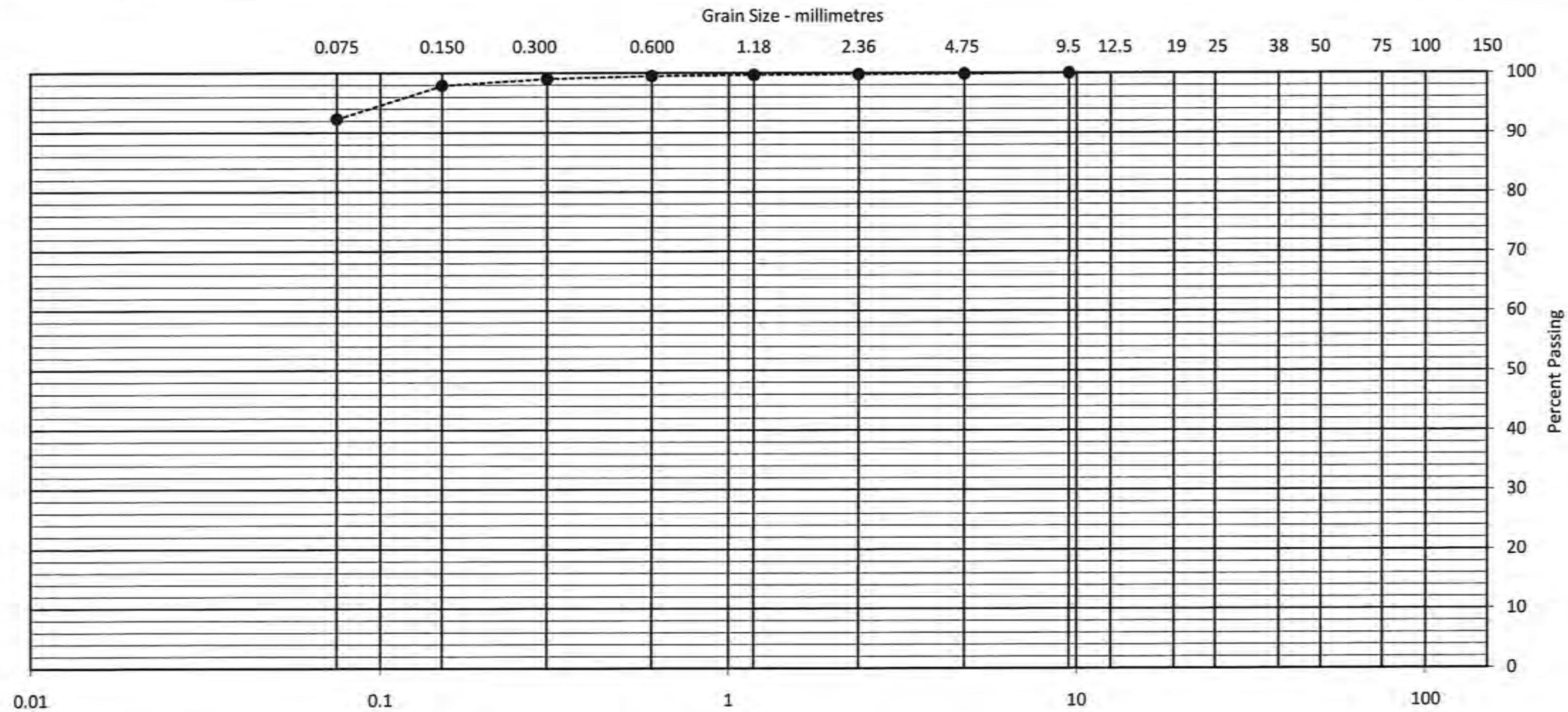
Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %
150			
100			
75			
50			
38			
25			
19			
12.5			

Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %
9.50	100		
4.75	99.9		
2.36	99.8		
1.18	99.7		
0.600	99.5		
0.300	99.0		
0.150	97.9		
0.075	92.3		

Remarks:

CCIL

Sample labelled:
478-240
TP #4
C:D
May 11/23



Reporting of this test result constitutes testing services only. Engineering interpretation or evaluation of the test result is provided only upon written request.

Data presented in this report is for the exclusive use of the Client listed above. F.P.A. will not take any responsibility for any unauthorized use.

FPA Fletcher Paine Associates Ltd.

Consulting Geotechnical and Materials Engineers

GRAIN-SIZE DISTRIBUTION

ASTM C136 & C117

Project: KWL Grain Size Distribution Testing **Client:** Kerr Wood Leidal Associates Ltd. **Project No.:** 6946 **Location:** Revelstoke, B.C.

Sample Label: Test Pit 5, Sample B:C-1 (478-240) **Source:** Unknown **Sampled By:** Client **Received:** 19-May-2023

Gradation Specifications: No Specification

Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %
150			
100			
75			
50	100		
38	95.7		
25	95.7		
19	94.3		
12.5	92.9		

Wash Analysis		Limits	
Sieve (mm)	% Passing	Min. %	Max. %
9.50	91.6		
4.75	89.5		
2.36	87.4		
1.18	84.6		
0.600	78.0		
0.300	61.9		
0.150	46.9		
0.075	34.9		

Remarks:

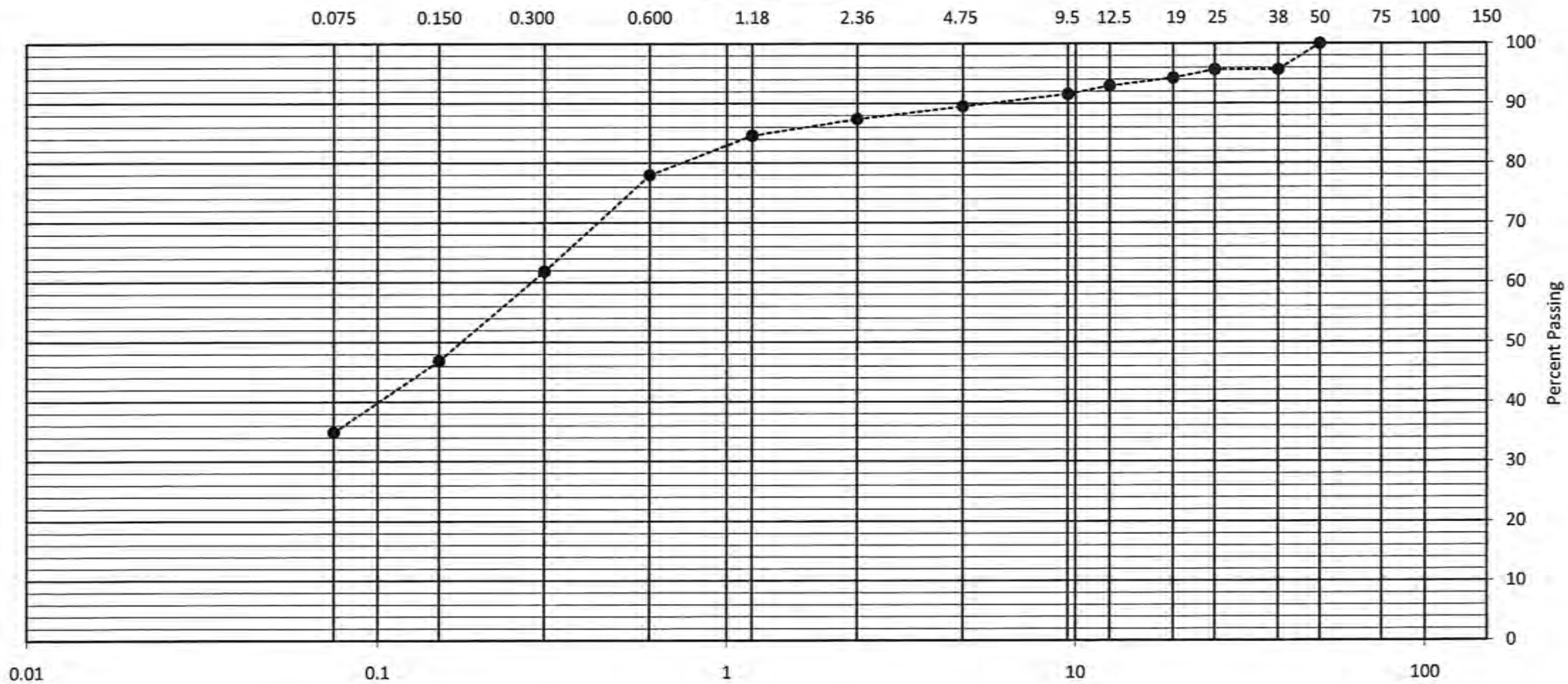
Sample labelled:

478-240

TP #5

B:C-1

May 11/23



Reporting of this test result constitutes testing services only. Engineering interpretation or evaluation of the test result is provided only upon written request.

Data presented in this report is for the exclusive use of the Client listed above. F.P.A. will not take any responsibility for any unauthorized use.

FPA Fletcher Paine Associates Ltd.
Consulting Geotechnical and Materials Engineers

GRAIN-SIZE DISTRIBUTION

ASTM C117 & C136

2250 -11th Avenue - Vernon, B.C. V1T 7X8
Tel: (250) 542-0377 / Fax: (250) 542-1220

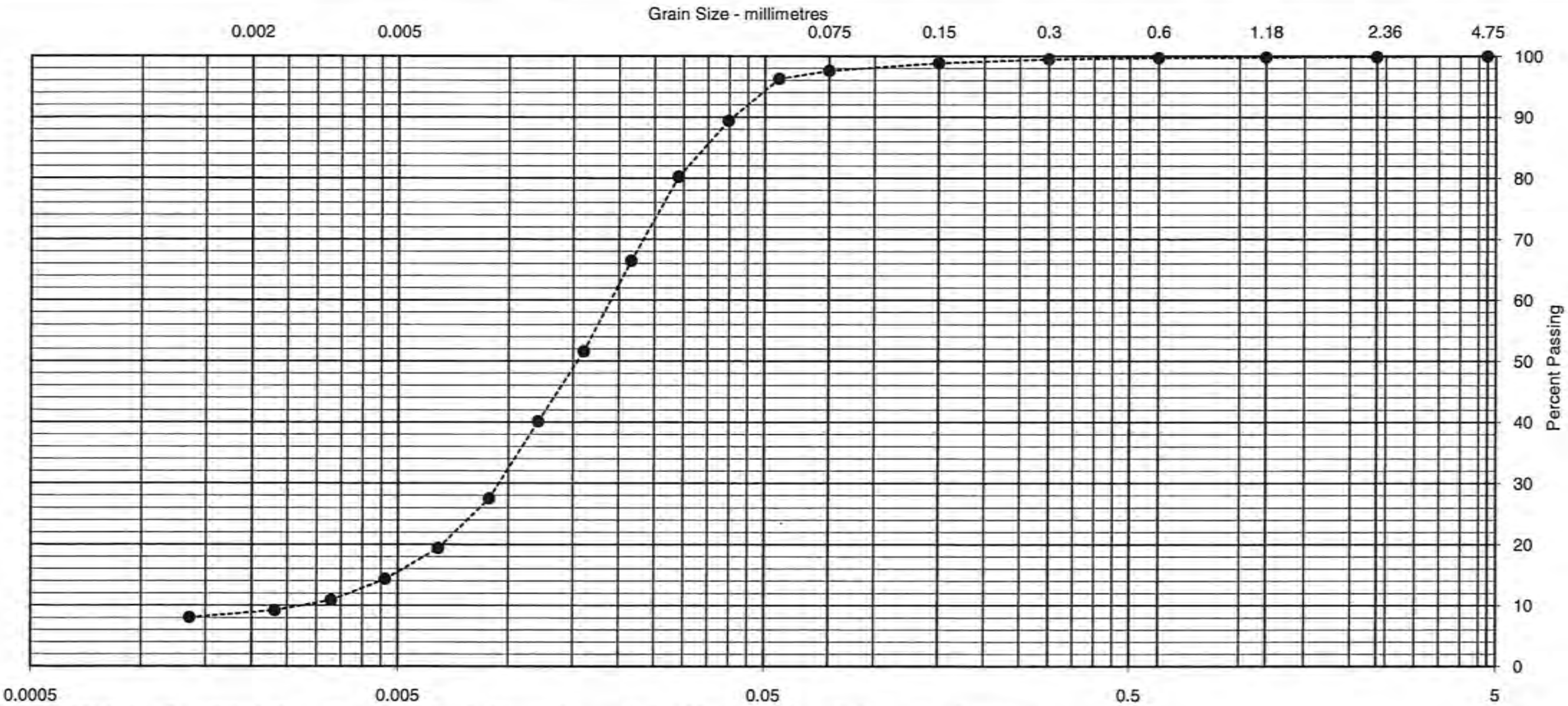
Project: KWL Grain Size Distribution Testing **Client:** Kerr Wood Leidel Ltd. **Project No.:** 6946 **Location:** Revelstoke, B.C.

Label: BC Hydro Site 6A Channel West **Source:** Unknown **Sampled By:** Client **Received:** 19-May-2023

Particle Size (mm)	Percent Passing	Particle Size (mm)	Percent Passing
		4.75	100
		2.36	99.9
		1.180	99.8

Particle Size (mm)	Percent Passing	Particle Size (mm)	Percent Passing
0.600	99.7	0.0160	51.6
0.300	99.5	0.0120	40.1
0.150	98.9	0.00885	27.5
0.0750	97.6	0.00643	19.4
0.0547	96.3	0.00462	14.3
0.0398	89.4	0.00329	10.9
0.0291	80.2	0.00231	9.2
0.0216	66.5	0.00136	8.0

Sample Label:
April 11/22
BC Hydro 6A
West Channel



FPA Fletcher Paine Associates Ltd.
Consulting Geotechnical and Materials Engineers

2250 -11th Avenue - Vernon, B.C. V1T 7X8
Tel: (250) 542-0377 / Fax: (250) 542-1220

GRAIN-SIZE DISTRIBUTION

ASTM C117 & C136

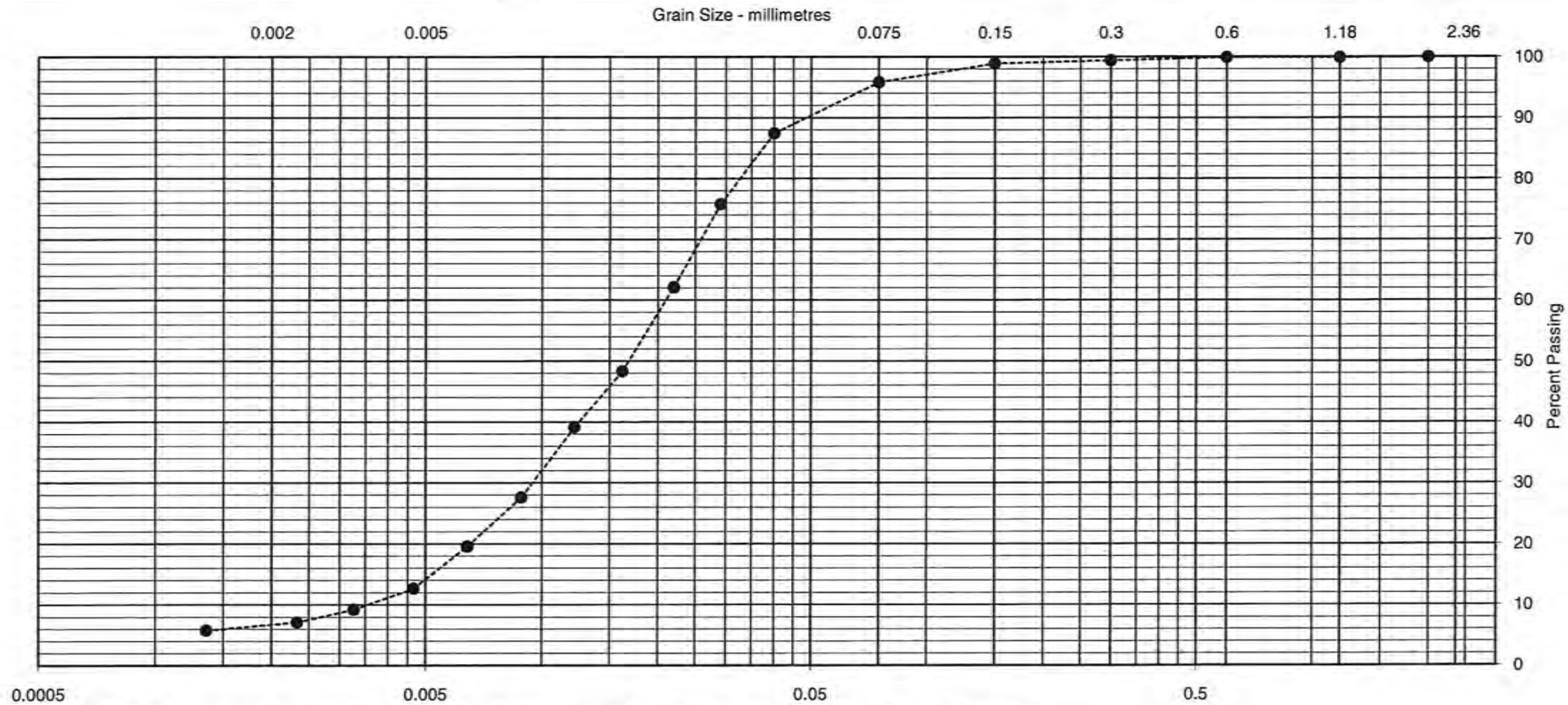
Project: KWL Grain Size Distribution Testing **Client:** Kerr Wood Leidel Ltd. **Project No.:** 6946 **Location:** Revelstoke, B.C.

Label: Test Pit 2, Sample (478-240) **Source:** Unknown **Sampled By:** Client **Received:** 19-May-2023

Particle Size (mm)	Percent Passing	Particle Size (mm)	Percent Passing
		2.00	100

Particle Size (mm)	Percent Passing	Particle Size (mm)	Percent Passing
1.18	99.9	0.0162	48.3
0.600	99.9	0.0121	39.1
0.300	99.4	0.00885	27.6
0.150	98.9	0.00642	19.6
0.075	95.8	0.00466	12.7
0.0400	87.4	0.00327	9.2
0.0291	75.8	0.00233	7.1
0.0220	62.1	0.00136	5.8

Sample Label:
478-240
TP #2
May 11/23



Enclosure C

Class D Cost Estimates

Cost Estimate
BC Hydro
Site 6A Mitigation Design
Project No. 478.240

Option 1 Class D Cost Estimate

Item	Description	Unit	Estimated Quantity	Unit Rate	TOTAL PRICE ($)	Comment
1	**General Conditions**					
1.01	Mobilization, Demobilization, and Access	Lump Sum	1	$ 60,000	$ 60,000	Assumes access through Kovatch Park and the pedestrian bridge over the Illecillewaet River. Accounts for minor road improvements to the trail for machinery.
1.02	Bonding & Insurance	Lump Sum	1	2%	$ 2,760	2% of construction cost (items 1-4)
1.03	Environmental Protection and Water Management Allowance	Lump Sum	1	10%	$ 13,800	10% of construction cost (items 1-4) Allowance for environmental protection (silt fencing, etc.) and water management
1.04	Survey	Days	3	$ 3,500	$ 10,500	Includes Layout and Record Surveys. Assumes a local surveyor from Revelstoke Area.
	SUBTOTAL FOR COMPONENT				**$ 87,060**	
2	**Earthworks and Revegetation - B:C-1 Plug**					
2.01	Soil/Sod Stripping and Stockpiling	m^2	33	$ 20	$ 660	
2.02	Local Borrow, Fill Placement and Compaction	m^3	4	$ 110	$ 440	Fill is sourced from local borrow. Unit rate may increase to $270/$m^3$ if imported fill (assumed 75 mm minus pit run) is needed to supplement fill.
2.03	Soil/Sod Placement	m^2	33	$ 70	$ 2,310	
2.04	Biodegradable Erosion Mat Supply and Placement	m^2	33	$ 20	$ 660	
	SUBTOTAL FOR COMPONENT				**$ 4,070**	
3	**Earthworks and Revegetation - B:C-2 Repair and Channel Outlet Modification**					
3.01	Soil/Sod Stripping and Stockpiling	m^2	81	$ 20	$ 1,620	
3.02	Excavation	m^3	26	$ 130	$ 3,380	On-site disposal or reuse
3.03	Local Borrow, Fill Placement and Compaction	m^3	1	$ 110	$ 110	Fill is sourced from local borrow. Unit rate may increase to $270/$m^3$ if imported fill (assumed 75 mm minus pit run) is needed to supplement fill.
3.04	Gravel Armor Supply and Placement	m^3	81	$ 400	$ 32,400	Assumed to be needed for all excavated areas in the conceptual stage. To be refined in detailed design.
3.05	Soil/Sod Placement	m^2	81	$ 70	$ 5,670	
3.06	Biodegradable Erosion Mat Supply and Placement	m^2	81	$ 20	$ 1,620	
	SUBTOTAL FOR COMPONENT				**$ 44,800**	
4	**Site Restoration**					
4.01	Site Restoration Allowance	Lump Sum	1	2%	$ 2,800	1% of construction cost (items 1-4)
	SUBTOTAL FOR COMPONENT				**$ 2,800**	
	SUBTOTAL CONSTRUCTION (ITEMS 1-4)				**$ 139,000**	**Rounded to nearest $1000**
	Contingency (40% for Class D)			40%	**$ 55,600**	
	Construction engineering and environmental allowance			25%	**$ 34,750**	25% of construction cost (items 1-4)
TOTAL CONSTRUCTION COST (excluding GST)					**$ 230,000**	**Rounded to nearest $1000**

Cost Estimate BC Hydro Site 6A Mitigation Design Project No. 478.240						

Option 2 Class D Cost Estimate

Item	Description	Unit	Estimated Quantity	Unit Rate	TOTAL PRICE ($)	Comment
1	**General Conditions**					
1.01	Mobilization, Demobilization, and Access	Lump Sum	1	$ 60,000	$ 60,000	Assumes access through Kovatch Park and the pedestrian bridge over the Illecillewaet River. Accounts for minor road improvements to the trail for machinery.
1.02	Bonding & Insurance	Lump Sum	1	2%	$ 2,500	2% of construction cost (items 1-4)
1.03	Environmental Protection and Water Management Allowance	Lump Sum	1	10%	$ 12,500	10% of construction cost (items 1-4) Allowance for environmental protection (silt fencing, etc.) and water management
1.04	Survey	Lump Sum	4	$ 3,500	$ 14,000	Includes Layout and Record Surveys. Assumes a local surveyor from Revelstoke Area.
	SUBTOTAL FOR COMPONENT				**$ 89,000**	
2	**Earthworks and Revegetation - B:C-2 Repair and Raise Outlet to Embankment Elevation**					
2.01	Soil/Sod Stripping and Stockpiling	m^2	27	$ 20	$ 540	
2.02	Excavation	m^3	2	$ 130	$ 260	
2.03	Local Borrow, Fill Placement and Compaction	m^3	1	$ 110	$ 110	Fill is sourced from local borrow. Unit rate may increase to $270/m^3 if 75 mm minus pit run fill is needed to supplement fill.
3.02	Soil/Sod Placement	m^2	27	$ 70	$ 1,890	
3.03	Biodegradable Erosion Mat Supply and Placement	m^2	27	$ 20	$ 540	
	SUBTOTAL FOR COMPONENT				**$ 3,340**	
3	**Earthworks and Revegetation - C:D Berm and Channel Plug**					
3.01	Soil/Sod Stripping and Stockpiling	m^2	229	$ 20	$ 4,580	
3.02	Local Borrow, Fill Placement and Compaction	m^3	23	$ 110	$ 2,530	Fill is sourced from local borrow. Unit rate may increase to $270/m^3 if 75 mm minus pit run fill is needed to supplement fill.
3.03	Soil/Sod Placement	m^2	229	$ 70	$ 16,030	
3.04	Biodegradable Erosion Mat Supply and Placement	m^2	229	$ 20	$ 4,580	
	SUBTOTAL FOR COMPONENT				**$ 27,720**	
4	**Site Restoration**					
4.01	Site Restoration Allowance	Lump Sum	1	2%	$ 2,500	1% of construction cost (items 1-4)
	SUBTOTAL FOR COMPONENT				**$ 2,500**	
	SUBTOTAL CONSTRUCTION (ITEMS 1-4)				**$ 123,000**	**Rounded to nearest $1000**
	Contingency (40% for Class D)			40%	**$ 49,200**	
	Construction engineering and environmental allowance			25%	**$ 30,750**	25% of construction cost (items 1-4)
TOTAL CONSTRUCTION COST (excluding GST)					**$ 203,000**	**Rounded to nearest $1000**

Cost Estimate
BC Hydro
Site 6A Mitigation Design
Project No. 478.240

Option 3 Class D Cost Estimate

Item	Description	Unit	Estimated Quantity	Unit Rate	TOTAL PRICE ($)	Comment
1	General Conditions					
1.01	Mobilization, Demobilization, and Access	Lump Sum	1	$ 60,000	$ 60,000	Assumes access through Kovatch Park and the pedestrian bridge over the Illecillewaet River. Accounts for minor road improvements to the trail for machinery.
1.02	Bonding & Insurance	Lump Sum	1	2%	$ 3,000	2% of construction cost (items 1-5)
1.03	Environmental Protection and Water Management Allowance	Lump Sum	1	10%	$ 15,000	10% of construction cost (items 1-5) Allowance for environmental protection (silt fencing, etc.) and water management
1.04	Survey	Lump Sum	4	$ 3,500	$ 14,000	Includes Layout and Record Surveys. Assumes a local surveyor from Revelstoke Area.
	SUBTOTAL FOR COMPONENT				**$ 92,000**	
2	Earthworks and Revegetation - B:C-2 Repair, Regrade, and Widen Outlet Channel					
2.01	Soil/Sod Stripping and Stockpiling	m^2	31	$ 20	$ 620	
2.02	Excavation	m^3	1	$ 130	$ 130	On-site disposal or reuse
2.03	Local Borrow, Fill Placement and Compaction	m^3	2	$ 110	$ 220	Fill is sourced from local borrow. Unit rate may increase to $270/$m^3$ if 75 mm minus pit run fill is needed to supplement fill.
2.04	Gravel Armor Supply and Placement	m^3	31	$ 400	$ 12,400	Assumed to be needed for all excavated areas in the conceptual stage. To be refined in detailed design.
2.05	Soil/Sod Placement	m^2	31	$ 70	$ 2,170	
2.06	Biodegradable Erosion Mat Supply and Placement	m^2	31	$ 20	$ 620	
	SUBTOTAL FOR COMPONENT				**$ 16,160**	
3	Earthworks and Revegetation - D Berm					
3.01	Soil/Sod Stripping and Stockpiling	m^2	97	$ 20	$ 1,940	
3.02	Local Borrow, Fill Placement and Compaction	m^3	9	$ 110	$ 990	Fill is sourced from local borrow. Unit rate may increase to $270/$m^3$ if 75 mm minus pit run fill is needed to supplement fill.
3.03	Soil/Sod Placement	m^2	97	$ 70	$ 6,790	
3.04	Biodegradable Erosion Mat Supply and Placement	m^2	97	$ 20	$ 1,940	
	SUBTOTAL FOR COMPONENT				**$ 11,660**	
4	Earthworks and Revegetation - Diversion Channel					
4.01	Soil/Sod Stripping and Stockpiling	m^2	57	$ 20	$ 1,140	
4.02	Excavation	m^3	6	$ 130	$ 780	On-site disposal or reuse
4.03	Gravel Armor Supply and Placement	m^3	57	$ 400	$ 22,800	Assumed to be needed for all excavated areas in the conceptual stage. To be refined in detailed design.
4.04	Soil/Sod Placement	m^2	57	$ 70	$ 3,990	
4.05	Biodegradable Erosion Mat Supply and Placement	m^2	57	$ 20	$ 1,140	
	SUBTOTAL FOR COMPONENT				**$ 29,850**	
5	Site Restoration					
5.01	Site Restoration Allowance	Lump Sum		2%	$ 3,100	1% of construction cost (items 1-5)
	SUBTOTAL FOR COMPONENT				**$ 3,100**	
	SUBTOTAL CONSTRUCTION (ITEMS 1-5)				**$ 153,000**	**Rounded to nearest $1000**
	Contingency (40% for Class D)			40%	**$ 61,200**	
	Construction engineering and environmental allowance			25%	**$ 38,250**	25% of construction cost (items 1-5)
TOTAL CONSTRUCTION COST (excluding GST)					**$ 253,000**	**Rounded to nearest $1000**

Cost Estimate BC Hydro Site 6A Mitigation Design Project No. 478.240						
Option 4 Class D Cost Estimate						
Item	**Description**	**Unit**	**Estimated Quantity**	**Unit Rate**	**TOTAL PRICE ($)**	**Comment**
1	**General Conditions**					
1.01	Mobilization, Demobilization, and Access	Lump Sum	1	$ 6,000	$ 6,000	Assumes access through Kovatch Park and the pedestrian bridge over the Illecillewaet River. Limited to several labourers with hand tools and materials, no equipment or vehicle access beyond the road.
1.02	Bonding & Insurance	Lump Sum	1	2%	$ 300	2% of construction cost (items 1-3)
1.03	Environmental Protection and Water Management Allowance	Lump Sum	1	20%	$ 3,000	10% of construction cost (items 1-3) Allowance for environmental protection (silt fencing, etc.) and limited water management
1.04	Survey	Lump Sum	0	$ 3,500	$ -	Assumes no survey completed for Option 4
	SUBTOTAL FOR COMPONENT				**$ 9,300**	
2	**Earthworks and Revegetation - C:D Channel Plug**					
2.01	Soil/Sod Stripping and Stockpiling	m^2	30	$ 26	$ 780	
2.02	Local Borrow, Fill Placement and Compaction	m^3	3	$ 150	$ 450	Fill is sourced from local borrow. Unit rate may increase to $270/$m^3$ if 75 mm minus pit run fill is needed to supplement fill.
2.03	Soil/Sod Placement	m^2	30	$ 100	$ 3,000	
2.04	Biodegradable Erosion Mat Supply and Placement	m^2	30	$ 26	$ 780	
	SUBTOTAL FOR COMPONENT				**$ 5,010**	
3	**Site Restoration**					
3.01	Site Restoration Allowance	Lump Sum	1	5%	$ 750	5% of construction cost (items 1-2)
	SUBTOTAL FOR COMPONENT				**$ 750**	
	SUBTOTAL CONSTRUCTION (ITEMS 1-4)				**$ 16,000**	**Rounded to nearest $1000**
	Contingency (40% for Class D)			40%	**$ 6,400**	
	Construction engineering and environmental allowance			25%	**$ 4,000**	25% of construction cost (items 1-3), limited environmental monitoring, limited engineering input (no field review or completion documents)
TOTAL CONSTRUCTION COST (excluding GST)					**$ 27,000**	**Rounded to nearest $1000**