Environmental Overview Assessment:

Peers Emergency Bank Stabilization & Flood Recovery

May 2023 | Final

Submitted to: Ministry of Transportation and Infrastructure

Prepared by McElhanney Ltd

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1. Introduction

The Ministry of Transportation and Infrastructure (MoTI) has retained McElhanney Ltd. (McElhanney) to complete an Environmental Overview Assessment (EOA) in response to emergency bank stabilization repairs along Peers Creek Road bordering the Coquihalla River (the Project). Atmospheric river flood events in November 2021 led to bank failure along a stretch of the river, and wash-out of Peers Creek Road, threating the Highway 5 north bound travel lane and preventing access to private property. In response to these events, MoTI completed temporary repairs to impacted watercourses under a *Water Sustainability Act* Section 91 Order (the “November 2021 Order”), and a DFO Letter to Avoid and Mitigate, File No. 22-HPAC-00212. Riprap armouring was installed along approximately 400 m as a temporary measure; however, the riprap was not sufficient to permanently stabilize the road. Approximately 1050 m^2 of new area will be impacted below the Q2 along the north/south part of the bank. Works are scheduled to occur during the reduced risk timing window in summer/late fall 2023.

These works are occurring in close proximity to the Coquihalla. Hence, this assessment is tailored to identify environmental features along the proposed Project alignment, quantify the effects thereto, and to propose mitigation strategies to achieve neutrality with respect to environmental effects.

1.1.SITE CONTEXT

The Project alignment occurs along the Coquihalla River, east of Highway 5 / Coquihalla Highway, and parallel to Peers Creek Road in Hope, BC (***Figure 1***). The site is located on provincially managed land (***Table 1***). The site is located in the Fraser Valley Regional District Electoral Area B and is zoned as LU – Limited Use area on a Crown Subdivision. The surrounding area consists of rural landscape along a main transportation corridor.

Table 1 includes the property ownership details and latitude and longitude for the Project alignment.

Table 1. Location details of Project alignment.

Civic Address	Ownership Class	Lat / Long	Plan Number	PID
N/A	Untitled Provincial	49.37818º, -121.34930º	No Plan	N/A
N/A	Untitled Provincial	49.392587°, -121.319254°	KAP238A	014-571-129

Extent of the flood damage is depicted in ***Figure 3*** and***Figure*** 4 and ***Photo 1***,Photo 2, and ***Photo*** 3.

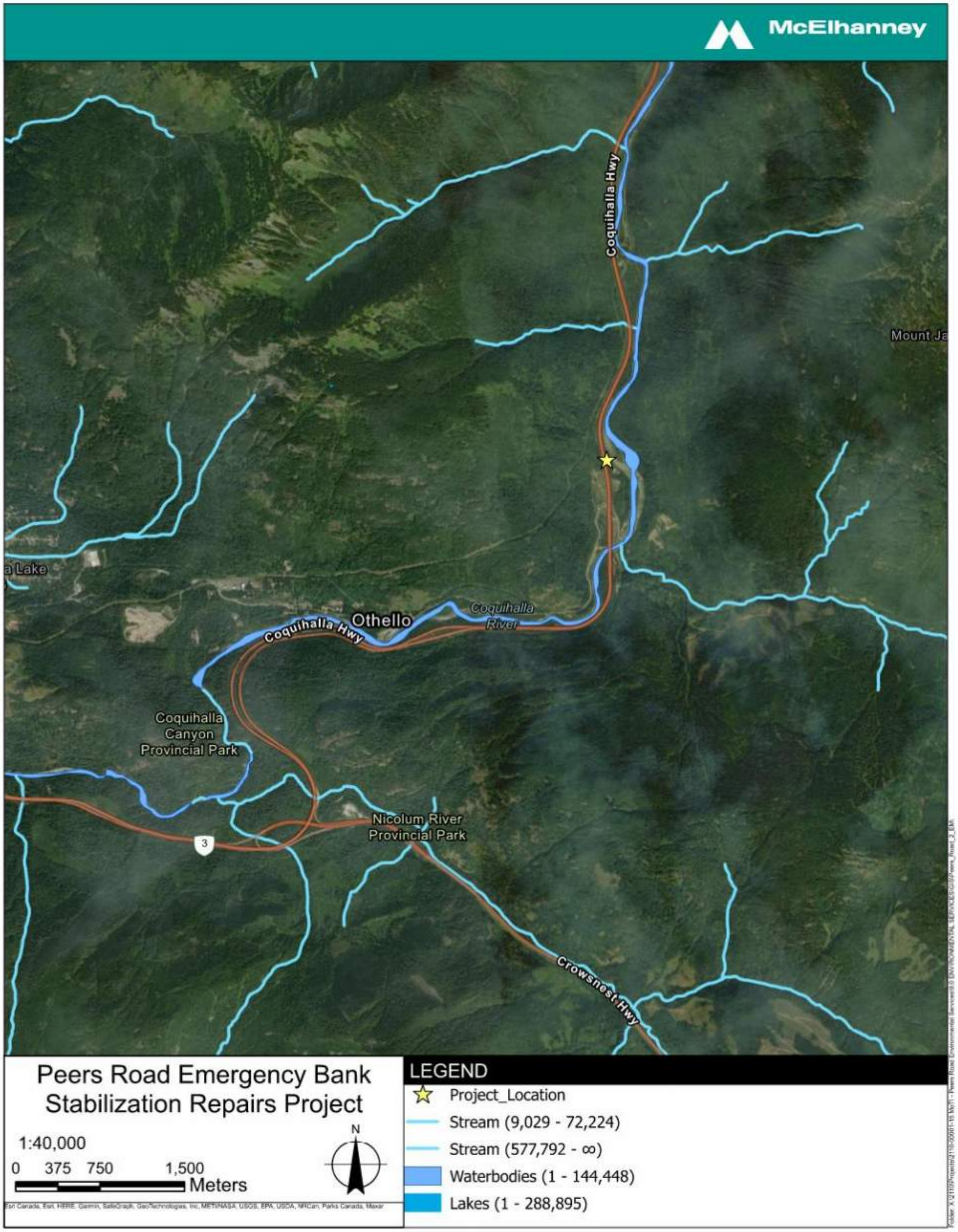

Figure 1. Location of Project alignment in relation to surrounding community.

Figure 2. Aerial photo of the Coquihalla River and site footprint (outlined in red) in March 2020 before flood events.

Figure 3. Orthophoto of the Coquihalla River and site footprint (outlined in red) on November 19, 2021 during flood events.

Figure 4. Orthophoto of the Coquihalla River and site footprint (outlined in red) on April 20, 2022 after flood events.

Photo 1. Looking south towards Peers Creek Road washout along Coquihalla River in November 2021.

Photo 2. Looking north from Peers Creek Road washout along Coquihalla River in November 2021.

Photo 3. Looking north at flooding and washout area along Highway 5 in November 2021.

2. Consultation and Engagement

2.1.FIRST NATIONS

MoTI initiated consultation and engagement for the Project with the following First Nations: Ashcroft Indian Band, Boston Bar First Nation, Coldwater Indian Band, Cook’s Ferry Indian Band, Lower Nicola Indian Band, Nicomen Indian Band, Nlaka’pamux Nation Tribal Council (Boothroyd Indian Band, Lytton First Nation, Oregon Jack Creek Band and Skuppah Indian Band), Nooaitch Indian Band, People of the River Referrals Office (Chawathil First Nation, Seabird Island Band, Shxw’ow’hamel, Soowahlie First Nation, Sto:lo Nation, Sto:lo Tribal Council, Yale First Nation), Peters First Nation, Popkum First Nation, Scw’exmx Tribal Council, Shackan Indian Band, Siska First Nation, Spuzzum First Nation, and Union Bar First Nation.

3. Description of Proposed Works

This section is intended to provide additional details relating to proposed construction schedules, phasing and constructability considerations, and potential methods to construct project scope items. Please note that the construction phasing which is presented is suggested; however, the means and methods of construction will ultimately be decided by the contractor (with input from an Appropriately Qualified Professional or AQP).

Following are key engineering details proposed for this project, which include:

- Permanent repairs to the existing riprap for a total new area of 1050 m^2 below Q2.
- Installation of experimental boulder seeding area along 70 m of the riprap toe.

Detailed Design engineering drawings are provided in ***Appendix A.***

3.1.PHASES AND SCHEDULE

Construction of the project will occur during late summer and fall of 2023 and is expected to be constructed in three phases. Works are proposed to occur within the 2023 South Coast Region reduced risk instream work window of August 1st to September 15th (FLNRORD 2019). Proposed phasing of works is presented below in ***Table 2.*** Summary of Proposed Construction Staging Plan Ultimately, the construction phasing and final plan will be the responsibility of the Construction Contractor and may be influenced by weather, availability of materials, and the advice of their AQPs, including the Environmental Monitor. However, the footprint will remain as outlined in this application and work shall occur within the least risk timing window (August 1 to Sept 15).

Table 2. Summary of Proposed Construction Staging Plan

Proposed Construction Phases	Timing	Scope of Work	Environmental Regulatory Instruments
Phase 1	Offline work outside of Reduced Risk Instream Work Window 2023	Rip rap stockpiling.	DFO Letter of Advice / MoF Approval
Phase 2	Least Risk Instream Work Window 2023	Install 1050 m^2 of 2000 kg rip rap per engineered design. Working out of the water and behind the existing riprap.	
Phase 3	Offline work outside of Reduced Risk Instream Work Window 2023	Roadworks.	

3.2.CONSTRUCTION METHODS

Table 3. Summary of Construction Methods provides details on the anticipated construction activities and methods proposed to occur in the project footprint. All works will be completed in the dry.

Table 3. Summary of Construction Methods

Proposed Construction Phases	Construction Methods	Required Equipment
Phase 1	• Stockpiling riprap for use during Phase 2	• Excavator • Haul truck • Bulldozer • Loader • Truck and step deck trailer • Roller

Proposed Construction Phases	Construction Methods	Required Equipment
Phase 2	• Re-application of existing rip rap that was placed for the temporary solution • Excavation to design grade • Placement of geotextile • Placement of rip rap	• Tracked excavator • Tracked bulldozer • Haul truck • Dump truck • Wheeled loader
Phase 3	• Embankment construction • Regrading of existing embankment • Sub-base and base gravel placement • Roadside drainage works • Paving	• Road grader • Paver • Compactor • Bulldozers • Excavator • Dump truck • Wheeled loader

4. Environmental Overview Assessment Methodology

4.1. ASSESSMENT OBJECTIVES

This Project environmental review was undertaken to establish the existing environmental baseline conditions within the temporal, spatial, and scope boundaries of the Project, and to evaluate potential effects or impacts to baseline conditions. This assessment was limited in scope to reflect the level of design and complexity associated with Detailed Design. This means potential effects, compensation, mitigation measures, and Best Management Practices (BMPs) are identified at an overview-level only.

Spatial assessment areas for this project were characterized as follow:

- **Local Assessment Area (LAA)**: defined as riparian areas around the Coquihalla River. The LAA extended 20 m from the Project footprint.
- **Extended Assessment Area (EAA)**: includes areas within 50 m of the engineering and construction footprint for fish, and up to 100 m of the footprint for wildlife.
- **Regional Assessment Area (RAA)**: includes areas within a 3 km radius of the site for broad-based reviews of biogeographical databases.

Figure 5 illustrates Project assessment boundaries showing the LAA, EAA and RAA.

The primary objective of this application is to meet the requirements outlined in the following resources:

- *Guidance on Submitting a Request for Review* (DFO 2022b).
- *Guidance for Applications or Notifications for Changes in and about a Stream under the Water Sustainability Act in the South Coast Region* (FLNRORD 2019).
- *User's Guide for Changes In and About a Stream in British Columbia* (BC 2022b).
- *Develop with Care 2014: Environmental Guidelines for Urban and Rural Land Development in British Columbia* (MOECCS 2014).

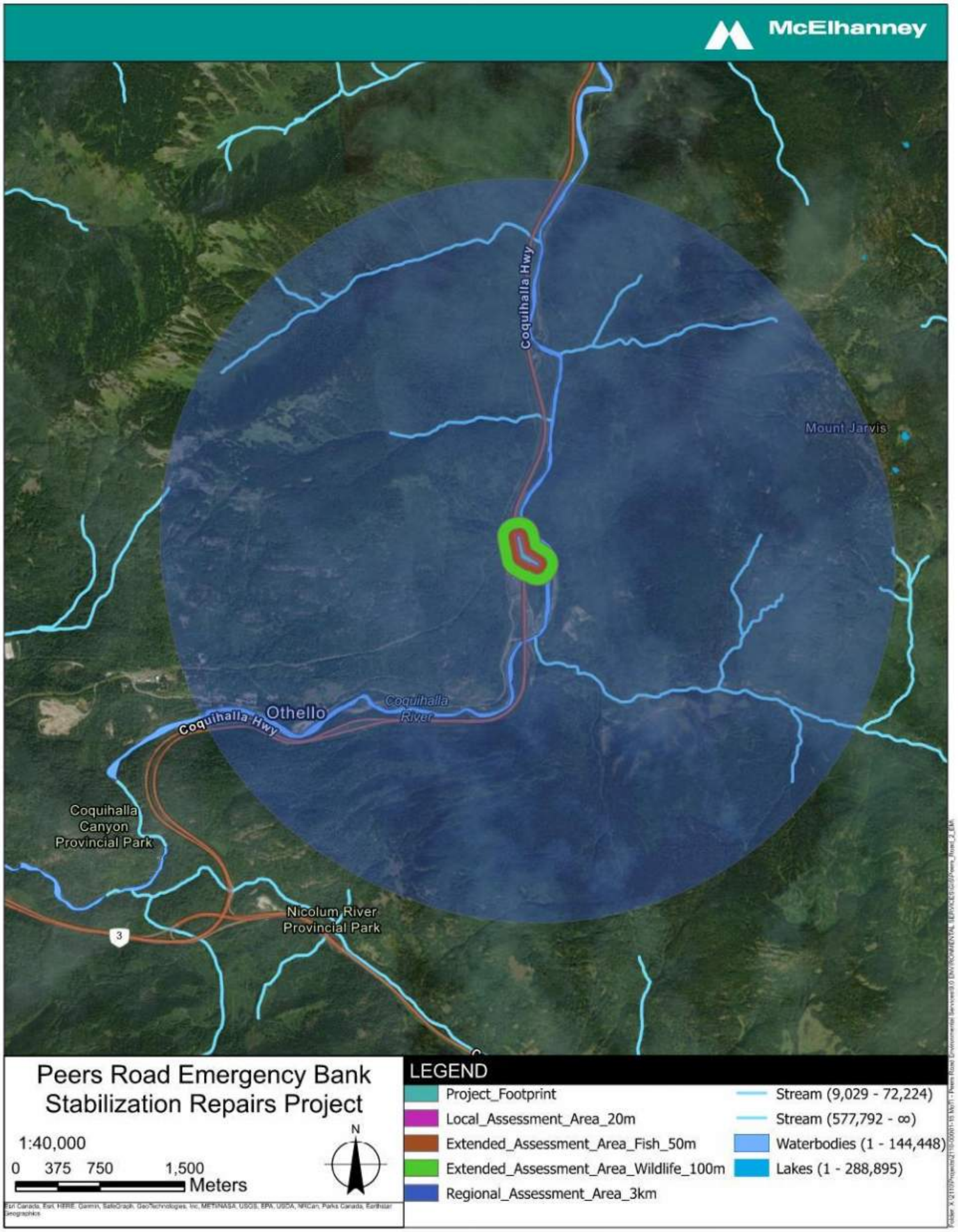

Figure 5. Assessment boundaries showing LAA, EAA and RAA.

4.2.ASSESSMENT METHODS

Data was collected through desktop review of federal, provincial and regional databases to identify any known environmentally sensitive elements in the area. A literature review was conducted, and relevant background information was assessed. A site visit was completed in January and March 2023 to document the habitat conditions and biological features within and adjacent to the proposed Project footprint. This inventory is not exhaustive nor conducted over several seasons.

4.2.1.Desktop Review

Ecological databases reviewed in the assessment of environmentally sensitive features included the following:

- BC Conservation Data Centre (BC CDC 2023a),
- BC Species and Ecosystems Explorer (BC CDC 2023b),
- Federally Listed Species at Risk (iMapBC 2023),
- Aquatic Invasive Species (iMapBC 2023),
- Federal Aquatic Species at Risk Map (DFO 2023),
- Invasive Alien Plant Program (IAPP) (BC 2023),
- British Columbia Breeding Bird Atlas (Davidson et al. 2015),
- British Columbia Ecological Reports Catalogue (MOE 2023),
- BC Great Blue Heron Atlas (CMN 2023a),
- Wildlife Tree Stewardship Atlas (CMN 2023b),
- Sensitive Habitat Inventory and Mapping (SHIM 2023),
- Habitat Wizard (MOECCS 2023a), and
- Fraser Valley Regional District FVRD Web Map (FVRD 2023).

5. Description of the Existing Environment

5.1.LAND USE

Within the Project EAA, land use primarily consists of crown land along the west side of the Coquihalla River, and a main transportation corridor, Highway 5 / Coquihalla Highway to the west. The footprint primarily consists of riprap and sand/gravel/cobbles, comprising the west bank of the Coquihalla River. The southeasternmost portion also includes a section of trees, which is connected to a larger forested area to the south.

A small access road runs along the western boundary of the property as Peers Creek Road. Recreational use of the Coquihalla River includes fishing and white-water rafting and kayaking.

The Westcoast Energy Inc. gas pipeline crosses the Coquihalla River approximately 0.7 km south of the Project EAA and runs north along the west side of Highway 5. The Trans Mountain Pipeline also runs north on the west side of Highway 5 until both pipelines cross the Coquihalla River 1.6 km north of the Project EAA.

5.2.AQUATIC RESOURCES

The following sections summarize the aquatic resources likely to have some interaction with the engineering design. These were identified through desktop review and field reconnaissance.

The Coquihalla River (ID 100-115400) is a 4th order stream that originates in the Cascade Mountains and flows southwest into the Fraser River approximately 8.8 km west of the Project alignment in Hope. The Coquihalla River is approximately 57 km in length, with a total drainage area of approximately 741 km^2, and a maximum elevation of 2,500 m (Taylor 2002). Peak flows generally occur during the fall and winter months, and during freshet in May to June (Ptolemy 1989). The channel is meandering and braided with long rapids and riffles and plenty of deep pools (DFO 1999). It is confined by a narrow canyon and has high velocities with an average gradient of 5% downstream of Othello Falls (DFO 1999).

The Coquihalla River and several of its tributaries are considered Endangered due to impacts from road construction, logging, pipelines and urban development (SHIM 2023; DFO 1999). Lower reaches of the river have been diked, channelized and riprapped, and sediment loading is high. Recommendations for enhancement include the creation of spawning and rearing habitat for steelhead, improved erosion control, and identifying off-channel enhancement opportunities (DFO 1999).

Within the Project alignment, the Coquihalla River morphology is comprised of rapids, run and pool habitat with a mix of boulder, cobble, gravel and sandy substrates (***Photo 4,***Photo 5, ***Photo*** 6Photo 7). It is a wide channel, with wetted width averaging approximately 20 m throughout the Project alignment. Large woody debris was not observed within the footprint, although it does occur downstream. Boulders were abundant as cover sources throughout the site. Vegetation along the roadside shoulder is absent except for approximately 50 m at the south end, which is comprised of coniferous and mixed forest habitat with a sparse shrub understorey.

One unnamed waterbody occurs approximately 45 m north of the site (***Figure 6***). The watercourse originates from headwaters approximately 1.5 km north-northwest of the footprint and crosses through a culvert beneath Highway 5 before discharging into the Coquihalla River. Works are not anticipated to encounter this watercourse. One ephemeral creek was observed during the site assessment in the forested area south of the Project alignment. The creek bed was followed from a culvert beneath Peers Creek Road north of the gravel pit heading east before it split into two streams heading south through the forest. It is unlikely staging areas will interfere with this waterbody (***Photo 4***.

Photo 4. Upstream conditions of the Coquihalla River from within the work zone.

Photo 5. Downstream conditions of the Coquihalla River from within the work zone.

Photo 6. Example of substrate composition within the work zone.

Photo 7. Example of riffle run habitat within the work site.

Photo 8. Unnamed waterbody observed in the forested area south of the Project alignment (west leg).

Photo 9. Unnamed waterbody observed in the forested area south of the Project alignment (east leg).

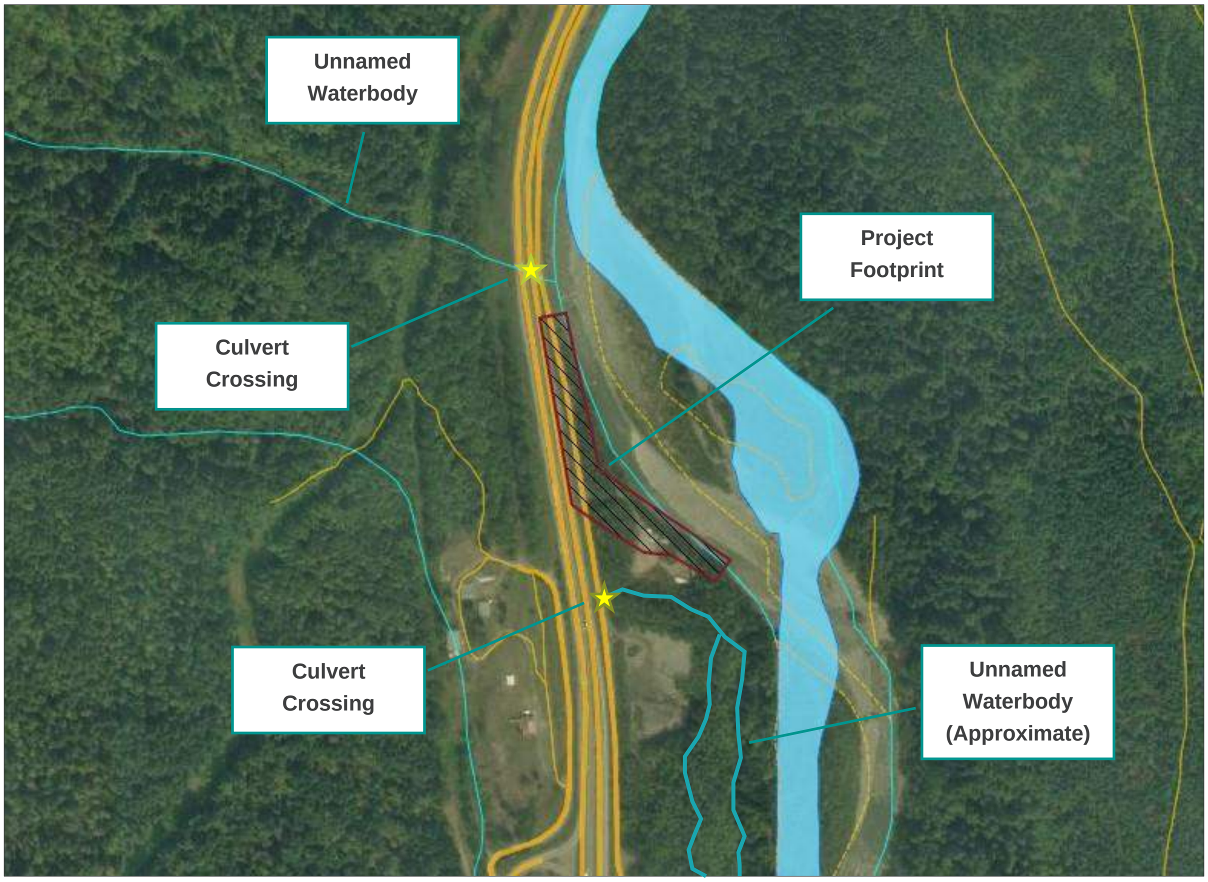

Figure 6. Waterbodies around the Project alignment. Map generated using CDC iMap (CDC 2023a).

5.2.1. Fish and Fish Habitat

The Coquihalla River is a Class A watercourse due to the presence of salmonids. Steelhead (*Oncorhynchus mykiss*) is the primary fishery of the Coquihalla River; coho salmon (*O. kisutch*) and Dolly Varden (*Salvelinus malma*) are also fished to a lesser extent (Taylor 2002). The river supports both summer and winter run stocks of steelhead, with winter runs returning from November to May, and summer runs returning from June to October (Taylor 2002). Steelhead spawning occurs between February and June at km 4.8, and upstream of the Project alignment between 17 and 28 km (DFO 1999). Chum (*O. keta*), coho and pink salmon (*O. gorbuscha*) spawn downstream of Othello Falls, but coho and chum may have been able to swim upstream of the falls during the high-water event in November 2021. Anecdotal evidence of chinook (*O. tshawytscha*) has also been reported above the falls since the flooding (pers. comm. A Morris DFO 2023). Sockeye spawn in the lower reaches of the Coquihalla River.

A list of documented fish occurrence in the Coquihalla River is summarized in ***Table 4***. No fish were observed during the field assessment. Othello Falls does under normal circumstances, act as a partial barrier to fish passage for anadromous species (***Figure 7***). Steelhead, rainbow trout (*O. mykiss*), bull trout (*Salvelinus confluentus*), Dolly Varden and lamprey (*Lampetra* sp.) have been documented upstream of this barrier (MOECSS 2023a). However, during the November 2021 floods it is possible that other species, such as chum or coho salmon, were able to breach this barrier. Preferred habitat requirements for these select species are described in ***Table 5***. Lamprey habitat needs were not described as observations were not defined to the species-level and habitat needs vary between different species.

Table 4. List of fish species with documented occurrence in the Coquihalla River (MOECCS 2023a; Taylor 2002).

Scientific Name	Common Name	BC List
Salvelinus confluentus	Bull Trout	Blue
Oncorhynchus tshawytscha	Chinook Salmon	Not Reviewed
Oncorhynchus keta	Chum Salmon	Not Reviewed
Oncorhynchus clarkii clarkii	Coastal Cutthroat Trout	Blue
Oncorhynchus kisutch	Coho Salmon	Not Reviewed
Oncorhynchus clarkii	Cutthroat Trout	No Status
Salvelinus malma	Dolly Varden	Yellow
Oncorhynchus nerka	Kokanee	Not Reviewed
Lampetra sp.	Lamprey (General)	-
Catostomus macrocheilus	Largescale Sucker	Yellow
Rhinichthys falcatus	Leopard Dace	Yellow
Rhinichthys cataractae	Longnose Dace	Yellow
Catostomus catostomus	Longnose Sucker	Yellow
Prosopium williamsoni	Mountain Whitefish	Yellow
Cyprinidae sp.	Minnows (General)	-
Ptychocheilus oregonensis	Northern Pikeminnow	Yellow
Oncorhynchus gorbuscha	Pink Salmon	Not Reviewed
Oncorhynchus mykiss	Rainbow Trout	Yellow
Cottus sp.	Sculpin	-
Oncorhynchus nerka	Sockeye Salmon	Not Reviewed
Oncorhynchus mykiss	Steelhead	Yellow

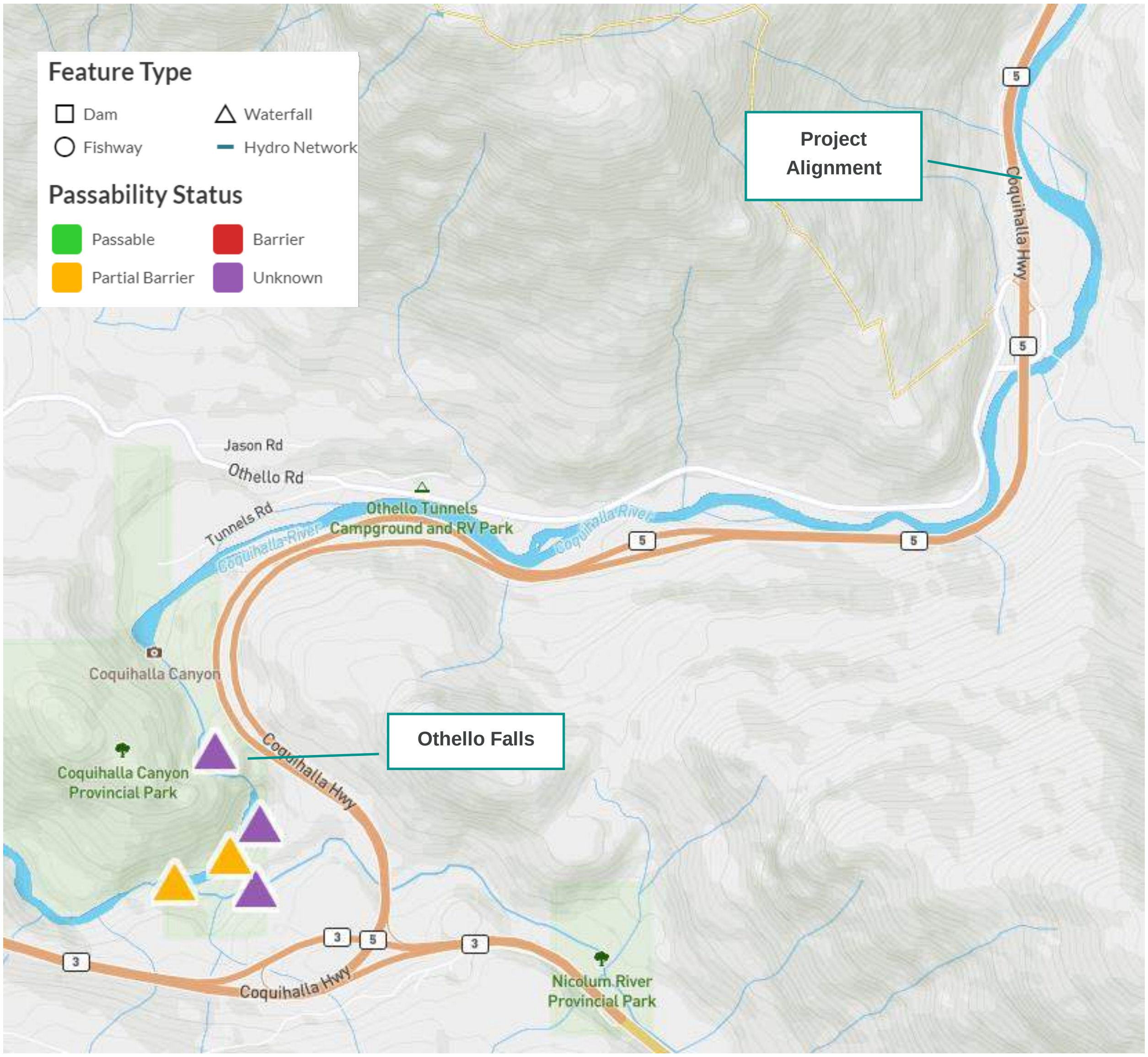

Figure 7. Barriers to fish passage along the Coquihalla River. Map generated from Canadian Aquatic Barriers Database (CWF 2023).

Prior to construction of the Coquihalla Highway in 1979, several reaches of high-quality, moderately productive steelhead habitat were documented and included features such as low sedimentation, larger streambed material and channel roughness providing suitable parr habitat (Ptolemy 1989). Hatchery steelhead stocking occurred sporadically from 1933 to 1972, then annually 1972 onward (Taylor 2002).

Table 5. Habitat requirements for fish species with documented occurrence upstream of the Project alignment.

Common Name	General Habitat Conditions	Spawning Behaviour & Habitat	Juvenile Rearing Habitat	Overwintering Habitat	Habitat Occurrence Potential within the Project Alignment
Bull Trout	Cold (<15°C), clean water in relatively undisturbed sites. They require stable channels, deep pools, abundant cover, and defined connectivity to spawning, rearing and overwintering habitats.	Spawn in shallow, low gradient gravel riffles of small tributary streams with groundwater upwelling or spring inputs in late summer or fall. They do not often spawn in large mainstem reaches of major rivers (Hagen and Decker 2011). Eggs hatch in late winter or early spring, with fry emerging in April or May. Spawning may occur annually or every second year.	Prefer large, unembedded rubble substrate of cobble and boulder with abundant cover such as LWD. Prefer cold, low velocity streams with shallow areas.	Require abundant cover, deep, low-velocity water with ice-free refuges.	Spawning potential: Low Juvenile rearing potential: Low Overwintering potential: Low Migration potential: High
Coastal Cutthroat Trout	Occupy low to intermediate gradient reaches (0-5%) with gravel substrate. Prefer riffles and pools with boulders and LWD for cover.	Spawn in small, cool, clean streams with gravel substrate during mid-winter to spring. Prefer pool tail-outs with 15-45 cm depth. Fry emerge between March and June.	Small low-velocity streams with abundant pools (parr), riffles (fry) and LWD. Prefer gravel-cobble substrates.	Require abundant cover such as log jams and rootwads, overhanging banks, and deep pools.	Spawning potential: Low Juvenile rearing potential: Low Overwintering potential: Low Migration potential: High
Dolly Varden	Occupy freshwater sources with perennial groundwater springs.	Spawn in low gradient (1-3%) streams with gravel substrate and relatively warm water between August and October. Prefer fast currents with well-oxygenated water and overhanging vegetation for food and cover. Can spawn multiple times. Fry emerge between April to June.	Occupy sites dominated by gravel substrates with abundant cover such as aquatic vegetation, LWD and boulders. Rearing habitat is typically close to overwintering habitat.	Overwinter in small streams with deep pools. Often overwinter in the same habitats they spawn in.	Spawning potential: Low Juvenile rearing potential: Low Overwintering potential: Low Migration potential: High
Rainbow Trout	Occupy cold, clear water with a fast current.	Spawn in smaller tributary streams of rivers or lakes. Prefer fine gravel substrates with riffle-pools and vegetated banks. Spawn between March and June.	Prefers cover area of ≥15%. Cover features include undercut banks, instream and bank vegetation, LWD and boulders. Occupy pool-riffle habitats.	Occupy deep pools with abundant cover sources. Fry overwinter in shallow, low-velocity areas along the stream margins. Rubble substrate, LWD, overhanging banks, boulders and riffles are used for cover.	Spawning potential: Low Juvenile rearing potential: Low Overwintering potential: Low Migration potential: High
Steelhead	Occupy cold, clear, low velocity freshwater streams with riffle-run and pool habitats. Prefer abundant bankside vegetation and instream cover.	Spawn in freshwater streams with gravel substrate in the spring. Typically spawns at the tail-out of a pool. May spawn multiple times throughout life. Fry emerge in the summer.	Occupy areas with abundant cover, pool, run and riffle habitats.	Prefer deep pools, side channels, undercut banks, LWD and boulder clusters.	Spawning potential: Low Juvenile rearing potential: Low Overwintering potential: Low Migration potential: High

Common Name	General Habitat Conditions	Spawning Behaviour & Habitat	Juvenile Rearing Habitat	Overwintering Habitat	Habitat Occurrence Potential within the Project Alignment
Coho Salmon	Occupy low velocity areas including side channels, deep pools, areas with LWD and other instream cover sources.	Spawn in slow flowing tributary streams and areas of the main river with pea-sized gravel substrate.	Occupy small tributary streams with slower flows than the mainstem river. Prefer abundant cover such as woody debris and areas shaded by riparian vegetation. May also use lakes for rearing when present in watercourse.	Adults spawn and die between the fall and early winter. Juveniles overwinter in areas away from main river channel including beaver ponds, side channels with low flow velocity, and large woody debris.	Spawning potential: Low Juvenile rearing potential: Low Overwintering potential: Low Migration potential: Low
Chum Salmon	Occupy moderate velocity flows of larger rivers and tributaries due to their ability to swim well against faster current.	Spawn in the main stem areas of streams and rivers with small gravel and abundantly oxygenated water.	Rear briefly in side channels and areas of the main stream with low velocity flows before migrating out to the estuary.	Adults spawn and die between the fall and early winter. Juveniles migrate to the estuary soon after hatching. As such, overwintering in freshwater would not be present.	Spawning potential: Low Juvenile rearing potential: Low Overwintering potential: N/A Migration potential: Low

Conditions of the river throughout the Project alignment and immediately surrounding area primarily support migration of bull trout, Dolly Varden, coastal cutthroat trout, rainbow trout and steelhead. Habitat suitability is depicted in ***Figure 8***. Spawning potential throughout the site is considered low, but there is suitable spawning habitat in the side channel east of the footprint (***Photo 10***).

Overall juvenile rearing and overwintering potential is limited due to high velocities, lack of holding pools and minimal instream and overhanging riparian cover. One location within the Project alignment contained suitable rearing habitat (***Photo 11***). Food sources, such as mayfly nymphs, were observed beneath small boulders in this area (***Photo 12***). The side channel east of the footprint contains suitable rearing habitat. Southeast of the Project alignment velocities slow and allow for some refuge area with LWD presence, which may be suitable for rearing and overwintering (***Photo 13***).

Figure 8. Fish habitat potential within and adjacent to the Project alignment.

Photo 10. Example of potential spawning and rearing habitat in a side channel east of the Project footprint (red arrow).

Photo 11. Rearing potential within the Project alignment.

Photo 12. Mayfly nymph observed beneath stone in suitable rearing habitat within the Project alignment.

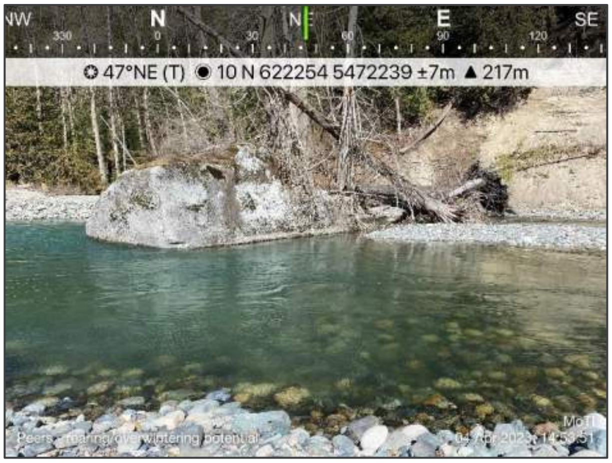

Photo 13. Area surrounding this rock outcrop southeast of the Project alignment may be suitable for rearing and overwintering.

5.2.1. Aquatic Species at Risk

A review of DFO's aquatic species at risk map shows that there are no at-risk species within 1 km of the Project alignment. Database searches resulted in no documented occurrences of at-risk species within a 3 km radius of the Project alignment.

Bull trout and coastal cutthroat trout (*Oncorhynchus clarkii clarkii*) are two Blue-listed species with documented occurrence in the Coquihalla River upstream of the Project footprint. A description of their habitat requirements is provided in ***Table 5***. Spawning, rearing and overwintering potential is limited for both these species within the Project alignment; however, migration through the site is likely.

5.2.2. Hydrology / Water Resources

In summary, BGC estimated a peak flood discharge of 850 m3/s for the November 14-15, 2021 flood event at Peers Creek Frontage Road washout site, which corresponds to a discharge of 1,100 m3/s at gauge 08MF068 (approximately a 90-year flood event). The Coquihalla River has been laterally active within the project area since 1968. Upstream of the Othello Interchange, the right (south) bank migrated 50-100 m between 1968 and 2015, and the November 2021 flood events caused additional erosion leading to a severe washout and avulsion along Peers Creek Frontage Road and Highway 5. Across the river from the Othello Interchange, the river migrated to the east by approximately 85 m between 1968 and 2015, abutting against the toe of the east valley slope, and then destabilized during the November 2021 flood events.

The selected design discharge of 1,813 m3/s at the Peers Creek Frontage Road washout site or

2,345 m3/s at gauge 08MF068 (i.e., the 200-year climate change-adjusted flow) is predicted to cause up to 160 m of erosion on average within the erosion assessment area based on the historical assessment. However, the potential effects of climate change on geomorphologic processes are complex as changes in hydrology may impact the long-term width of the Coquihalla River as well as the frequency and magnitude of erosion events. At the Peers Creek Frontage Road site a change in the channel configuration in the future (with more flow occupying the side channel) could also limit erosion and land sliding, reducing erosion in the future.

The hydrotechnical report provided by BGC (2023) is available in ***Appendix B***.

5.3. TERRESTRIAL RESOURCES

5.3.1. Ecosystem and Climate

Canadian Ecological Land Classification hierarchy queries indicate the project alignment occurs within the:

- Humid Temperate Ecodomain
  - Cool Hypermaritimes and Highlands Ecodivision
    - Coast and Mountains Ecoprovince
      - Pacific Ranges Ecoregion
        - **Eastern Pacific Ranges Ecosection**

The Project alignment occurs within the Southern Dry Submaritime Coastal Western Hemlock Variant (CWHds1) biogeoclimatic zone. The CWHds1 zone occurs at lower elevations in drainages of the Upper Fraser River and in the eastern portion of the Coast Mountains. Climate is characterized by warm, dry summers and moist, cool winters with moderate snowfall (Green and Klinka 1994). Water deficits occur during growing seasons on zonal sites (Green and Klinka 1994).

Vegetation is dominated by coniferous species such as Douglas fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), and, to a lesser extent, western redcedar (*Thuja plicata*). The understory consists of a poorly developed shrub and herb layer which includes falsebox (*Paxistima myrsinites*) with occurrences of prince’s pine (*Chimaphila umbellate*), dull Oregon-grape (*Mahonia nervosa*), and queen’s cup (*Clintonia uniflora*). The moss layer is well-developed and consists of step moss (*Hylocomium splendens)*, pipecleaner moss (*Rhytidiopsis robusta*), red-stemmed feathermoss (*Pleurozium schreberi*), and with fewer occurrences of big shaggy-moss (*Rhytidiadelphus triquetrus*) and lanky moss (*Rhytidiadelphus loreus*).

5.3.2. Ecological Communities at Risk

A search for publicly available occurrences of ecological communities at risk mapped within RAA resulted in identification of one at-risk community for the Western Hemlock – Douglas-fi / Electrified Cat's-tail Moss Dry Submaritime 1 within 3 km.

5.3.3. Vegetation

Riparian vegetation within the Project alignment is absent except for a 50 m stretch at the south end of the footprint, which consisted of sparse instances of grand fir (*Abies grandis*), paper birch (*Betula papyrifera*), vine maple (*Acer circinatum*), and red elderberry (*Sambucus racemosa*) (***Photo 14***). The roadside shoulder north of the Project alignment is sparsely vegetated with Douglas fir and black cottonwood (*Populus balsamifera*) saplings (***Photo 15***). The forested area south of the Project alignment consists of mature coniferous and mixed forest habitat. Observed species included Douglas fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), red alder (*Alnus rubra*), paper birch, grand fir, bigleaf maple (*Acer macrophyllum*), vine maple, dull Oregon grape (*Mahonia nervosa*), swordfern (*Polystichum munitum*) and bracken fern (*Pteridium aquilinum*). The site was assessed in March after snowfall, and then again in April while plants were emerging; consequently, this is not an exhaustive list of potential species.

Photo 14. Vegetation composition at the southernmost extent of the Project alignment.

Photo 15. Vegetation composition at the northernmost extent of the Project alignment.

5.3.3.1. Invasive Species

The provincial IAPP database did not document any invasive species within the LAA. The closest occurrences are approximately 110 m south of the Project footprint and consisted of bull thistle (*Cirsium vulgare*), common tansy (*Tanacetum vulgare*), giant hogsweed (*Heracleum mantegazzianum*), orange hawkweed (*Hieracium aurantiacum*), scotch broom (*Cytisus scoparius*), and yellow hawkweed (*Hieracium pratense*) and a patch of Japanese knotweed (*Reynoutria japonica*) occurring approximately 117 m north-west of the northern portion of the Project (BC 2023).

A single small (<5 m^2) patch of noxious Japanese knotweed was observed approximately 15 m south of the southernmost portion of the Project alignment along the riverbank (***Photo 16***). Japanese knotweed is a provincially noxious weed under the *BC Weed Control Act* (1996) and can be costly to treat or remove. MoTI guidelines for knotweed management indicate that a 20 m buffer around the infestation should be demarcated to avoid disturbing the knotweed (MoTI 2016). If soil disturbance is required within the 20 m buffer, a Ministry Representative should be contacted ahead of works.


Photo 16. Japanese knotweed patch observed near the south end of the Project alignment.

5.4. WILDLIFE AND WILDLIFE HABITAT

5.4.1. General Wildlife

Search results for Incidental and Documented Wildlife Occurrence data within 1 km of the Project alignment were generated using the provincial Habitat Wizard database and are listed in ***Table 6***.

Table 6. Wildlife with documented or incidental occurrence data within 1 km of the Project alignment (MOECCS 2023a).

English Name	Scientific Name	Type	BC List*	Description of Occurrence
Mule Deer	*Odocoileus hemionus*	Mammal	Yellow	Survey observation data
Coastal Tailed Frog	*Ascaphus truei*	Amphibian	Yellow	Survey observation data
Typical owl**	*Strigidae* family	Avian	--	Incidental observation

*Yellow-listed Species: considered secure in the region and are not at risk of extinction.
**Typical owl, or true owl, is one of the two main families of owls. As it includes numerous species of owl, a status is not assigned.

The Project alignment occurs in amidst an extensive green corridor paralleling the Coquihalla River immediately east of Highway 5, making the general area suitable to a diverse array of wildlife species. Mammals anticipated in the area include squirrels, raccoon (*Procyon lotor*), deer, and bats. American black bear (*Ursus canadensis*) and cougar (*Puma concolor*) may pass through the area. Several Ungulate Winter Range (UWR) areas for mule deer (*Odocoileus hemionus*) and one UWR for mountain goat (*Oreamnos americanus*) occur within 3 km of the Project alignment, but not within the work footprint (***Appendix C***). UWR includes areas with habitat sufficient to support the winter requirements of an ungulate species. UWR u-2-001 is a no timber harvest zone in habitat that supports mountain goat. UWR u-2-006 is a conditional harvest zone in habitat that supports mule deer.

Habitat to support wildlife is sparse within the Project alignment, and mostly occurs at the southern extent adjacent to riparian habitat. Suitable habitat for wildlife does occur in the EAA in the green areas immediately surrounding the site, particularly the densely forested area to the south. Coarse woody debris (CWD) and freshwater inputs found throughout this area provide suitable habitat to support amphibians, such as salamanders and frogs. Reptiles, such as snakes and lizards also have the potential to occur in the EAA. Exposed slopes may provide basking opportunity for reptiles. No hibernacula were observed during the site assessment.

The terrestrial habitat south of the footprint provides suitable features to support woodpeckers, passerines (perching birds) and raptors, including owls and hawks. No raptor nests were observed within the footprint or immediately surrounding area. Several dead standing wildlife trees with peeling bark and nest cavities were observed throughout the site, which may provide habitat for a variety of bird and bat species. Species observed during site assessments included pileated woodpecker (*Dryocopus pileatus*), black-capped chickadee (*Poecile atricapillus*) and Canada goose (*Branta canadensis*). The Canada goose pair was actively nesting on a boulder outcrop in the river approximately 135 m southeast of the Project footprint on 4 April 2023 (***Photo 17***). A pair of black-capped chickadees was also observed potentially nesting; they were seen investigating and entering a wildlife tree cavity approximately 180 m south of the footprint (***Photo 18***).

No eBird hotspots occur within the RAA; however, two hotspot locations occur within a 5 km radius of the site, with nearly 100 species being recorded between the two nearest hotspots at Coquihalla Canyon Falls and Nicolum Creek Provincial Park (eBird 2023). Non-at risk, yet noteworthy species include pileated woodpecker, osprey (*Pandion haliaetus*), and bald eagle (*Haliaeetus leucocephalus*). The nests of all three species are protected year-round under the MBCA (for pileated woodpecker) and BC *Wildlife Act* (osprey and bald eagle). No nests for these species were observed during the site assessment or through desktop review within 3 km (CMN 2023b); however, if discovered during the course of works, management plans to mitigate potential impacts to the nests of these three species must be implemented.

Photo 17. Canada goose incubating nest on a boulder outcrop in the Coquihalla River southeast of the Project alignment documented during the April assessment.

Photo 18. Black-capped chickadee nest cavity documented during the April assessment.

5.4.2. Wildlife Species at Risk

The potential for species at risk occurrences within the Project footprint was largely determined based on existing habitat suitability and capability. Provincial database information is presented in ***Appendix D*** for the general area.

5.4.2.1. Provincial Occurrence Non-Sensitive and Masked Database

The proximity search of Conservation Data Center (CDC) and Habitat Wizard non-sensitive and masked database occurrences resulted in the identification of one documented occurrence of an at-risk species within 3 km of the Project alignment. The data is masked and identified as Object ID: 57354 (as of March 17, 2023). Discussions with the CDC indicate that Project works are unlikely to impact this species; therefore, the species identity has not been disclosed.

5.4.2.2. Critical Habitat Database and Wildlife Habitat Areas

No results were identified within a search radius of 3 km from the Project footprint for federally designated species at risk with critical habitat. However, two results for Wildlife Habitat Areas (WHA) are documented, including:

1. WHA no. 2-498: Coquihalla/Sowaqua Long Term Owl Habitat Areas (LTOHA) A for northern spotted owl (*Strix occidentalis*).
2. WHA (Proposed) no. 2-694: Peers Creek for northern goshawk (*Accipiter gentilis laingi*).

WHAs are areas of critical habitat where activities are managed to minimize impacts to an Identified Wildlife element.

The Project alignment occurs within WHA no. 2-498. Activities within LTOHA are only permitted if they enhance or create quality spotted owl habitat. As such, timber harvesting and road construction are not permissible. Spotted owl is red-listed provincially and is a Schedule 1 – Endangered species federally. They use mature and old growth coniferous and mixed-coniferous forests. Important habitat features include a multi-layered, densely closed canopy, trees with broken tops, cavities and deformed limbs, large snags, and abundant coarse woody debris (Chutter et al. 2004). They nest in tree cavities (>50 cm diameter), on broken treetops, mistletoe brooms, abandoned raptor nests, or clusters of branches. Nest sites may be re-used over multiple years. Roosting occurs in cool, shady areas. The forested area south of the Project alignment contains suitable habitat for spotted owl.

WHA no. 2-694 occurs approximately 1.1 km east of the Project alignment. It is a newly (January 2023) proposed WHA identified as core habitat for northern goshawk, the *laingi* subspecies, which is red-listed provincially and is listed as Schedule 1 - Threatened federally. Northern goshawks occupy old-growth and mature second growth coniferous forests in low- to mid-elevation stands. They prefer relatively closed canopies (≥50%) and large diameter trees (~1 m), snags and deformed limbs to support their large stick nests (NGRT 2008). They typically build their nests >200 m from hard edges in stands >100 ha (NGRT 2008). Goshawks typically forage in areas away from their nest sites in open understoreys in riparian areas, estuaries, and forest edges (NGRT 2008). Proximity to the highway (i.e., a “hard edge”) may deter goshawks from nesting in the forested area south of the Project footprint; however, the site offers potential foraging habitat, which is a critical component of the species’ home range (NGRT 2008).

Efforts to protect these important habitat features on site for both species should be implemented throughout the duration of the Project, particularly within the WHA.

5.4.2.3. Potential Occurrence for At-risk Species

A complete list of provincially listed species at risk (MOECCS 2022) for the CWHds biogeoclimatic subzone and their probability of occurrence within the footprint is presented in ***Appendix D***. Species were selected based on their potential use of forest habitat (coniferous, deciduous and mixed), riparian areas, and stream/river habitat. Probability of occurrence within the footprint was ranked based on the following criteria:

- **High Probability:** species record within the study area and suitable habitat present within the footprint.
- **Moderate-High:** no species record within the study area, but suitable habitat present within the footprint.
- **Moderate-Low:** species record within the study area, but suitable habitat not present within the footprint.
- **Low:** no species record within the study area and no suitable habitat present within the footprint.

Species with a High or Moderate-High likelihood of occurrence within the EAA are summarized in ***Table 7***, and are discussed further below. Mitigation measures to avoid impacts to these species, and others described below are outlined in ***Section 7.2***.

Table 7. Select at-risk species with potential to occur within the EAA based on habitat requirements and results generated for site conditions within the CWHds biogeoclimatic subzone (CDC 2023b).

Scientific Name	English Name	Type	BC List	SARA	Probability
Accipiter gentilis laingi	Northern Goshawk, *laingi* subspecies	Bird	Red	1-T	High
Contopus cooperi	Olive-sided Flycatcher	Bird	Yellow	1-T	Moderate-High
Aplodontia rufa	Mountain Beaver	Mammal	Yellow	1-SC	Moderate-High
Patagioenas fasciata	Band-tailed Pigeon	Bird	Blue	1-SC	Moderate-High
Hirundo rustica	Barn Swallow	Bird	Yellow	1-T	Moderate-High
Chordeiles minor	Common Nighthawk	Bird	Blue	1-T	Moderate-High
Coccothraustes vespertinus	Evening Grosbeak	Bird	Yellow	1-SC	Moderate-High
Ardea herodias fannini	Great Blue Heron, *fannini* subspecies	Bird	Blue	1-SC	Moderate-High
Falco rusticolus	Gyrfalcon	Bird	Blue	-	Moderate-High
Lasiurus cinereus	Hoary Bat	Mammal	Blue	-	Moderate-High
Charadrius vociferus	Killdeer	Bird	Blue	-	Moderate-High
Myotis lucifugus	Little Brown Myotis	Mammal	Blue	1-E	Moderate-High
Mustela frenata altifrontalis	Long-tailed weasel, *altifrontalis* subspecies	Mammal	Red	-	Moderate-High
Rana aurora	Northern Red-legged Frog	Amphibian	Blue	1-SC	Moderate-High
Sorex rohweri	Olympic Shrew	Mammal	Red	-	Moderate-High
Allogona townsendiana	Oregon Forestsnail	Invertebrate	Red	1-E	Moderate-High
Pinicola enucleator carlottae	Pine Grosbeak, *carlottae* subspecies	Bird	Blue	-	Moderate-High
Lepus americanus washingtonii	Snowshoe Hare, *washingtonii* subspecies	Mammal	Red	-	Moderate-High
Strix occidentalis	Spotted Owl	Bird	Red	1-E	Moderate-High
Corynorhinus townsendii	Townsend's Big-eared Bat	Mammal	Blue	-	Moderate-High
Sorex trowbridgii	Trowbridge's Shrew	Mammal	Blue	-	Moderate-High

Scientific Name	English Name	Type	BC List	SARA	Probability
Megascops kennicottii kennicottii	Western Screech-Owl, *kennicottii* subspecies	Bird	Blue	1-T	Moderate-High
Carychium occidentale	Western Thorn	Invertebrate	Blue	-	Moderate-High
Falco peregrinus anatum	Peregrine Falcon, *anatum* subspecies	Bird	Red	1-SC	Moderate-High (foraging)
Falco peregrinus pealei	Peregrine Falcon, *pealei* subspecies	Bird	Blue	1-SC	Moderate-High (foraging)
Anaxyrus boreas	Western Toad	Amphibian	Yellow	1-SC	Moderate-High (post-breeding)
Tanypteryx hageni	Black Petaltail	Invertebrate	Blue	-	Moderate-Low
Ascaphus truei	Coastal Tailed Frog	Amphibian	Yellow	1-SC	Moderate-Low
Butorides virescens	Green Heron	Bird	Blue	-	Moderate-Low

Only the northern goshawk has a High probability of occurrence within the EAA based on incidental occurrence data and suitable habitat presence. No raptors nests were observed within the EAA during site assessments, but it does not preclude them from occurring at any time during Project works. Goshawk presence is more likely to occur in the forested area south of the footprint.

6. Assessment of Impacts on Ecological Values

The Project activities and phases will interact with biophysical components in the receiving environment on a multitude of levels. ***Table 8*** summarizes the progressive phases of the Project and lists project activities that are anticipated to interact with biological systems, physical systems, and atmospheric conditions. This summary table lays the foundation of understanding as to how certain activities can interact with a variety of systems, so that appropriate mitigation measures can be selected. Throughout this Section, a more detailed account of recommended mitigations measures is presented.

Table 8. Potential environmental effects of Project activities including preparation, construction, operation and maintenance phases.

PROJECT PHASES / COMPONENTS	Biological Systems					Physical		Atmospheric	
	Aquatic Species/ Watercourses	Vegetation/ Ecosystems	Wildlife / Wildlife Habitat	Species at Risk	Invasive Species	Surface Water Quality	Surface Water Quantity	Air Quality (dust)	Acoustic Environment (noise)
Temporary Access	x	x	x	x	x	x	x	x	
Staging Areas		x	x		x	x		x	
Excavation	x		x	x	x	x		x	x
Grading	x		x	x		x		x	x
Cuts and Fills	x		x	x	x	x		x	x

PROJECT PHASES / COMPONENTS	Biological Systems					Physical		Atmospheric	
	Aquatic Species/ Watercourses	Vegetation/ Ecosystems	Wildlife / Wildlife Habitat	Species at Risk	Invasive Species	Surface Water Quality	Surface Water Quantity	Air Quality (dust)	Acoustic Environment (noise)
Armouring	x	x	x	x	x	x			x
Boulder Seeding	x	x	x	x	x	x	x		

6.1.CONSTRUCTION IMPACTS TO AQUATIC SYSTEMS

Based on the information review and field assessments, we examined valued components within the Project footprint that could be affected through project design and construction. Environmental effects are any changes that the design, construction, and operation of the Project may have on the existing environmental condition. We categorized environmental effects potentially resulting from the Project as:

- Permanent changes where the Project footprint increases compared to the baseline condition.
- Temporary changes or effects during site preparation and construction.

Aquatic effects were classified when below the modelled Q2 based on flooding impacts (BGC 2023). Riparian impacts are considered for vegetation up to 30 m above the high-water mark. Details of potential impacts are discussed below.

6.1.1.Temporary Impacts to Aquatic and Riparian Habitats

Temporary impacts are defined as areas within riparian or aquatic habitats which require some degree of modification to facilitate construction. Types of temporary impacts that have been accounted for are construction / impact zones for access roads or receiving areas.

GIS mapping of these predicted temporary impacts are graphically outlined in ***Appendix A***. The GIS calculations indicate the following temporary disturbance and reinstatement areas is anticipated to be:

- Aquatic Habitat: 1050 m^2
- Riparian Habitat: 0 m^2

6.1.2.Impacts to Fish and Fish Habitat

Key activities impacting fish habitat are the armouring on the river side of the north/south part of the bank.

Impacts to fish and fish habitat through Project-related activities may include:

- ***Changes to water quality*** – may result from construction which may lead to the introduction of deleterious substances or a change contaminant concentration that can cause bioaccumulation or biomagnification. Such impacts can alter fish growth, reproductive success, competitive abilities, and may result in increased predation and potential mortality.

- ***Loss or alteration of habitat*** – will occur through changes from the installation of riprap along the north/south section of the river banks. Construction may result in alterations to cover, changes in bank stability (improved), and increased risk of erosion and sedimentation.
- ***Direct impacts to species physiology and/or behaviour*** – includes an individual / species response to potential disturbance stimuli such as undetected metabolic changes, vocalizations, and dispersion away from the source of disturbance. Elevated noise levels (e.g., from machinery and people within close proximity), olfactory stimuli, visual stimuli and subsurface vibrations (e.g., from compacting) constitute various types of disturbance stimuli.
- ***Direct mortality*** – may cause harm or death to fish, eggs or ova from physical disruption from construction equipment. No inwater works will be conducted, resulting in a Nil probability of this occurrence.

Impacts to habitat have been characterized, mitigated and proposed offset (the boulder seeding may be used at this location or part of a lager balance for the Hwy 5 corridor) accordingly to achieve a net balance to fish habitat. Proposed works have been carefully designed to minimize overall impacts to fish and fish habitat, and efforts to avoid and minimize impacts were assessed (refer to BGC design) in ***Appendix B.*** Where these impacts were unavoidable, mitigative measures have been proposed to neutralize losses. Additionally, temporary impacts to fish habitats are planned to be fully remediated following Project works.

6.1.2.1. Fish Species at Risk and Sensitive Fish Species

Bull trout and coastal cutthroat trout are two provincially Blue-listed species with documented occurrences in the Coquihalla River. Steelhead, rainbow trout, and Dolly Varden are commercially viable species with documented occurrences upstream of the Project alignment.

The reduced risk window for bull trout and Dolly Varden is June 15 to August 31, for rainbow trout, steelhead and cutthroat trout is August 1 to October 31. Works conducted outside of these windows may result in impacts to these species during sensitive periods such as spawning, rearing and overwintering, despite habitat to support these periods being limited within the footprint. No in water works are planned at this site. ***Table 9*** highlights key life history phases for select fish species.

Table 9. Fish life history periodicity for species with potential to occur within the EAA.

Species	Life Stage	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Bull Trout	Spawning								■	■	■		
	Fry Rearing				■	■	■	■	■	■	■		
	Juvenile Migration			■	■	■	■	■	■				
	Adult Migration								■	■			
Coastal Cutthroat Trout	Spawning		■	■	■	■							
	Fry Rearing			■	■	■	■						
	Juvenile Migration					■	■	■					
	Adult Migration										■	■	■
Dolly Varden	Spawning								■	■	■		
	Fry Rearing				■	■	■	■					
	Juvenile Migration				■	■							
	Adult Migration								■	■			
Rainbow Trout	Spawning			■	■	■	■						
	Fry Rearing					■	■	■	■				
	Juvenile Migration												
	Adult Migration				■	■	■						
Steelhead	Spawning		■	■	■	■	■	■					
	Fry Rearing					■	■	■	■				
	Juvenile Migration					■	■	■					
	Adult Migration	■	■	■	■	■	■	■	■	■	■	■	■
Coho Salmon	Spawning									■	■	■	■
	Fry Rearing		■	■	■	■							
	Juvenile Migration			■	■	■			■	■	■	■	
	Adult Migration								■	■	■	■	
Chum Salmon	Spawning									■	■	■	■
	Fry Rearing		■	■	■								
	Juvenile Migration			■	■	■	■						
	Adult Migration								■	■	■	■	

6.1.3. Impacts to Hydrology and Water Resources

Hydraulic modeling results indicate that both Highway 5 and Peers Creek Frontage Road will become inundated during the design flood event (the climate change-adjusted 200-year peak flow, 1,815 m3/s). Due to high flow velocities modelled within the main channel of the Coquihalla River, and the extent of overbank flooding observed, various hydrotechnical design components are recommended including a riprap revetment along the right riverbank, a deflection berm to reduce potential inundation of Highway 5 and Peers Creek Frontage Road, and additional armouring in select overbank areas to reduce the potential for erosion of road and highway fill. Riprap of minimum sizes ranging from 10 kg to 2000 kg Class are recommended throughout the project area (BGC 2023).

6.2. CONSTRUCTION IMPACTS TO TERRESTRIAL RESOURCES

Construction activities may result in soil compaction or erosion, which may also affect the quality of vegetation or ecosystems. Soil compaction can limit the ability for native species to grow, and erosion can result in the loss of fertile soils for vegetation to germinate. Equipment moving within the construction area has potential to spread invasive plants or their seeds to new areas, including native ecosystems located adjacent to the LAA, resulting in potential reductions to ecosystem quality.

6.3. CONSTRUCTION IMPACTS TO WILDLIFE AND WILDLIFE HABITATS

The LAA consists of limited habitat to support wildlife, but the forested area south of the footprint within the EAA consists of high-quality wildlife habitat. Impacts to wildlife and wildlife habitat through Project-related activities may include:

- **Changes in habitat** – any changes to the area that do not necessarily render the habitat unusable or unsuitable but may decrease the quality of the habitat or result in a permanent or temporary change in use.
- **Changes to the quality of habitat** – may occur in areas within and adjacent to the footprint and may include habitat fragmentation, and increased susceptibility to invasive species distribution and abundance.
- **Habitat loss** – may result from the construction of access points and staging areas. This can be avoided by strategically placing access points and staging areas in areas where vegetation clearing is not required.
- **Changes in wildlife habitat use** – noise and vibration resulting from construction activities may cause habitat avoidance or movement deflections during seasons where movements are important to certain wildlife species. Wildlife may disperse temporarily or permanently from areas of disturbance.
- **Direct impacts to species physiology and/or behaviour** – an individual / species response to potential disturbance stimuli includes undetected metabolic changes, vocalizations, and dispersion away from the source of disturbance. Elevated noise levels (e.g., from machinery and people within close proximity), olfactory stimuli, visual stimuli and subsurface vibrations (e.g., from compacting) constitute various types of disturbance stimuli.
- **Direct mortality** – potential for injury / mortality to species, including collisions with construction machinery.

6.3.1. Impacts to Birds

The Project has the potential to disturb nesting birds. Vegetation clearing during the bird breeding window (i.e., March 15 to August 15), or raptors nesting period (i.e., February 1 to September 30), can displace nesting birds and result in mortalities if active nests are cleared (***Figure 9***). Breeding birds may respond to disturbance stimuli by vocalization, undetected metabolic changes and dispersion, which may lead to nest abandonment and/or nest predation.

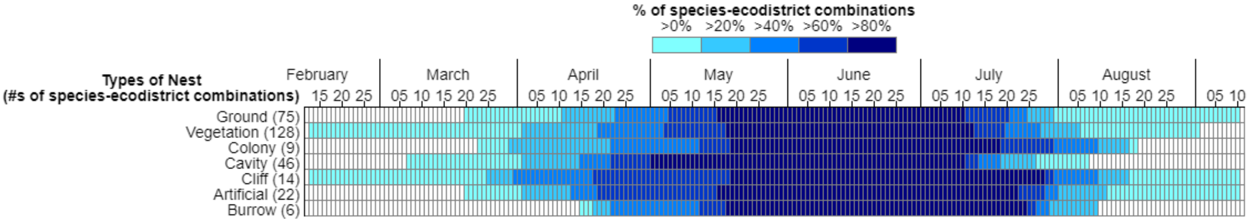

Figure 9. Nesting calendar query in the A1 Nesting Zone for the Eastern Pacific Ranges Ecodistrict (Birds Canada 2003).

Wildlife trees were present within the EAA and may be disturbed during construction. These large diameter (e.g., >60 cm diameter) standing dead or decaying trees provide perching, nesting and feeding opportunities for a variety of bird species (e.g., woodpeckers, raptors, owls). Consequently, removal or disturbance of wildlife trees may impact breeding success or other life processes.

6.3.2. Impacts to Amphibians and Reptiles

Impacts or disturbances to waterbodies, seepages, coarse woody debris or leaf litter within the EAA may result in habitat loss or fragmentation, changes to water quality, moisture loss through tree clearing, removal of woody debris, or direct mortality for amphibians. Works amongst the road shoulder or existing riprap slope above the Q2 have the potential to disturb basking reptiles such as snakes and lizards. Construction works within and immediately adjacent to these areas may result in fewer direct impacts to amphibians and reptiles if carried out during the reduced risk window (March 2 to September 30). Works conducted outside this reduced risk window may impact overwintering amphibians and reptiles because they cannot be salvaged and relocated. Wildlife sweeps targeting at-risk species such as northern red-legged frog (*Rana aurora*) should be conducted ahead of construction.

6.3.1. Impacts to Mammals

Project impacts could include tree clearing of areas in the EAA, particularly where there are large, old, dead trees that serve as potential roosting habitat for the little brown myotis (*Myotis lucifugus*), hoary bat (*Lasiurus cinereus*), and Townsend's big-eared bat (*Corynorhinus townsendii*). Removal of vegetation may affect the availability of insects for bat foraging. Minimizing vegetation removal through the strategic placement of access/egress routes and by only removing vegetation necessary to complete bank stabilization works may reduce impacts to riparian habitat or wildlife tree removal.

6.3.2. Impacts to Wildlife Species at Risk

At-risk species may be impacted through alterations or removal of important habitat features, such as wildlife trees, coarse woody debris, riparian vegetation, waterbodies, or leaf litter. While the Project alignment does not occur within critical habitat for at-risk species, it does occur within a WHA for spotted owl. Tree removal within the WHA is not permitted. The forested area south of the Project alignment consists of suitable habitat for spotted owl nesting and foraging. Spotted owls typically breed between early February and the end of July (ECCC 2023) and are most sensitive during this period.

A WHA for northern goshawk occurs within 1.5 km of the Project alignment. The forested area south of the Project alignment contains suitable foraging habitat but is not ideal for nesting.

Raptor nest surveys completed in March 2023 did not result in identification of any raptor nests within the EAA, but trees should be assessed by a QEP immediately prior to removal to confirm that no raptors, particularly spotted owls, are present. Wildlife sweeps and breeding bird nest surveys may be conducted throughout works to target other at-risk species with High or Moderately-High probability of occurrence within the EAA.

7. Environmental Mitigations and Offsetting

The provincial mitigation hierarchy for environmental values is described in four levels:

1. Avoid.
2. Minimize.
3. Restore onsite.
4. Off-set (offsite or onsite).

Measures to avoid and minimize Project impacts start early in design when the environmental features are identified, and the design is modified to avoid those features. As this Project is a permanent repair of temporary works, impacts will largely be limited to the existing footprint.

A residual effect is an effect that remains when mitigation measures cannot be applied or cannot fully address a stressor. The design team has implemented a mitigation hierarchy of measures for the conservation and protection of the environment, with the ultimate goal to avoid or minimize residual effects (***Table 10***). Consistent with these measures, BMPs will be applied during construction (as detailed in ***Section 7.2***).

Table 10. Hierarchy of measures.

Hierarchy of Measures		How the Measure was Implemented
1	**Prevent** (measures to avoid) the occurrence of adverse effects	Several design alterations were made to better accommodate environmentally sensitive areas throughout the alignment, as detailed in the BGC design (***Appendix B***). Mainly, all inwater impacts along the southern portion of the bank armouring was relocated to the landside of the works, reducing the original design impacts from 1220 m^2 to 1050 m^2
2	**Minimize** (measures to mitigate) the extent of the death of fish and wildlife and adverse effects on fish and wildlife habitat resulting from the proposed work	Several measures to protect the environment have been considered, which include BMPs for these Works, preparation of a Construction Environmental Management Plan (CEMP), and consideration of sensitive timing windows and construction staging and schedule to address potential lag times in ecological form and function associated with habitat loss and associated offsets. Additionally, proposed works have been designed to maintain and improve fish passage.
3 & 4	**Counterbalance** this loss of habitat **through positive contributions to the aquatic and riparian ecosystems** (measures to restore and offset)	Habitat enhancement offsets include the installation of a boulder seeding area planted with willow stakes. Decision pending on how this offset to be utilized as it maybe used for the greater area required for Hwy 5 offsets.

7.1.PROJECT DESIGN

Stability seeding could be incorporated into bank stabilization works, as detailed in a technical memorandum provided by BGC (***Appendix E***). Stability seeding is an experimental approach to minimizing bank erosion that simultaneously allows minor widening and sediment recruitment along riverbanks (Eaton 2023). It minimizes the need for excavation within the main channel and can be combined with riparian planting to enhance rooting strength. Boulder seeding is to incorporate size 400 mm to 600 mm boulders placed in a gridded configuration with 2 m spacing between the rocks where willow (*Salix* spp.) stakes will be planted (***Figure 10***). Design drawings are provided in ***Appendix A***.

Figure 10. Proposed boulder seeding configuration to be implemented.

7.2.ENVIRONMENTAL MITIGATIONS DURING CONSTRUCTION

Impacts are minimized during the Project design, construction, operation, and restoration phases through the implementation of BMPs. The following guidelines and BMPs were used to develop appropriate avoidance and mitigation measures:

- DFO Policy for applying measures to offset adverse effects on fish and fish habitat under the *Fisheries Act* (DFO 2021).
- DFO Measures to Protect (DFO 2022c) and Standards and Codes of Practice (DFO 2022a).
- Requirements and Best Management Practices for Making Changes In and About a Stream in British Columbia (BC 2022a).
- A User’s Guide for Changes In and About a Stream in British Columbia (BC 2022b).

A variety of environmental protection and mitigation measures for the Project are proposed to minimize harmful effects to wildlife and the environment. The expected required measures employed per Project phase are summarized in ***Table 11.*** A detailed outline of mitigation strategies to be employed is provided in ***Table 12***. Additional details are provided in ***Sections 7.2.1*** to ***7.2.17.***

Table 11. Mitigation measures intended for the Coquihalla River and adjacent riparian habitat.

Environmental Mitigation Measures	Phase			
	Design	Construction	Operation	Restoration
CEMP	X	X	X	X

Environmental Mitigation Measures	Phase			
	Design	Construction	Operation	Restoration
Environmental Monitoring		X	X	X
Fish and Fish Habitat Protection		X		
Erosion and Sediment Control		X	X	X
Spill Control and Emergency Response		X		X
Vegetation Management		X		X
Wildlife and Wildlife Habitat Protection		X		X
Species at Risk Management	X	X		X
Soil Management		X		X
Water Management		X		
Hazardous Materials Management		X		
Dust and Emissions Control		X		
Noise and Vibration Management		X		
Waste Management		X		X
Restoration Plan				X

Table 12. Environmental components to be protected and recommended mitigation strategies.

Component	Project Activities That May Impact Environmental Component	Description of Potential Environmental Impacts	Recommended Mitigation Measures or BMPs
Invasive Species	• All ground disturbances	• Invasive species may spread through construction activities	• Provide a Work Procedure. • Ensure proper removal and handling of noxious weeds. • Employ methods to prevent spread of propagules on tires of vehicles. • Provide protective cover of disturbed soils through native species revegetation.
Wildlife & Wildlife Habitat	• Noise • Stripping • Excavation	• Direct wildlife mortality	• Conduct a salvage of organisms from wildlife habitat to be impacted by construction of the project. • Employ an AQP to provide onsite monitoring.
		• Wildlife encounters	• Retain an AQP to be on site during site clearing and grading to salvage and relocate wildlife, if encountered. • Develop a plan to reduce attracting birds and other wildlife to construction site through proper waste control.

Component	Project Activities That May Impact Environmental Component	Description of Potential Environmental Impacts	Recommended Mitigation Measures or BMPs
Birds & Bird Nests	• Noise	• Non-compliance with the *Wildlife Act* through disturbance of breeding birds • Non-compliance with the *Migratory Birds Convention Act* through disturbance of migratory birds	• Conduct breeding bird nest surveys if vegetation disturbance is proposed during the bird breeding season (March 15 to August 15). • Conduct nest surveys for raptors and MBCA Schedule 1 species during early stages of project to allow modification of project design. Additional surveys should be undertaken prior to vegetation clearing. • Demarcate "no work" buffer zones around active nests, nests of species with year-round nest protection, or species listed under Schedule 1 of the MBCA. • Monitor active nests for disturbance during construction. • Removal of protected nests under *Wildlife Act* 34b is not permitted. • Removal of the nest of a Schedule 1 species under the MBCA requires routine monitoring during the designated wait time for that species to declare the nest abandoned prior to removal.
Fish & Fish Habitat	• General construction works • Equipment access below Q2	• Potential increase in water turbidity of watercourses downslope of work area • Potential change in quality of adjacent fish habitat • Increased sedimentation risk	• Apply BMPs to control erosion and sedimentation. • Operate equipment from the top of bank or from dry land. • Conduct works during the least risk window for pacific salmon, trout, and Dolly Varden (August 1 to August 31).
	• Accidental spills of deleterious substances • Runoff from construction activities and impermeable surfaces	• Transport of substances to watercourses reducing water quality	• Monitor water quality parameters such as TSS and turbidity during construction activities in or near a watercourse. *Fisheries Act* (1985) requires protection of water quality. • Follow a spill contingency plan. Spill kits should be located on heavy equipment and throughout Project site. • Use biodegradable fuels when working over or adjacent to a watercourse. • Use secondary containment for all fuel and hazardous materials storage containers. • Contain and collect all effluent and debris from construction activities and dispose of in accordance with BC *Environmental Management Act* (BC 2003).
Air Quality / Noise & Vibration	• General construction works	• Dust generation • Noise generation	• Provide AQP monitoring of wildlife that may be impacted by noise.
Soils & Water Quality	• Exposed working surfaces • Accidental spills of deleterious substances	• Disturbance and compaction reducing soil permeability • Contamination of soil	• Follow Project-specific CEMP and standard BMPs for the works. • Restrict vehicles and equipment from accessing natural soil surfaces. • Develop/follow a spill contingency plan. • Keep spill kits on heavy equipment and throughout Project site.

Component	Project Activities That May Impact Environmental Component	Description of Potential Environmental Impacts	Recommended Mitigation Measures or BMPs
	• Placement of materials • Work during heavy rains	• Sediment release into watercourse • Erosion and sedimentation causing increased water turbidity • Bank stability	• Design and implement erosion protections. • Install and monitor site isolation procedures and materials. • Reseed, plant and/or cover impacted areas for soil stabilization. • Employ an AQP to monitor water quality parameters such as TSS and turbidity during construction activities that have the potential to release turbid water to the aquatic environment. • Ensure an EM/AQP is onsite to regularly monitor effectiveness of any erosion measures employed. • Avoid soil disturbance during heavy rain conditions. • Place soil stockpiles in a location that ensures that sediment or debris does not enter downstream waters. • Protect stockpiles from wind and rain erosion. • Pump sediment-laden water to a vegetated area away from the stream where it can seep into the ground sufficiently far from the channel and allow sediment to settle out before the water returns to the stream. • Re-vegetate disturbed areas with native species.

7.2.1. Construction Environmental Management Plan (CEMP)

Environmental protective measures and mitigation strategies will be implemented during Project works to minimize potential effects. The contractor will retain an AQP with environmental experience related to linear developments to develop a Construction Environmental Management Plan (CEMP). The Standard Specifications for Highway Construction - Protection of the Environment (SS 165; MoTI 2020) requires that the CEMP include location-specific environmental procedures for activities such as works below the high-water mark and fish and wildlife salvages. Under the CEMP, the contractor’s responsibility includes clear demonstration of understanding for elements relating to protection of the environment. The CEMP is a living document, updated as conditions change, and will be available to the Regulators and affected First Nations communities in advance of construction.

The CEMP will incorporate measures outlined in SS 165.02.03 and is to include:

- Air Quality and Dust Control Plan
- Archaeology Management Plan
- Clearing and Grubbing Plan
- Concrete Waste Management Plan
- Construction and Waste Management Plan
- Environmental Incident Reporting Plan
- Environmental Monitoring Plan
- Erosion and Sediment Control Plan
- Invasive Plant Management Plan
- Reclamation Plan
- Spill Contingency Plan

7.2.2. Construction and Environmental Monitoring

The Contractor’s AQP will conduct environmental monitoring during environmentally sensitive works (e.g., works close to water, vegetation clearing, riprap placement below the modelled Q2). Monitoring frequency will correspond to the sensitivity of the location and the nature of the works occurring and will comply with any permit or contract requirements, and the AQP's recommendations outlined in the CEMP. The AQP will provide the contractor and MoTI with routine environmental monitoring reports documenting construction activities, implemented mitigation measures, any environmental issues observed, and recommended corrective actions. The AQP will have written authority to modify and/or halt any construction activity if deemed necessary for the protection of fish and wildlife populations or their habitats.

7.2.3. Erosion and Sediment Control

The Contractor and their AQP will develop an Erosion and Sediment Control (ESC) Plan prior to construction for inclusion within the CEMP. The ESC Plan will include details of the measures, both temporary and permanent, to minimize the potential for soil erosion within the Project area. An example of the methods used in an ESC plan may include:

- Minimizing the amount of shrub and ground vegetation clearing in the work area to minimize exposed soil.
- Completing clearing and ground disturbance immediately prior to construction activities to decrease the duration of soil exposure.
- Installing ESC measures (e.g., silt fencing and catch basin liners) prior to construction activities, including detour routes. Silt fence should be properly installed at the top-of-bank of any watercourses, ditches. Catch basins in the vicinity of construction works should be lined with approved catch basin liners. ESC measures should be routinely inspected and maintained throughout the construction period.
- Halting construction activities if sediment is observed to be moving into a waterbody.
- Locating any stockpiled soil or spoil material at least 30 m from any watercourses, cover with an impermeable material (e.g., polyethylene sheeting), and install silt fencing as needed between the pile and waterbodies.
- Re-vegetating graded and disturbed soils with a suitable erosion control mix of seed emphasizing native species and apply mulch or other stabilizer on slopes to minimize erosion until vegetation establishes.
- Implementing standard BMPs for ESC, spill prevention, and emergency response to prevent release of deleterious substances into the aquatic and terrestrial habitats.

7.2.4. Spill Control and Emergency Response

A comprehensive Spill Response Plan and Emergency Response Plan will be developed by the AQP prior to construction and included in the CEMP. The plan will specify the following measures to prevent introduction of deleterious substances into the watercourse:

- Except for excavation and installation of riprap armouring, prohibit all other equipment and machinery from operating below the high-water mark at any time.
- Inspect construction equipment and machinery daily to verify it is in good working order and free of leaks.
- Refuel and service equipment at least 30 m from any watercourse.
- Store all fuel and/or hazardous materials in trucks or containment areas that are at least 30 m from any watercourse.
- Keep emergency spill kits on site and train crews in their proper application.

- Keep emergency contact information on site with all Project personnel and government agency phone numbers to be contacted in the event of a spill.

7.2.5. Fish and Fish Habitat Protection

Works close to water will aim to adhere to the reduced risk instream works window for the respective fish species occurring along the alignment (***Table 13***). Given the variety of species, August 1 to September 15 (MoE 2006) is the period with the reduced risk as it avoids the spawning and incubation periods of most fish species in the waterbodies impacted by the Project.

All BMPs and mitigation measures prescribed within the provincial Change Approval, federal DFO permits, other regulators' permit conditions, and the accepted CEMP will be implemented by the Contractor. Works will be completed as quickly as possible once works have commenced, and will be completed, where possible, during favourable weather and low water conditions. Where works cannot be completed within the reduced risk instream works window, additional mitigation will be implemented by the Contractor, such as, but not limited to more intense monitoring. If works are to be completed outside of the reduced risk instream works window, discussions with the AQP are required to adequately prepare.

The Contractor will be required to follow their AQP's Environmental Procedure for these works (included in the CEMP) to avoid changes to downstream water quality, and to avoid direct disturbance to fish and aquatic habitat. Such work may include:

- Installing exclusion measures to isolate fish and amphibians from the work areas.
- Implementing sediment containing measures (e.g., silt curtain) during excavation works.
- Minimizing removal of vegetation, natural woody debris, rocks, or other materials from the banks and restore, replace, and enhance accordingly as per approved plan.

7.2.5.1. Aquatic Species at Risk Management

Proposed works and works must be managed appropriately to minimize impacts to species distribution, focusing on bull trout and coastal cutthroat trout.

7.2.6. Wildlife and Wildlife Habitat Protection

Under SS 165, Contractors are obligated to adhere to all provincial and federal legislation and regulations protecting wildlife and habitat for wildlife. The CEMP implemented by the Contractor will aim to prevent, minimize or manage potential effects on wildlife within and adjacent to the construction footprint:

- Avoid disturbing wildlife (BC 1996b). Construction work may need to be rescheduled if wildlife is using habitats scheduled for construction.
- Obtain a *Wildlife Act* permit to relocate animals that may be disturbed within the Project alignment.
- Conduct wildlife sweeps and/or salvages to relocate wildlife out of the Project alignment.
- Where spotted owl WHA overlaps the Project footprint, prepare a site-specific species management plan based on extent, presence of species' biophysical attributes, and construction activities and/or methods.
- Develop a plan to reduce attracting birds and other wildlife to the construction site through proper waste control.
- Avoid feeding wildlife.

- Schedule vegetation clearing and tree removal outside the breeding bird nesting period to minimize conflict (ECCC 2018).
- Conduct nest surveys for raptors and breeding birds ahead of clearing, if vegetation removal cannot be avoided during the nesting period for breeding birds (March 15 to August 15) and raptors (January 1 to September 30). Active nests require a minimum 30 m protective buffer where no works may occur until the nest has fledged. Buffers for raptor nests are species-specific and are to be determined by the AQP. The nests of bald eagles, great blue heron, pileated woodpecker and osprey are protected year-round whether active or inactive. A nest mitigation plan may be required if active nests are documented within the Project alignment.
- Retain wildlife trees, or other large diameter (>60 cm), decaying trees where possible to maintain suitable habitat for woodpeckers or other cavity nesting birds such as western screech owl.

7.2.7. Timing Windows

Scheduling construction during the period of least risk to species present on site will aid in minimizing overall affects. ***Table 13*** outlines least risk windows for focal species in the lower mainland region.

Table 13. Summary of timing windows and environmental restrictions on construction.

Focal Species	Reduced Risk Window	Constraints
Amphibians and Reptiles	March 2 to September 30	BMPs recommend no salvages between October 1 to March 1. Permits may not be issued outside of the least risk window.
Fish (Pacific Salmon)	July 15 to September 15	Works should be scheduled during the reduced risk window to minimize impacts to fish.
Fish (Rainbow, Steelhead, Cutthroat Trout)	August 1 to October 31	
Fish (Bull Trout, Dolly Varden)	June 15 to August 31	
Migratory Birds	September 1 to February 28	Breeding bird surveys must precede works within the sensitive window for breeding birds (March 15 to August 15). Preliminary surveys to detect the nests of Schedule 1 species should be conducted at any time of year to prevent construction delays.
Raptors	October 1 to December 31 (but may vary per species)	Raptor nest surveys must precede works, year-round.

7.2.8. Species at Risk Management

In order to prevent, minimize or manage potential effects on species at risk within and adjacent to the construction footprint, BMPs from the following documents will be incorporated into the CEMP and implemented by the contractor as a requirement:

- Best Management Practices for Amphibian and Reptile Salvages in British Columbia (FLNRO 2016).
- Standard Operating Procedures: Hygiene Protocols for Amphibian Fieldwork (MOE 2008).
- Inventory Methods for Pond-breeding Amphibians and Painted Turtle - Standards for Components of British Columbia's Biodiversity No. 37 Version 2.0 (RIC 1998).
- Guidelines for Amphibian and Reptile Conservation During Road Building and Management Activities in British Columbia (MOECCS 2020).

- Oregon Forestsnail Best Management Practices Guidebook (SCCP 2018).
- Section Five (Species and Habitats) in Develop with Care 2014: Environmental Guidelines for Urban and Rural Land Development in British Columbia (MOECCS 2014).
- Guidelines for Raptor Conservation during Urban and Rural Land Development in British Columbia (BC 2013).
- Inventory Methods for Forest and Grassland Songbirds - Standards for Components of British Columbia's Biodiversity No. 15 Version 2.0 (RIC 1999a).
- Inventory Methods for Woodpeckers – Standards for Components of British Columbia's Biodiversity No. 19 Version 2.0 (RIC 1999b).

7.2.9. Vegetation and Invasive Plant Management

The Contractor's CEMP may include a vegetation and invasive species management plan to prevent, minimize, or manage potential effects on vegetation, specifically within riparian areas and the mature mixed forest south of the footprint. Where construction activities and schedule allow, the following practices may be included:

7.2.9.1. General Vegetation Protection

- Restrict clearing and grubbing to areas required to complete construction activities.
- Delineate the work area using a physical barrier (e.g., snow fencing) to limit clearing and grubbing to areas in the Project footprint and areas required to complete construction activities.
- Restrict fill placement to only those areas where this is required to complete construction activities.

7.2.9.2. Rare Plants

- Conduct rare plant surveys in sensitive habitat (e.g., undisturbed wetlands and riparian areas) at the appropriate time of year, in advance of clearing and grubbing. If a rare plant species is encountered, develop a site-specific mitigation and / or salvage and translocation plan.

7.2.9.3. Invasive Species

- Identify areas of invasive plants within the Project area, remove with root structures and dispose of off-site (incineration is preferred).
- Source seed mixes that are free of weeds or invasive species.
- In order to minimize the spread of invasive species during the advanced site preparation phase and restoration phase of the Project, guidance from the "Best Practices for Managing Invasive Plants on Roadsides" (MoTI 2019) will be incorporated in the CEMP and implemented by the contractor.
- Develop a Japanese Knotweed Management Plan to address the knotweed patch located approximately 15 m south of the Project alignment. The patch should be surveyed to determine its full extent.

7.2.10. Water Management

During construction excavation, it is possible that zones of previously unidentified contamination will be intersected. Contaminated water management measures will be included as a component of the Waste Management Plan of the CEMP. The plan may specify the following measures to manage water from the work areas to prevent contaminated water from entering any watercourses in the Project area.

- Implement work area isolation and fisheries protection measures.
- Pump construction water (e.g., dewatering from excavations) to an onsite water containment and treatment system.
- Conduct water quality testing and analysis (by an AQP) to confirm that water treated and intended for discharge to watercourses is within provincial and federal water quality criteria for the protection of aquatic life.
- Ensure that water that has the potential to be deleterious to aquatic life is not discharged. Provide additional treatment to achieve water quality standards, or if water quality standards are not achievable through onsite treatment, offsite disposal at an approved facility licensed to accept this water may be required by the AQP.

7.2.11. Waste Management

The following measures may be implemented by the Contractor to prevent, minimize, or manage potential effects to human health and the environment and are consistent with environmental regulatory requirements.

- Educate personnel on the management of their own waste (e.g., proper food storage and disposal).
- Have wildlife-proof waste disposal facilities (i.e., bear-proof garbage bins).
- Keep the work site clean and tidy.
- Strategically place porta potties in accessible locations close to work areas set back from sensitive habitats.
- Recycle and reuse materials where possible.
- Locate and manage stockpiles in accordance with the Surface Water Quality and ESC Plan.
- Undertake vegetation clearing on the Project in a manner that reduces waste generation and ensures proper management prior to subsequent beneficial use or disposal.

7.2.12. Hazardous Materials Management

In accordance with specifications, the CEMP will incorporate the following:

- Keep onsite storage of hazardous materials to the bare minimum by coordinating the arrival of hazardous materials to match an imminent onsite need.
- Dispose of all hazardous waste in accordance with the applicable regulations.
- Label all onsite hazardous materials, controlled hazardous products, and wastes properly as per WHMIS.
- Transport hazardous materials and wastes only by appropriately licensed transporters and transportation will be carried out in accordance with relevant regulations, in appropriate containers.
- Establish environmentally sound procedures for refueling, painting, staining, chemical application and/or transfer, and storage of hazardous materials including petroleum products.

7.2.13. Dust and Emissions Control

Some mitigative measures may include:

- Avoid idling unless indicated otherwise.
- Remove soil, or mud deposited on public roads.
- Suppress dust onsite with water trucks as and when required.

7.2.14. Archaeological and Heritage Resources

The following measures will be incorporated into the CEMP as an Archaeology Management Plan and implemented by the Contractor to assist in the responsible management of heritage sites and resources:

- If suspected heritage objects or sites (either intact or disturbed) are encountered, stop work within 30 m of the find and secure the area.
- Do not undertake further work that could disturb the site, including the movement of soil and/or spoil.
- Immediately inform the MoTI site representative or Project contact of the discovery.
- The MoTI representative will contact the Archaeology Branch (MoF) and a professional archaeologist. They will advise on the next steps. A field visit to examine suspect soils or artifacts may be appropriate.

MoTIs Chance Find Management Plan will be onsite as a reference for the Contractor and staff.

7.2.15. Contaminated Sites

A Spill Response Plan will be incorporated into the CEMP and implemented by the contractor to assist in the handling/disposal procedures and/or remediation in the event contamination is encountered, or an accidental release or other accident occurs resulting in soil, groundwater, or surface water contamination. The plan may include:

- Identifying and managing known and suspected contaminated sites in compliance with applicable provincial and federal legislation and regulations.
- Ensuring coordination between this plan, the Health and Safety Plan, Emergency Response Plan, the Surface Water Quality and Sediment Control Plan.
- Developing and implementing a health and safety plan consistent with SS 135 Construction Site Safety.

Contaminated soil management measures will be developed by the AQP prior to construction and will be included as a component of the Waste Management Plan of the CEMP. The plan will specify measures to manage sediment from major watercourses, and soil either identified or caused during construction activities. The following measures will be implemented by the Contractor at minimum to prevent, minimize, or manage potential effects on sediments and soils:

- Stopping work immediately if unexpected soil contamination is encountered and consult the contaminated sites specialist(s) for direction.
- Implementing sediment and/or soil containing measures during excavation works.
- Appropriately disposing the excavated sediment and/or soil in accordance with the BC Environmental Management Act, its regulations (Contaminated Sites and Hazardous Waste regulations)

7.2.16. Noise Management

The CEMP will include a noise mitigation plan. Such a plan may include:

- Post signage to inform the public of periods of noisy activity.

- Ensure machinery is in good condition prior to construction and that contractors do not excessively use noisy equipment. Carry out regular maintenance on all equipment, including lubrication and replacement of worn parts, especially exhaust systems.

7.2.17. Restoration of Temporary Impacts

Areas of temporary impact will be reinstated in the same location. Elements to be included in restoration plans are further detailed in ***Section 7.3***. Temporary impacts rehabilitation will seek to return the area to original pre-disturbed condition or better.

The following measures will be incorporated into the CEMP and implemented by the contractor to improve the success of temporary impact restoration:

- Avoid compaction of topsoil especially where replaced over root networks.
- Restore full extent of riparian and aquatic disturbance footprint to similar or enhanced habitat condition with adequate vegetative cover to prevent erosion, in accordance with the contract.
- Follow the Invasive Plant Management Plan in the CEMP.
- Follow the ESC Plan in the CEMP. See ***Section 7.2.3*** for further detail.
- Remove all temporary ESC BMPs once no longer necessary, and any excess non-biodegradable materials are to be disposed of at an appropriate location.
- Post-construction monitoring is to be undertaken by the Ministry to assess vegetation establishment and site stability. See ***Section 7.3.5*** for further detail.

7.3. OFFSETTING PLAN

Project works will result in permanent residual impacts to the environment. A residual effect is an effect that remains when mitigation measures cannot be applied or cannot fully address a stressor. Such impacts are to be mitigated through habitat enhancement and offsetting to achieve a net balance in habitat loss versus gains. Experimental 'boulder seeding' is proposed at this location and can be accomplished at the time of the bank armouring, at a later date, or included in the larger offsetting for Hwy 5 (***Figure 11***).

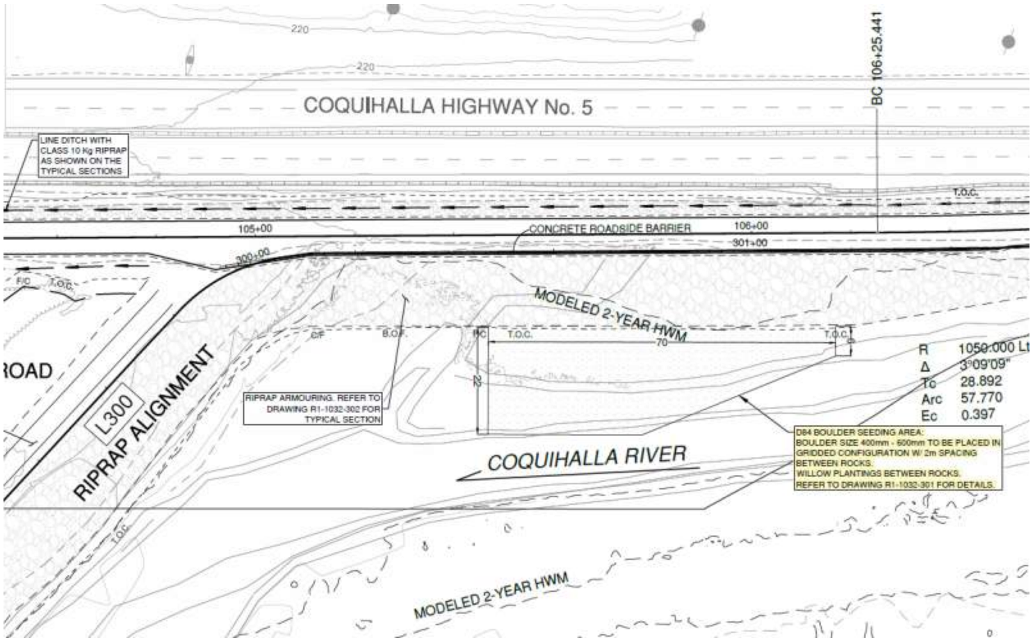

Figure 11. Proposed boulder seeding area.

7.3.1. Geographic Locations

The boulder seeding location is within the project site.

7.3.2. Methods for Offset Construction

Offset construction of the boulder seeding will require little to no heavy equipment and willow staking by hand adjacent to the watercourse (***Drawing R1-1032-102***).

The standard specifications will be augmented with MoTI Special Provisions prepared at the end of detailed design. There will be special provisions related to the boulder seeding, management of adverse effects and construction environmental management.

7.3.3. Timeline of Implementation Plan

Offsetting will be implemented according to the Project schedule outlined in ***Section 3.1***. The construction sequence has been planned to minimize the ecological lag between fishery impacts and their replacements or offsets.

7.3.4. Adverse Effects from Offsetting Implementation and Measures to Avoid

Potential adverse effects due to implementing the offsets and possible ways to avoid them have been summarized in ***Table 14***.

Table 14. Adverse effects from offsetting implementation and measures to avoid.

Offset Component	Adverse Effect	Measures to Avoid
Works Close to Water	Siltation	• Conduct bank stabilization works during the reduced risk window • All works to be conducted outside of the current water level.
Aquatic Banks	Scour or undermining	• Provide maintenance access should repairs with equipment be needed • Armour where warranted • Design for Q_{200} plus climate change
Aquatic Banks	Sloughing or erosion	• Develop geotechnical design criteria during detailed design • Use hydraulic modelling to determine expected velocities, surfacing, aggregate sizing or planting to resist erosion

7.3.5. Monitoring Measures

The monitoring of this experimental practice will be the responsibility of the researchers at UBC under contract with MoTI. Results can be provided to MoF.

Habitat offsetting, long-term post-construction monitoring, and adaptive management are common to MoTI infrastructure projects, and the habitat enhancement measure proposed represent a full commitment to offsetting Project impacts.

8. Recommendations

8.1.CONTRACTUAL IMPLEMENTATION OF ENVIRONMENTAL PROTECTIONS

The various BMPs and Terms and Conditions provided throughout this report and in issued regulatory permits should be made available to bidders and included in the successful Tender such that environmental protection requirements are contractually enforceable. This includes identifying a CEMP as a minimum standard for environmental conduct, to be implemented throughout the duration of the project by the successful contractor.

8.2.WATER QUALITY

Water quality parameters such as TSS and turbidity will be monitored during construction activities in or near the watercourse. Threshold targets will be closely monitored to ensure they are within the BC Water Quality Guidelines and the CCME Water Quality Guidelines (MOECCS 2021; CCME 1999). Impacts to water quality may be mitigated through proper use and maintenance of ESC measures, ensuring spill prevention materials are on site and accessible, and keeping equipment and machinery in sound operable condition.

8.3. ENVIRONMENTAL MONITORING AND AQP REQUIREMENTS

Requirements for Environmental Monitoring and AQP duties are included in the CEMP; however, this critical role is included here for emphasis. The successful contractor shall retain an independent AQP with a background in providing construction related AQP services. The contractor's AQP will be responsible for environment compliance related to the contractor's work. This includes obtaining any required permits for wildlife sweeps or salvages and implementing other necessary BMP work, as required for environmental compliance.

9. In Closing

This report has been prepared with information available at the time of writing. All works will be done in the dry. Should any questions arise, please do not hesitate to contact the undersigned.

Yours truly,

McELHANNEY LTD

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APPENDIX A – ENGINEERED DESIGN DRAWINGS

BRITISH COLUMBIA

Ministry of
Transportation
and Infrastructure

PROJECT No. 14092-0000

PEERS CREEK FRONTAGE RD

WASHOUT RECOVERY

I. PILKINGTON, CHIEF ENGINEER

100% DETAILED DESIGN

2023-05-12

PLOT DATE: 2023/05/11 X:\2121\2121-00865-15 MoTI - Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\000_CoverKeyPlanLegend\R1-1032-000.dwg

PLOT DATE: 2023/05/15 X:\2121\2121-00865-15 MoTI – Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\000_CoverKeyPlanLegend\R1-1032-001.dwg

DRAWING INDEX

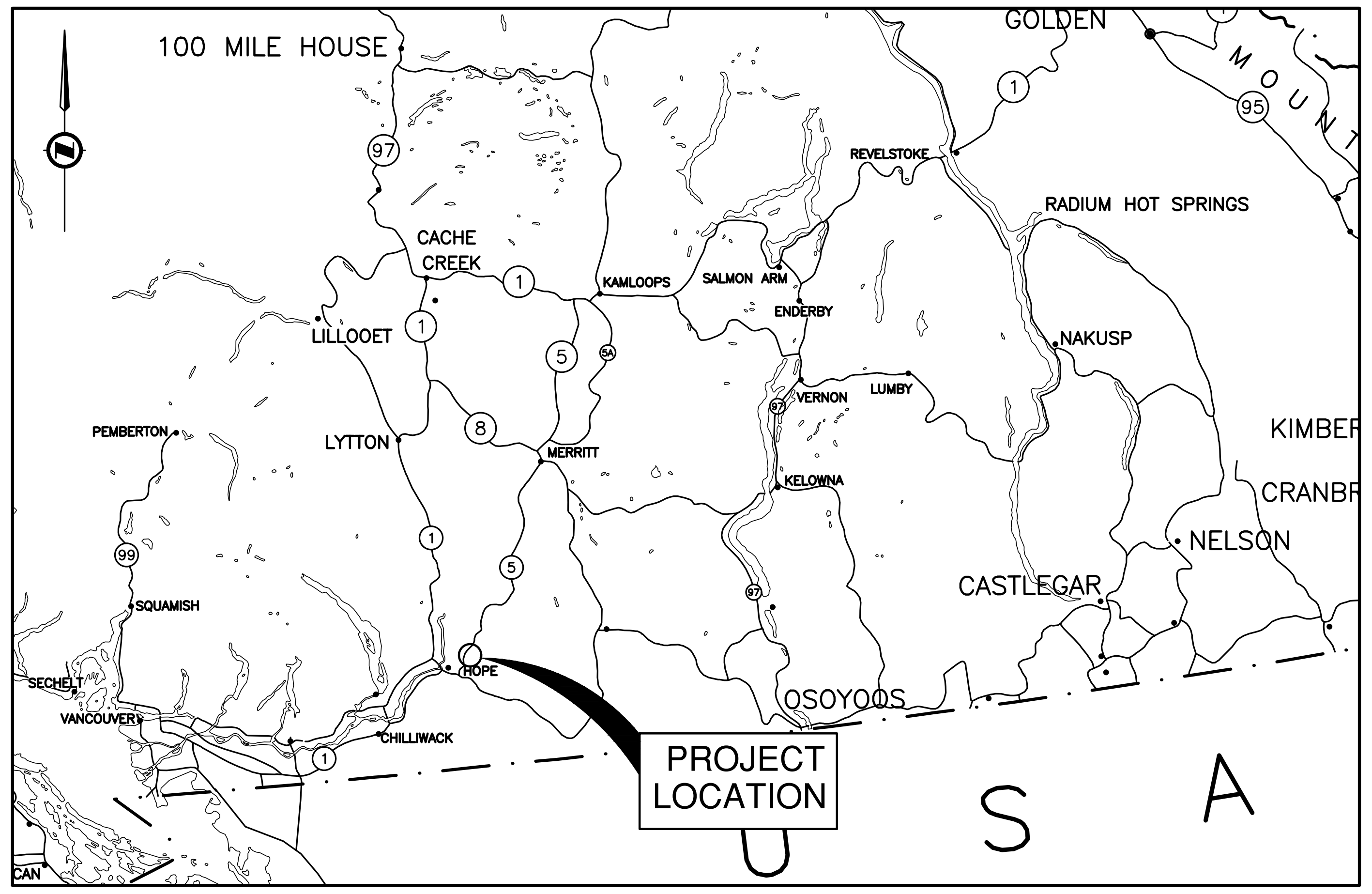
BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

PROJECT No. 14092-0000

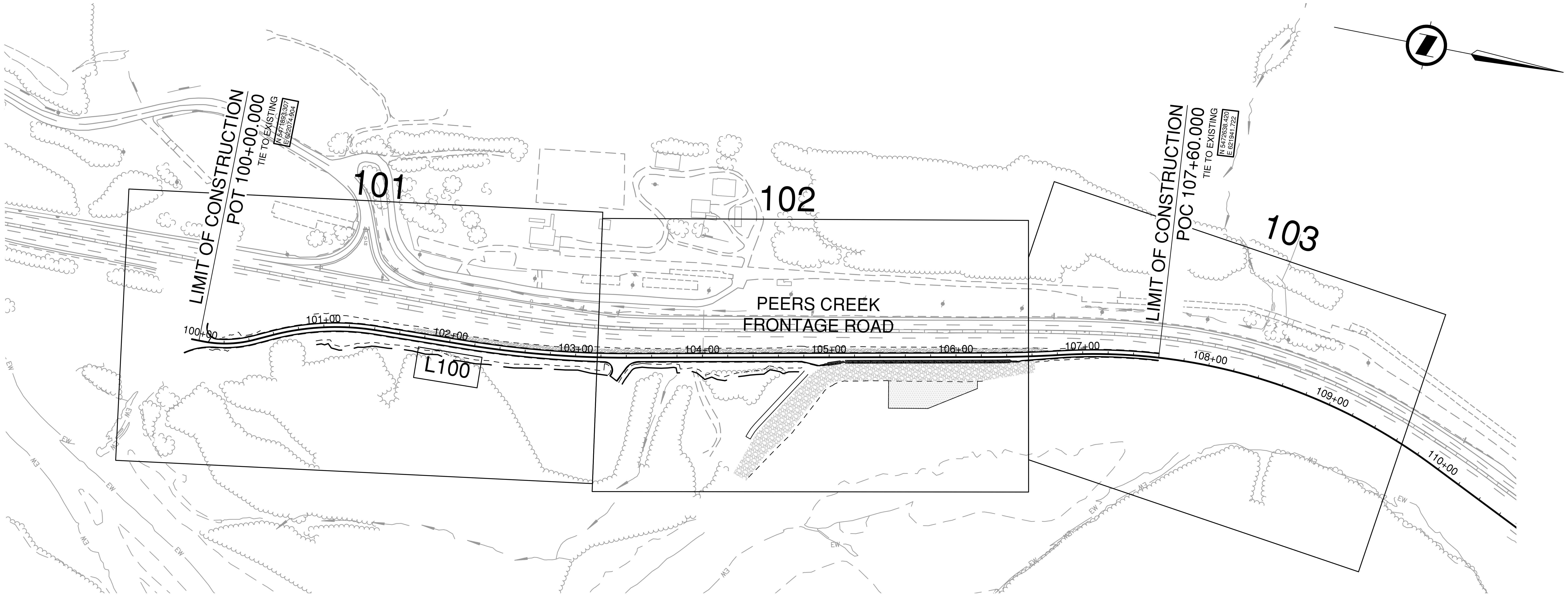
PEERS CREEK FRONTAGE RD

WASHOUT RECOVERY

L100
L100 STA. P.O.T. 100+00.000 - STA. P.O.C. 107+60.000
0.76 km



LOCATION MAP
N.T.S.



KEY PLAN
1:2,000

FOR DISCUSSION ONLY

PERMIT TO PRACTICE
McElhanney Ltd.
PERMIT NUMBER: 1003299
Engineers and Geoscientists of British Columbia

APPROVED SEAL

McElhanney
Suite 200
858 Beatty Street
Vancouver BC
Canada V6B 1C1
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BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

SCALE 0 20 1:2000 100m

CAD FILENAME R1-1032-001
PLOT DATE 2023/05/15

REV	DATE	REVISIONS	NAME
B	2023-05-12	100% DETAILED DESIGN	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

KEY PLAN AND INDEX
PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY
L100 - STA. 100+00.000 TO 107+60.000

N. GUARAN P. ENG.
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T.PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
2121-00865-15	14092-0000	1	R1-1032-001	B

LEGEND

EXISTING SYMBOLS

SURVEY

- SPOT ELEVATION
- BENCHMARK
- REFERENCE POINT
- DETAIL HUB
- OLD IRON PIN
- CONCRETE POST MONUMENT
- CONTROL MONUMENT
- ROCK POST MONUMENT
- STANDARD BRASS CAP MONUMENT
- LEAD PLUG
- TEST HOLE
- TEST PIT
- WOODEN POST
- ALUMINUM POST
- ANGLE IRON POST
- WITNESS POST
- DOMINION IRON POST
- NON-STD. ROUND IRON POST
- NON-STD. SQUARE IRON POST

AERIAL UTILITIES

- POWER GUY POLE
- TELEPHONE GUY POLE
- POWER / TELEPHONE GUY POLE
- DEADMAN
- ANCHOR GUY WIRE
- HIGH TENSION POLE
- HIGH TENSION TOWER
- POWER POLE
- TELEPHONE POLE
- POWER / TELEPHONE POLE
- POWER POLE WITH TRANSFORMER
- POWER / TELEPHONE WITH TRANSFORMER
- PEDESTAL (TELUS)
- TELEPHONE BOOTH

DETAIL

- GATE POST
- GUARD POST
- FLAG POLE
- DELINEATOR POST
- MAILBOX
- TREE
- WELL
- COMMERCIAL SIGN
- SWAMP
- POST MOUNTED DELINEATOR (YELLOW)
- POST MOUNTED DELINEATOR (WHITE)

DRAINAGE & UTILITIES

- MANHOLE
- POWER MANHOLE
- SANITARY SEWER MANHOLE
- STORM SEWER MANHOLE
- TELEPHONE MANHOLE
- UNKNOWN MANHOLE
- VAULT MANHOLE
- WATER MANHOLE
- MH/CB DRYWELL
- CATCH BASIN
- CATCH BASIN MANHOLE
- ASPHALT SPILLWAY
- DRAINAGE GRATE
- CULVERT
- CULVERT INLET
- CULVERT OUTLET
- CULVERT KINK
- RIPRAP

ROAD SIGNS

- ONE-POST SIGN
- TWO-POST SIGN
- BREAKAWAY STEEL
- STD. DAVIT POLE - TYPE 3
- STD. COMBINATION POLE - TYPE 1
- HEAVY DUTY DAVIT POLE - TYPE 6
- H.D. COMBINATION POLE - TYPE 7
- HEAVY POLE - TYPE H
- H. COMBINATION POLE - TYPE H
- CANTILEVER STRUCTURE
- SIGN BRIDGE STRUCTURE
- SIGN - MOUNTED ON STRUCTURE

EXISTING LINE TYPES

FEATURES

- CONCRETE ROADSIDE BARRIER
- BROKEN WHITE LINE RURAL
- SOLID WHITE LINE
- SOLID YELLOW LINE
- DOUBLE YELLOW LINE
- CENTRELINE
- ROAD SHOULDER
- PAVEMENT EDGE
- ASPHALT CURB
- GRAVEL ROAD
- SIDEWALK
- FENCE
- GUARD RAIL ROAD SIDE BARIER
- GARDEN, LAWNS, VEGETATION
- HEDGE, BUSH LINE & TREE LINE
- RETAINING WALL
- CN TRACK BED

TOPOGRAPHY

- BOTTOM OF SLOPE
- TOP OF BANK
- CONTOURS MAJOR
- CONTOURS MINOR

BOUNDARIES

- EASEMENT
- GAZETTE
- PARCEL, LEGAL SUBDIVISIONS
- QUARTER SECTION LINE
- SECTION LINE & DISTRICT LOT
- RIGHT OF WAY
- JURISDICTION BOUNDARY

HYDROLOGY

- EDGE OF WATER
- DITCH CENTER/CREEK CENTER / DRAINAGE
- EDGE OF DITCH

PROPOSED SYMBOLS

DETAIL

- DELINEATOR POST
- SPOT ELEVATION

DRAINAGE & UTILITIES

- ISOLATION / WEIR STRUCTURE / DITCH BLOCK
- RIPRAP SPILLWAY C/W DRAINAGE BARRIER
- CULVERT INLET / OUTLET
- RIPRAP PAD / SPLASH PAD

PROPOSED LINE TYPES

FEATURES

- ALIGNMENT CONTROL LINE
- SECONDARY ALIGNMENT
- PAVEMENT EDGE
- GRAVEL SHOULDER
- ASPHALT CURB
- CONCRETE ROADSIDE BARRIER
- SOLID WHITE LINE
- SOLID YELLOW LINE
- BROKEN WHITE LINE
- RUMBLE STRIP
- ROAD TOES
- SAWCUT LINE
- CLEARING & GRUBBING
- INDEX CONTOUR
- INTERMEDIATE CONTOUR

BOUNDARIES

- LICENSE TO CONSTRUCT

UTILITIES

- DITCH
- EDGE OF DITCH
- CULVERT

HYDROGRAPHIC

- MODELED 2-YEAR HIGH WATER MARK (HWM)

FOR DISCUSSION ONLY

PERMIT TO PRACTICE

McElhanney Ltd.
PERMIT NUMBER: 1003299

Engineers and Geoscientists
of British Columbia

APPROVED SEAL

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BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

SCALE
CAD FILENAME R1-1032-002
PLOT DATE 5/12/2023

REV	DATE	REVISIONS	NAME
B	2023-05-12	100% DETAILED DESIGN	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

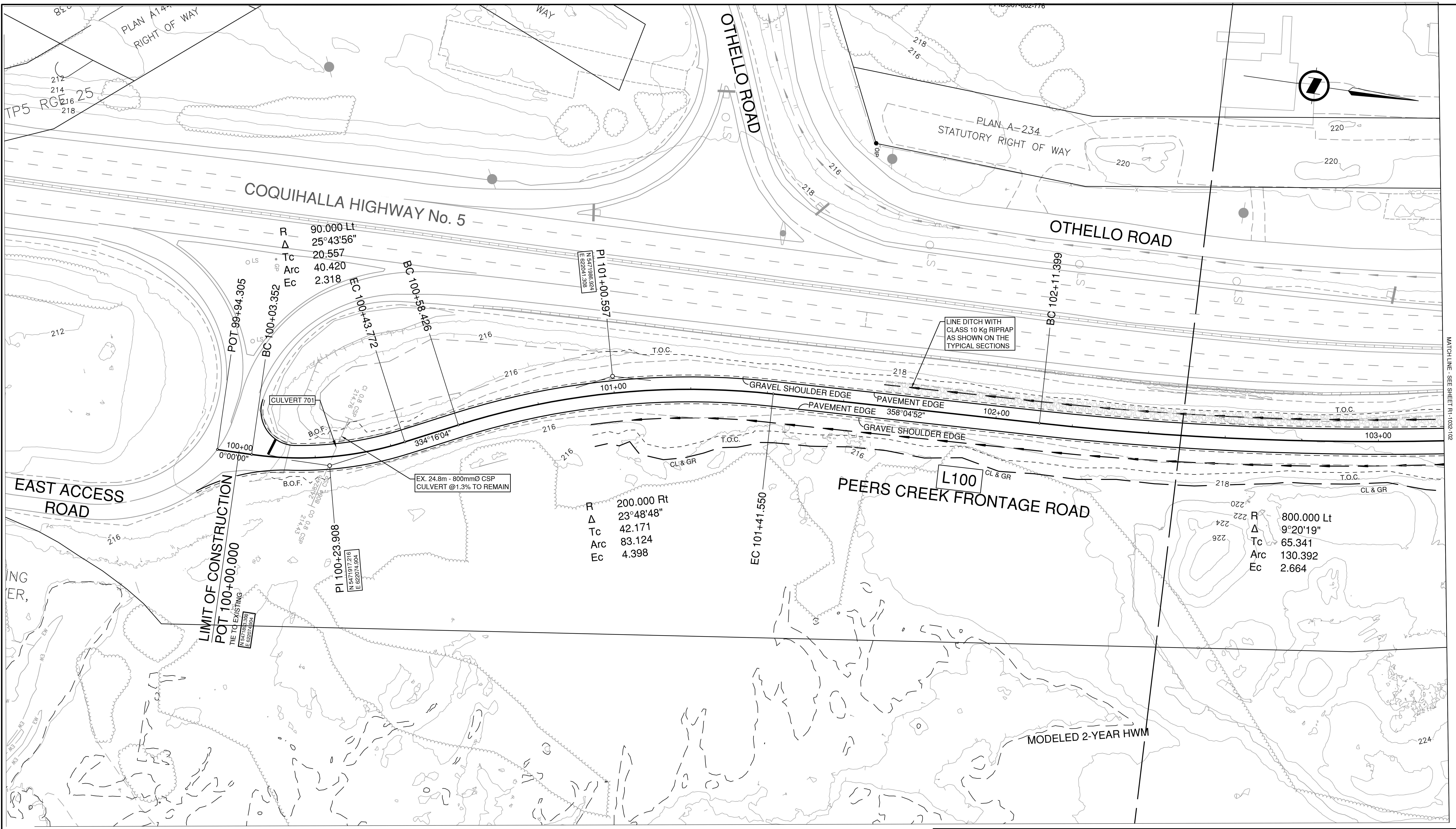
LEGEND
PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY
STA. 100+00.000 TO 107+60.000

N. GUARAN P. ENG.
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
2121-00865-15	14092-0000	1	R1-1032-002	B

PLOT DATE: 2023/05/12 X:\2121\2121-00865-15 MoTI - Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\000_CoverKeyPlanLegend\R1-1032-002.dwg



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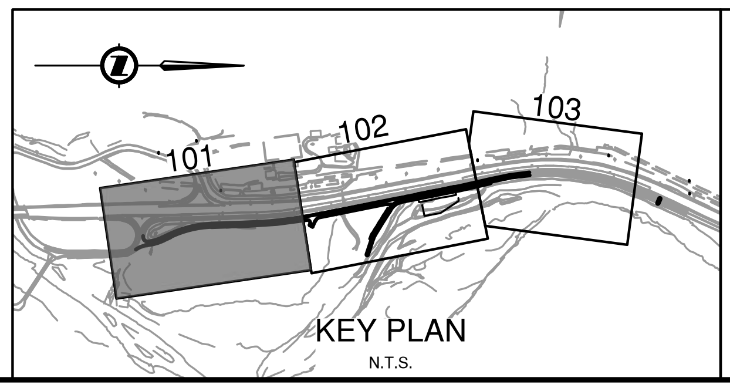
ALIGNMENT	CLASSIFICATION	DESIGN SPEED
L100	RLU	30 km/h

REFERENCE DRAWINGS

FOR PROFILE SEE DWG. R1-1032-201
FOR TYPICAL SECTIONS SEE DWG. R1-1032-301
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-401
FOR CROSS SECTIONS SEE DWG. R1-1032-1001 TO 1006

FOR DISCUSSION ONLY



KEY PLAN
N.T.S.

PERMIT TO PRACTICE

McElhanney Ltd.
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McElhanney

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Tel 604 683 8521

SCALE 0 5 1:500 25m

CAD FILENAME R1-1032-100
PLOT DATE 2023-05-09

REV	DATE	REVISIONS	NAME
C	2023-05-12	100% DETAILED DESIGN	N. GUARAN
B	2023-03-06	FOR REGULATORY APPROVAL	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

BRITISH COLUMBIA

MINISTRY OF TRANSPORTATION
AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

PLAN

PEERS CREEK FRONTAGE ROAD
WASHOUT RECOVERY

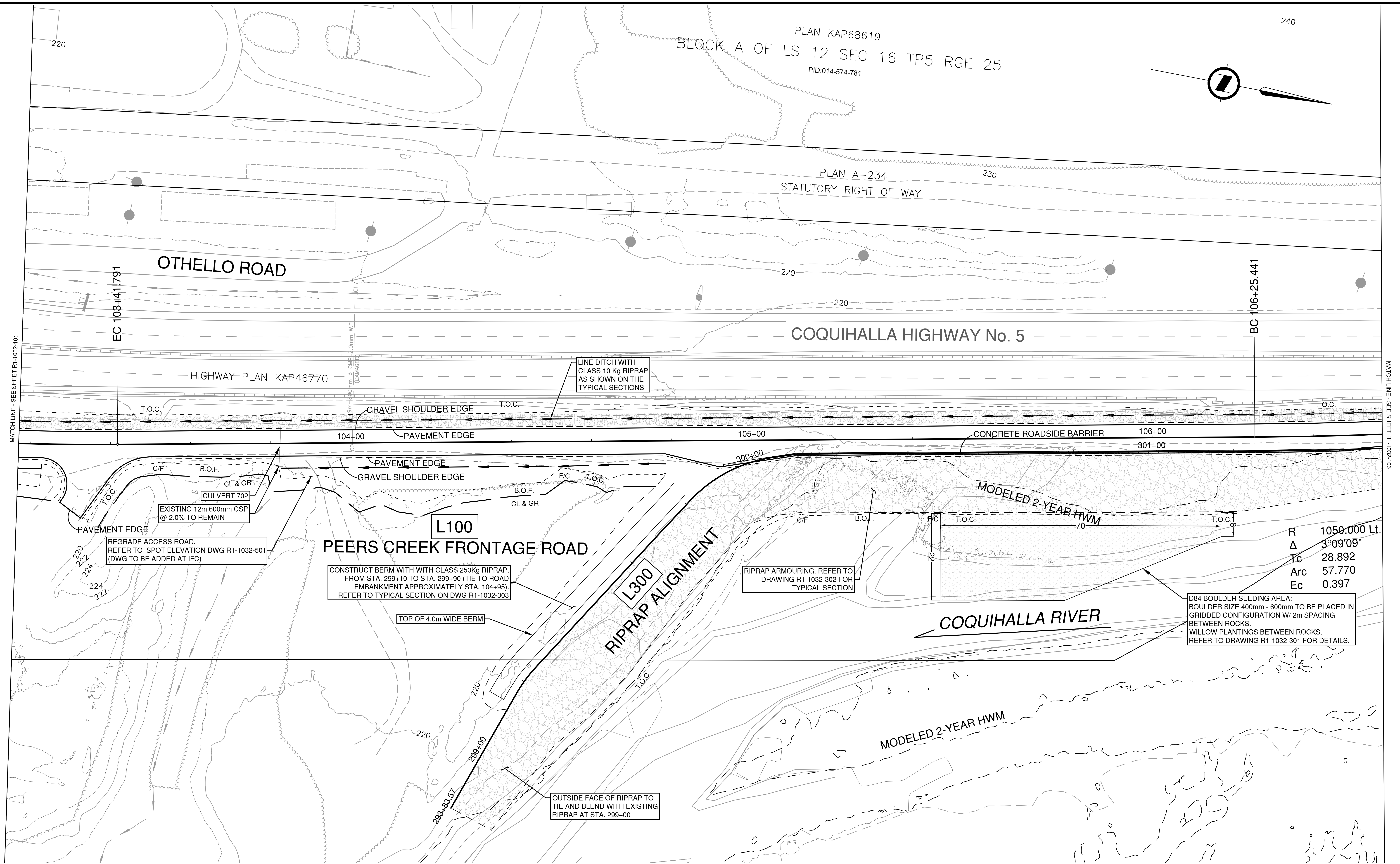
STA. 100+00.000 TO 103+20.000

N. GUARAN P. ENG.
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
2121-00865-15	14092-0000	1	R1-1032-101	C

PLOT DATE: 2023/05/15 X:\2121\2121-00865-15 MoTI - Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\100_Plans\R1-1032-100.dwg

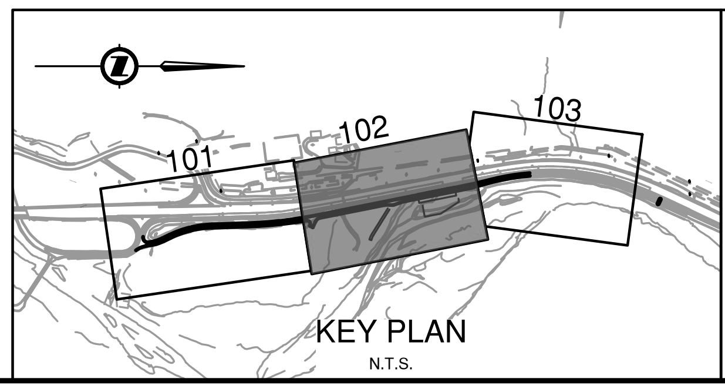


ALIGNMENT	CLASSIFICATION	DESIGN SPEED
L100	RLU	30 km/h

REFERENCE DRAWINGS

FOR PROFILE SEE DWG. R1-1032-202
FOR TYPICAL SECTIONS SEE DWG. R1-1032-301 TO 302
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-402
FOR CROSS SECTIONS SEE DWG. R1-1032-1001 TO 1006

FOR DISCUSSION ONLY



KEY PLAN
N.T.S.

PERMIT TO PRACTICE

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SCALE 0 5 1:500 25m

CAD FILENAME R1-1032-100
PLOT DATE 2023-05-09

REV	DATE	REVISIONS	NAME
C	2023-05-12	100% DETAILED DESIGN	N. GUARAN
B	2023-03-06	FOR REGULATORY APPROVAL	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

BRITISH COLUMBIA

MINISTRY OF TRANSPORTATION
AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

PLAN

PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY

STA. 103+20.000 TO 106+60.000

N. GUARAN P. ENG.
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
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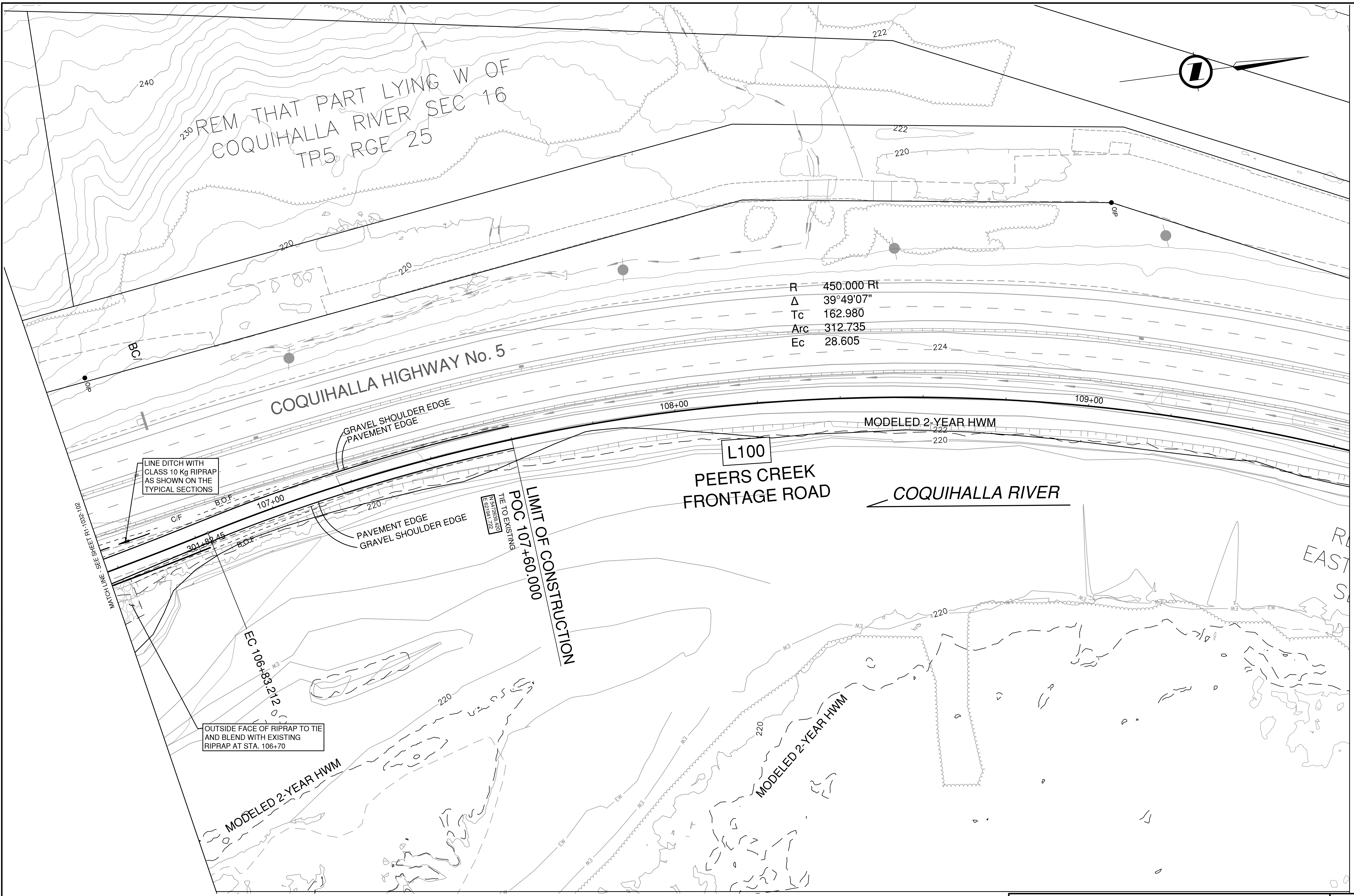

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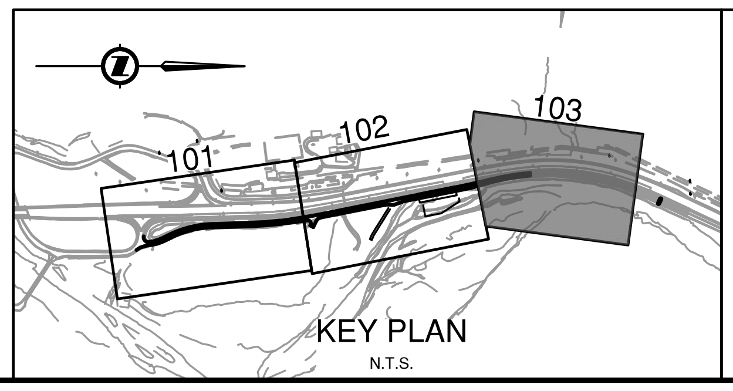
ALIGNMENT	CLASSIFICATION	DESIGN SPEED
L100	RLU	30 km/h

REFERENCE DRAWINGS

FOR PROFILE SEE DWG. R1-1032-202
FOR TYPICAL SECTIONS SEE DWG. R1-1032-301 TO 303
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-403
FOR CROSS SECTIONS SEE DWG. R1-1032-1001 TO 1006

FOR DISCUSSION ONLY



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SCALE 0 5 1:500 25m

CAD FILENAME R1-1032-100
PLOT DATE 2023-05-09

REV	DATE	REVISIONS	NAME
C	2023-05-12	100% DETAILED DESIGN	N. GUARAN
B	2023-03-06	FOR REGULATORY APPROVAL	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

BRITISH COLUMBIA

MINISTRY OF TRANSPORTATION
AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

PLAN

PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY

STA. 106+60.000 TO 107+60.000

N. GUARAN P. ENG.
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
2121-00865-15	14092-0000	1	R1-1032-103	C

FOR DISCUSSION ONLY

REFERENCE DRAWINGS

FOR PLAN SEE DWG. R1-1032-101
FOR TYPICAL SECTIONS SEE DWG. R1-1032-301
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-401
FOR CROSS SECTIONS SEE DWG. R1-1032-1001 TO 1005

PERMIT TO PRACTICE

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SCALE 0 10 H 1:1000 50m
0 1 V 1:100 5m

CAD FILENAME R1-1032-200
PLOT DATE 2023-05-16

REV	DATE	REVISIONS	NAME
B	2023-05-12	100% DETAILED DESIGN	N. GUARAN
A	2022/10/27	50% DETAILED DESIGN	N. GUARAN

BRITISH COLUMBIA

MINISTRY OF TRANSPORTATION
AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

PROFILE

PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY

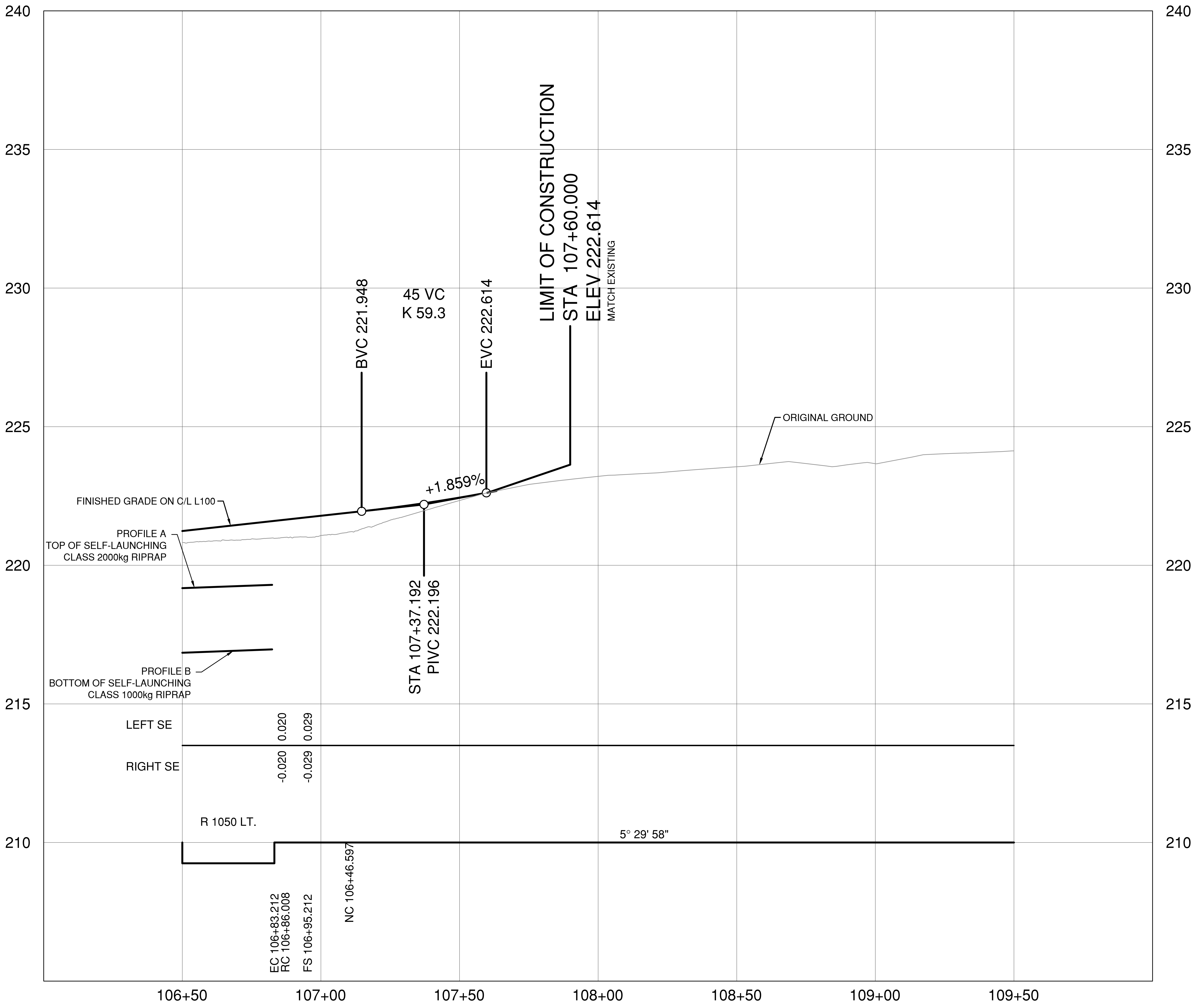
STA. 100+00.000 TO 106+60.000

N. GUARAN P. ENG
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
2121-00865-15	14092-0000	1	R1-1032-201	B

PLOT DATE: 2023/05/16 X:\2121\2121-00865-15 MoTI - Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\200_Profiles\R1-1032-200.dwg



FOR DISCUSSION ONLY

REFERENCE DRAWINGS

FOR PLAN SEE DWG. R1-1032-103
FOR TYPICAL SECTIONS SEE DWG. R1-1032-301
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-403
FOR CROSS SECTIONS SEE DWG. R1-1032-1001 TO 1006

PERMIT TO PRACTICE
McElhanney Ltd.
PERMIT NUMBER: 1003299
Engineers and Geoscientists
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Tel 604 683 8521

SCALE 0 10 H 1:1000 50m
0 1 V 1:100 5m

CAD FILENAME R1-1032-200
PLOT DATE 5/16/2023

REV	DATE	REVISIONS	NAME
B	2023-05-12	100% DETAILED DESIGN	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION
AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

PROFILE

PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY

STA. 106+60.000 TO 109+50.000

N. GUARAN P. ENG
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
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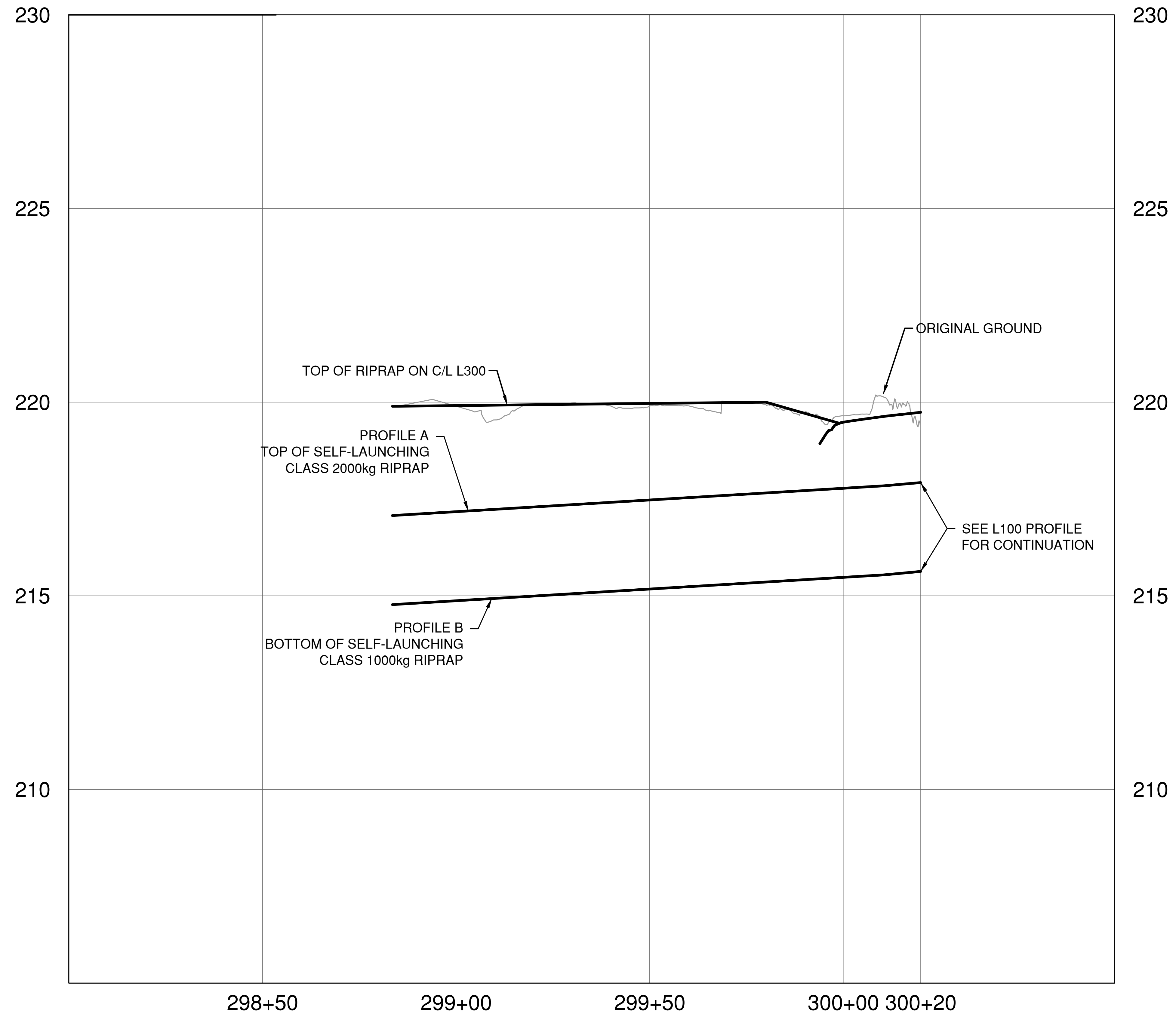

FOR DISCUSSION ONLY

REFERENCE DRAWINGS

FOR PLAN SEE DWG. R1-1032-103
FOR TYPICAL SECTIONS SEE DWG. R1-1032-301
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-403
FOR CROSS SECTIONS SEE DWG. R1-1032-1001 TO 1006

PERMIT TO PRACTICE

McElhanney Ltd.
PERMIT NUMBER: 1003299

Engineers and Geoscientists
of British Columbia

APPROVED SEAL

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858 Beatty Street
Vancouver BC
Canada V6B 1C1
Tel 604 683 8521

SCALE 0 10 H 1:1000 50m
0 1 V 1:100 5m

CAD FILENAME R1-1032-200
PLOT DATE 5/16/2023

REV	DATE	REVISIONS	NAME
B	2023-05-12	100% DETAILED DESIGN	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

BRITISH
COLUMBIA

MINISTRY OF TRANSPORTATION
AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

PROFILE

PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY

STA. 298+80 TO 300+20

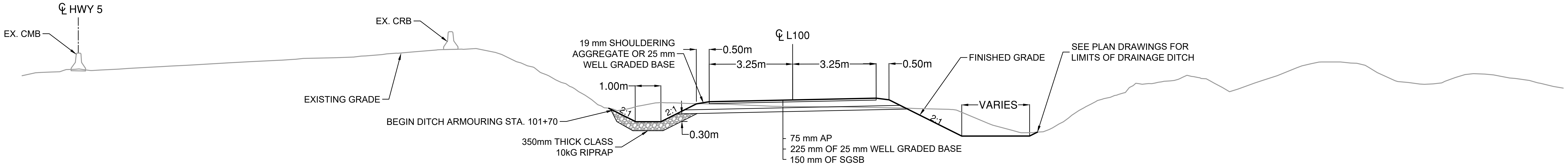
N. GUARAN P. ENG
ENGINEER OF RECORD

DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

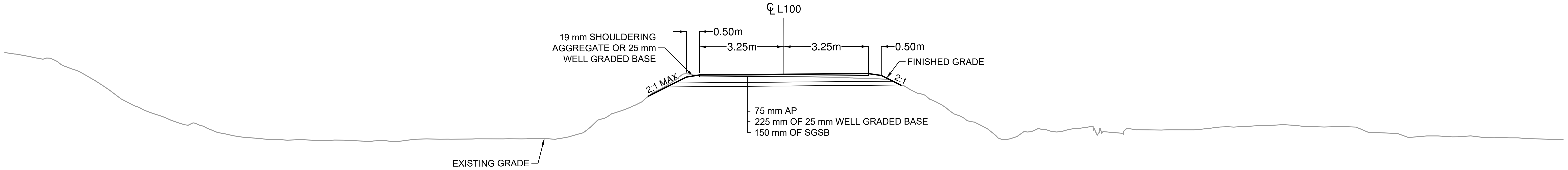
FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
2121-00865-15	14092-0000	1	R1-1032-203	B

PLOT DATE: 2023/05/16 X:\2121\2121-00865-15 MoTI - Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\200_Profiles\R1-1032-200.dwg



L100 - PEERS CREEK FRONTAGE ROAD

STA. 101+00 TO STA. 103+40
STA. 103+90 TO STA. 104+80



L100 - PEERS CREEK FRONTAGE ROAD

STA. 100+00 TO STA. 101+00

FOR DISCUSSION ONLY

REFERENCE DRAWINGS
FOR PROFILE SEE DWG. R1-1032-101 TO 103
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-401 TO 403

PERMIT TO PRACTICE
McElhanney Ltd.
PERMIT NUMBER: 1003299
Engineers and Geoscientists of British Columbia

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Tel 604 683 8521

SCALE 0 1 1:100 5m
CAD FILENAME R1-1032-300
PLOT DATE 2023-05-09

REV	DATE	REVISIONS	NAME
B	2023-05-12	100% DETAILED DESIGN	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

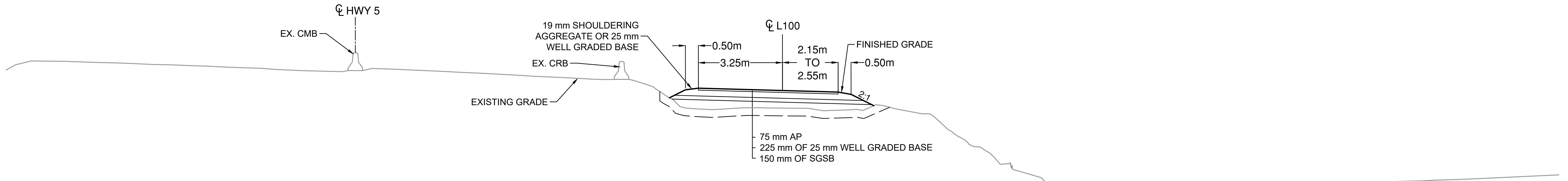
TYPICAL SECTIONS
PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY

N. GUARAN P. ENG
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

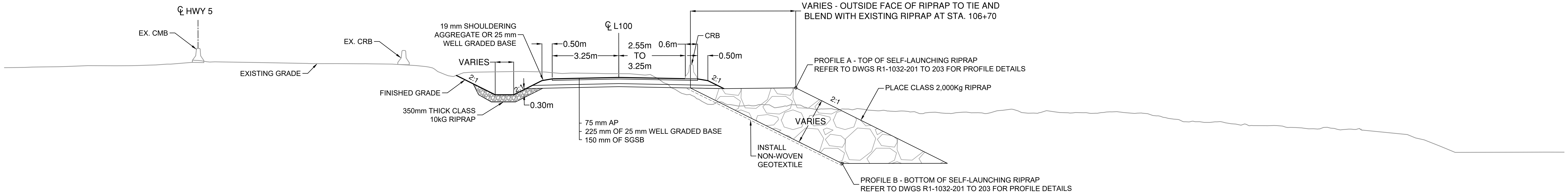
FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
2121-00865-15	14092-0000	1	R1-1032-301	B

PLOT DATE: 2023/05/12 X:\2121\2121-00865-15 MoTI - Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\300_TypicalSections\R1-1032-300.dwg



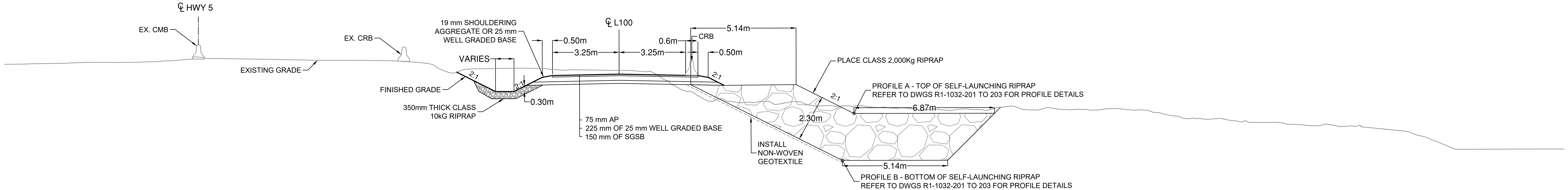
L100 - PEERS CREEK FRONTAGE ROAD

STA. 106+70 TO STA. 107+60



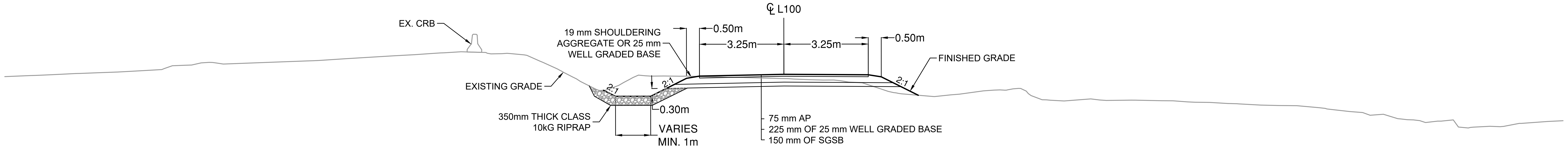
L100 - PEERS CREEK FRONTAGE ROAD

STA. 106+30 TO STA. 106+70



L100 - PEERS CREEK FRONTAGE ROAD

STA. 104+80 TO STA. 106+30



L100 - PEERS CREEK FRONTAGE ROAD

STA. 103+40 TO STA. 103+90

FOR DISCUSSION ONLY

REFERENCE DRAWINGS

FOR PLAN SEE DWG. R1-1032-101 TO 103
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-401 TO 403

PERMIT TO PRACTICE
McElhanney Ltd.
PERMIT NUMBER: 1003299
Engineers and Geoscientists of British Columbia

APPROVED SEAL

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BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

SCALE 0 1 1:100 5m
CAD FILENAME R1-1032-300
PLOT DATE 5/15/2023

REV	DATE	REVISIONS	NAME
B	2023-05-12	100% DETAILED DESIGN	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

TYPICAL SECTIONS

PEERS CREEK FRONTAGE RD
WASHOUT RECOVERY

N. GUARAN P. ENG
ENGINEER OF RECORD
DATE 2023-05-12

DESIGNED T.PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
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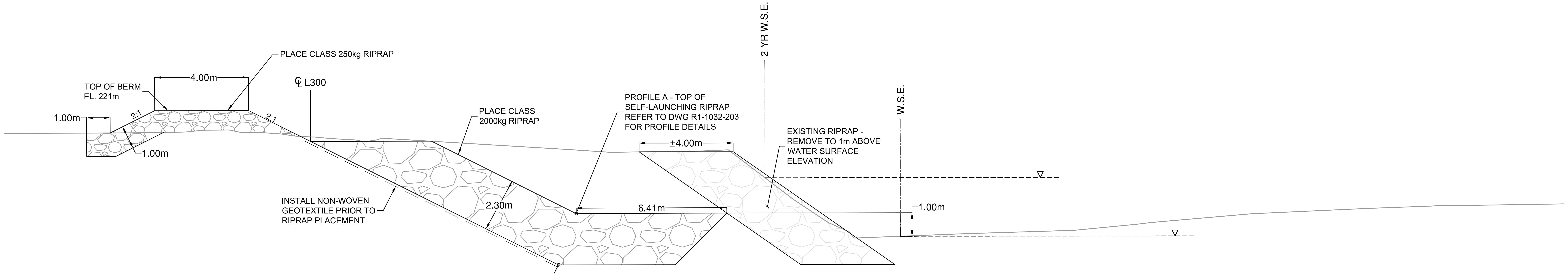
PLOT DATE: 2023/05/15 X:\2121\2121-00865-15 MoTI - Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\300_TypicalSections\R1-1032-300.dwg

PLOT DATE: 2023/05/15 X:\2121\2121-00865-15 MoTI - Peers Creek Frontage Rd\10.0 DRAWINGS\10.3 Engineering\PeersCreek\DrawingProduction\300_TypicalSections\R1-1032-300.dwg



L300 - RIPRAP REVETMENT
STA. 298+90 TO STA. 299+80
(FROM L300 STA. 299+80, REFER TO L100 STA. 104+80)

FOR DISCUSSION ONLY

REFERENCE DRAWINGS
FOR PLAN SEE DWG. R1-1032-101 TO 103
FOR GEOMETRICS AND LANING SEE DWG. R1-1032-401 TO 403

PERMIT TO PRACTICE

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BRITISH COLUMBIA

MINISTRY OF TRANSPORTATION
AND INFRASTRUCTURE
SOUTH COAST REGION
HIGHWAY ENGINEERING AND GEOMATICS

SCALE 0 1 1:100 5m

CAD FILENAME R1-1032-300
PLOT DATE 2023-05-09

REV	DATE	REVISIONS	NAME
B	2023-05-12	100% DETAILED DESIGN	N. GUARAN
A	2022-10-27	50% DETAILED DESIGN	N. GUARAN

TYPICAL SECTIONS
PEERS CREEK FRONTAGE ROAD
WASHOUT RECOVERY

N. GUARAN P. ENG
ENGINEER OF RECORD

DATE 2023-05-12

DESIGNED T. PETTET DATE 2023-05-12
QUALITY CONTROL N. GUARAN DATE 2023-05-12
QUALITY ASSURANCE R. BEDARD DATE 2023-05-12
DRAWN K. MADRIGAL DATE 2023-05-12

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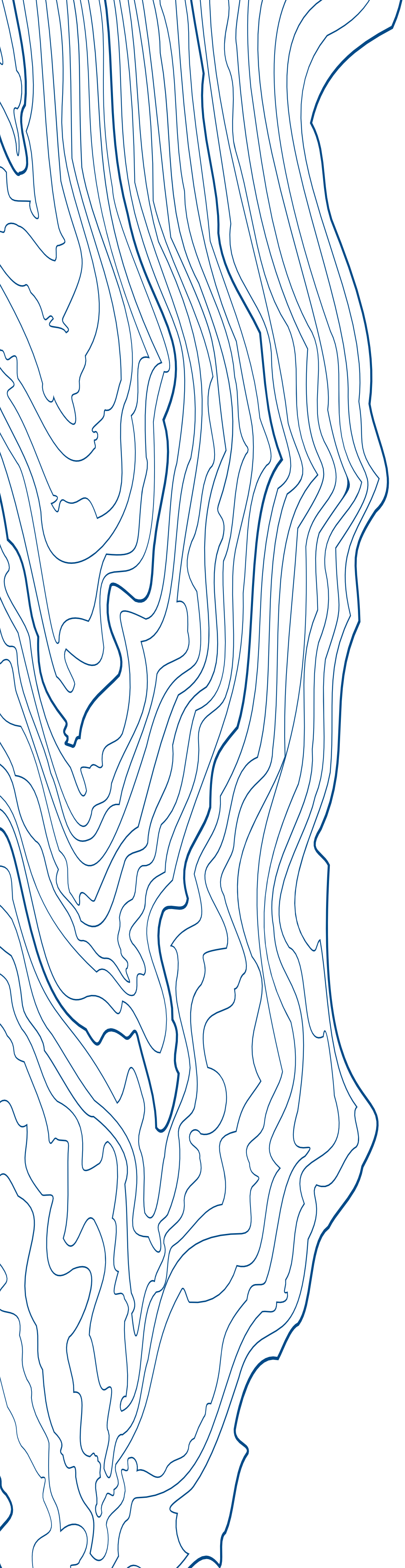
APPENDIX B – BGC HYDROTECH REPORT



BGC

Peers Creek

Hydrotechnical Assessment and Design for Peers Creek Frontage Road Washout Site

Prepared by BGC Engineering Inc. for:

BC Ministry of Transportation and Infrastructure

May 23, 2023

Project 0272097

Pioneering responsible solutions to complex earth science challenges

May 23, 2023 Project 0272097

BC Ministry of Transportation and Infrastructure
310-1500 Woolridge Street
Coquitlam, BC V3K 0B8

Attention: Mr. Chung, P.Eng.

Hydrotechnical Assessment and Design for Peers Creek Frontage Road Washout Site

Please find the above referenced report attached. We appreciate the opportunity to collaborate with you on this challenging and interesting project.

Should you have any questions, please do not hesitate to contact the undersigned.

Yours sincerely,

BGC Engineering Inc.
per:

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EXECUTIVE SUMMARY

Flooding on the Coquihalla River in November 2021 caused extensive erosion and damage to infrastructure throughout the river valley, including washouts of Peers Creek Frontage Road (PCFR) near Hope, British Columbia (BC). BC Ministry of Transportation and Infrastructure (MoTI) retained BGC Engineering Inc. (BGC) to provide hydrotechnical engineering support for the reinstatement of PCFR.

BGC completed a detailed hydrological assessment to support design of the road and associated erosion protection. Analysis by BGC suggested that the Water Survey of Canada hydrometric gauge located nearest to the PCFR washout site may have malfunctioned during the November 2021 flood event and failed to capture its full magnitude. To estimate the magnitude of the November 2021 peak flow at the project site, BGC prepared a two-dimensional (2D) hydraulic model and calibrated the modeled water surface elevation to high water marks approximated from post-flood orthoimagery and aerial photographs. A peak flow was estimated by BGC to be approximately 900 m^3/s. The estimated peak flow was used to support flood frequency analysis (FFA) to update flood quantiles at the project site. As the Coquihalla River is subject to both snowmelt- and atmospheric river-related flood events, BGC applied a dual maximum series approach to the FFA.

A climate change assessment was completed using streamflow projections from the Pacific Climate Impacts Consortium (PCIC) to develop a climate change-adjusted FFA. BGC estimated trends in peak flows due to changes in atmospheric rivers and snowmelt independently and then combined the two processes to create an ensemble climate-adjusted model. A 69% increase in the 200-year flood magnitude is predicted within a 75-year timeline extending to 2097. The design flood event, defined by MoTI as the 200-year return period climate adjusted peak flow, was estimated to be 1,813 m^3/s at the project site.

During the detailed design phase, additional 2D hydraulic modelling was conducted to estimate design flood hydraulics for the proposed revetment configuration and to reflect instream works that had been completed by MoTI (for the reconstruction of Highway 5). Based on the modelling results, overtopping of the road is predicted to occur over most of PCFR within the project area. As overtopping of PCFR is also predicted to occur in areas outside of the project area, MoTI ultimately confirmed that overtopping of the reconstructed road is acceptable during the design flood event.

The proposed riprap revetment along PCFR spans an approximate length of 300 m along the previously washed-out section of the road and extending downstream along the natural bankline. The revetment will be constructed along the PCFR embankment at a 2H:1V slope. A launching apron is incorporated into the toe of the revetment to minimize excavation depths during construction. High design velocities estimated throughout the project reach necessitate the use of 2000 kg Class riprap for the majority of the revetment.

TABLE OF REVISIONS

Date	Revision	Remarks
April 12, 2023	0	Draft report
May 23, 2023	1	Final report

CREDITS AND ACKNOWLEDGEMENTS

This work was a collaborative effort conducted by several qualified subject matter experts, each of whom take responsibility for specific technical components and sections of this report. Responsible authors and relevant sections are listed below.

- Evan Shih, M.Eng., P.Eng.: Hydrotechnical assessment and design
- Melissa Hairabedian, M.Sc., P.Geo.: Hydrology and climate change assessment
- Sarah Davidson, Ph.D., P.Geo.: Geomorphic assessment

In addition, technical review was conducted by:

- Robert Millar, Ph.D., P.Eng., P.Geo.: Hydrotechnical assessment and design, geomorphic assessment
- Hamish Weatherly, M.Sc., P.Geo.: Hydrology and climate change assessment

BGC would like to acknowledge the following additional contributors to this report:

- Kenneth Lockwood PhD., P.Eng., Intermediate Hydrotechnical Engineer
- Steven Brazda, M.Sc., EIT, Engineer in Training
- Steven Rintoul, EIT, Engineer in Training
- Martin Devonald, M.Sc., P.Eng., Principal Geotechnical/Geological Engineer

LIMITATIONS

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1.0 INTRODUCTION

Flooding on the Coquihalla River in November and December 2021 caused extensive erosion and damage to infrastructure throughout the river valley, including the washout of Peers Creek Frontage Road (PCFR) near Hope, British Columbia (BC) (Figure 1-1 and Figure 1-2). The PCFR washout occurred during two separate flood events:

- November 15-16, 2021: the Coquihalla River eroded through PCFR and removed a small section of Highway 5. The river also avulsed along a portion of PCFR (Figure 1-2a).
- November 28-December 2, 2021: the Coquihalla River eroded further into Highway 5 upstream of the avulsion. The river also avulsed along the original mid-November avulsion path but continued further south, re-entering the mainstem of the Coquihalla River near the Peers Creek Highway 5 Bridge (Figure 1-2b).

BGC Engineering Inc. (BGC) is pleased to provide this document to the BC Ministry of Transportation and Infrastructure (MoTI) presenting our design basis for the hydrotechnical components of the PCFR recovery works. BGC is also providing engineering support to MoTI for recovery works at the Othello Road Washout and Site C project sites (Figure 1-1).

1.1 Project Scope

The scope of the work described in this report includes:

- An overview of the site hydrology and geomorphology (Section 2.0).
- Hydraulic modelling of the Coquihalla River at PCFR (Section 3.0).
- Hydrotechnical design of riprap bank protection along PCFR (Section 4.0).

This report should be read in conjunction with detailed design drawings produced by MoTI's road design and project management consultant, McElhanney Consulting Services Ltd. (McElhanney). BGC has also provided support for geotechnical aspects of the road design, which are discussed under a separate cover (BGC, November 2, 2022).

All work has been completed under the existing As & When Geotechnical Engineering and Design Services contract (Contract No. 861CS1183) between BGC and MoTI, dated September 16, 2021.

Figure 1-1. Site location map (Google Satellite imagery dated July 30, 2022).

Figure 1-2. **Photographs from a) November 17, 2021 and b) December 2, 2021 showing the erosion and avulsion at Peers Creek Frontage Road.**

Introduction Summary

The November 2021 floods caused extensive damage to PCFR. The current report describes interim works that have been completed within the project area to date, and the hydrotechnical components of the long-term design for PCFR.

2.0 HYDROLOGY AND GEOMORPHOLOGY

2.1 Hydrologic Assessment

Two Water of Survey of Canada (WSC) hydrometric gauges record real-time discharge on the Coquihalla River in the vicinity of the PCFR washout site. Gauge 08MF062 (*Coquihalla River below Needle Creek*) is located approximately 28 km upstream (northeast) from the washout site and Gauge 08MF068 (*Coquihalla River above Alexander Creek*) is located approximately 8 km downstream (southwest). Details for these gauges are provided in Table 2-1.

Table 2-1. WSC hydrometric station information.

Station Name	**Coquihalla River below Needle Creek**	**Coquihalla River above Alexander Creek**
Station ID	08MF062	08MF068
Real Time Gauge	Yes	Yes
Latitude	49° 32' 30" N	49° 22' 06" N
Longitude	121° 07' 11" W	121° 23' 04" W
Drainage Area (km^2)	85.5	720
Record Period	1965-2022	1985-2022
Record Length (complete years of data)	47	26
Regulation Type	Unregulated	Unregulated
Location with Respect to Project Site	28 km upstream	8 km downstream

Based on provisional data, the gauges recorded two flood peaks in November. The first peak was recorded on November 14-15, 2021, and the second on November 28, 2021. The November 14-15 flood peak was the largest flood on record for gauge 08MF062 and the third largest flood on record for gauge 08MF068, which has been in operation since 1985 (Figure 2-1).

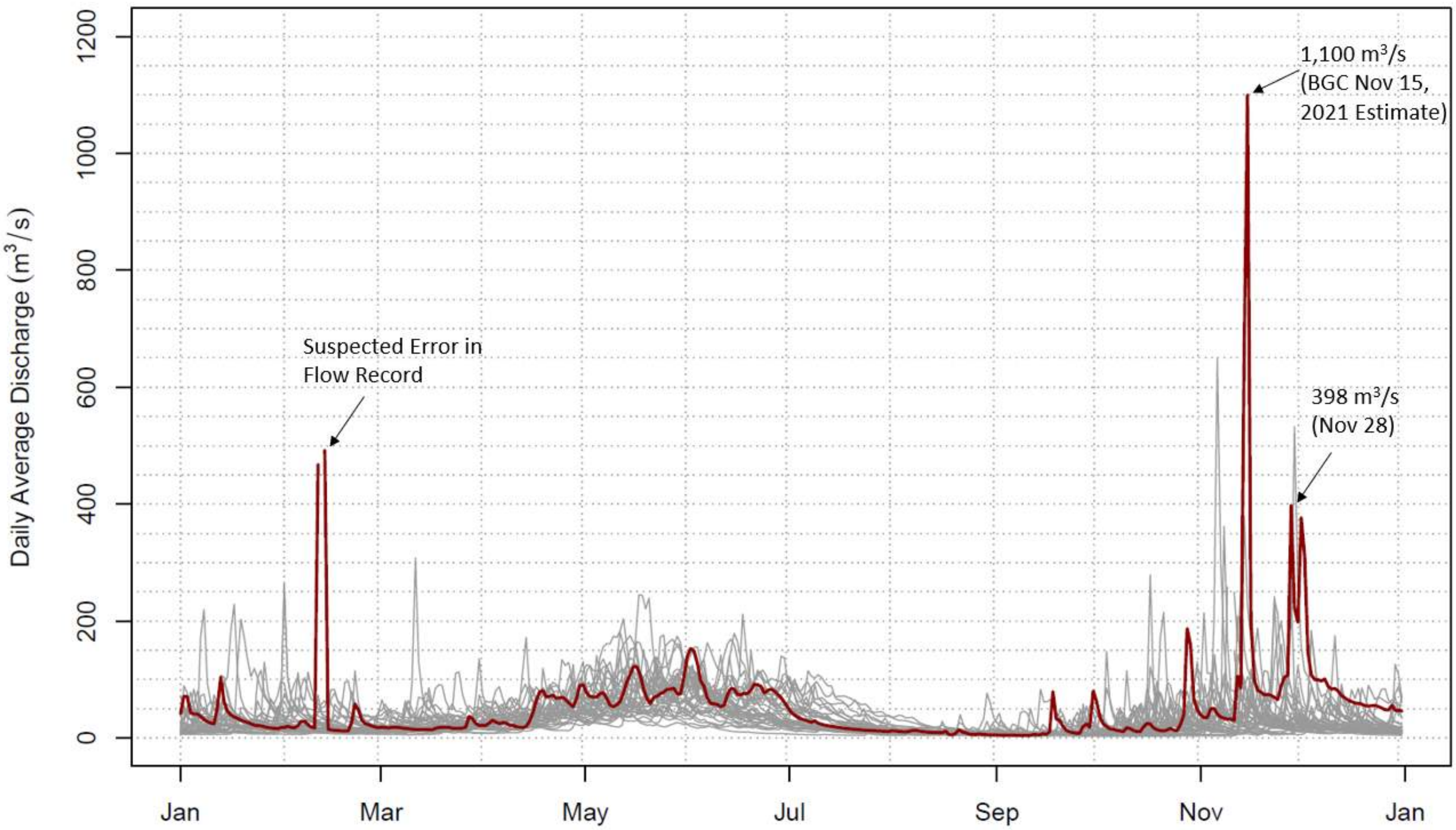

Figure 2-1. Daily flows at gauge 08MF068 from 1981 to 2020 (grey), which is located 8 km downstream of the PCFR washout site. Provisional daily flows for 2021 are shown in dark red and include BGC's estimated value of 1,100 m^3/s for November 15, 2021. The peaks recorded in February 2021 are suspected to be an error in the provisional data as the temperature was below freezing from February 11-13 and precipitation fell as snow.

Analysis by BGC suggests that gauge 08MF068 likely malfunctioned during the November 14-15 flood and underreported the full flood peak. BGC used the following approach to estimate flood magnitudes for a range of return periods at the PCFR project site[1]:

- Develop a two-dimensional (2D) hydrodynamic model for the reach using HEC-RAS (Hydrologic Engineering Center – River Analysis System) version 6.3, a publicly available software package developed and distributed by the U.S. Army Corps of Engineers (USACE). The model was first used to estimate the November 14-15 flood discharge at the nearby Othello Road washout site by matching the modeled water surface elevation to high water marks approximated from post-flood orthoimagery and aerial photographs (BGC, February 6, 2023). This resulted in a peak flow estimate of 900 m^3/s at the Othello Road washout site (which corresponds to a flow of 850 m^3/s at the PCFR washout site). Further discussion on development of the hydraulic model is provided in Section 3.0.
- Prorated the estimated November 14-15 peak flood discharge from the Othello Road washout site to gauge 08MF068 using Equation 2-1:

$$\frac{Q_1}{Q_2} = \left(\frac{A_1}{A_2}\right)^n \quad \text{[Eq. 2-1]}$$

  where n is a proration coefficient, Q_1 and Q_2 are the discharge at the gauge 08MF068 and the Othello Road washout site (900 m^3/s), and A_1 and A_2 are the drainage area at the gauge (720 km^2) and the Othello Road washout site (602 km^2). BGC used a proration coefficient (n) of 1.1 based on the observed relationship between gauges 08MF062 and 08MF068 during historical fall and winter peak flows. This produced an estimated peak flow of 1,100 m^3/s at gauge 08MF068 during the November 14-15 flood (Figure 2-1).
- Used the extended dataset for gauge 08MF068 (i.e., including the estimated November 14-15 peak flow) to update the flood frequency analysis (FFA) for the gauge. As the Coquihalla River is subject to both snowmelt- and atmospheric river-related flood events, BGC applied a dual maximum series approach to the FFA (Appendix A). The estimated November 14-15 peak flow of 1,100 m^3/s at gauge 08MF068 has a return period of approximately 90 years (Table 2-2).
- Used streamflow projections from the Pacific Climate Impacts Consortium (PCIC), based on six Global Climate Models (GCMs), to develop a climate change-adjusted FFA. BGC estimated trends in peak flows due to changes in atmospheric rivers and snowmelt independently and then combined the two processes to create an ensemble climate-adjusted model. The atmospheric river-driven peak flows are expected to increase rapidly later in the century, resulting a 69% increase in the 200-year (i.e., 0.5% annual exceedance probability) flood magnitude within a 75-year timeline extending to 2097 (Table 2-2).

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[1] Hydrologic assessment for the PCFR project site was preceded by similar assessment and design work completed for the Othello Road washout site located approximately 4 km downstream. The November 2021 flood peak discharge estimated at the Othello Road washout site was used to extend the flood record at gauge 08MF068 for the FFA. Flood quantiles were then prorated from gauge 08MF068 to the PCFR project site.

- Prorated the climate change adjusted flows to the PCFR project site

Detailed discussion on the estimation of flood magnitudes in the Coquihalla River are provided in Appendix A. A MoTI Design Criteria Sheet for Climate Change Resilience is provided at the end of Appendix A. The climate change-adjusted 200-year return period peak flow estimate has been selected by MoTI as the ‘design’ event for the hydrotechnical design of PCFR.

Table 2-2. Peak flow estimates for a range of return periods at gauge 08MG068 and the PCFR washout site.

Return Period	Stationary Flow		Climate Change-Adjusted Flow	
	Gauge 08MF068 (m^3/s)	PCFR Washout Site (m^3/s)	Gauge 08MF068 (m^3/s)	PCFR Washout Site (m^3/s)
2	240	190	310	240
5	395	305	615	475
10	540	420	865	670
20	700	500	1,140	880
50	930	720	1,555	1,200
100	1,135	880	1,920	1,485
200	1,380	1,070	2,345	1,815
500	1,785	1,380	3,035	2,345

2.2 Geomorphic Assessment

The Coquihalla River has a low sinuosity meandering to wandering planform in the vicinity of the PCFR site. The river contains a mid-channel island and large exposed bars composed of gravel- to boulder-sized sediment. Wandering rivers are transitional between more stable meandering rivers and highly unstable braided rivers and are susceptible to sudden widening, lateral shifting, and avulsion during flood events (Rice, Church, Woolridge, & Hickin, 2009). Wandering planforms typically develop in aggrading environments with coarse bedload, as the banks lack cohesion and the wide and shallow channel promotes avulsion (Desloges & Church, 1989).

The November 2021 flood events caused extensive bank erosion at the PCFR site; bank erosion was the primary mechanism for damage to infrastructure within the project area. BGC used historical air photographs, satellite imagery, orthoimagery, and lidar to characterize historical geomorphic change within a 1.5 km-long erosion assessment reach that encompasses the project area using imagery from 1968 to December 2021 (Table 2-3).

Table 2-3. Air photographs, satellite imagery, and lidar used to assess geomorphic change along the Coquihalla River within the 1.5 km-long erosion assessment reach.

Year[1]	Type	Flight Line	Frame	Scale	Source
1968	Air Photo	BC5286	170, 174-176	1:24000	Government of BC
2015	Satellite Imagery	-	-	-	ESRI World Imagery
2021	Orthoimagery (Nov 19, 2021)	-	-	-	McElhanney
2021	Lidar (April 20, 2022)	-	-	-	McElhanney

1. All photo years cover the 3.5 km-long erosion assessment reach. Imagery from 1968, 2015/2016 (combined), and lidar from 2021 covers the entire 6.1 km-long reach shown in Figure 2-2, which includes the landslide upstream from the Peers Creek Highway 5 Bridge.

BGC delineated the channel banks and islands throughout the 1.5 km-long erosion assessment reach for the three years using GIS software (Figure 2-2). The measurement error associated with the channel mapping estimated to be ±5 m. Between 1968 and 2021, the sinuosity of the Coquihalla River generally increased at the PCFR site.

For this qualitative assessment, the reach was split into two sections herein referred to as the “Upstream Section” and “Landslide Section”. The Upstream Section encompasses a section of the project reach where the river flows directly alongside the PCFR. In this section the river bend migrated downstream (south) by approximately 50 m to 100 m from 1968 to 2015 (Figure 2-2). In 1968, the main stem of the river in the upstream section was located on the left (east) side of the floodplain and a side channel was present on the right (west) side of the floodplain. Between 1968 and 2015, the main stem of the river migrated west toward the right side of the floodplain and occupied the historical side channel (Figure 2-2). Following construction of Highway 5 in the mid 1980s the progression of the eroding right bank was limited by the riprap armouring placed along PCFR. By 2015 the east side of the floodplain had become vegetated, with only a small side channel present.

Within the Upstream Section the 2021 flood event damaged the riprap along the PCFR (and Highway 5) as the river eroded toward the west. The damage was enhanced by the avulsion along the PCFR south of the washed-out section of the road and parallel to Highway 5 (Figure 2-2). The side channel along the east side of the floodplain was reactivated and enlarged during the flood event but did not convey the majority of the flow (Figure 1-2). The vegetated mid-channel bar remained intact through the flood event.

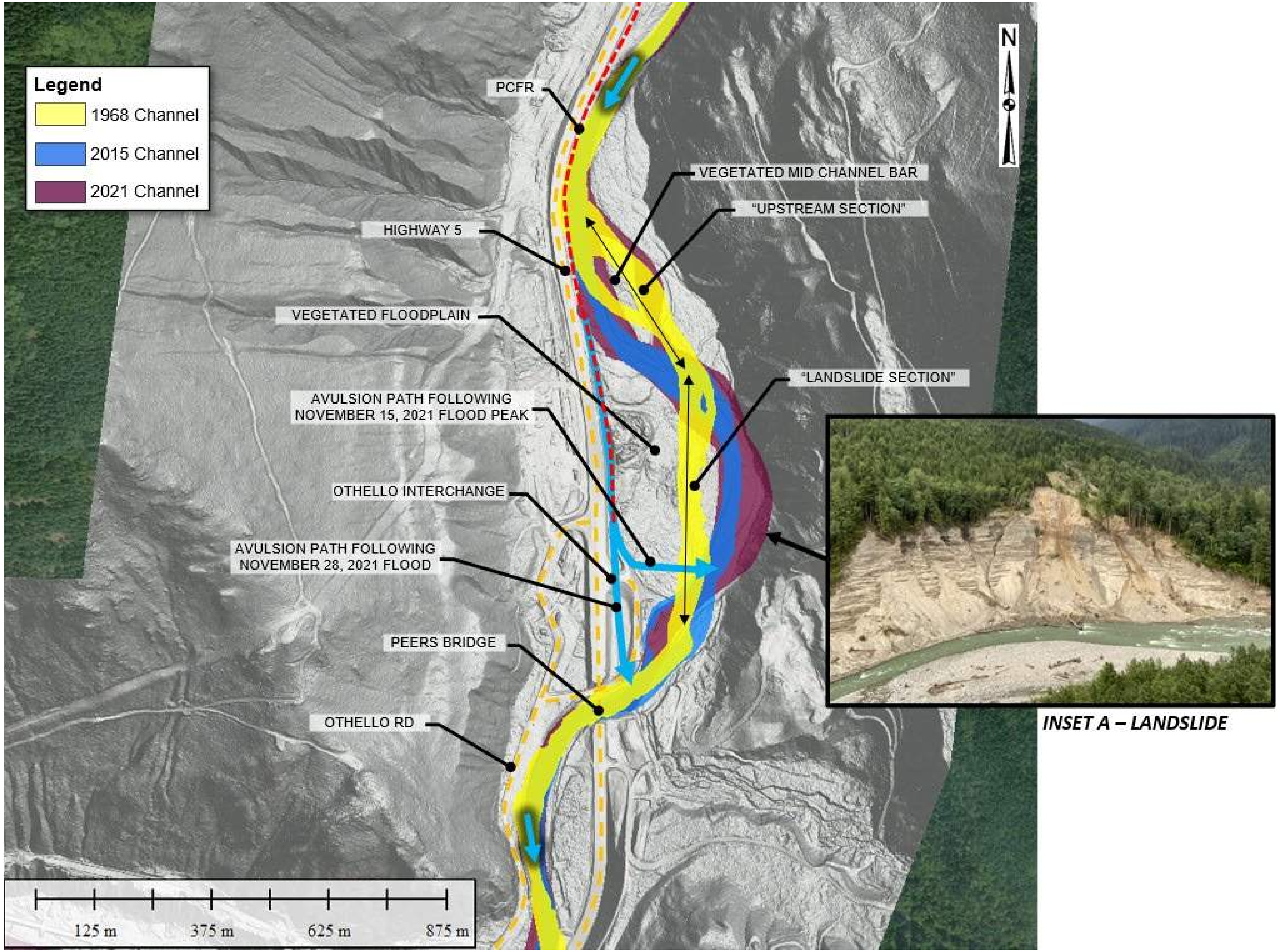

Figure 2-2. Overview of the PCFR project reach. Inset A photograph taken by BGC on June 21, 2022. Base imagery source is ESRI (August 11, 2015) overlain with post-flood lidar obtained by McElhanney (April 22, 2022).

The Landslide Section is located immediately downstream from the Upstream Section, where the river diverges from the PCFR and flows along the eastern side of the floodplain. In the Landslide Section, the river migrated to the east by approximately 85 m between 1968 and 2015, abutting against the toe of the east valley slope (Figure 2-2). During the 2021 flood events the east bank eroded an additional 110 m to the east, destabilizing the valley side and triggering the landslide (Inset A, Figure 2-2). It is suspected that the majority of this erosion occurred during the mid-November 2021 flood event and that partial blockage of the river by the deposited landslide material contributed to the avulsion along the PCFR during the subsequent flood, as the majority of the avulsion occurred during the late-November event (Figure 1-2 and Figure 2-2). The Coquihalla River is confined both up- and downstream from the erosion assessment reach and did not migrate significantly between 1968 and 2021.

In the future erosion could progress in a similar pattern to the observed erosion from 1968 to 2021, with the reach sinuosity increasing as the river erodes toward the west in the Upstream Section and toward the east in the Landslide Section, triggering additional landslide activity. However, armouring along the PCFR and Highway 5 is likely to limit erosion toward the west . Alternatively, flow may increasingly occupy the side-channel along the east side of the floodplain in the Upstream Section (similar to the 1968 configuration in Figure 2-2). This shift has the potential to reduce velocities along the PCFR and could also reduce the potential for landslide activation in the future by directing flow at a less severe angle toward the toe of the landslide.

Climate change may also change the erosion potential in the future; at the downstream Othello Road reach BGC predicted that erosion could increase by 100 m (to 160 m) during a 200-year flood event due to a large increase in the 200-year flood magnitude (BGC, February 6, 2023). Erosion magnitude at the PCFR site is likely to be similar.

However, the potential effects of climate change on geomorphologic processes are complex as changes in hydrology may impact the long-term width of the Coquihalla River as well as the frequency and magnitude of erosion events. As flood magnitude and year-to-year variability increase there is likely to be an increase in the average width of the many rivers (e.g., Davidson & Eaton, 2018; EGBC, 2020; Mauger et al., 2021; Eaton & Davidson, 2022). Modelling for rivers in the Fraser River basin for example showed a 25% increase in mean (long-term) river width in the period from 2055-2094 relative to a baseline period from 1955-1994, as well as less frequent (but higher magnitude) bank erosion (Davidson et al., 2019).

Hydrology and Geomorphology Summary

BGC estimated a peak flood discharge of 850 m^3/s for the November 14-15, 2021 flood event at the PCFR washout site, which corresponds to a discharge of 1,100 m^3/s at gauge 08MF068 (approximately a 90-year flood event). The Coquihalla River has been laterally active within the project area since 1968. Upstream of the Othello Interchange, the right (south) bank migrated 50-100 m between 1968 and 2015, and the November 2021 flood events caused additional erosion leading to a severe washout and avulsion along PCFR and Highway 5. Across the river from the Othello Interchange, the river migrated to the east by approximately 85 m between 1968 and 2015, abutting against the toe of the east valley slope, and then destabilized during the November 2021 flood events.

The selected design discharge of 1,813 m^3/s at the PCFR washout site or 2,345 m^3/s at gauge 08MF068 (i.e., the 200-year climate change-adjusted flow) is predicted to cause up to 160 m of erosion on average within the erosion assessment area based on the historical assessment. However, the potential effects of climate change on geomorphologic processes are complex as changes in hydrology may impact the long-term width of the Coquihalla River as well as the frequency and magnitude of erosion events. At the PCFR site a change in the channel configuration in the future (with more flow occupying the side channel) could also limit erosion and landsliding, reducing erosion in the future.

3.0 HYDRAULIC MODELLING OF COQUIHALLA RIVER AT PCFR

Flood hydraulics along the PCFR project reach of the Coquihalla River were evaluated using the 2D model that was initially developed to estimate the November 2021 flood peak flow at the Othello Road washout site (Section 2.1). The model results were used to: (i) simulate hydraulic conditions in the vicinity of the planned mitigation work for a range of flows (ii) assess inundation extents along the project reach, and (iii) estimate hydrotechnical design parameters.

The 2D model was developed using a digital elevation model (DEM) that combined bathymetric survey data collected by McElhanney from August 29-31 and September 16, 2022, with lidar data collected by McElhanney on April 22, 2022. The upstream model boundary was located approximately 1.5 km upstream of the project area. The downstream model boundary was set approximately 5 km downstream of the project area, just upstream of the Coquihalla River canyon. The parameters used in the 2D model simulations are summarized in Table 3-1.

Table 3-1 Parameters used for 2D hydrodynamic modelling using HEC-RAS.

Hydraulic Parameter	Value
Manning’s n roughness coefficient in the channel	0.035
Manning’s n roughness coefficient in the floodplain	0.1
Manning’s n roughness coefficient over roads	0.025
Slope at the downstream model boundary (m/m)	0.016
General mesh spacing (m)	25 m x 25 m
Grid spacing at breaklines (m)	5 m x 5 m
Model time step	Variable based on Courant condition

Insufficient information exists to calibrate the hydraulic model given that the November flood discharge was back-estimated and high-water marks were not surveyed. BGC matched the modelled inundation extents as closely as possible to the observed inundation extents and high-water marks from the November 14-15, 2021 flood peak at the Othello Road washout site by adjusting the downstream boundary location, the downstream model boundary slope, and the Manning’s n values (Table 3-1). The modelled inundation extents were then compared to observed inundation extents in the vicinity of the PCFR project site and also found to match well. Model results were used to inform hydrotechnical design recommendations for interim road repair works completed by Kiewit Corporation (Kiewit) from late fall 2022 through spring 2023 (Section 4.0), and detailed design of the long-term solution (Section 5.0).

Hydraulic Modelling Summary

Hydraulic modelling was completed to simulate hydraulic conditions along the PCRF project reach of Coquihalla River over a range of flows. Modelling results were used to inform hydrotechnical design recommendations for interim road repair works and detailed design of the long-term solution.

4.0 INTERIM CONSTRUCTION

Two phases of repair work have occurred at the PCFR project site since the November 2021 flood event:

Phase 1: Emergency repairs completed by MoTI to reinstate and protect Highway 5

Phase 2: Interim repairs along PCFR by Kiewit for the Trans Mountain Expansion Project

Emergency repairs were completed by MoTI in December 2021 involving temporary placement of riprap along the approximately 140 m washed-out section of PCFR to provide bank stabilization for Highway 5 (Figure 4-1and Figure 4-2). As the PCFR was not reinstated at this time, access along the along the road was provided through temporary offramps from Highway 5 north and south of the washout. An additional 170 m of riprap bank protection was installed along the natural bankline downstream of washout. Limited documentation of the emergency repairs is available. Based on visual inspection, BGC estimates that the installed riprap consisted of a range of sizes of approximately 500 kg Class and larger.

Figure 4-1. Looking downstream along emergency bank protection place on the right bank of the Coquihalla River. Photo Source: BGC, May 9, 2022

Figure 4-2. Overview of emergency repair extents along PCFR and Highway 5. Base Imagery Source: McElhanney, April 20, 2022

On September 30, 2022, Kiewit requested that MoTI's project team provide highway and hydrotechnical design recommendations to inform Kiewit's overall design of interim repairs to the road. The purpose of the interim repairs was to reinstate the road and provide construction access for the Trans Mountain Expansion Project until a long-term solution can be implemented by MoTI. BGC submitted a memo to MoTI that was subsequently shared with Kiewit titled "Preliminary Hydrotechnical Assessment for Interim Repairs of Peers Creek Frontage Rd" (BGC, October 25, 2022) (Appendix B). Given the interim nature of the repairs, and to allow Kiewit to reuse riprap previously installed during emergency repairs, MoTI selected the 10-year return period peak flow as the design flood. Based on a preliminary hydrotechnical analysis, BGC's recommendations for the interim repairs are summarized as follows:

- Ideally, the top elevation of the riprap revetment would be installed above the water surface elevation associated with the 10-year return period peak flow, although this may not be feasible given site constraints. Based on discussions with McElhanney and MoTI, BGC understands that overtopping of the revetment may be tolerated given that the interim works will repair the site to an improved condition.
- A minimum riprap size of 500 kg Class is required for hydraulic stability of the proposed riprap revetment. BGC has not estimated the gradation of riprap that was installed onsite immediately following the November 2021 flood. However, based on visual inspection, the riprap appeared to consist of a range of sizes of approximately 500 kg Class and larger. BGC understands that Kiewit will be repurposing existing riprap onsite to construct the temporary revetment. BGC recommends that a sorting of riprap onsite be completed to the extent possible such that the temporary revetment is constructed of 500 kg Class riprap or larger, while meeting the gradation specifications provided in Section 205 of the MoTI Standard Specifications (MoTI, 2020). The revetment should be constructed at slopes no steeper than 2H:1V and the minimum thickness of the riprap should align with the riprap size selected (i.e., if a larger class of riprap is used, it should match the corresponding thickness indicated in Table 205-D of MoTI (2020)).
- Geotextile filter fabric should be installed beneath all riprap to reduce the potential for migration of soil particles from the underlying insitu soils. Mirafi 1100N or equivalent is recommended and overlain with a 150 mm gravel bedding layer.
- The riprap revetment should be blended into the existing revetments upstream and downstream to provide smooth transitions, and keyed into the channel bed to an elevation of 216.0 m.

BGC and McElhanney completed a site visit of the interim repair works with Kiewit and their subcontractor Tuya Construction Ltd. (Tuya) on March 23, 2023. Although interim repairs were ongoing at the time of the site visit, the riprap bank protection had been fully installed. BGC’s site observations and understanding of the construction sequence, based on discussions with Tuya, are summarized as follows:

- Riprap previously installed during emergency repairs was reused. Riprap installed along the repaired road embankment was 500 kg Class and larger (Figure 4-3 and Figure 4-4).
- Some oversized rocks were relocated to the downstream end of the washout area where the riverbank departs from the road embankment towards the southeast (Figure 4-3 and Figure 4-4). At this location, the riprap size was estimated to be approximately 1000 kg Class.
- The riprap revetment was keyed into the riverbed to an elevation of 216.0 m. An additional approximately 5 m wide launching apron was incorporated along the toe of the revetment at elevation 216.0 m.
- Natural boulders and cobbles encountered during excavation were placed and spread along the river bar adjacent to the road (Figure 4-3 and Figure 4-4).
- Riprap (approximately 100 kg Class) was placed intermittently along both the PCFR and Highway 5 embankments towards the south end of the project extents near the Othello interchange (Figure 4-5 and Figure 4-6).

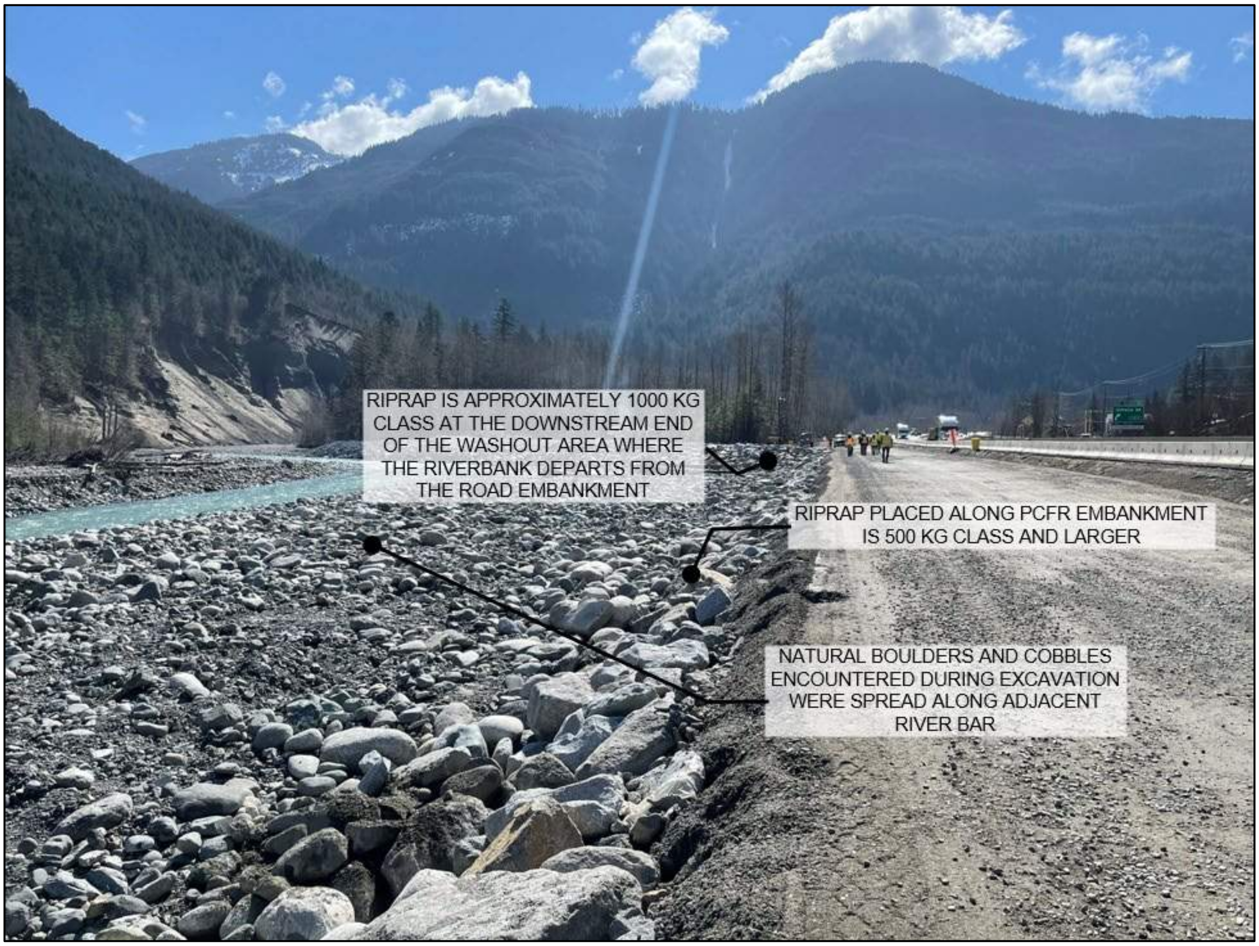

Figure 4-3. View of interim road repairs looking downstream (south). Photo Source: BGC, March 21, 2023.

Figure 4-4. View of interim road repairs looking upstream (north). Photo Source: BGC, March 21, 2023.

Figure 4-5. View of interim road repairs looking north near the Othello interchange. Photo Source: BGC, March 21, 2023.

Figure 4-6. **View of interim road repairs looking south near the Othello interchange. Photo Source: BGC, March 21, 2023.**

Interim Construction Summary

Interim construction within the PCFR project area has been completed in two phases: 1.) emergency repairs to reinstate and protect Highway 5 in December 2021 and 2.) interim repairs by Kiewit to provide access for the Trans Mountain Expansion Project from late fall 2022 to spring 2023.

5.0 DETAILED HYDROTECHNICAL DESIGN

5.1 Design Flood Event

The design flood adopted by MoTI for the PCFR project is the climate change-adjusted 200-year peak flow (1,815 m^3/s).

5.2 Hydrotechnical Design Components

The hydrotechnical design for PCFR consists of four main components as shown on Figure 5-1. These components have been developed in coordination with the MoTI project team and are summarized as follows:

- Riprap Revetment – A riprap revetment is proposed along the previously washed-out section of PCFR and extending downstream along the natural riverbank. Details regarding the sizing and configuration of the riprap revetment are provided in Section 5.5. A decision was made in coordination with the project team to avoid embedment of large wood directly into the riprap revetment as this could negatively impact its long-term integrity.
- Deflection Berm – An approximately 1 m high deflection berm is proposed near the downstream end of the riprap revetment. The purpose of the berm is to partially deflect flows from PCFR and Highway 5, which are predicted to overtop during design flood conditions (discussed further in Section 5.3). The berm will function to reduce inundation extents along PCFR and Highway 5, but not eliminate overbank flows in those areas. The berm is armoured with riprap and designed to be overtopped during the design flood event.
- Overbank Armouring (Ditch, Road Embankment and Knickpoint Armour) – As inundation of both PCFR and Highway 5 is anticipated during the design flood event, riprap armouring is proposed within the ditch that runs between PCFR and Highway 5, and along the eastern PCFR embankment including an area where there is a potential for knickpoint erosion immediately south of the previously washed-out section of the road (Figure 5-2). Details regarding the sizing and configuration of the riprap armour are provided in Section 5.5.
- Stability Seeding – Stability seeding is an experimental approach whereby sediment similar in size to the D_{84} to D_{90} (or the 84th to 90th percentile of the grain size distribution) of sediment observed on a riverbed is strategically placed on or adjacent to the riverbanks. Results from laboratory experiments indicate that stability seeding has the potential to provide various channel stability and fish habitat benefits as discussed in further detail in Appendix C. At the PCFR project site, stability seeding is proposed along the river bar adjacent to the previously washed-out section of the road. The long-term performance of the stability seeding measures will be monitored through various research programs through the University of British Columbia (UBC).

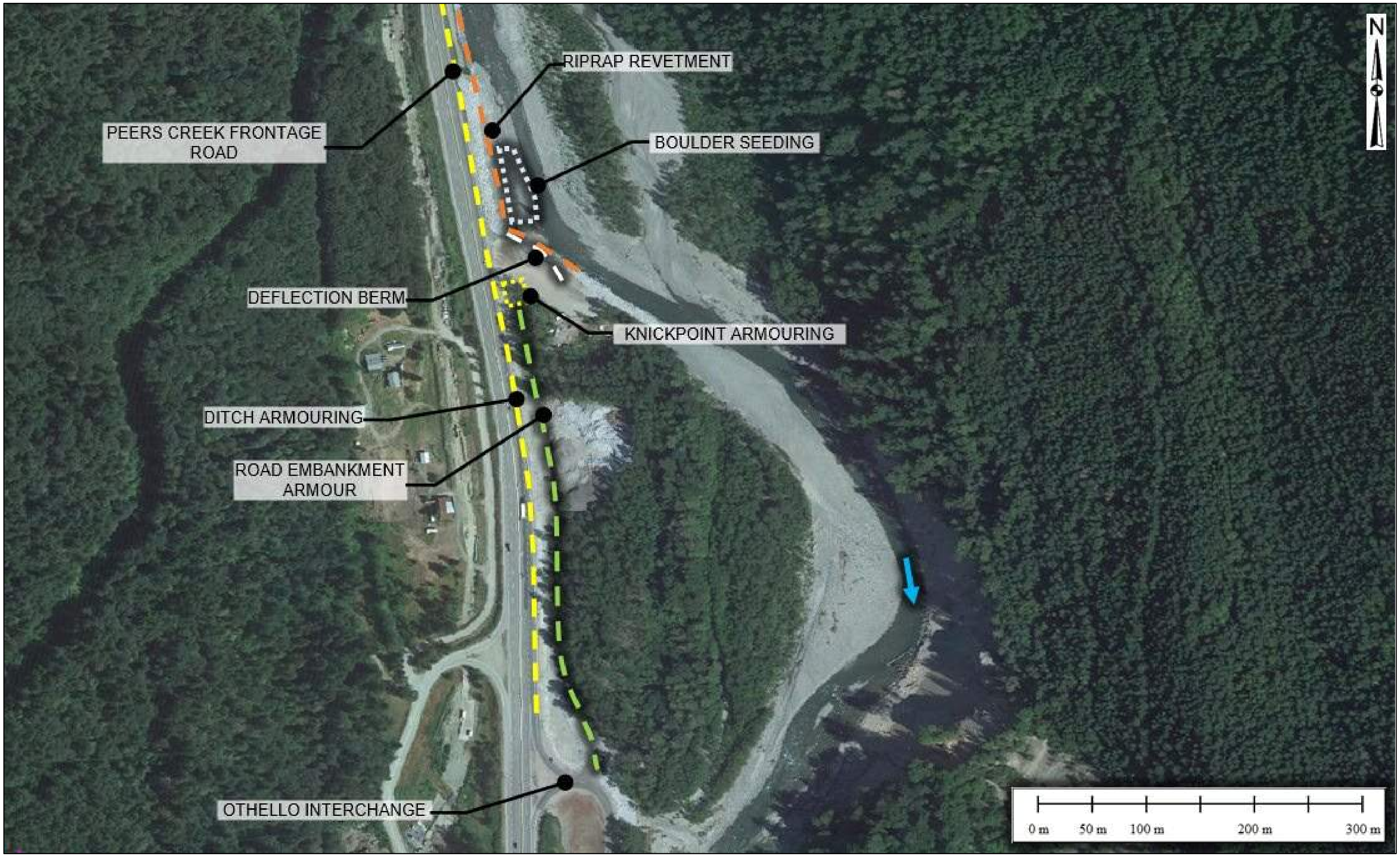

Figure 5-1. Detailed Design Components

Figure 5-2. View of potential knickpoint immediately south of previously washed-out section of PCFR. Photo Source: BGC, March 21, 2023.

5.3 Hydraulic Model Updates

5.3.1 Terrain Modifications

BGC modified the DEM of the hydraulic model in the following ways to represent the design condition of the project reach:

- The proposed PCFR alignment was incorporated. Road elevations were based on the 50% design surface provided by McElhanney.
- The channel bathymetry adjacent to the proposed riprap revetment was modified such that it maintained the same width before and after incorporation of the road.
- Road barriers along the side and centerline of Highway 5 which were not captured in the lidar were added to the DEM. These barriers were assumed to be impermeable for simplicity of modelling. The barrier along the center of the highway was raised 0.8 m above the surface of the lidar and the barrier along the east side of the road was raised 0.7 m above the surface of the lidar.
- An approximately 1 m high deflection berm was added along the right riverbank near the downstream end of the riprap revetment.

The terrain modifications are shown in Figure 5-3.

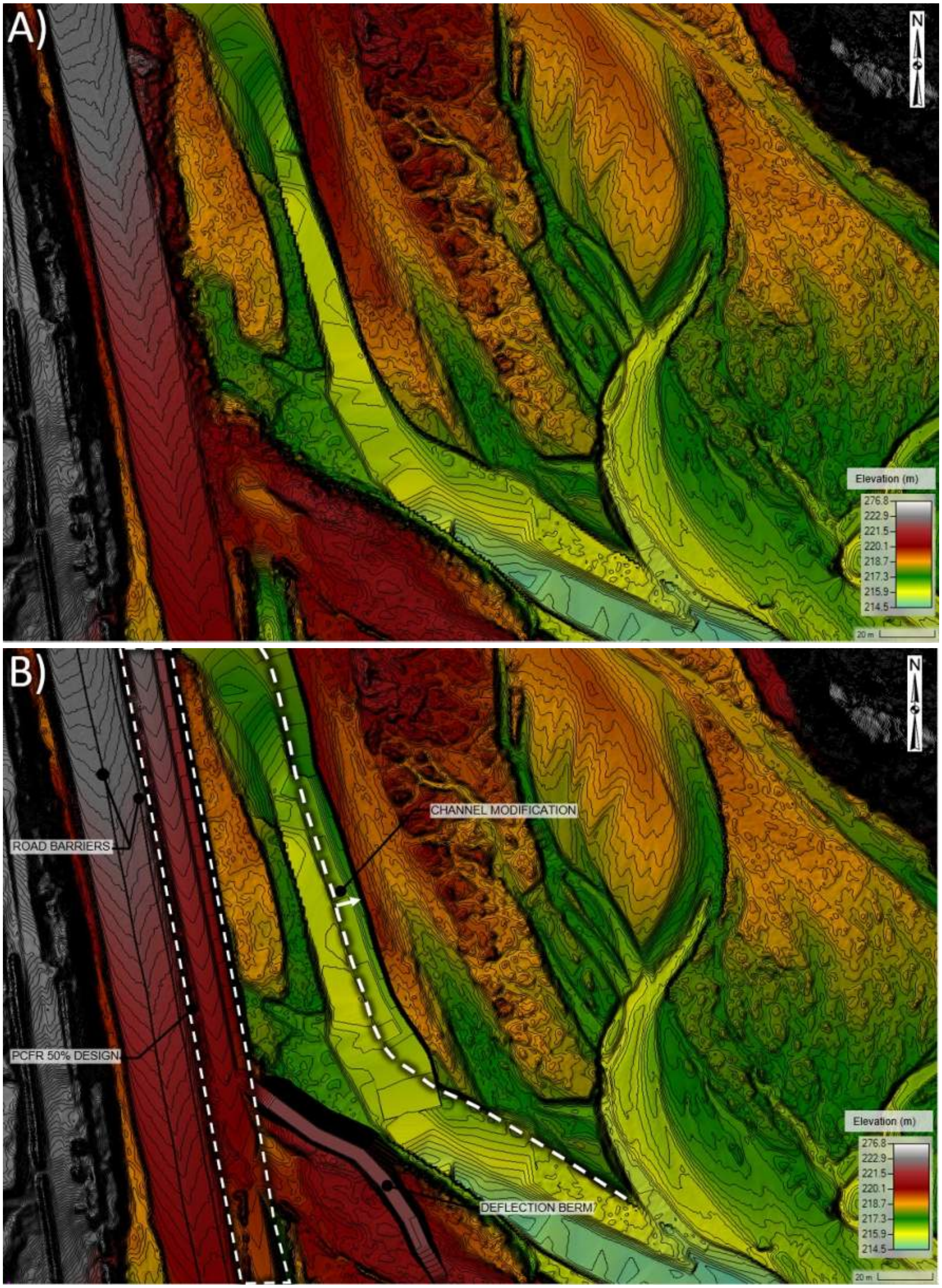

Figure 5-3. Model terrain of existing conditions (A) and design conditions (B).

5.3.2 Results

Modelled water surface elevations (WSE), flow velocities, and flow depths were evaluated throughout the project reach for the design flood event and used to inform design of the components described in Section 5.2. at the design peak flow, overbank flooding is predicted to occur, resulting in inundation of PCFR and Highway 5 south of the previously washed-out section of PCFR (Figure 5-4a). Inclusion of the deflection berm results in a reduction in the inundated extent of Highway 5 (Figure 5-4b). Model simulations indicate that raising the berm higher than 1 m provides little additional benefit with regards to reducing inundation along PCFR and Highway 5. Simulated overbank flow velocities were observed to be similar with and without inclusion of the berm.

Final modelling results along the entire project reach indicate that the majority of PCFR will be inundated during the design flood event (Figure 5-5). Main channel velocities in excess of 7 m/s are simulated. Maximum overbank flow velocities of up to approximately 3.5 m/s are simulated along the road surface where lower Manning’s n values were assumed (Table 3-1).

Flooding over Highway 5 is limited by Jersey barriers that run along the eastern side of the highway as well as between northbound and southbound highway lanes. As mentioned in Section 5.3.1, the Jersey barriers were assumed to be impermeable within the model. Actual flood extents may be greater than what is represented by the modelling results, particularly if the barriers are damaged during flooding.

Key parameters for hydraulic design of the various hydrotechnical components were extracted from the model as discussed further in Section 5.5.

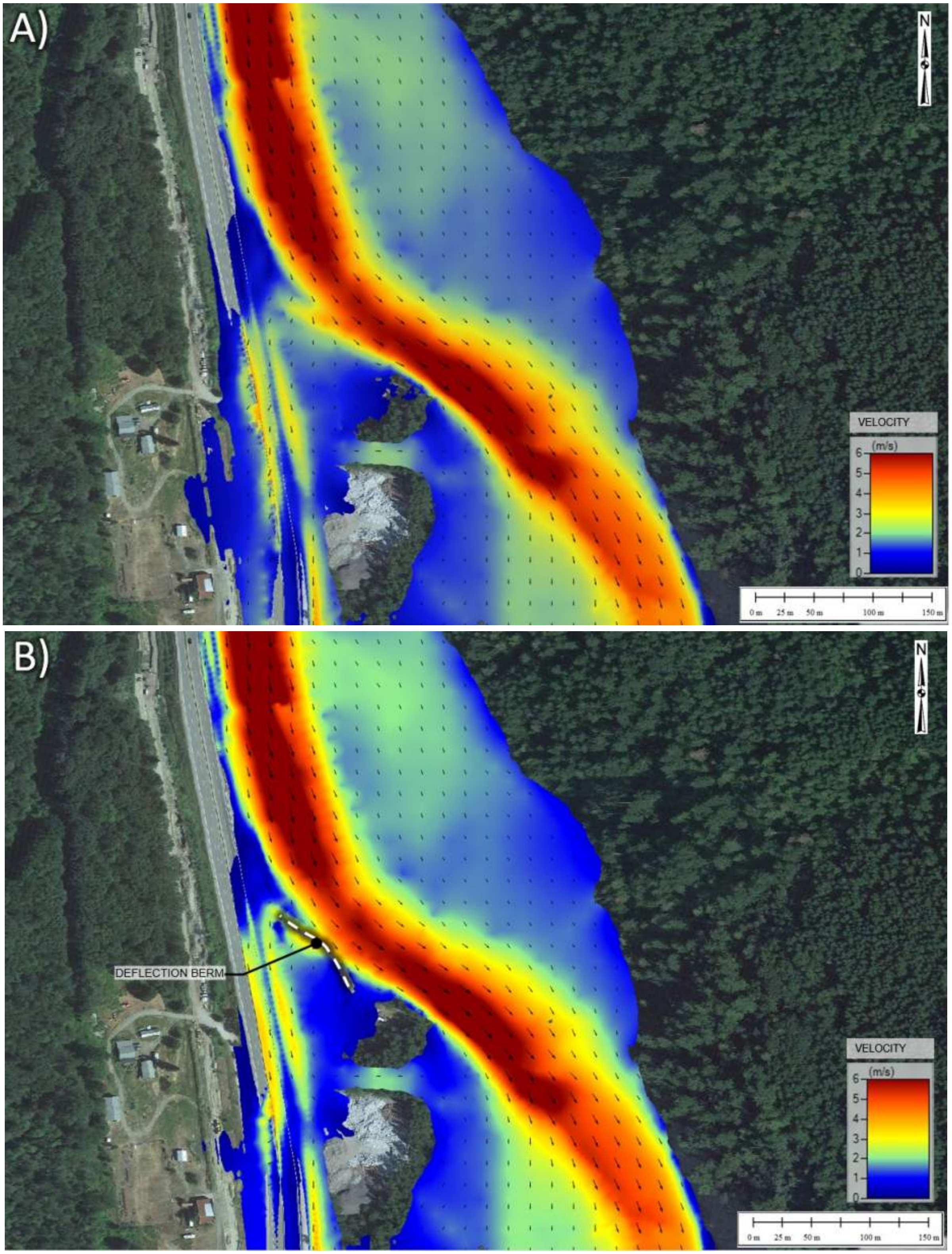

Figure 5-4. Model results demonstrating the effect of the 1.0 m deflection berm. A: No deflection berm. B: With deflection berm installed.

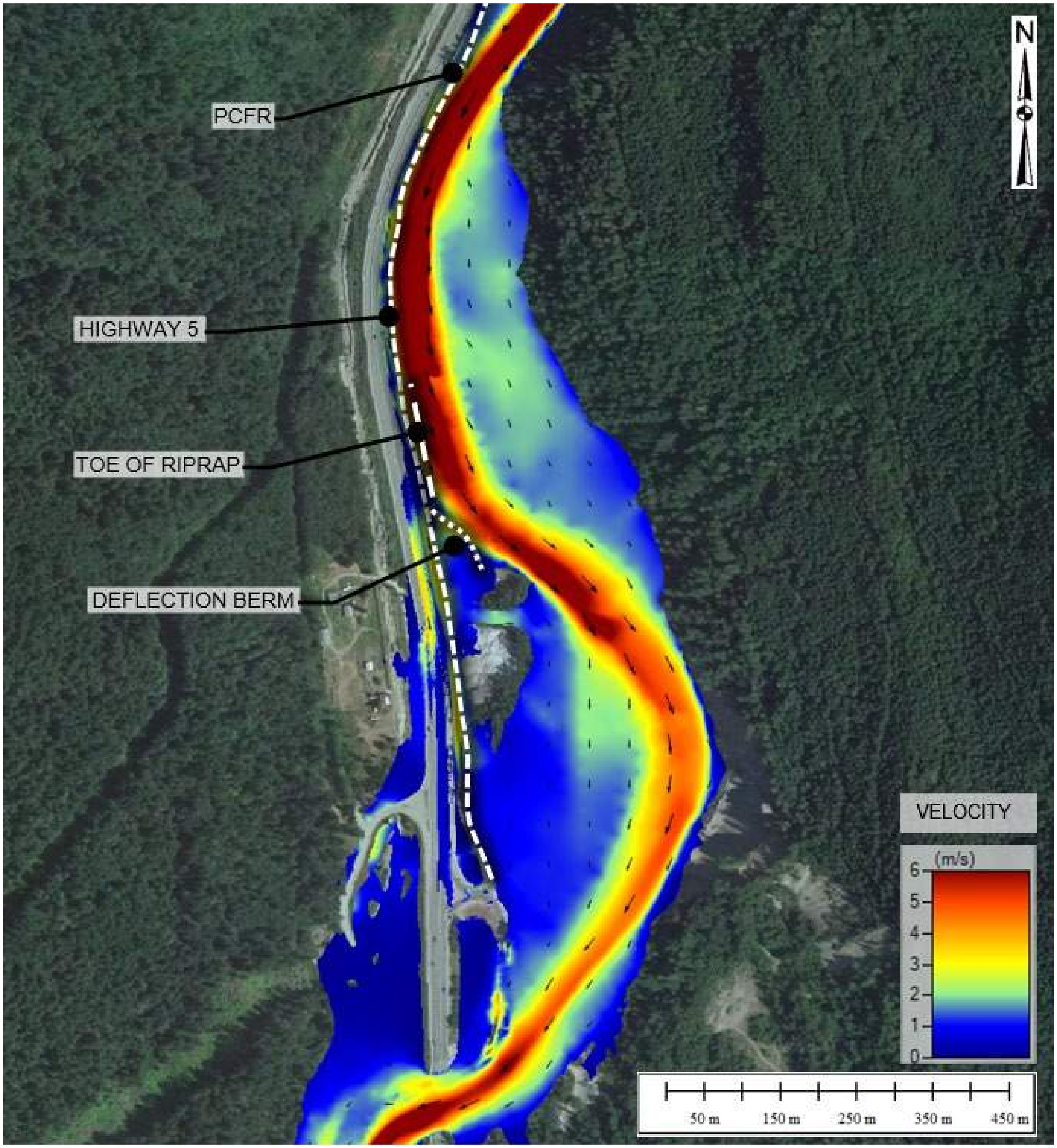

Figure 5-5. Velocity and inundation results within the project reach during design flood conditions ($Q = 1,815\ m^3/s$).

5.4 Scour Analysis

A scour assessment was performed to support design of the riprap revetment using results from the hydraulic model taken at the cross section shown in shown in Figure 5-6.

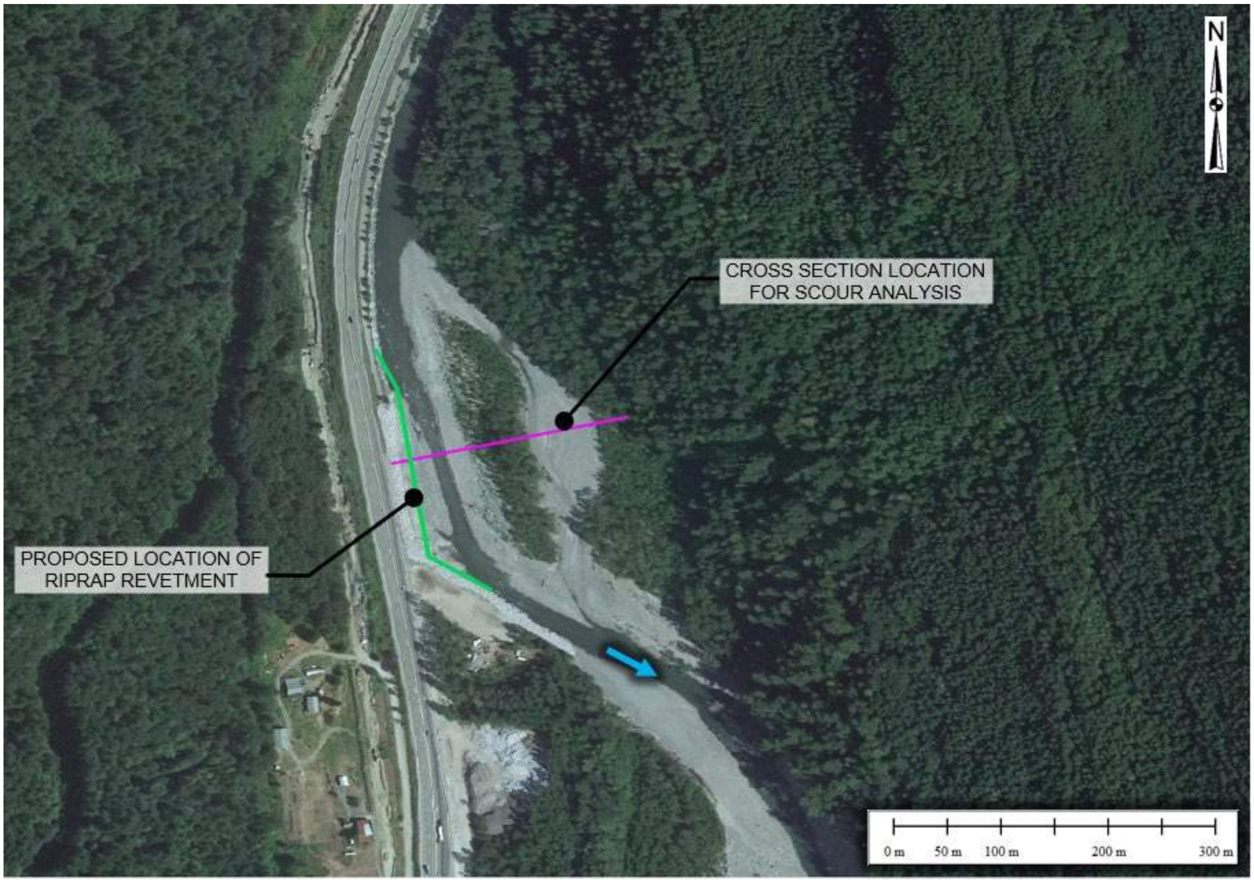

Figure 5-6. Location of cross section used for scour analysis.

Natural scour was estimated using the Blench regime method (Blench, 1969). The Blench method extended previous regime methods to include cases of different bank material. Blench defined the regime depth as follows:

$$d_r = q^{2/3}/F_b^{1/3}$$

Where d_r is the regime depth (m), q is the unit discharge (m^2s^{-1}) found by taking the return period discharge of interest and dividing by the water surface width, and F_b is the bed factor (m/s^2).

Estimation of F_b involves an iterative calculation using the regime depth, bed load charge, C (parts per hundred thousand), and the median bed material particle size, D_{50} (mm). The first approximation of regime depth is the average flow depth for the given flood (e.g., 200-year). The estimated bed load charge is used when significant bed load transport occurs, such that a portion of the stream's energy is committed to sediment transport rather than the scouring of the channel bed. Essentially, it is an adjustment factor to dampen estimated scour depths.

A Z factor is then applied to the regime depth to account for the channel morphology. The final scour depth (d_s) is estimated relative to the estimated design water surface elevation (Equation 4-2):

$$d_s = Z \times d_r \qquad \text{[Eq. 4-2]}$$

The Z factor used is unique to the channel morphology at the project site (Table 5-1). Given that the site is at a moderate bend in the river, a Z factor of 1.6 was adopted A mean scour depth of 1.8 m is estimated below the channel thalweg during the design flood event.

Table 5-1. Typical Z factors for estimation of scour depth.

Channel Morphology	Z Factor
Straight Reach	1.3 - 1.4
Moderate Bend	1.5
Severe Bend	1.75
Right Angle Bend	2.0
Vertical Rock Bank or Wall	2.25

Table 5-**2** provides the input parameters used in the natural scour estimate and the mean scour depth below the design water surface elevation.

Table 5-2. Input parameters and results for natural scour estimates.

Parameter	Value
F_b	6.27
q	19.5
d_r	3.9
Z	1.6
d_s	6.3

5.5 Riprap Design

5.5.1 Riprap Sizing and Filter Requirements

Riprap sizes for the design components discussed in Section 5.2 were estimated using the hydraulic modelling results. Riprap sizing for slopes with gradients shallower than ~5% were completed based on methods provided in USACE EM 1110-2-1601 (USACE, 1994), and the TAC Guide to Bridge Hydraulics (TAC 2004). Riprap sizing for slopes with gradients steeper than ~5% were estimated based on Equation 4-3 provided in Robinson et al. (1998).

$$D_{50} = \left[\frac{qS^{0.58}}{8.07 \times 10^{-6}}\right]^{1/1.89} \qquad \text{[Eq. 4-3]}$$

Where:

D_{50} is the median riprap particle size (mm)
q is the design flood discharge per unit bottom width ($m^3/s/m$)
S is the energy gradient

Key design parameters for riprap sizing of the various design components are provided in Table 5-3. Recommended riprap sizes are provided in Table 5-4.

Table 5-3. Key design parameters for riprap sizing.

Riprap Sizing Method	**Parameter**	**Riprap Revetment**[1]	**Ditch Armour**[2]	**Knickpoint Armour**	**Road Embankment Armour**[2]	**Deflection Berm**[3]
USACE (1994)	Design Velocity (m/s)	5.2	2.5	-	3.5	-
	Average Flow Depth (m)	2.7	1.1	-	1.5	-
Robinson et al. (1998)	Design Flood Discharge per Unit Bottom Width ($m^3/s/m$)	-	-	2.7		2
	Energy Gradient (m/m)	-	-	0.15		0.33

1. Design flow velocities for the riprap revetment were approximated as the maximum depth-averaged velocity at a point measured 20% of the way up the slope length from the bank toe based on the hydraulic modelling results.
2. Design flow velocities for the ditch and road embankment armour were approximated as the maximum depth-averaged velocity along the proposed ditch line based on the hydraulic modeling results.
3. Riprap sizing for the deflection berm was estimated using both the USACE (1994) method (based on flow parallel to the berm) as well as the Robinson et al. (1998) method (based on flow overtopping the berm). Results from the Robinson et al. (1998) method govern riprap sizing for the deflection berm.

Table 5-4. Recommended riprap sizes for design components.

Design Component	Minimum Recommended Riprap Sizing and Thickness
Riprap Revetment	2000 kg Class (D_{50} ~ 1,150 mm) 2.3 m Thick
Ditch Armour	10 kg Class (D_{50} ~ 200 mm) 0.35 m Thick
Knickpoint Armour	250 kg Class (D_{50} ~ 575 mm) 1.0 m Thick
Road Embankment Armour	100 kg Class (D_{50} ~ 425 mm) 0.7 m Thick
Deflection Berm	250 kg Class (D_{50} ~ 575 mm) 1.0 m Thick

1. A factor of safety of 1.2 was applied to the riprap sizing and a specific gravity of 2.5 was assumed. The actual specific gravity of the available quarry material is expected to be higher than 2.5 (likely between 2.6 and 2.7); however, specific gravities in this range are not expected to reduce the recommended riprap sizing.

Non-woven geotextile filter fabric will be required beneath all riprap to reduce the potential for migration of soil particles from the underlying road fill or in situ soils. Geotextile filter fabric shall meet the specifications of Mirafi 1100N or an equivalent product. A 300 mm thick layer of well-graded cobble bedding material will be required between the geotextile and 2000 kg Class riprap layers. The cobble bedding material should meet the gradation specification provided in Table 5-5. A 100 mm thick gravel bedding layer will be required between the geotextile and 250 kg Class riprap layers.

Table 5-5. Recommended granular bedding material gradation.

Intermediate Dimension (mm)			
Percent Smaller than Intermediate Dimension			Maximum Size
15%	50%	85%	
50	150	250	300

5.5.2 Riprap Configuration

Riprap Revetment: The proposed riprap revetment consists of 2000 kg Class riprap spanning an approximate length of 300 m along the previously washed-out section of the road and extending downstream along the natural bankline (Figure 5-1). The proposed revetment would be installed to a thickness of 2.3 m, at a maximum slope of 2H:1V, overtop of the interim revetment installed by Kiewit (Figure 5-7). The toe of the revetment will be configured as a launching apron to minimize overall excavation requirements. BGC understands that MoTI and McElhanney intend to constrain the extents of the riprap revetment such that flow isolation will not be required at the time of construction. Therefore, the downstream end of the revetment (i.e., section extending east of PCFR along the natural bankline) will be setback from the existing bankline. The launching apron at the upstream end of the revetment will gradually reduce in width as it transitions into the existing riprap revetment upstream from the project area. The riprap revetment will not contain a sufficient volume of material to launch to the design scour elevation within this transition area; however, the hydraulic stability of the bank armour will be improved compared to the existing condition.

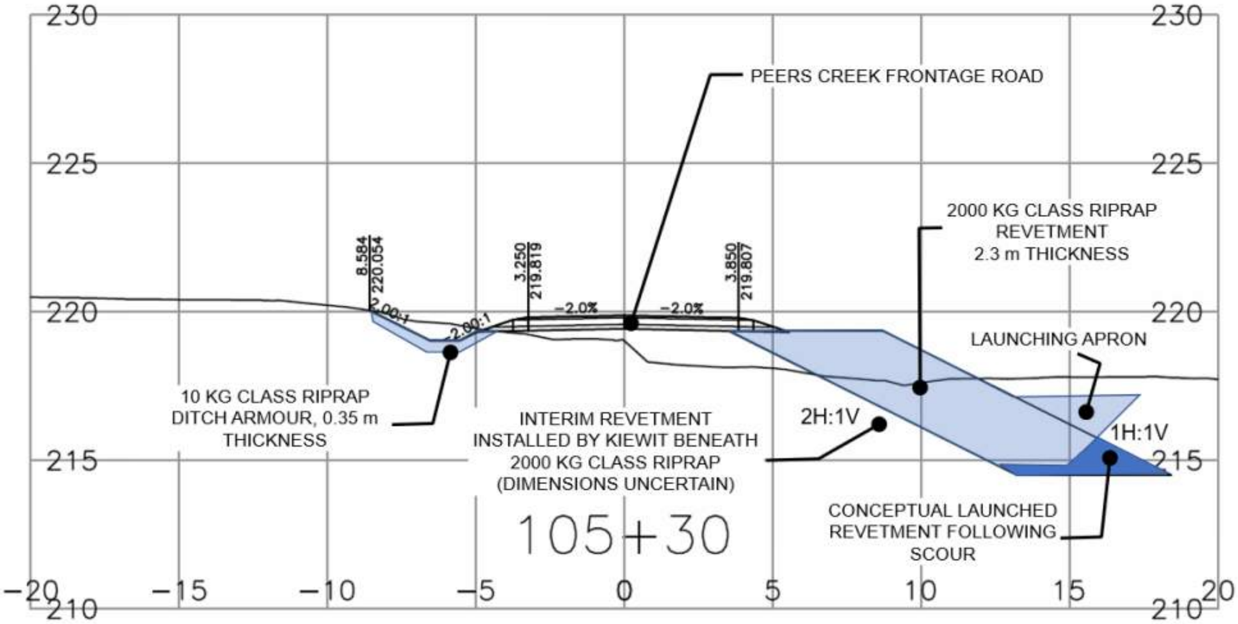

Figure 5-7. Typical cross section for riprap revetment along PCFR.

Deflection Berm: The proposed deflection berm spans a length of approximately 80 m along the downstream end of the riprap revetment. The berm should have a height of 1 m and a top width of 4 m. The road side slope of the berm should be 3H:1V whereas the river side slope should be 2H:1V. The core of the berm may consist of compacted fill. The sides and end of the berm should be armoured with 250 kg Class riprap. If setback from the Coquihalla River, the armour on both sides of the berm should be keyed into the surrounding terrain to a depth of 1 m Figure 5-8a. If set directly adjacent to the Coquihalla River, the riprap armour on the river side slope may be placed directly over the 2000 kg Class riprap revetment Figure 5-8b.

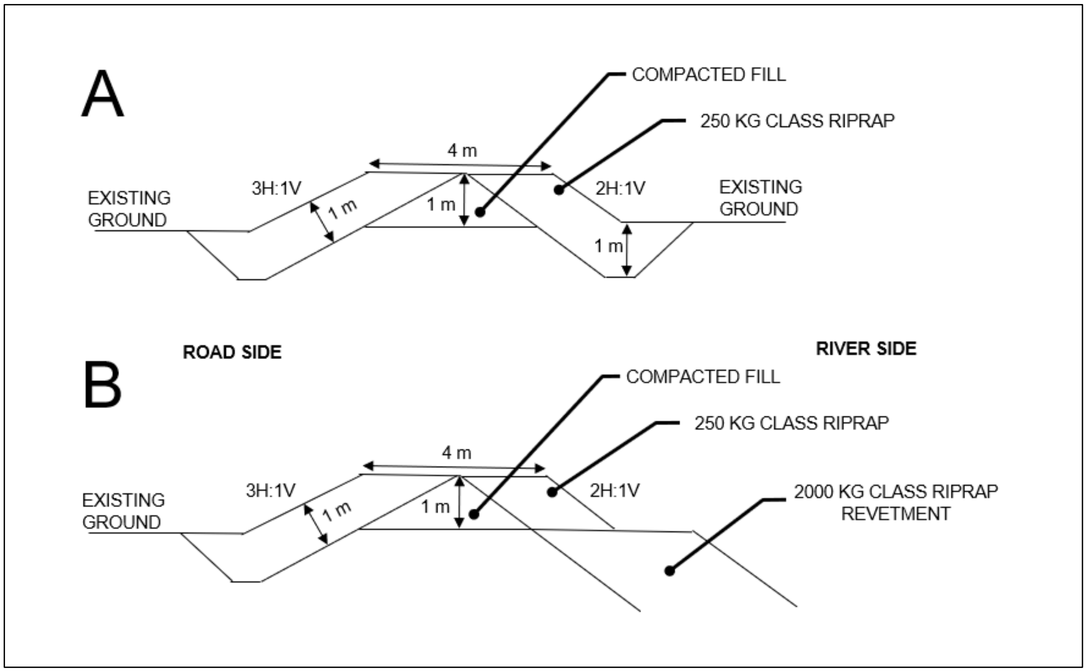

Figure 5-8. Typical cross sections for deflection berm setback from the Coquihalla River riprap revetment (A) and adjacent to riprap revetment (B), (not to scale).

Overbank Armouring: The ditch armour consists of a 0.35 m thick layer of 10 kg Class riprap extending from the upstream end of the project area south to the Othello interchange. The armour should line the entire ditch between Highway 5 and PCFR such that no road fill remains exposed (Figure 5-7).

The potential knickpoint located immediately south of the previously washed-out section of the road (Figure 5-2) should be armoured using a 1 m thick layer of 250 kg Class riprap. The knickpoint area should be graded as a trapezoidal channel with a minimum base width of 3 m, and 2H:1V side slopes. Grading of the area should be completed so that the maximum slope parallel to the direction overbank stream flow is no steeper than 15%.

Riprap should be placed along the full PCFR road embankment so that no road fill remains exposed. The road embankment armour consists of a 0.7 m thick layer of 100 kg Class riprap. The upstream end of the road embankment armour should tie in with the 250 kg armour placed in the knickpoint area and the downstream end of the armour should tie in with the 100 kg Class riprap placed by Kiewit as part of the interim road repairs near the Othello interchange (Figure 4-6).

Detailed Hydrotechnical Design Summary

Hydraulic modeling results indicate that both Highway 5 and PCFR will become inundated during the design flood event (the climate change-adjusted 200-year peak flow, 1,815 m^3/s). Due to high flow velocities modelled within the main channel of the Coquihalla River, and the extent of overbank flooding observed, various hydrotechnical design components are recommended including a riprap revetment along the right riverbank, a deflection berm to reduce potential inundation of Highway 5 and PCFR, and additional armouring in select overbank areas to reduce the potential for erosion of road and highway fill. Riprap of minimum sizes ranging from 10 kg to 2000 kg Class are recommended throughout the project area.

6.0 CLOSURE

We trust the above satisfies your requirements. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC Engineering Inc.
per:

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37934
2023-05-23

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APPENDIX A

FREQUENCY-MAGNITUDE RELATIONSHIP FOR THE COQUIHALLA RIVER

1.0 INTRODUCTION

BGC Engineering Inc. (BGC) conducted a flood frequency analysis (FFA) to characterize the flood hydrology for the Coquihalla River, British Columbia (BC). The standard practice to conduct an FFA is to fit a statistical model to the annual maxima series (AMS), a dataset consisting of the largest flood per year, to estimate the probability of different flood magnitudes based on a frequency-magnitude (FM) relationship. A typical AMS approach does not consider that floods in the watershed may be driven by different process, like snowmelt or rainfall, resulting in two different populations of flood events. As a result, this method may not be appropriate for watersheds where floods are caused by more than one hydrological process (Waylen and Woo, 1982; Waylen and Woo, 1983; Bobotas and Koutras, 2019).

The Coquihalla River being subject to both rainfall-related floods caused by atmospheric rivers (ARs[1]) in the fall and winter and snowmelt-related floods in the spring, is an example of a watershed with mixed flood-generating processes. ARs are related to the largest ten floods on record, not including the November 2021 flood event, indicating that AR-related floods exert an important control on the distribution of floods in the watershed (Figure 1-1). Snowmelt-related floods dominate the smaller floods. On occasion, a rain-on-snow event occurs in the spring, but these events do not dominate the historical record[2].

Given the presence of multiple processes driving floods, BGC constructed a combined statistical model using a dual maxima series (DMS) approach of AR-related and snowmelt-related floods to develop an updated FM relationship in the Coquihalla River watershed. This report includes a description of the data that was used to compile the dataset for analysis (Section 2.0). A description of the methodology that pertains specifically to the Coquihalla River is included in Section 3.0. The results include the FM relationship (stationary and climate-adjusted) for the lower (between Hope and above Alexander Creek) and upper (below Needle Creek) gauged watersheds as well as an ungauged location in the watershed (Jessica Bridge as an example) (Section 4.0). A discussion on the implications for hydrotechnical design (Section 5.0), limitations, assumptions, and sources of uncertainty (Section 6.0), as well as conclusions (Section 7.0) are included at the end of the report.

This report is intended to provide a high-level description of how the FM relationship was developed for the Coquihalla River. The reader is referred to BGC's recently completed FFA study of the Coldwater River for additional methodology details (BGC, May 20, 2022).

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[1] ARs are long, conveyor belts of warm, moist air typically occurring in the atmosphere during the late fall and early winter.

[2] Floods were separated into two populations based on the time of year they occurred, recognizing that floods are typically a combination of snowmelt and rainfall in the Nicola River watershed.

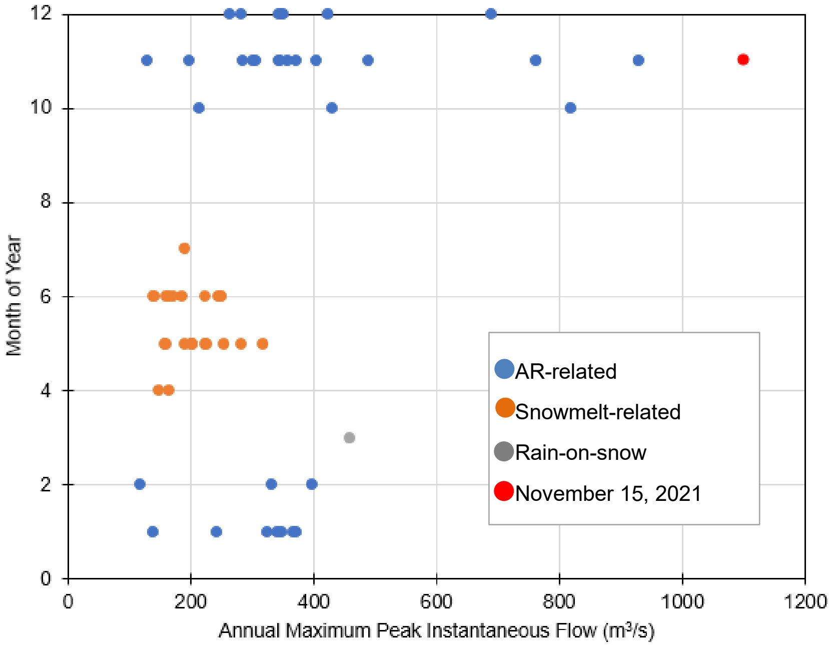

Figure 1-1. Timing of the historical floods recorded at the *Coquihalla River near Hope* (08MF003) and the *Coquihalla River above Alexander Creek* (08MF068) hydrometric stations over the 1958 to 2021 period.

2.0 DATA ACQUISITION AND COMPILATION

2.1. Historical Streamflow

The Water Survey of Canada (WSC) maintains three hydrometric stations in the Coquihalla River watershed (Figure 2-1,Table 2-1).

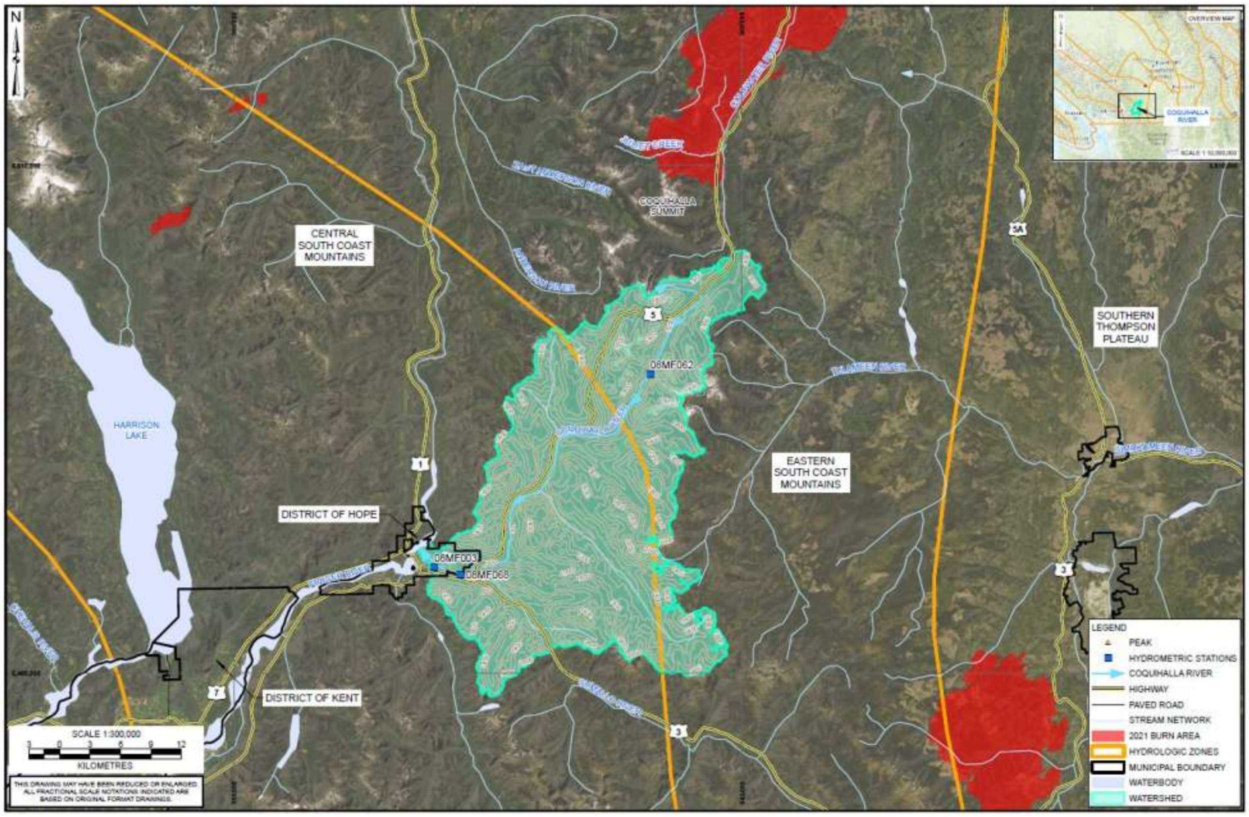

Figure 2-1. Coquihalla River watershed at Hope showing the location of the three hydrometric stations.

The *Coquihalla River near Hope* (08MF003) and the *Coquihalla River above Alexander Creek* (08MF068) hydrometric stations are located in the lower Coquihalla watershed. The streamflow record at Alexander Creek station essentially represents an extension of the Hope station, which was destroyed in 1984 during a large flood event. Due to concerns that the rating curve at Hope would not be stable in the long-term, the hydrometric station was re-located upstream by the WSC in 1987 to the vicinity of Alexander Creek. Given their proximity and similar watershed area, records from these two stations were combined by BGC, providing 59 years of streamflow data. Out of this 59-year dataset, 40 annual instantaneous peak flows (Q_{IPF}) are available, of which 19 occurred between October and February. The remaining 21 occurred following snowmelt in the spring.

The *Coquihalla River below Needle Creek* (08MF062) hydrometric station records streamflow in the upper watershed. A total of 54 years of data are available from this station, including 21 Q_{IPF} values. Of these instantaneous values, 7 occurred from October through February and the remaining 14 are associated with spring snowmelt.

Table 2-1. Hydrometric station information for the Coquihalla River.

Station Information	Lower Watershed		Upper Watershed
	Coquihalla River near Hope	Coquihalla River above Alexander Creek	Coquihalla River below Needle Creek
Station ID	08MF003	08MF068	02MF062
Latitude (°)	49.37527	49.36833	49.54189
Longitude (°)	-121.41944	-121.38444	-121.11997
Watershed Area (km^2)	741	720	85.5
Approximate elevation (m)	60	105	810
Hydrologic regime	Natural	Natural	Natural
Real-time recording	Yes	Yes	Yes
Record Period	1911-1983[1]	1987-2021[3]	1965-2021
Record Length (years)	27	38[4]	56
Missing Years on Record	1	5	3
Number of published instantaneous peak flows[2]	40		21
Number of published instantaneous peak flows that are rainfall-related	19		7
Number of published instantaneous peak flows that are snowmelt-related	21		14

Notes:

1. Early data from 1911-1922 at the Coquihalla River near Hope (08MF003) hydrometric station was not considered because there is no historic AR event data for that time period.
2. Records do not all have both the daily mean and daily instantaneous values.
3. The November 15, 2021, flood was estimated by BGC.
4. Instantaneous peak flows for 2020 was included in the analysis but considered provisional by the WSC. The estimate of the November 15, 2021 made by BGC was included in the analysis but is not published by the WSC.

2.2. Historical Dataset Compilation

A Dual Maximum Series (DMS) dataset was compiled where one snowmelt-related flood and one rainfall-related flood (if present) were included for each year on record. A DMS dataset was built for both the lower and upper watershed stations.

The WSC publishes the Q_{IPF} for the annual maximum and the daily mean streamflow time series for all years on record. The DMS was constructed by using available Q_{IPF} data first. The years with missing Q_{IPF} were filled in using the annual maximum mean daily flow (Q_{MDF}) value from April through August for snowmelt-related floods and from September through March for rainfall-related floods if present. The methodology used for this fill-in procedure is described in Section 3.2.

The timing of the rainfall-related floods was cross-referenced with AR events using a historical dataset. Historical AR events have been catalogued by the Scripps Institute of Oceanography (SIO-R1-AR), which is available at http://cw3e.ucsd.edu/Publications/SIO-R1-Catalog/. This AR catalogue provides the frequency, duration, and landfalling location of ARs along the North American West Coast from 20° to 60°N from 1948 to 2017 (Gershunov, Shulgina, Ralph, Lavers, and Rutz., 2017). This dataset has been used by a number of researchers to characterize changes to AR characteristics over time (Sharma and Déry, 2019; 2020a; 2020b). Rainfall-related floods were defined as AR-related if the hydrological response occurred on or up to five days after the AR event.

2.3. Missing Historical Floods

In 1984, the *Coquihalla River near Hope* (08MF003) hydrometric station was destroyed during a flood event. The hydrometric station was rebuilt further upstream above Alexander Creek (08MF068) and made operational in 1987. The 1984, 1985, and 1986 floods are thus missing from the WSC record. Furthermore, AR-related floods in the fall of 1989 and 1990 are also missing from the WSC record.

In 1994, Northwest Hydraulics Consultants (NHC) published estimates of the magnitude of the winter 1984 flood as well as the fall floods of 1989 and 1990 (NHC, 1994) (Table 2-2). Unfortunately, the methodology supporting these estimates was not published. Based on the lack of supporting information and absence of corresponding WSC estimates, the NHC values were not included in the analysis here-in.

Table 2-2. Estimated missing instantaneous peak flows (Q_{IPF}) in the Coquihalla River (NHC,1994).

Hydrometric Station	Date (mm-dd-yyyy)	Peak Flow Estimate (m^3/s)
08MF003	01-04-1984	779
08MF068	10-11-1989	475
08MF068	10-11-1990	725

2.4. Projected Streamflow

The FM relationship for floods on the Coquihalla River is projected to increase in the future as the atmosphere warms. Projected daily mean streamflow at the *Coquihalla River above Alexander* (08MF068) hydrometric station have been modelled from 1945 to the end of the century by the Pacific Climate Impacts Consortium (PCIC, 2020) for two emission scenarios and six global circulation models (GCMs). The simulation used for the analysis here-in assumes a radiative forcing of +8.5 Watts/m^2 by 2100 with negligible carbon emission reduction[3]. Six GCMs were

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[3] Since 2006, this scenario has tracked most closely to observed emissions and warming and, given that many governments are falling short of their greenhouse gas emission reduction targets, it can be assumed that 8.5 is presently the most realistic scenario for future climate projections. http://www.iiasa.ac.at/web-apps/tnt/RcpDb (retrieved June 22, 2022).

selected for analysis. The projected daily mean streamflows from the six GCMs were used by BGC to infer the impacts of climate change in the Coquihalla River watershed. The future trends in floods were characterized by extracting a DMS with one annual maximum rainfall-related (AR and non-AR) flood from September to March and one annual maximum snowmelt-related flood from April to August. The September to March floods were not differentiated between AR-related and those related with other types of rainfall systems.

Information on the climate models and calibration performance are detailed further in BGC (June 4, 2021).

3.0 METHODS

3.1. November 15, 2021 Event

The *Coquihalla River below Needle Creek* (08MF062) hydrometric station recorded the peak flow of the November 15, 2021 event. However, the *Coquihalla River above Alexander Creek* (08MF068) station stopped working before the peak of the event with the hydrograph being updated months later (Figure 3-1). Therefore, BGC estimated the Q_{IPF} of the November 2021 flood in the lower watershed using available data from other WSC gauges during the event, historic gauge data and a two-dimensional (2D) hydraulic model developed in the HECRAS 6. Additional information on the estimate of the November 15, 2021 flood magnitude at the *Coquihalla River above Alexander Creek* (08MF068) hydrometric station is included in Attachment I.

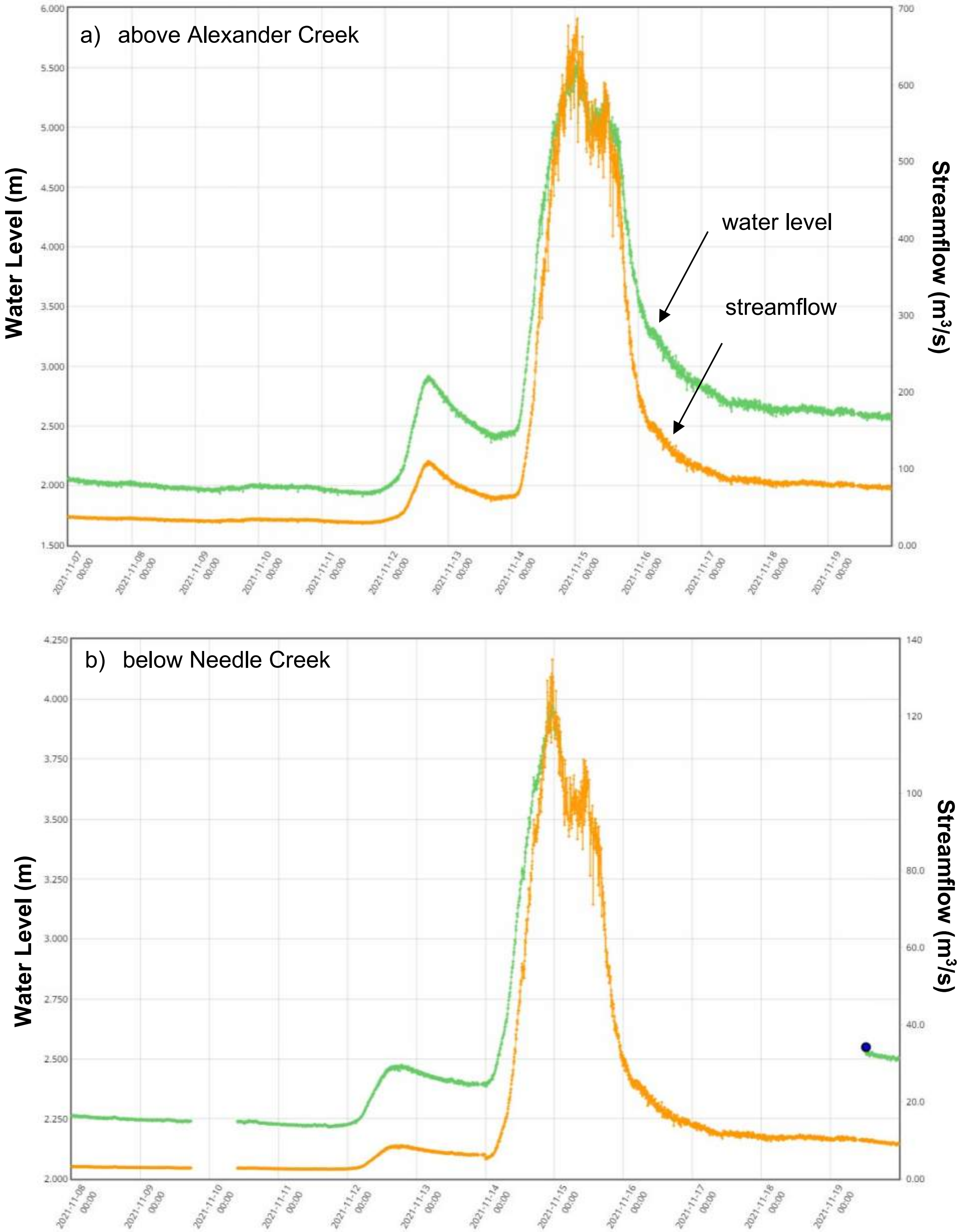

Figure 3-1. **Hydrograph for the November 15, 2021 event recorded at the a) *Coquihalla River above Alexander Creek* (08MF068) and the b) *Coquihalla River below Needle Creek* (08MF002) hydrometric stations.**

3.2. From Q_{DMF} to Q_{IPF}

A flood type-specific linear regression was built to estimate missing Q_{IPF} from available daily mean Q_{DMF} records[4]. The regression was built using paired observations of Q_{IPF} and Q_{DMF} from the historical record. The slope of the regression was calculated by minimizing the difference between observed value and the fitted value (provided by the regression) using the least squares estimate fitted through the origin. The overall fit of the regression was assessed using the coefficient of determination (R^2).

3.3. Historical Trend Assessment

A historical trend was evaluated for both snowmelt- and AR-related floods to determine whether a non-stationary approach was warranted. The trends were estimated using the Sen's[5] slope and the Mann-Kendall[6] test. The alpha threshold level was selected to be 0.01 for statistical significance to increase our confidence that the trend is not due to random chance.

3.4. Statistical Model Development

The FM relationship was built by first developing statistical models for snowmelt-related floods and AR-related floods separately. Seven[7] different probability distributions were compared to determine which had the best fit, particularly how well the distribution fit the larger floods. Three statistical tests[8] were used to determine best choice of distributions for AR-related and snowmelt-related floods. The Generalised Extreme Value (GEV) and the Log Pearson Type III were considered regardless of test score given their prominent use in Canada (Zhang et al., 2019) and the United States (England et al., 2018). Several methods[9] were considered to fit the model to the data.

A "leave one out" cross validation based on the quantile score was used to inform the final distribution selection for analysis. The quantile score is a specific way of evaluating how well the quantile estimate from the statistical model compares to the annual maximum Q_{IPF} recorded at the hydrometric station over all years on record with a penalty depending on whether the quantile estimate is above or below. The overall quantile score was obtained by averaging each year's quantile score. The best distributions were defined by the lowest quantile scores. This process was done for all return periods.

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[4] Q_{DMF} is defined as the average streamflow over the course of the day from midnight to midnight the following day.

[5] The Sen's Slope is a non-parametric estimate of the slope of the line practical when the data elements don't fit a straight line.

[6] The non-parametric Mann-Kendall test is widely used to detect consistently increasing or decreasing trends through time.

[7] The seven distributions include Normal, Log Normal, Gumbel (EV1), Freshet (EV2), GEV, Pearson Type III, and Log Pearson Type III. The GEV and Log Pearson Type III were included regardless of their test scores due to their standard use in Canada and the US, respectively.

[8] The tests include the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC) and Anderson-Darling Criterion (ADC).

[9] The maximum likelihood estimate (MLE) method, the maximum goodness-of-fit estimates (MGE), the method of moments (MM), and linear moments (l-moments).

The snowmelt-related and AR-related statistical models were subsequently combined by a maximization process where floods from each distribution was randomly generated and the highest value between the two estimates was selected to build the combined model. The combined model was based on the collection of maxima of randomly drawn pairs between both models and was calculated using the distplyr R package (Coia, Joshi, Tan, and Zhu, 2022).

The FM relationship was built for the following return periods (% AEP): 2-year (50% AEP), 5-year (20% AEP), 10-year (10% AEP), 20-year (5% AEP), 50-year (2% AEP), 100-year (1% AEP), 200-year (0.5 % AEP), and 500-year (0.2 % AEP).

3.5. Sensitivity Analysis

A sensitivity analysis was conducted to assess the influence of a range of 2021 peak flow estimates on the FM relationship. The sensitivity of the FM relationship was assessed using flood magnitudes of 900 m^3/s and 1300 m^3/s for the November 15, 2021 flood at the lower hydrometric station and flood magnitudes of 100 m^3/s and 150 m^3/s at the upper station.

3.6. Future Trend Characteristics

Curves were fit to the PCIC generated rainfall-related (AR and non-AR) and snowmelt-related floods separately to infer the potential impacts of climate change. The curve consisted of the geometric mean across time of the pooled data from the six GCMs (i.e., LOESS[10] regression). The scales were removed from each curve by dividing out the current (2022) value of the curve, and then capturing how many times greater each future year's geometric mean (of the pooled data from the six GCMs) is compared to the geometric mean in 2022. The end result is “dimensionless scaling factors”.

The dimensionless scaling factors were subsequently used to re-scale the flood distributions (snowmelt-related, and rainfall-related [AR and non-AR]), so that future flood distributions compare to the current flood distribution by the same multiple that future geometric means compare to the current geometric mean in PCIC’s projections. A distribution for the annual maximum was obtained for each future year, from which a single climate-adjusted FM relationship was obtained.

The variability in the six GCMs was characterized using a bootstrap statistical approach. The floods generated from the different GCMs were pooled, from which many resamples (more than just six) were drawn. This variability was taken together with the uncertainty in the distribution fitting method to get overall confidence intervals for the climate-adjusted FM relationship. The 90% confidence intervals were calculated using 1000 bootstrap iterations.

The magnitude shift due to climate change is not likely to be the same for different quantiles (e.g., 2-year [50% AEP] and 200-year [0.5% AEP] events). The reliability of the scaling assumption was verified using PCIC’s projected streamflow data by observing the residuals (as

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[10] Loess regression is a nonparametric technique that uses local weighted regression to fit a smooth curve.

defined as a ratio of simulated peak flows to the LOESS geometric mean) of the simulated maxima about the fitted geometric mean curves. The residuals appear to be stationary over time for the rainfall-related (AR and non-AR) peak flows suggesting that the distribution is not changing due to climate change aside from this scaling factor. Additional information on the validity of the scaling factors is discussed in BGC (June 4, 2021).

3.7. Transfer to Ungauged Watersheds

Flood information was transferred from the hydrometric stations to Jessica Bridge (Latitude: 49.447651° and Longitude: -121.270165°) above Sowoqua Creek (watershed area 373 km^2) on the Coquihalla River using a weighted function. The lower and upper watershed of the Coquihalla River are hydro-climatically different reflecting the elevation gradient of the Coast Mountains. The mean temperature averaged across the upper watershed below Needle Creek is lower given its higher mean elevation compared to the watershed above Alexander Creek. As a result, the upper watershed receives 13% more precipitation as snow based on data from Wang, Hamann, Spittlehouse, and Carroll (2016).

Given Jessica Bridge is located between the hydrometric stations (08MF003/08MF068 and 08MF062) in the watershed, a weighted function was used estimate floods at the bridge location based on the following three equations:

$$Q_c = Q_{c,d} + Q_{c,u}\beta \qquad \text{[Eq. 3-1]}$$

$$\alpha = \frac{\log A_c - log\ A_u}{log A_d - log\ A_u} \qquad \text{[Eq. 3-2]}$$

$$\beta = 1 - \alpha \qquad \text{[Eq. 3-3]}$$

where Q_c is the flood estimate at Jessica Bridge, $Q_{c,d}$ and $Q_{c,u}$ are the flood estimates pro-rated from the downstream and upstream hydrometric stations to the ungauged location, α and β are the weighting factors, and A_c, A_d, A_u are the watershed areas at the ungauged location (c), at the downstream hydrometric station (d) (08MF003/08MF068), and the upstream hydrometric station (u) (08MF062).

The flood estimates were pro-rated to Jessica Bridge from the downstream and upstream hydrometric stations using the following equation:

$$\frac{Q_U}{Q_G} = \left(\frac{A_u}{A_G}\right)^n \qquad \text{[Eq. 3-4]}$$

where Q_U is the flow (m^3/s) at Jessica Bridge, Q_G is the flow (m^3/s) at the hydrometric station, A_U is the watershed area (km^2) at the Jessica Bridge, and A_G is the watershed area at the hydrometric station, and *n* is a site-specific exponent related to peak flow data at both locations.

Typically, a value for *n* is chosen based on the watershed area size and takes on a value between 0.2 to 0.8 (Watt, 1989). A higher *n* is recommended for smaller watershed and indicates that streamflow will approach a value almost proportional to watershed area. An exponent of 1.0 was adopted for the Coquihalla River. The average exponent when comparing flood estimates between the two hydrometric stations is 1.15 for AR-related floods. Similar results are obtained when an *n* value of 1.15 is used in the weighted calculation.

4.0 RESULTS

4.1. The November 15, 2021 Event

BGC's best estimate of the November 15, 2021, Q_{IPF} at the *Coquihalla River above Alexander Creek* (08MF068) hydrometric station is 1100 m^3/s. The November 15, 2021 Q_{IPF} at the *Coquihalla River below Needle Creek* (08MF062) hydrometric station is 135 m^3/s, which was recorded at the gauge.

4.2. From Q_{DMF} to Q_{IPF}

The linear regression shows that AR-related Q_{IPF} are typically larger than their corresponding Q_{DMF} compared to the relationship for snowmelt-related floods at both the lower (Figure 4-1) and upper (Figure 4-2) stations. The database of AR-related and snowmelt-related Q_{IPF} for the lower and upper watershed is shown in Table 4-1.

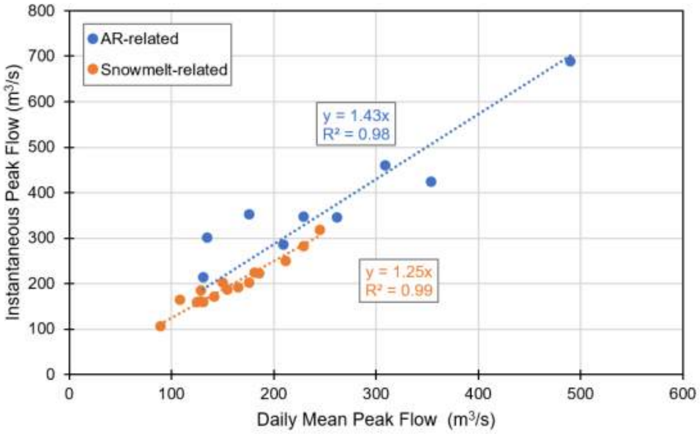

Figure 4-1. The linear regression between paired observation of Q_{IPF} and Q_{DMF} for AR-related (blue) and snowmelt-related (orange) floods in the lower watershed.

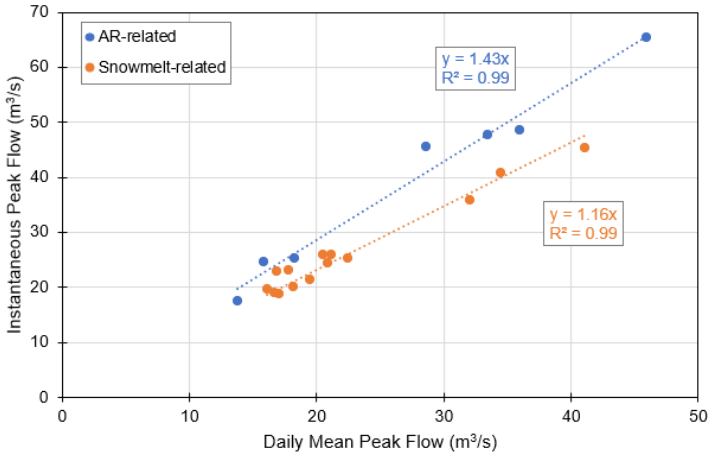

Figure 4-2. **The linear regression between paired observation of Q_{IPF} and Q_{DMF} for AR-related (blue) and snowmelt-related (orange) floods in the upper watershed.**

Table 4-1. **Q_{IPF} for AR-related and snowmelt-related floods in the lower (08MF003/08MF068) and upper (08MF062) watershed. Values in bold and highlighted are estimated using the linear regression.**

Date	Lower Watershed (08MF003/08MF068)		Upper Watershed (08MF062)	
	AR-related (m³/s)	Snowmelt-related (m³/s)	AR-related (m³/s)	Snowmelt-related (m³/s)
1957	**73**	Na	Na	Na
1958	**283**	**150**	Na	Na
1959	**343**	**262**	Na	Na
1960	**71**	**249**	Na	Na
1961	**242**	**173**	Na	Na
1962	**332**	**120**	Na	Na
1963	**406**	**127**	Na	Na
1964	**159**	**244**	Na	Na
1965	**155**	**165**	Na	Na
1966	**348**	**185**	**24**	**17**
1967	**819**	**238**	46	**24**
1968	**367**	**283**	**20**	19
1969	**38**	**227**	**4.5**	**23**
1970	**107**	**202**	**3.1**	21
1971	**152**	192	**12**	24
1972	**196**	283	**28**	45
1973	**121**	159	**9.0**	20
1974	**206**	223	**19**	**28**
1975	425	**237**	**27**	**22**
1976	**78**	187	**8.7**	**20**
1977	348	**155**	18	**14**

Date	Lower Watershed (08MF003/08MF068)		Upper Watershed (08MF062)	
	AR-related (m^3/s)	Snowmelt-related (m^3/s)	AR-related (m^3/s)	Snowmelt-related (m^3/s)
1978	390	**173**	**29**	**20**
1979	345	**133**	25	**20**
1980	689	**133**	65	**27**
1981	Na	Na	**3.9**	23
1982	**86**	161	**5.4**	**24**
1983	**191**	185	**16**	23
1984	Na	Na	48	**21**
1985	Na	Na	**18**	**27**
1986	Na	Na	**27**	**27**
1987	**81**	202	**4.1**	26
1988	Na	Na	**36**	Na
1989	**264**	**168**	**34**	**24**
1990	**371**	**119**	**6.3**	**15**
1991	**160**	171	**9.7**	**18**
1992	**140**	**131**	**6.6**	**17**
1993	**67**	225	**69**	**11**
1994	130	**128**	**12**	**16**
1995	**764**	**197**	**22**	**17**
1996	138	**142**	**6.4**	Na
1997	**181**	203	**19**	41
1998	**132**	160	**5.2**	**31**
1999	286	**223**	**17**	**44**
2000	**75**	**138**	**31**	26
2001	199	**151**	**41**	**24**
2002	372	**217**	**18**	**48**
2003	432	**128**	**27**	**19**
2004	352	**132**	25	**15**
2005	342	**82**	**22.7**	**10**
2006	**931**	**206**	**69**	**26**
2007	460	**195**	**45**	**22**
2008	**205**	319	**23**	**39**
2009	214	**147**	**17**	**21**
2010	**121**	165	**9.7**	19
2011	326	**203**	**21**	25
2012	**116**	250	**17**	36
2013	**94**	**254**	**7.5**	**35**
2014	**357**	**192**	**41**	**26**

Date	Lower Watershed (08MF003/08MF068)		Upper Watershed (08MF062)	
	AR-related (m^3/s)	Snowmelt-related (m^3/s)	AR-related (m^3/s)	Snowmelt-related (m^3/s)
2015	301	**52**	**31**	**8.2**
2016	**119**	107	**23**	20
2017	**346**	176	49	**24**
2018	**307**	171	**28**	**29**
2019	Na	148	**11**	**17**
2020	399	207[2]	**35**	**33**
2021	1100[1]	152[2]	135[2]	Na

Notes:

1. Estimated by BGC using a hydraulic model.
2. Considered provisional by the WSC.

4.3. Historical Trend Characteristics

There is no significant trend in the magnitude of historical AR-related and snowmelt-related floods in either the lower or upper watershed of the Coquihalla River, with or without the November 15, 2021 event (Table 4-2). Though, the snowmelt-related floods are approaching are approaching significance. The relatively flat 10-year moving average is consistent with this finding (Figure 4-3 and Figure 4-4). The absence of a significant trend supports the use of a stationary frequency analysis based on the historical data in the Coquihalla River watershed.

Table 4-2. Significance of historical trend as shown by the p-value.

Flood type	Lower Watershed	Upper Watershed
AR-related peak flows *with* November 15, 2021, event	0.31	0.22
AR-related peak flows *without* November 15, 2021, event	0.52	0.16
snowmelt-related peak flows	0.13	0.05

Note: The alpha threshold level was selected to be 0.01 for statistical significance to increase our confidence that the trend is not due to random chance

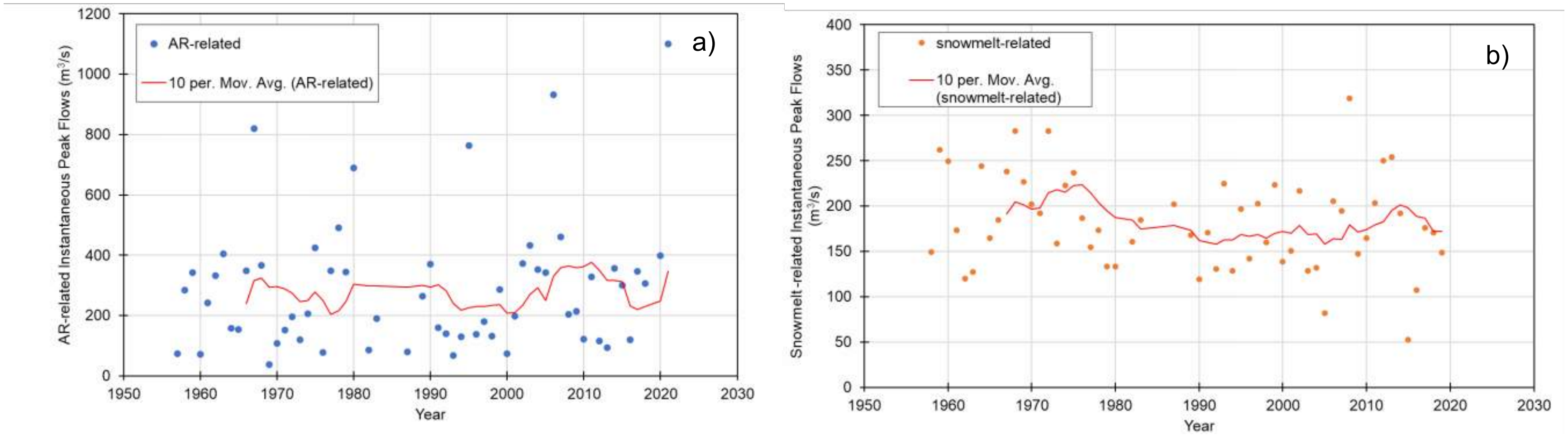

Figure 4-3. Temporal change in AR-related floods a) and snowmelt-related floods b) in the lower Coquihalla watershed over 1958 to 2021.

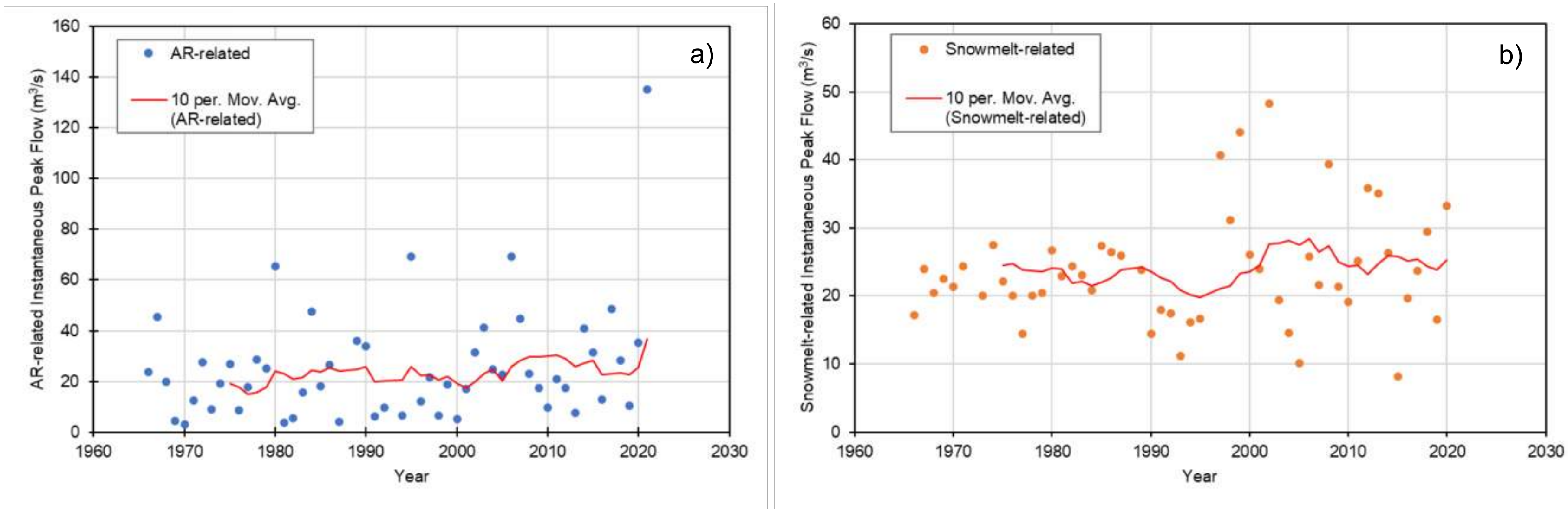

Figure 4-4. Temporal change in AR-related floods 2) and snowmelt-related floods b) in the upper Coquihalla watershed over 1966 to 2021.

4.4. Stationary FM Relationship

While the statistical model for snowmelt-related floods was relatively insensitive to the choice of distribution, the GEV distribution was ultimately selected because of its flexibility when extrapolating to longer return periods (lower % AEPs).

Unlike the snowmelt-related floods, the different distributions resulted in a range of options to characterize the largest AR-related floods (Figure 4-5). As a result, an ensemble of the best three distributions (as defined by the lowest quantile scores) was used to define them: the GEV, Log Normal, and Pearson Type III.

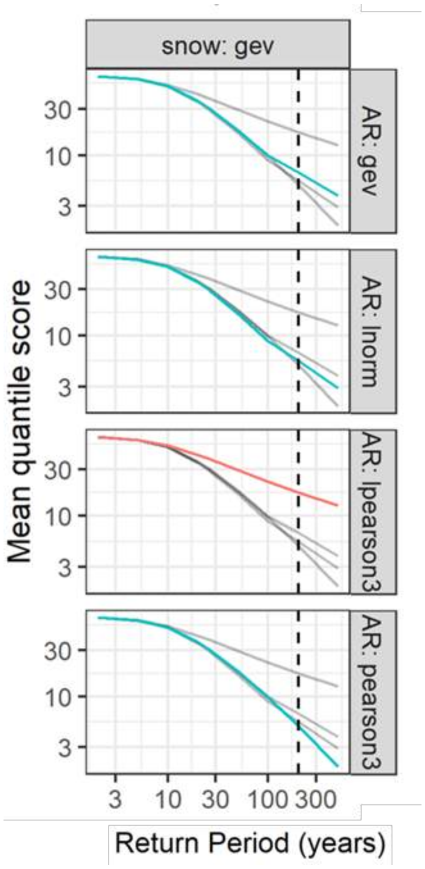

Figure 4-5. Mean quantile scores comparing each DMS model combination, plotted for each return period (% AEP) on a log-10 scale. The dashed line shows the 200-year (0.5% AEP) event. Smaller scores indicate a better model. Comparisons are only meaningful within each return period (% AEP).

The maximum likelihood estimate (MLE) fit method was used to estimate the parameters of the GEV and Log Normal distributions. The maximum goodness-of-fit estimates (MGE) method was used to fit the Pearson Type III distribution for the AR-related floods due to convergence issues during the iterative procedure with the MLE.

The stationary 200-year (0.5% AEP) event is estimated to be 1380 m^3/s in the lower watershed, with a 10th and 90th percentile confidence interval (CI) range of 975 to 2075 m^3/s (Table 4-3). This best estimate is based on the assumption that the November 15, 2021 flood was 1100 m^3/s. Correspondingly, the return period (% AEP) of the November 15, 2021 event is approximately 100 years (1% AEP).

Table 4-3. Stationary FM relationship for the lower Coquihalla River watershed (08MF003/08MF068). The 10th and 90th percentiles are included as the lower and upper confidence interval (CI).

Return Period (% AEP)	Combined Approach with November 15, 2021 (m^3/s)		
	Estimate	Lower CI	Upper CI
2 (50% AEP)	240	220	265
5 (20% AEP)	395	335	450
10 (10% AEP)	540	445	645
20 (5% AEP)	700	555	860
50 (2% AEP)	930	705	1225
100 (1% AEP)	1135	835	1595
200 (0.5% AEP)	1380	975	2075
500 (0.2% AEP)	1785	1185	3170

In the upper Coquihalla watershed, the stationary 200-year (0.5% AEP) event is estimated at 115 m^3/s with 10th and 90th percentile estimates of 85 and 165 m^3/s (Table 4-4). This estimate is based on the gauged November 15, 2021 peak flow of 135 m^3/s for the upper Coquihalla River watershed (08MF062). The corresponding return period (% AEP) of the November 15, 2021 flood is between a 100 (1% AEP) and 200-year (0.5% AEP) event.

Table 4-4. Stationary FM relationship in the upper Coquihalla River watershed (02MF062). The 10th and 90th percentiles are included as the lower and upper confidence interval (CI).

Return Period (% AEP)	Combined Approach with November 15, 2021 (m^3/s)		
	Estimate	Lower CI	Upper CI
2 (50% AEP)	30	25	30
5 (20% AEP)	40	35	45
10 (10% AEP)	50	40	60
20 (5% AEP)	65	20	85
50 (2% AEP)	80	60	110
100 (1% AEP)	95	70	135
200 (0.5% AEP)	115	85	165
500 (0.2% AEP)	150	105	220

4.5. Sensitivity Analysis

The influence of the November 15, 2021 flood magnitude on the FM relationship is summarized over a range of return periods (% AEP) in the lower (Table 4-5) and upper (Table 4-6) watershed. Results show that as the estimate of the November 12, 2021 flood increases, the FM relationship shifts upwards with higher flood magnitudes. For example, the estimate of the 200-year (0.5% AEP) flood ranges from 1335 m^3/s (assuming 900 m^3/s) to 1425 m^3/s (assuming 1300 m^3/s). However, when compared to the 10th and 90th percentile confidence intervals, all three estimates fall with the range of uncertainty.

Table 4-5. Select flood quantiles based on a range of estimates for the November 15, 2021 event in the lower watershed (08MF003/08MF068).

November 15, 2021 Peak Flow Estimate (m^3/s)	20-year (5% AEP) Peak Flow (m^3/s)			50-year (2% AEP) Peak Flow (m^3/s)			200-year (0.5% AEP) Peak Flow (m^3/s)		
	estimate	Lower CI	Upper CI	estimate	Lower CI	Upper CI	estimate	Lower CI	Upper CI
900	690	550	845	915	700	1190	1335	970	1980
1100	700	555	860	930	705	1225	1380	975	2075
1300	705	555	880	950	705	1260	1425	985	2180
Range	15	5	35	35	5	70	90	15	200

Table 4-6. Select flood quantiles based on a range of estimates for the November 15, 2021 event in the upper watershed (02MF062).

November 15, 2021 Peak Flow Estimate (m^3/s)	20-year (5% AEP) Peak Flow (m^3/s)			50-year (2% AEP) Peak Flow (m^3/s)			200-year (0.5% AEP) Peak Flow (m^3/s)		
	estimate	Lower CI	Upper CI	estimate	Lower CI	Upper CI	estimate	Lower CI	Upper CI
100	60	50	80	80	60	105	110	85	155
135	60	50	80	80	60	110	115	85	165
150	65	50	80	80	60	110	115	85	165
Range	5	0	0	0	0	5	5	0	10

4.6. Climate-adjusted FM Relationship

The rainfall-related (AR and non-AR) floods are projected to increase over time (Figure 4-6a) while the snowmelt-related floods are projected to decrease over time (Figure 4-6b).

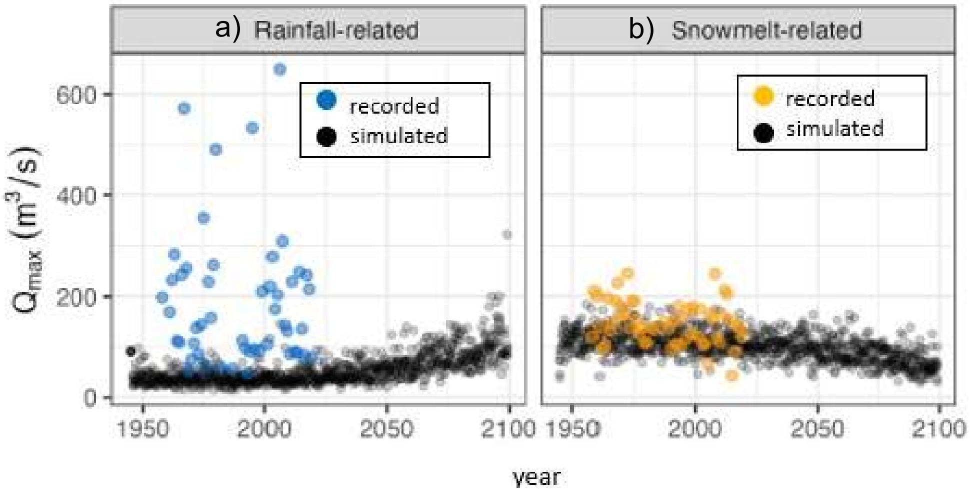

Figure 4-6. Time series for a) Q_{IPF} for rainfall-related (AR and non-AR) floods, and (b) Q_{IPF} for snowmelt-related floods in the lower watershed as recorded by WSC (coloured circles) and modelled by PCIC using six GCMs (black circles).

Return period (% AEP) projections based on dimensionless scaling factors see an immediate and rapid positive increase in the lower (Figure 4-7) and upper (Figure 4-8) watershed.

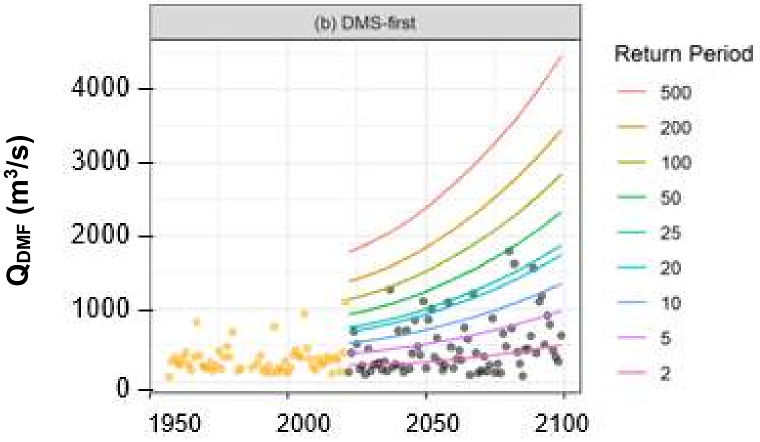

Figure 4-7. Return period (% AEP) projections in the lower watershed (08MF003/08MF068). Historical recorded data are in yellow; simulated data from the PCIC model are in black.

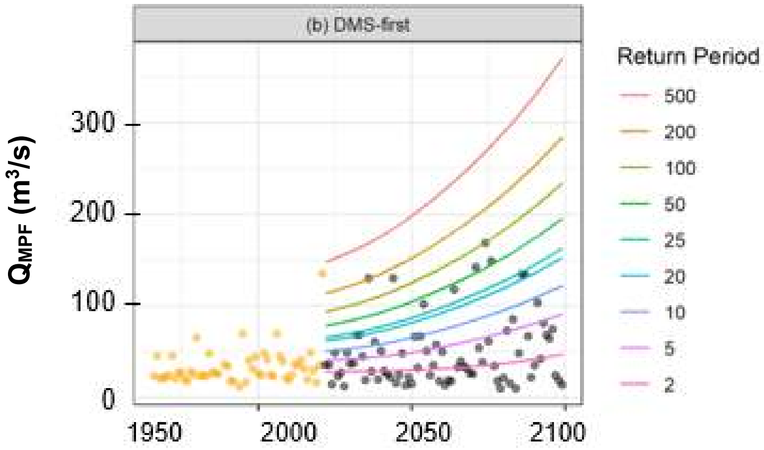

Figure 4-8. **Return period (% AEP) projections in the upper watershed (02MF062). Historical recorded data are in yellow; simulated data from the PCIC model are in black.**

In a non-stationary context, the FM relationship requires explicit definition because the exceedance probability associated with a flood magnitude changes with each consecutive year. The FM relationship can be defined as the flood that is exceeded once every 2, 5, 10, 20, 50, 100, 200, and 500 years on average. The climate adjusted FM relationship over the next 75 years can be defined as the flood that is exceeded 75/200 (0.5% AEP) times on average over the next 75 years.

Based on this definition, the climate-adjusted 200-year (0.5% AEP) flood in the lower watershed is estimated to be 2345 m^3/s – a 70% increase from to the stationary case (i.e., 1380 m^3/s). The stationary 200-year (0.5% AEP) flood (e.g., 1380 m^3/s) is projected to become approximately the 30-year flood in 75 years (Figure 4-7). The climate-adjusted 200-year (0.5% AEP) flood in the upper watershed is estimated to be 195 m^3/s – a 70% increase compared to the stationary case (i.e., 115 m^3/s). The stationary 200-year (0.5% AEP) flood event (e.g., 115 m^3/s) is also projected to become approximately the 30-year flood in 75 years.

The climate-adjusted FM relationship for the lower and upper watershed is provided in Table 4-7 and Table 4-8.

Table 4-7. Climate-adjusted FM relationship for the lower Coquihalla River watershed (08MF003/08MF068).

Return Period (% AEP)	Combined Approach with November 15, 2021 (m^3/s)		
	Estimate	Lower CI	Upper CI
2 (50% AEP)	310	265	365
5 (20% AEP)	615	525	735
10 (10% AEP)	865	720	1085
20 (5% AEP)	1140	930	1470
50 (2% AEP)	1556	1190	2105
100 (1% AEP)	1920	1410	2690
200 (0.5% AEP)	2345	1665	3565
500 (0.2% AEP)	3035	2030	5145

Table 4-8. Climate adjusted FM relationship for the upper Coquihalla River watershed (08MF062).

Return Period (% AEP)	Combined Approach with November 15, 2021 (m^3/s)		
	Estimate	Lower CI	Upper CI
2 (50% AEP)	30	25	35
5 (20% AEP)	60	50	70
10 (10% AEP)	75	65	100
20 (5% AEP)	100	80	125
50 (2% AEP)	135	100	180
100 (1% AEP)	160	120	225
200 (0.5% AEP)	195	140	280
500 (0.2% AEP)	250	180	365

4.7. Transfer to Ungauged Watersheds

The Jessica Bridge is located on the Coquihalla River approximately halfway up the watershed between both hydrometric stations with a watershed area of 373 km^2. Using Equation 3-4 and an n value of 1, the pro-rated 200-year (0.5% AEP) at Jessica Bridge using the lower and upper watershed FM relationships varies by more than 30% for the stationary and climate-adjusted cases (Table 4-9).

Table 4-9. Stationary and climate-adjusted 200-year (0.5% AEP) at Jessica Bridge using the lower (08MF003/08MF068) and upper (08MF062) watershed FM relationship.

Location	Watershed Area (km2)	Stationary (m3/s)	Climate-adjusted (m3/s)
Jessica Bridge based on lower watershed FM relationship	373	710	1200
Jessica Bridge based on upper watershed FM relationship	373	500	1660

The weighting factors show that the flood magnitude at Jessica bridge is influenced 70% by the downstream hydrometric station and 30% by the upstream hydrometric station based on watershed area (Table 4-10).

Table 4-10. Weighting factors.

Variable	Result
log (watershed area) at downstream hydrometric station (08MF003 / 08MF068)	2.86
log (watershed area) at upstream hydrometric station (08MF062)	1.93
log (watershed area) at Jessica Bridge	2.57
α	0.69
β	0.31

The stationary and climate-adjusted 200-year (0.5% AEP) at Jessica bridge as calculated using a weighted function based on watershed area is listed in Table 4-11. The November 15, 2021, event was estimated to be 560 m^3/s using this weighted function.

Table 4-11. Stationary and climate-adjusted 200-year (0.5% AEP) the lower (08MF003/08MF068) and upper watershed (08MF062).

Location	Watershed Area (km^2)	Stationary (m^3/s)	Climate-adjusted (m^3/s)
Jessica Bridge	373	640	1090

5.0 DISCUSSION

The combined FM relationship shows that the higher return period (% AEP) floods are AR-related while the lower return period (% AEP) events are snowmelt-related in the Coquihalla River watershed. The 200-year (0.5% AEP) flood can be expected to occur in the fall and winter, with a quick hydrological response occurring over several days. Snow on the ground in the watershed could exacerbate the flood if present (Gillett at al., 2022).

Climate change projections show that the rainfall-related (AR and non-AR) floods will increase over time while the snowmelt-related floods will decrease over time. Because the 200-year (0.5% AEP) flood is AR-related, we can expect this event to increase in magnitude in the

Coquihalla River. For example, the 200-year (0.5% AEP) is projected to become the 30-year (33% AEP) by the end of the century in the lower Coquihalla River watershed. A similar increase in floods has been shown for the Fraser River (Curry, Islan, Zwiers, and Déry, 2019).

In the FFA for the Coldwater River (BGC, May 20, 2022), the following topics were addressed:

- To include or not include the November 15, 2021 event in the analysis?
- Is the FM relationship “right”?
- Is the projected trend in rainfall-related (AR and non-AR) floods realistic?

The reader is referred to that report for a detailed discussion of these topics.

6.0 LIMITATIONS, ASSUMPTIONS, AND UNCERTAINTY

Limitations, assumptions, and sources of uncertainty in this study are listed below:

- The role of ARs on snowmelt in the spring contributing to rain-on-snow events is not considered explicitly in the statistical model for the following reasons:
    - There is only one of these events in the dataset.
    - The flood magnitude seems to be in between snowmelt-related and AR-related.
    - The AR frequency is typically lowest in the spring.
- The stationary FM relationship is based on the historical floods. Large magnitude floods control the statistical distribution, especially if AR-related. The FM relationship may require a re-calculation following a large (greater than 50-year, 2% AEP) flood.
- It is assumed that projected trends in Q_{DMF} apply to Q_{IPF}, which is a realistic assumption given these two quantities are highly correlated.
- The FM relationship should be interpreted in context of the confidence intervals, which highlight increased uncertainty with increasing return period (% AEP) events.
- The climate-adjusted FM relationship is based on the projection information available at this time. The assumptions made on changes to floods due to climate change should be revised in the future as scientific understanding of AR and snowmelt processes evolve. Human decisions and assumptions on behaviour today determines the rate of climate change in the future.
- Watershed disturbances such as land use change (e.g., conversion to agriculture), forestry (e.g., logging), insect infestations (e.g., mountain pine beetle), and wildfires may increase peak flows due to changes to hydrological processes. The projected increase in the frequency of watershed disturbances imply that the floods will likely be higher in the future. Detailed analyses on the extent of disturbance in the Coquihalla River watershed was beyond the scope of this work. As a result, the historical and projected influence of disturbances to peak flows in the Coquihalla River watershed is unknown.

7.0 CONCLUSIONS

- BGC considers the DMS approach as the preferred methodology to establish a FM relationship in the Coquihalla River.
- The 200-year (0.5% AEP) flood is AR-related and is projected to increase in magnitude over time (lower return period [higher %AEP]) due to climate change in the Coquihalla River watershed.
- The 200-year (0.5% AEP) flood in the lower watershed (08MF003/08MF068) is estimated to be 1380 m^3/s (with 10th and 90th percentile confidence intervals ranging from 975 to 2075 m^3/s). This estimate is based on the combined approach and assuming the November 15, 2021, event was 1100 m^3/s. The climate-adjusted 200-year (0.5% AEP) flood is estimated to be 2345 m^3/s – a 70% increase compared to the stationary case (i.e., 1380 m^3/s).
- The 200-year (0.5% AEP) flood in the upper watershed (08MF62) is estimated to be 115 m^3/s with 10th and 90th confidence intervals of 85 and 165 m^3/s. The climate-adjusted 200-year (0.5% AEP) flood is estimated to be 195 m^3/s – a 70% increase compared to the stationary case (i.e., 115 m^3/s).

8.0 CLOSURE

The material in this document reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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Yours sincerely,

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Attachment I: HEC-RAS Modelling

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ATTACHMENT I
HEC-RAS MODELLING

1.0 INTRODUCTION

As an independent effort from the WSC, the magnitude of the November 15, 2021, flood at the *Coquihalla River above Alexander Creek* (08MF068) hydrometric station was estimated using high water marks (HWMs) observed on a reach of the river in the vicinity of Othello Road. This site is located approximately 2.8 km upstream of the Alexander Creek station and has a drainage area of 602 km^2, compared to 730 km^2 at the WSC station.

HEC-RAS (version 6.2) modelling software was used to relate the HWMs to a range of discharges. HEC-RAS is a public domain hydraulic modelling program developed and supported by the United States Army Corps of Engineers (USACE) (Brunner & CEIWR-HEC, 2021). For this study, a two-dimensional (2D) hydraulic model was developed. The 2D model provides more detailed information on the flow depths and velocities than a one-dimensional (1D) model. A 2D model also removes some of the subjective modelling techniques which are involved in the development of 1D models such as defining ineffective flow areas, levee markers and cross-section orientation.

Detailed topographic data of the floodplain for the Coquihalla River at Othello Road are available from a high-resolution lidar dataset obtained by BGC from McElhaney. The lidar was acquired on December 3, 2021. HWM locations were geolocated by BGC on December 2, 2021 (Figure 1-1). The highwater marks collected by BGC staff had an uncertainty associated with the geographic coordinates of typically +/- 4 m from the accuracy of the GPS of the devices used to take the photos (phones and tablets). As a result of the uncertainty in the coordinates of the HWMs and the large elevation gradients at many of the locations measured only three of the collected HWMs were able to determined with enough certainty to be used for the present analysis.

Figure 1-1. Example of a HWM from the Coquihalla River flooding. Sediment deposited along Othello Road is clearly visible. Photo: BGC, December 2, 2021.

2.0 HYDRAULIC MODELLING

2.1. Model Domain and Boundary Conditions

The model domain covers an approximately 4.5 km stretch of the Coquihalla River ending 6.5 km upstream of Kawkawa Lake Road in Hope (Figure 2-1).

The upstream boundary of the Coquihalla River was set as steady inflow hydrograph. Flow hydrograph boundary conditions comprise of an inflow value and a hydraulic gradient to distribute this inflow along the length of the boundary condition line. The gradient used across the upstream boundary condition was measured from the lidar Digital Elevation Model (DEM) (0.8%).

A normal depth assumption was used as the downstream boundary for the Coquihalla River using a gradient measured from the lidar DEM (1.6%).

Figure 2-1. Overview of modelling location.

2.2. Manning's Roughness Values

Manning's roughness values (n)[1] were assigned by land cover type. A Manning's n of 0.1 was used for forested regions and 0.025 for roads. As it was not possible to calibrate the Manning's n value for the main channel (due to a lack of preflood bathymetry), a sensitivity analysis was instead performed. Manning's n for the main channel was varied between 0.035, based on the bed material, to 0.55, as calculated using Jarrett's equation (Jrett, 1985). This range in

---

[1] Manning's n is a coefficient representing the friction applied to flow by the channel it is passing through.

roughness produced an average 0.3 m change in water surface elevation (WSE) for the modelled discharges. A value of 0.035 was ultimately selected for the channel as it produced regions of supercritical flow that best matched those observed by BGC staff when visiting the site.

The Manning's n values used for the present work are shown in Table 2-1 and Figure 2-2.

Table 2-1. Associating land class with Manning's n.

Land Class	Manning's n	Color
1. Roads	0.025	⬜
2. Forest	0.1	🟩
3. Main Channel	0.035	🟦

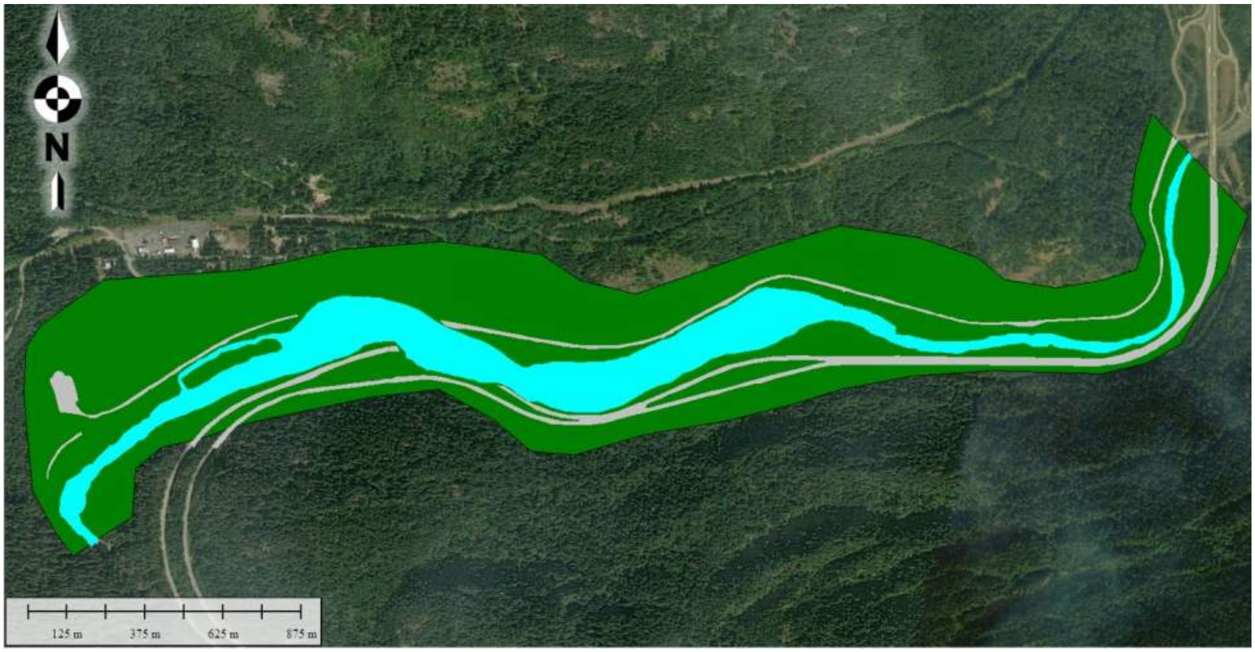

Figure 2-2. Manning's n roughness layer defined for the model.

2.3. HEC-RAS Model Meshing

The HEC-RAS software for 2D modelling uses an irregular mesh to simulate the flow of water over the terrain. Irregular meshes are useful for the development of numerically efficient 2D models to allow refinement of the model in locations where the flow is changing rapidly and/or where additional resolution is desired. With 2D models, the objective of mesh development is to use the coarsest mesh possible to reduce model runtime, while preserving the desired level of accuracy in the hydraulic results.

The default cell geometries created by HEC-RAS are rectangular, but other geometries can be selected to suit the problem under consideration. Within HEC-RAS, a 2D mesh is generated based on:

- Refinement areas to define sub-domains where the mesh properties (e.g., mesh resolution) are adjusted.
- Breaklines to align the mesh with terrain features which influence the flow such as dikes, ditches, terraces, and embankments. HEC-RAS provides options to adjust the mesh resolution along breaklines.

From these inputs, HEC-RAS generates the mesh consisting of interconnected grid cells with computational points at the cell centroids and along the faces of the cells (i.e., along the cell sides). The mesh was cleaned and checked for errors, such as a cell having more than 8 faces and gaps in the mesh.

2.4. Initial Mesh Development

For the Coquihalla River study area, a base mesh resolution of 25 m was selected. Breaklines were placed along the channel centerline, and along terrain features such as natural ridges and road embankments. Cell resolution on either side of breaklines was 5 m with 0 – 5 repeats.[2] An example of the mesh developed is provided in Figure 2-3.

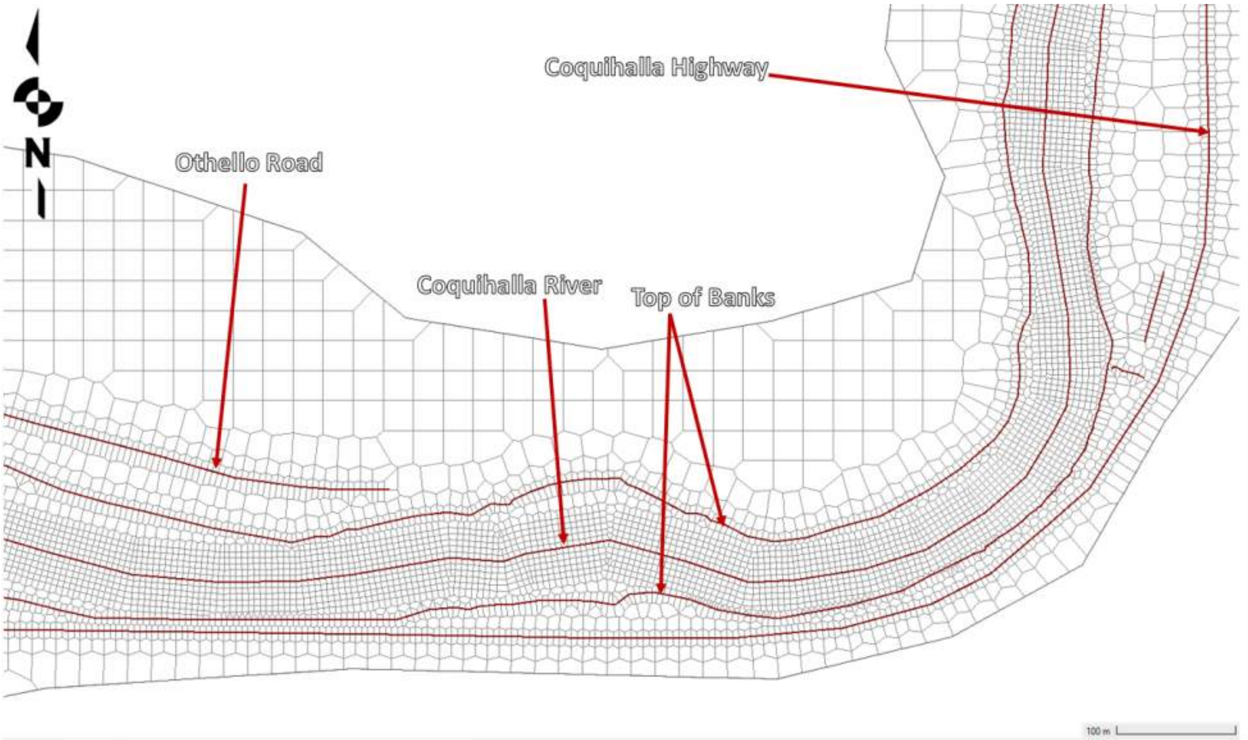

Figure 2-3. Manning's n roughness layer defined for the model.

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[2] Repeats are rows of cells adjacent to those along the breakline using the same resolution and orientation defined by the breakline. As an example, a breakline with a 1 m resolution and 1 repeat would have 2 rows of 1x1 m cells on either side of it.

2.5. Simulation Settings

The HEC-RAS 2D model was run using the shallow water equations with a Courant-controlled time step[3]. The shallow-water equations provide an accurate representation of vertically-averaged flow dynamics, especially where sharp constrictions/expansions/changes in direction of flow are observed (e.g., meander bends, bridges, etc.). The initial time step was six seconds, and the maximum Courant number was 2. The model was run to simulate a 48-hour period to reach steady flow within the model domain.

2.6. Sensitivity Analysis

Five different discharge scenarios for the Coquihalla River were run to compare against the HWMs: 850, 900, 950, and 1050 and 1150 m^3/s. As there was no channel bathymetry surveyed, the lost capacity of the channel was accounted for by subtracting the flow measured at the *Coquihalla River above Alexander Creek gauge* the date the lidar was captured, 150 m^3/s, from the modelled scenarios (i.e., 700, 750, 800, and 900 and 1000 m^3/s were the modelled discharges). This work around is an approximation as the cross-sectional area that conveyed the 150 m^3/s discharge on the date the lidar was flown would be able to convey a higher flow at higher discharges (i.e., the same cross-sectional area would be inundated but the average channel velocity would be higher). Each scenario was run for 6 hours with the model reaching steady state after 3 hours.

3.0 MODEL CALIBRATION

The model was calibrated to three key areas of interest adjacent to where Othello Road was washed out:

1. Water cannot overtop the right bank of the river at the residential area location shown in Figure 3-1. There was no evidence of inundation in that area.
2. The water needs to overtop the road at the location shown in Figure 3-2. This area had sediment deposited over Othello Road and corresponds to the photo shown in Figure 1-1.
3. The WSE should match the HWM recorded by BGC at the location shown in Figure 3-3.

For area of interest one, the model shows overtopping of the banks for the 1150, 1050 and 950 m^3/s runs suggesting that flood flows were likely under 950 m^3/s. Likewise for area of interest two, inundation onto Othello Road was not observed for the 850 m^3/s case suggesting that flood flows were likely above 850 m^3/s. The HWM in area of interest is most closely aligned with the 900 m^3/s run. As such a peak flow of 900 m^3/s is the best estimate for the November 15, 2021 flood on the Coquihalla River at Othello Road. When prorated downstream to the *Coquihalla River above Alexander Creek* gauge, this yields an estimate of 1100 m^3/s.

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[3] The Courant number is the product of the velocity and the time step divided by the distance step. For a Courant-controlled time step, the time step is halved if the Courant number for any cell exceeds the maximum Courant number set by the user. A maximum Courant number of up to 5 is recommended by the HECRAS 2D User Manual when using the Diffusion Wave equations, 3 when using the Shallow Water Equations, Eulerian-Lagrangian Method and 1 when using the Shallow Water Equations, Eulerian Method (Brunner & CEIWR-HEC, 2021).

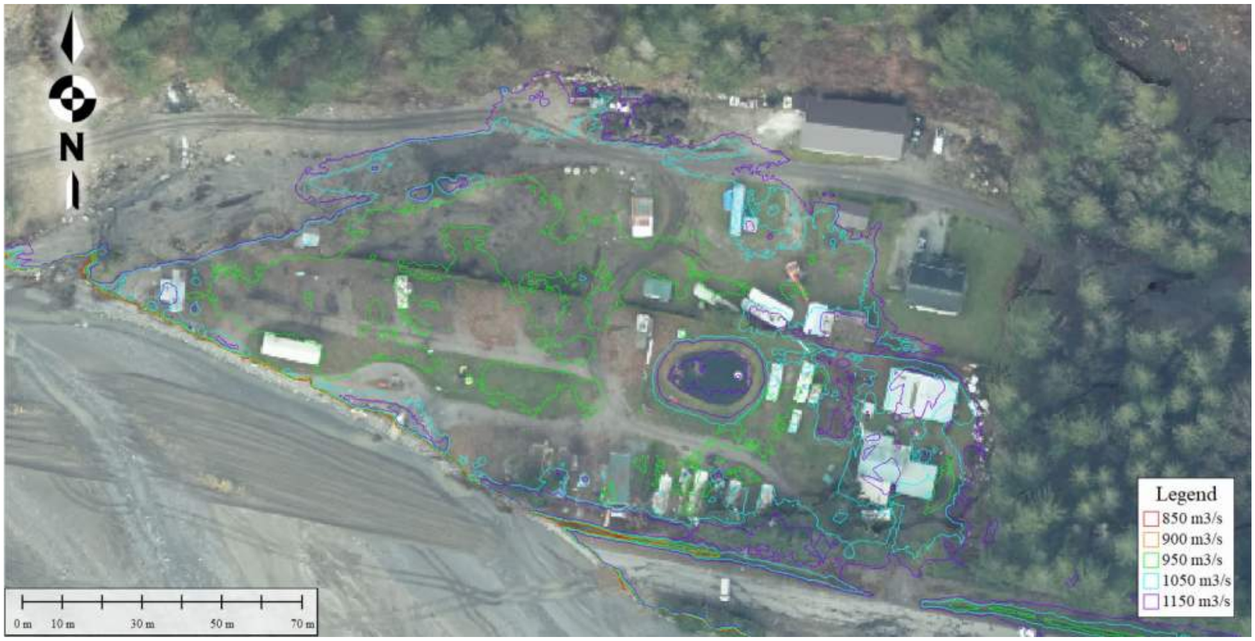

Figure 3-1. Modelled flooding extents at area of interest one.

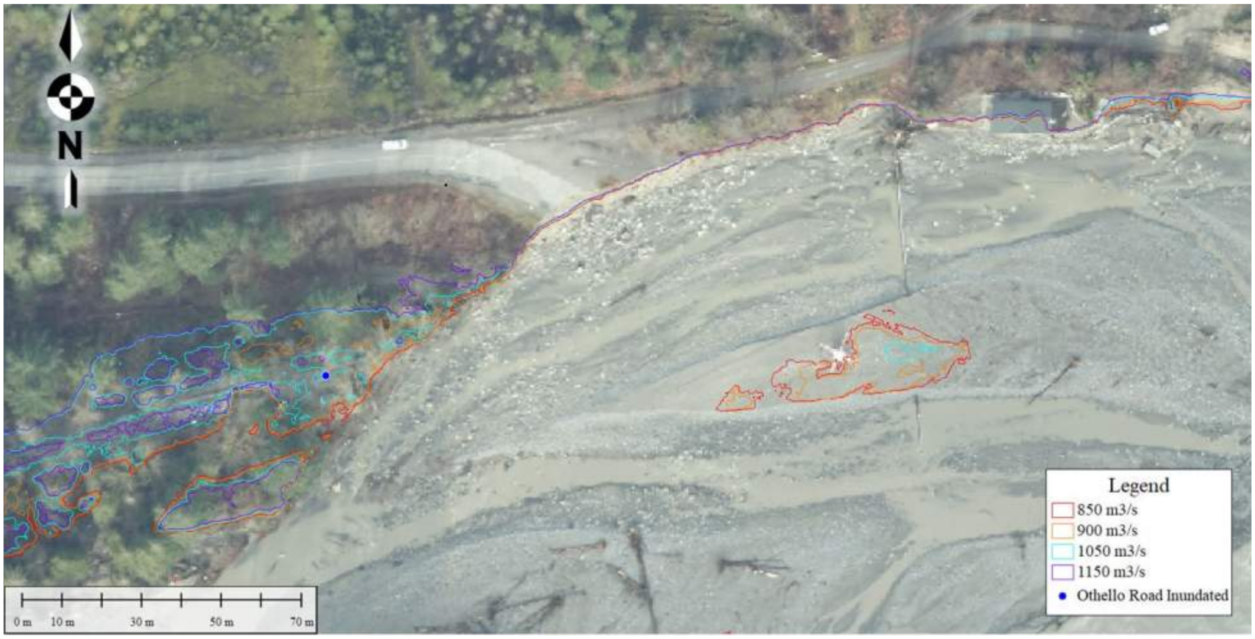

Figure 3-2. Modelled flooding extents at area of interest two.

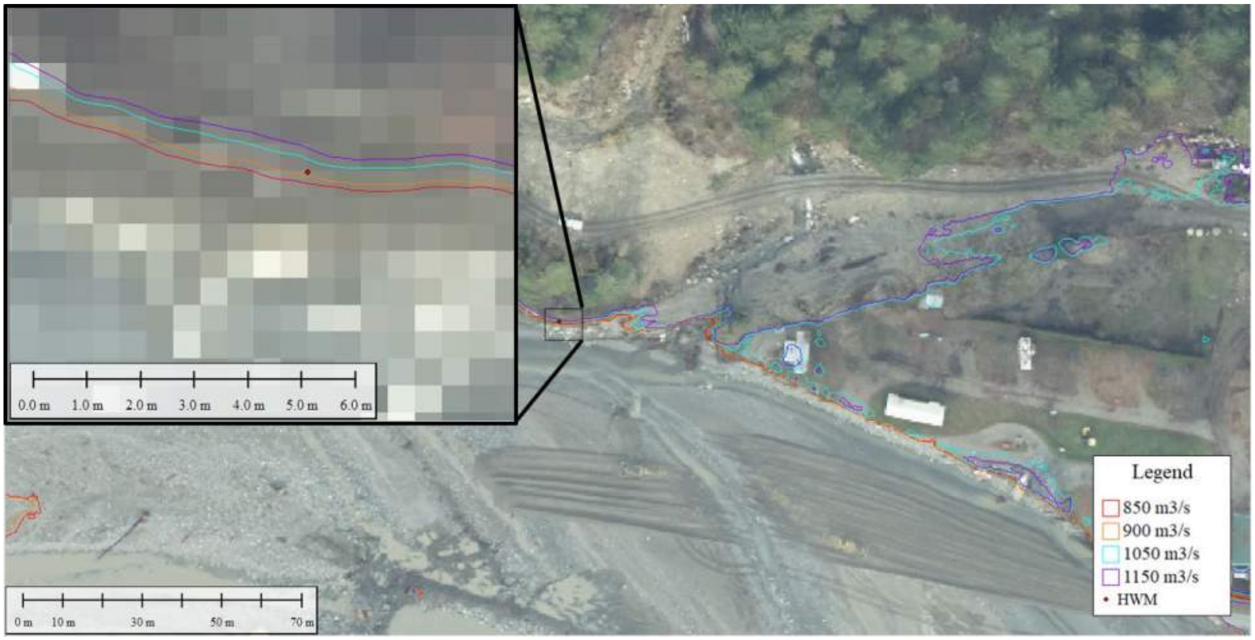

Figure 3-3. Modelled flooding extents at area of interest three.

4.0 SUMMARY AND LIMITATIONS

Using a 2D hydraulic model of the Coquihalla River and observed HWMs, BGC's estimated the magnitude of the November 15, 2021 flood on the Coquihalla River at Othello Road. The results are sensitive to the selected Manning's n value used in the hydraulic model. An average difference of 0.15 m exists in WSEs measured for the 850 and 950 m^3/s model runs. However, an increase to the Manning's n value from 0.035 to 0.055 produces a 0.3 m change to WSE, double that difference. No supercritical flow was shown in the model results when using an n value of 0.055 which does not match with the observed site conditions indicating the lower value is more accurate. There is a continuum of Manning's n and discharge values that would produce the observed HWMs, but based on the information currently available, 900 m^3/s is BGC's best estimate of the peak flow for the November 15, 2021 flood on the Coquihalla River at Othello. When prorated downstream to the *Coquihalla River above Alexander Creek* gauge, this yields an estimate of 1100 m^3/s.

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Design Criteria Sheet for Climate Change Resilience

Highway Infrastructure Engineering Design and Climate Change Adaptation
BC Ministry of Transportation and Infrastructure
(Separate Criteria Sheet per Discipline)
(Submit all sheets to the Chief Engineers Office at: BCMoTI-ChiefEngineersOffice@gov.bc.ca)

Project:	*Peers Creek Frontage Road Washout Site*
Type of work:	*2021 Flood Recovery Repair*
Location:	*Coquihalla River at Peers Creek Frontage Road, near Hope, B.C.*
Discipline:	*Hydrotechnical*

Design Component	Design Life or Return Period	Design Criteria + (Units)	Design Value Without Climate Change	Change in Design Value from Future Climate	Design Value Including Climate Change	Adaptation Cost Estimate ($)	Comments / Notes / Deviations / Variances
Hydrotechnical design of riprap features	200-year RP	Instantaneous Flow Rate (m^3/s)	1,070 m^3/s	+69% on instantaneous flow rate	1815 m^3/s	$1,270,000	As summarized in Table 1

Explanatory Notes / Discussion:

Flooding on the Coquihalla River in November and December 2021 resulted in extensive erosion and damage to Peers Creek Frontage Rd (PCFR) and Highway 5 located near Hope, BC. The BC Ministry of Transportation and Infrastructure (MoTI) plans to reinstate PCFR adjacent to Highway 5.

The PCFR site is vulnerable to changes in future peak flows as a consequence of climate change. As requested by MOTI, an assessment was undertaken by BGC to estimate climate-adjusted design flows. The Pacific Climate Impacts Consortium (PCIC) provides daily streamflow projections for the *Coquihalla River above Alexander Creek* (08MF068) hydrometric station under naturalized conditions. The daily mean streamflow is simulated using runoff and baseflow generated with an upgraded version of the Variable Infiltration Capacity (VIC-GL) model that is coupled to a glacier model (Schnorbus, in prep) and routed with RVIC (Lohmann et al., 1998, 1996; Hamman et al., 2016).

Rainfall-related peak flows were extracted for the September to March period from the PCIC forecasted data. The snowmelt-related peaks were extracted for the April to August period. Curves were fit to the projected annual maximum flows for the three separate time series (e.g., yearly maximums, rainfall-related, and snowmelt-related). The scales were removed from each curve by dividing out the current (2022) value of the curve, capturing how many times greater each future year's geometric mean is compared to the geometric mean in 2022 – the "dimensionless scaling factors". The dimensionless scaling factors were subsequently used to re-scale the peak flow distributions (snowmelt-related and rainfall-related).

The results indicate that the climate-adjusted 200-year (0.5% AEP[1]) instantaneous peak flow increases by 69% to a value of 2345 m^3/s from the stationary case (1380 m^3/s) at the *Coquihalla River above Alexander Creek* (08MF068) hydrometric station. The instantaneous peak flows were prorated to the PCFR site, resulting in flows of 1,070 m^3/s for the stationary 200-year instantaneous peak flow and 1815 m^3/s for the climate-adjusted 200-year instantaneous peak flow.

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[1] Annual exceedance probability

Proposed riprap protection works along the section of the PCFR to be reinstated include five components:

1. A 300 m long riprap revetment along Peers Creek Road.
2. An 80 m long deflection berm at the downstream end of the revetment.
3. Knick point armouring immediately downstream of the deflection berm.
4. Ditch armouring along Peers Creek Road from the proposed revetment south to the Othello interchange.
5. Road embankment armouring along Peers Creek Road from the proposed revetment south to the Othello interchange.

Differences in flood hydraulics between the climate-adjusted 200-year flow and the stationary 200-year flow results in differences in armouring requirements for the five riprap design components. The differences in design, estimated material quantities, and estimated total costs are summarized in Table 1.

Table 1. Summary of differences in design, estimated material quantities, and estimated costs for the riprap design components.

Design Component	Difference in Armouring Requirement	Material Quantity Difference	Cost Difference
Riprap Revetment	For the climate-adjusted 200-year flow, the design velocity is 5.2 m/s and the required riprap size is 2000 kg Class riprap. For the stationary 200-year flow, the design flow velocity is 4.5 m/s and the required riprap size is 1000 kg Class riprap.	**Riprap Quantity Difference ~ 1700 m^3** Climate-Adjusted Volume ~ 7600 m^3 (Class 2000 kg riprap) Stationary Volume ~ 5900 m^3 (Class 1000 kg riprap)	**Cost Difference ~ $960,000** Climate Adjusted Cost: $3,040,000 Assumed Unit Price (Class 2000 kg riprap): $400/m^3 Stationary Cost: $2,080,000 Assumed Unit Price (Class 1000 kg riprap): $350/m^3
Deflection Berm	The deflection berm is recommended for the climate-adjusted 200-year flow, but not required for the stationary 200-year flow	**Riprap Quantity Difference ~ 560 m^3** Climate-Adjusted Volume = 800 m^3 (Class 250 kg riprap) Stationary Volume = 0 m^3	**Cost Difference ~ $170,000** Climate Adjusted Cost: $170,000 Assumed Unit Price (Class 250 kg riprap): $300/m^3 Stationary Cost: $0
Knick Point	There is no difference between the design of the knick point armouring for the stationary or climate-adjusted 200-year flow.	-	-
Ditch Armouring	There is a small reduction in flow velocity between the climate-adjusted 200-year flow and the stationary 200-year flow, but there is no difference in the design of the ditch armouring.	-	-
Road Embankment	For the climate-adjusted 200-year flow, the design velocity is 3.5 m/s and the required riprap size is Class 100 kg riprap. For the stationary 200-year flow, the design flow velocity is 1.0 m/s and the required riprap size is Class 10 kg riprap.	**Riprap Quantity Difference ~ 500 m^3** Climate-Adjusted Volume = 1000 m^3 (Class 100 kg riprap) Stationary Volume = 500 m^3 (Class 10 kg riprap)	**Cost Difference ~ $140,000** Climate Adjusted Cost: $250,000 Assumed Unit Price (Class 100 kg riprap): $250/m^3 Stationary Cost: $110,000 Assumed Unit Price (Class 10 kg riprap): $220/m^3
			Total Cost ~ $1,270,000

The estimated cost for adapting the riprap protection to climate change is estimated to be $1,270,000. Costs of other project elements (e.g., road repair) are not considered here.

For a complete discussion of the climate change assessment and design, please refer BGC's report titled "Hydrotechnical Assessment and Design for Peers Creek Frontage Road Washout Site", dated May 12, 2023.

Recommended by: Engineer of Record: Evan Shih, P.Eng.

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PROVINCE OF
E. Y. SHIH
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BRITISH COLUMBIA
ENGINEER
2023-05-23

Date: May 12, 2023

Engineering Firm: BGC Engineering Inc.

Accepted by BCMoTI Consultant Liaison: 2023.05-15
(For External Design)

Deviations and Variances Approved by the Chief Engineer: ________________________
Program Contact: Chief Engineer BCMoTI

APPENDIX B

MEMO – PRELIMINARY HYDROTECHNICAL ASSESSMENT FOR INTERIM REPAIRS OF PEERS CREEK FRONTAGE ROAD

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Project Memorandum

To:	**BC Ministry of Transportation and Infrastructure**		
Attention:	**Dickson Chung, Senior Highway Design Engineer; Maureen Kelly, Senior Geotechnical Engineer**	**cc:**	**Neetu Bhatti, McElhanney Senior Project Manager**
From:	**Evan Shih, BGC Engineering Inc.**	**Date:**	**October 25, 2022**
Subject:	**Preliminary Hydrotechnical Assessment for Interim Repairs of Peers Creek Frontage Road**		
Project No.:	**0272-097**		

1.0 INTRODUCTION

In November 2021, landfalling of an atmospheric river brought two days of intense rainfall to southwestern British Columbia resulting in extreme streamflow and extensive geomorphic change in watersheds across a large spatial extent of the lower Fraser River watershed, including the Coquihalla River. Flooding on the Coquihalla River in November and December 2021 resulted in extensive erosion and damage to infrastructure throughout the river valley, with washouts of Othello Road, Highway 5 (located valley-opposite to Othello Road) and Peers Creek Frontage Road near Hope, British Columbia (BC).

BGC Engineering Inc. (BGC) was retained by the BC Ministry of Transportation and Infrastructure (MoTI) to provide hydrotechnical engineering support for the long-term repair of Peers Creek Frontage Road in coordination with MoTI's road design and project management consultant, McElhanney Consulting Services Ltd (McElhanney). Design for long-term repair of the road is currently in the conceptual phase; however, BGC understands that Kiewit Corporation (Kiewit) intends to complete interim repairs of the road to provide construction access for the Trans Mountain Expansion Project until a long-term solution can be implemented by MoTI. Construction of the interim works is expected to initiate sometime between late October and early November 2022 pending acquisition of permits and approvals. On September 30, 2022, Kiewit requested that BGC provide recommendations to inform hydrotechnical design of a section of the road that washed out during the November 2021 flood and where instream works (i.e., riprap armouring) will be required for the interim repairs. McElhanney is providing design recommendations from a highway design perspective.

This memo provides an overview of BGC's preliminary hydrotechnical assessment and recommendations for Kiewit's proposed interim instream works. Key hydrotechnical design parameters were estimated including the design water surface elevation, riprap size, and scour depth. All work was conducted in accordance with the existing As & When Geotechnical Engineering and Design Services contract (Contract No. 861CS1183) between BGC and MoTI, dated September 16, 2021. BGC understands that MoTI will share this memo will Kiewit.

2.0 HYDROTECHNICAL ASSESSMENT

2.1. General

The preliminary hydrotechnical assessment was conducted to support Kiewit's design of interim repairs to Peers Creek Frontage Road. The assessment utilizes a two-dimensional (2D) hydrodynamic model of the Coquihalla River prepared by BGC using HEC-RAS (Hydrologic Engineering Center – River Analysis System). The hydrodynamic model was originally prepared to support design of the Othello Rd washout site (i.e., Othello Road Site B). The model domain was subsequently extended upstream to encompass the river reach adjacent to Peers Creek Frontage Road. Due to the urgency of this assessment, calibration and validation of the model has not been completed. Therefore, the results presented herein are considered preliminary and may vary from those reported following detailed assessment and design of the long-term repair works.

2.2. Design Flood Event

As part of the Othello Road Site B project, BGC conducted a detailed analysis to estimate flood magnitudes for a range of return periods. Details of that analysis are summarized in BGC (July 13, 2022). The estimated quantiles were prorated by drainage area to the Peers Creek Frontage Road site (Table 2-2). BGC understands that MoTI typically requires temporary flood protection works to be designed to the 10-year return period peak flow. Recommendations within this memo are provided in consideration of this flood magnitude (i.e., 420 m^3/s)

Table 2-1. Peak flow estimates for a range of return periods at Peers Creek Frontage Road site.

Return Period	Peers Creek Washout Site Flow (m^3/s)
2	190
5	305
10	420
20	500
50	720
100	880
200	1070

2.3. Flood Hydraulics

The 2D hydrodynamic model was developed using a digital elevation model (DEM) that combined bathymetric survey data collected by McElhanney from August 29-31 and September 16, 2022 with lidar data collected by McElhanney on April 22, 2022. The upstream model boundary was located approximately 1.5 km upstream of the project area. The downstream model boundary was set approximately 5 km downstream of the project area, just upstream of the Coquihalla River canyon. The parameters used in the 2D model simulations are summarized in Table 2-3. Water surface elevations (WSE), flow velocities and flow depths were extracted from the model at the location shown in Figure 2-1, where the road washed out during the November 2021 flood and where instream installation of a temporary riprap revetment is proposed.

During the 10-year peak flow event, the channel is estimated to have an average flow depth of approximately 3 m and flow velocity of approximately 4 m/s at the area of interest. A profile of the modelled WSE along the blue line shown in Figure 2-1 is illustrated in Figure 2-2.

Table 2-2. Parameters used for 2D hydrodynamic modelling using HEC-RAS.

Hydraulic Parameter	Value
Manning’s n roughness coefficient in the channel	0.035
Manning’s n roughness coefficient in the floodplain	0.1
Slope at the downstream model boundary (m/m)	0.016
General mesh spacing (m)	25 m x 25 m
Grid spacing at breaklines (m)	5 m x 5 m
Model time step	Variable based on Courant condition

Figure 2-1 Location of hydraulic parameter estimation. WSEs, flow velocity and flow depth were estimated along the blue line. A scour analysis was conducted using a typical cross section along the red line.

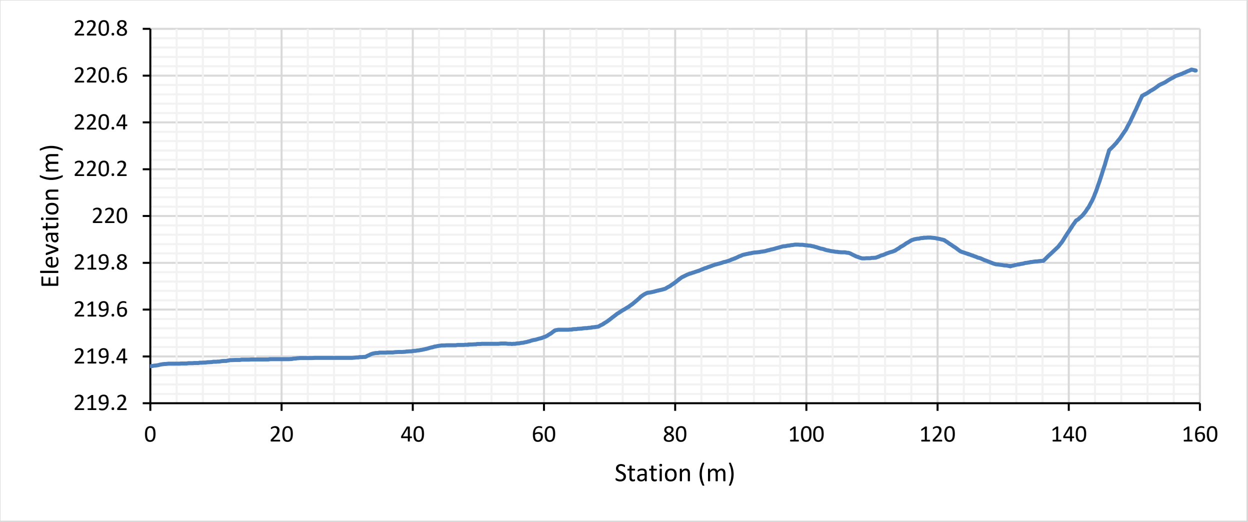

Figure 2-2 Modelled WSE profile for 10-year return period peak flow. The WSE was extracted from the 2D model along the blue line shown in Figure 2-1 with station 0 located at the downstream extent of the line.

2.4. Scour Assessment

A scour assessment was completed using outputs from the hydraulic model taken along a typical cross section at the area of interest (red line shown in Figure 2-1). Natural scour was estimated using the Blench Regime method (Blench, 1969). Results of the analysis indicate that limited scour is expected to occur below the channel thalweg elevation (216.7 m) during the 10-year peak flow event.

Immediately following the November 2021 flood event, considerable sediment aggradation was observed along the project reach. In the period following, the channel bed was observed to have degraded considerably; potentially up to 2 m in areas. The morphology of the project reach and potential for additional channel degradation had not been reviewed at the time of preparation of this memo. Although limited scour is predicted during the 10-year peak flow event, keying the riprap revetment into the channel bed to an elevation of 216.0 m, or approximately 0.7 m below the surveyed channel thalweg, would provide an allowance for uncertainty in the analysis and the potential for ongoing degradation.

2.5. Riprap Sizing

Riprap sizing for the proposed riprap revetment was estimated based on methods provided in USACE EM 1110-2-1601 (USACE 1994). Design flow velocity and depth were estimated from the 2D modelling results as discussed in Section 2.3. Assuming a 2H:1V bank slope, the analysis indicates that a minimum riprap size of 500 kg Class (D_{50} = 725 mm) would be required to maintain hydraulic stability during the 10-year peak flow event.

3.0 RECOMMENDATIONS

Based on the preliminary hydrotechnical analysis, BGC's recommendations are summarized as follows:

- Ideally, the top elevation of the riprap revetment would be installed above the 10-year WSE, although this may not be feasible given site constraints. Based on discussions with McElhanney, BGC understands that overtopping of the revetment may be tolerated given that the interim works will repair the site to an improved condition from what presently exits.
- A minimum riprap size of 500 kg Class is required for hydraulic stability of the proposed riprap revetment. BGC has not estimated the gradation of riprap that was installed onsite immediately following the November 2021 flood. However, based on visual inspection, the riprap appeared to consist of a range of sizes of approximately 500 kg Class and larger. BGC understands that Kiewit will be repurposing existing riprap onsite to construct the temporary revetment. BGC recommends that a sorting of riprap onsite be completed to the extent possible such that the temporary revetment is constructed of 500 kg Class riprap or larger, while meeting the gradation specifications provided in Section 205 of the MoTI Standard Specifications (MoTI, 2020). The revetment should be constructed at slopes no steeper than 2H:1V and the minimum thickness of the riprap should align with the riprap size selected (i.e., if a larger class of riprap is used, it should match the corresponding thickness indicated in Table 205-D of MoTI (2020)).
- Geotextile filter fabric should be installed beneath all riprap to reduce the potential for migration of soil particles from the underlying in-situ soils. Mirafi 1100N or equivalent is recommended and overlain with a 150 mm gravel bedding layer.
- The riprap revetment should be blended into the existing revetments upstream and downstream to provide smooth transitions, and keyed into the channel bed to an elevation of 216.0 m.

4.0 CLOSURE

BGC Engineering Inc. (BGC) prepared this document for the account of BC Ministry of Transportation and Infrastructure. The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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Yours sincerely,

BGC ENGINEERING INC.
per:

E. Y. SHIH
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2022-10-25

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APPENDIX C

STABILITY SEEDING MEMO FROM DR. BRETT EATON

Habitat benefits of using a stability seeding approach to channel stabilization

Brett Eaton

2023-03-08

1 executive summary

New proof-of-concept experiments demonstrate the potential impact of the “stability seeding” approach to channel stabilization. This approach involves introducing sediment (typically in the boulder size class range) that is consistent with the largest sediment transported by the river at the site requiring stabilization. This stabilizing sediment includes sediment ranging from 50% to 100% of the largest mobile particle at the site. This size of sediment has been shown to control the stability of the banks, bars, pools and riffles in gravel bed streams by controlling the deposition of the rest of the sediment found in the bed of the river.

There are a range of methods for implementing stability seeding, including: positioning the stabilizing sediment on the floodplain surface adjacent to the channel banks and relying on bank erosion to recruit them; placing stabilizing sediment directly on the channel banks (either on top of existing riprap or on top of an eroding cut-bank) so that high flows can recruit the sediment before bank erosion occurs; and placing the stabilizing sediment on the channel bed at key locations to mimic the redistribution of these sediments that naturally occur during high flows. While the nature of the potential habitat impacts produced by stability seeding are well defined, the degree to which they can be realized in a real-world implementation depends on how well the stabilizing sediment can be recruited by the river and transported to key locations that control the channel morphology. Therefore, it is important to remember that the extent of the habitat improvement that will result remains to be demonstrated in the field.

Relative to standard riprap designs, channel rehabilitation using stability seeding approaches has the potential to retain a diverse set of physical habitats (including riffles, pools and bars) within the stabilized reach, and to maintain the exchange of water between the stream and the river bed (which is key to maintaining potential spawning habitat quality associated with riffles).

When used to stabilize actively retreating meander bends, the stability seeding approach will help offset the reduction in bed sediment supply associated with stabilizing the bank, thereby reducing the potential for degradation of the riffles downstream of the bend. This should reduce the potential for the bank stabilization activities to have negative impacts on downstream habitat quality.

Stability seeding also limits the potential for vertical bed scour, which not only simplifies the channel morphology and degrades the physical habitat, but can expose and damage buried infrastructure (which can obviously have negative effects on the local riverine ecology). The degree to which this effect can be realized depends on how much of the stabilizing sediment can be entrained by the flow and transported to key locations (such as riffles) that control the stability of the stream bed. In situations where vertical scour is an imminent threat to infrastructure and physical habitat, direct placement of stabilizing sediment in the stream channel may be preferable to a standard riprap installation.

2 stability seeding overview

The gravel bed streams found in mountainous regions like British Columbia are commonly referred to as threshold streams (Church 2006) because they seldom experience flows that are much more powerful than those capable of eroding and transporting the median sized sediment particle on the surface of the river bed (called D_{50}).

The relative strength of a flow can be indexed using the average shear stress, which is the force per unit area exerted on the channel bed (τ). It depends primarily on the water depth, d, and the water surface gradient, S. Relative flow strength is also often indexed using the average flow velocity (U), which depends on d, S, and the roughness of the channel boundary. The key equations used to analyse sediment transport are most often constructed using τ. To more explicitly link channel stability to the hydrological events that produce channel change, specific discharge, q, (or discharge divided by the width of the river at that discharge) is used in this memo to represent the power of the river to erode and transport sediment. The threshold specific discharge, q_{c50}, is the discharge at which the median sized sediment on bed surface (D_{50}) is first entrained, and significant transport of the sediment found in the river channel begins. This typically occurs at flows less than the bank-full flow; experience in BC at Fishtrap Creek suggests that q_{c50} is about half the bank-full flow (Eaton et al. 2010).

The reason that gravel bed streams typically never experience flows that exceed q_{c50} by more than a factor of about 3 is that their banks are weak compared to the stream bed. Shortly after flows exceed q_{c50}, an unarmoured gravel bank is subject to forces capable of eroding it. While riparian vegetation can delay the onset of bank erosion in smaller rivers, the effect of riparian vegetation on bank strength disappears for rivers much deeper than 2 m at their bank-full flood stage (Eaton and Giles 2009), making large gravel bed streams particularly prone to hazardous lateral migration. Once bank erosion is initiated, gravel bed streams will widen, spreading the total flow over a greater area and maintaining specific discharge values close to about 3 times q_{c50}. This negative feedback between bank erosion and specific discharge is an important mechanism by which these systems maintain their relative stability.

Because gravel bed streams tend to respond to rare flood events by rapid bank erosion and channel widening, they often are transformed from single-threaded channels into multi-threaded (or braided) channels. In contrast, the larger sand bed streams found further downstream where valley gradients are lower typically have banks that are relatively strong due the the cohesive sediment found in them, which means they can (and do) sustain specific discharges much greater than 3 times q_{c50} (Church 2006). As a result, they are far less likely to experience extensive channel migration and seldom are transformed from single-thread to braided morphologies.

Recent research has demonstrated that, in threshold gravel bed streams, the stability of the channel is not controlled by the median sized sediment on the bed surface as has long been assumed; it is controlled by the largest grains on the bed surface, which most likely form a stable skeletal structure that traps and stores the smaller material found on the bed surface. Experiments by Eaton and Church (2004) and Eaton, MacKenzie, and Booker (2020) showed that gravel bed streams could not establish a stable, single-thread channel morphology for flow conditions during which the coarsest sediment in the stream was eroded and transported. Subsequent research demonstrated that the addition of a small quantity of sediment from the coarse tail of the bed surface grain size distribution was sufficient to prevent significant lateral migration of an experimental stream channel during bank-full flows (MacKenzie and Eaton 2017); the channels with and without the additional stabilizing sediment are shown in Fig. 1. Booker and Eaton (2020) similarly showed that the coarse tail of the bed sediment distribution controlled the stable gradient for in-channel sediment deposits at near-threshold flow conditions.

These findings indicate that there is the potential to modulate erosion and transport in gravel bed streams with only minor additions of stabilizing coarse sediment to the system. Eaton, MacKenzie, and Tatham (2022) tested one possible means of implementing a stability seeding approach that relies on bank erosion to recruit stabilizing sediment from the floodplain and high flows to redistribute the material within the channel. The stabilizing sediment used in these proof-of-concept experiments is close to the 90th percentile of the bed surface sediment size distribution, as shown in Fig. 2. The stabilizing sediments are mobilized during the highest flows but they are entrained less frequently and move shorter distances than do the majority of the sediment sizes on the bed surface.

More generally, sediment ranging from 50% to 100% of the largest mobilized particle in the stream can be used as stabilizing sediment. This corresponds approximately to sediment coarser than the 84th percentile of

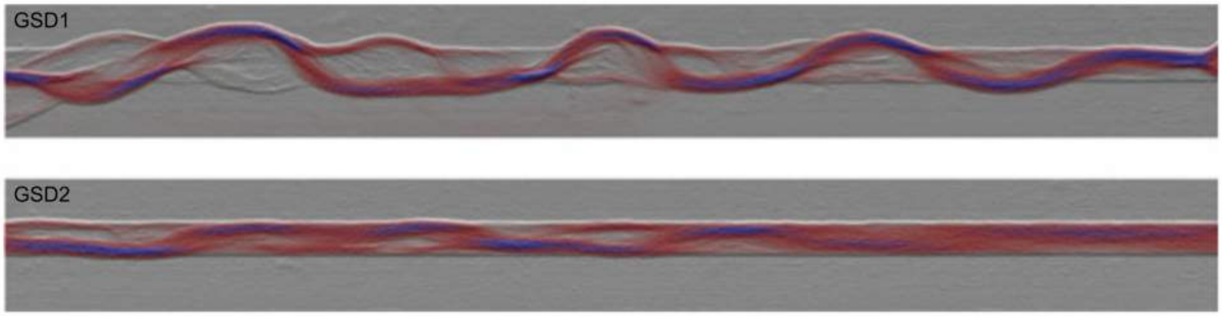

Figure 1: Maps of specific discharge are presented for two channels with nearly identical bed sediment distributions. The upper panel shows the channel pattern formed in the original bed material. The lower panel shows the morphology of a stream with a small addition of coarse sediment to the bed material. Figure taken from MacKenzie and Eaton, 2017.

the bed surface grain size distribution. Ideally, it should be rounded to sub-rounded in shape, consistent with sediment naturally found within the river. In most gravel bed streams, this will include sediment in the boulder size range, though some large cobbles will also act as stabilizing sediment in some gravel bed rivers.

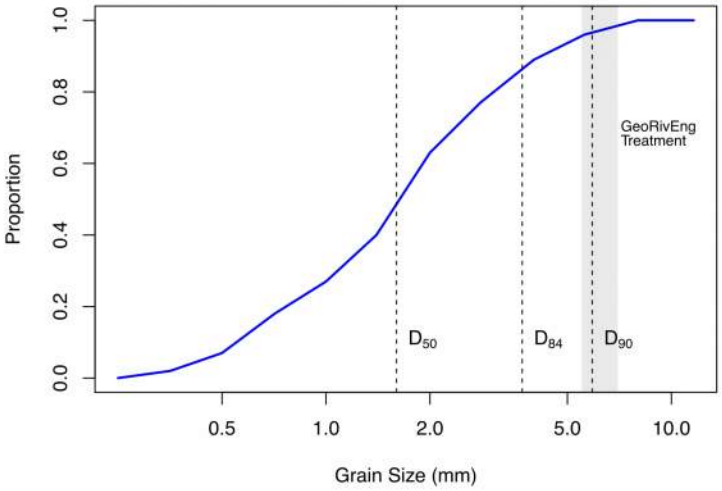

Figure 2: Experimental sediment size distribution and stabilizing sediment size range (GeoRivEng Treatment) for the proof-of-concept experiments by Eaton, MacKenzie and Tatham, 2022.

The treatment using this size of sediment will be referred to as the “stability seeding” experiments. Fig. 3. shows the channel morphology at the beginning of each experiment (top panel), the morphology after three floods of increasing magnitude (the largest of which is 3 times larger than the bank-full flood) for an untreated reach (second panel), the morphology after three floods for the reach with stability seeding (third panel), and the morphology for a reach with standard class 3 riprap (bottom panel).

The detailed post-flood morphology of the stability seeding treatment reach is shown in Fig. 4. The treatment involved placing a layer of stabilizing sediment one grain diameter thick on the bank top, right up to the edge of the channel but not within the channel. Fig. 5 presents the same information for the riprap treatment. Riprap was installed following the conventional design, including toeing the installation into the channel bed.

Briefly, the stability seeding treatment was able to modulate the rate of bank erosion during a range of flood events. As a result, the natural channel morphology comprising cut-banks, bars, pools and riffles was maintained throughout the experiment, although the channel was prevented from widening so much

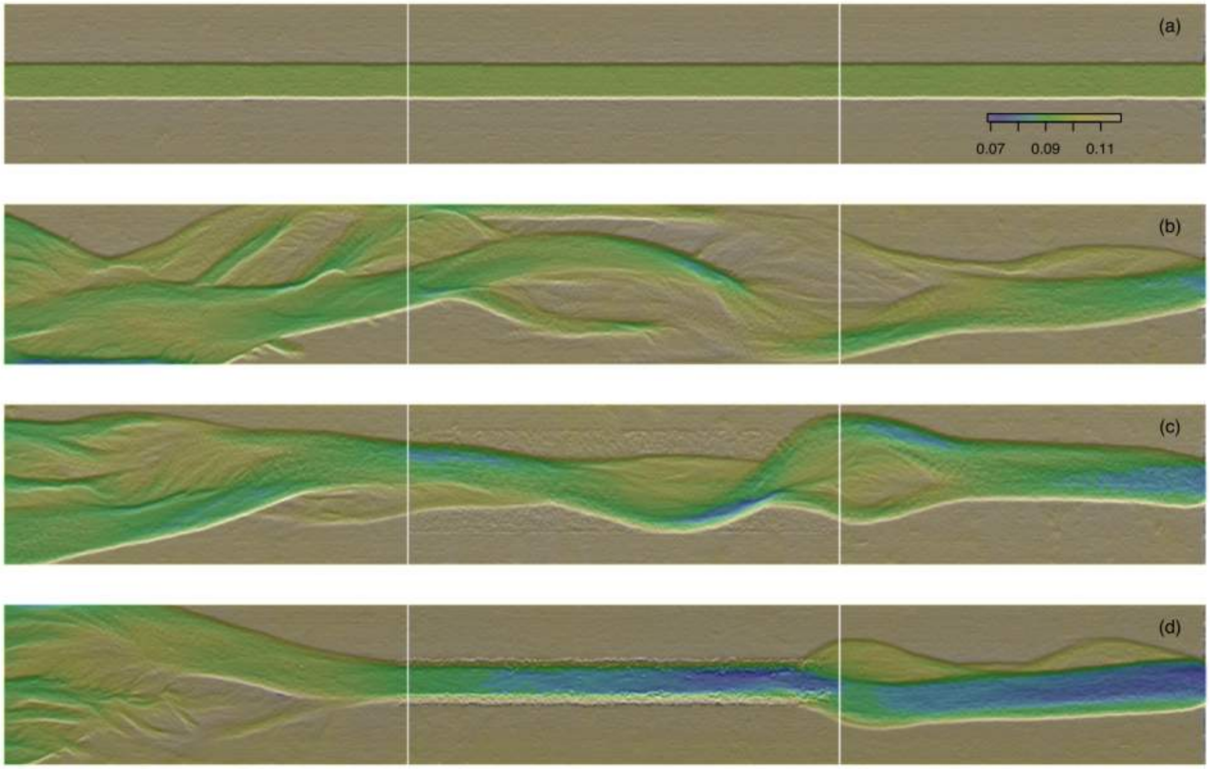

Figure 3: Hillshade images of channel morphology (a) at the beginning of each run; (b) with no stabilizing treatment; (c) with stability seeding treatment; and (d) with standard class 3 riprap treatment. Each experiment involved three floods of increasing magnitude, with the largest flood reaching 3 times the size of the bankful flood. Flow direction is from right to left. Only the middle sections of the experimental channels were stabilized; the upstream and downstream sections were left unprotected.

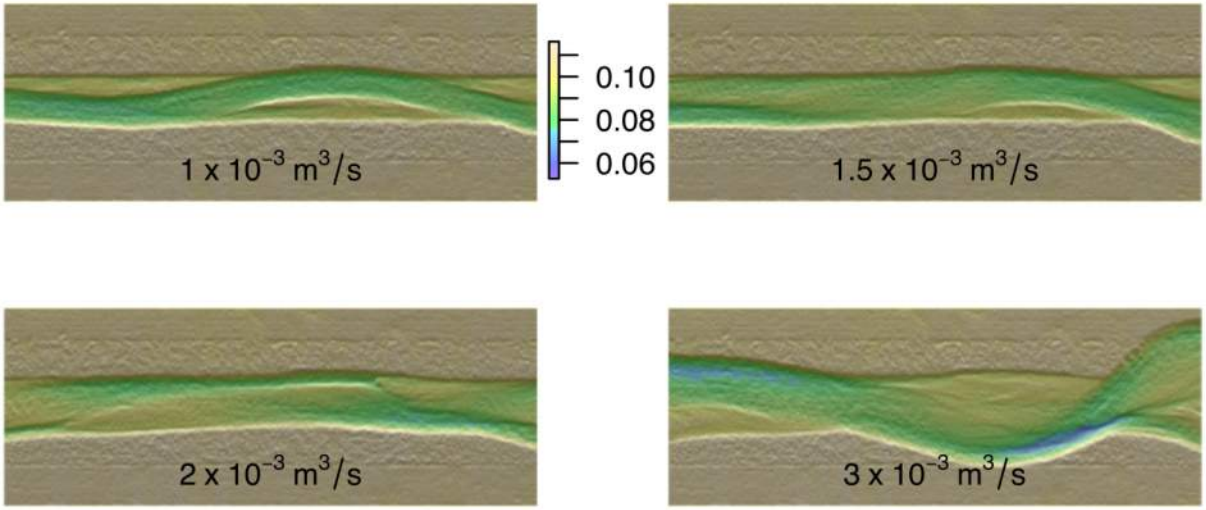

Figure 4: Morphology of the treated reach with stability seeding after four floods, ranging from the bankfull flow to 3 times the bankfull flow.

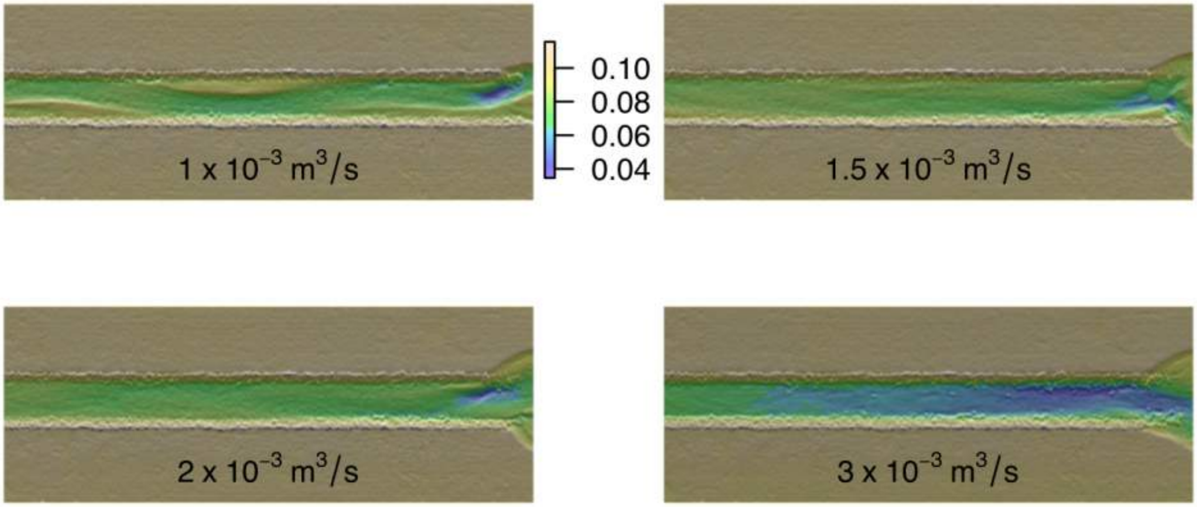

Figure 5: Morphology of the treated reach with class 3 riprap after four floods, ranging from the bankfull flow to 3 times the bankfull flow.

that it would transition to a braided channel pattern. As a result, a diverse suite of physical habitats was maintained, and the topographic variations responsible for generating flow into and out of the stream bed were maintained, thereby maintaining the quality of the potential spawning habitat associated with these hyporheic exchange patterns.

In contrast, standard riprap prevented any lateral channel migration, and prevented the stabilizing feedback between channel widening and specific discharge reduction from occurring. As a consequence, the riprap reach was subject to excessively high shear stresses and high rates of sediment transport, which produced significant vertical bed degradation, and the loss of channel complexity; by the end of the last flood, no bars, pools or riffles remained in the riprap reach. Over 75% of the channel bed in the riprap reach experienced net vertical bed scour that exceeded the mean bank-full water depth, which could pose a significant risk to buried linear infrastructure beneath the stream bed.

3 geomorphic effects and habitat benefits

There are several ways in which the stabilizing sediment could be delivered to the stream channel. The potential habitat benefits of each approach are slightly different and are described separately below. The actual habitat benefits of stability seeding in the field have not yet been studied, so the discussion below is speculative. The actual benefits that will occur in the field will depend largely on (a) how much of the stabilizing sediment is recruited by the river; and (b) where on the river bed it is deposited. Furthermore, the recruitment and redistribution of these stabilizing sediments only happens during floods capable of producing wide-spread bank erosion and channel widening (e.g. 50-year return period floods), so they would have no direct (negative or positive) effects on river habitat until after a rare flood event occurred.

3.1 stability seeding on the channel floodplain

The placement of a layer of stabilizing sediment on the floodplain adjacent to the channel banks has been tested experimentally (Eaton, MacKenzie, and Tatham 2022) and the potential benefits of this approach are reasonably well documented. It can be applied to both banks and in straight reaches where a straight channel alignment needs to be maintained (as in Figs 3, 4 and 5), to both banks of a sinuous, meandering channel (tested by Eaton, MacKenzie, and Tatham 2022 but not shown), or along a single eroding meander bend (tested in the lab, but not yet published).

(1) The first benefit of this approach is that it involves the minimum possible disturbance to the treated reach. No sediment is placed directly on the stream bed or banks, and sediment only enters the channel when it is recruited by bank erosion. In addition, the added material is indistinguishable from the bed material in terms of size and roundness. As a result, the effects on bed surface structure and porosity would be analogous to those that occur naturally.

(2) This approach could also be combined with riparian planting in and around the stabilizing grains, which would increase the likelihood that the plantings would remain undisturbed for long enough to establish a mature forest cover capable of moderating bank erosion rates on its own. This combination of stabilization and revegetation would help restore the natural linkages between the river and the rehabilitated riparian forest. This approach is likely to be particularly successful on streams with average bank heights of 1 m or less, since root reinforcement can be moderately to highly effective in streams of this size (Eaton 2006).

(3) If/when stabilizing sediments are introduced to the treated reach via bank erosion, it is likely that the natural sequences of bars, pools, and riffles will be maintained to a greater degree than if traditional riprap were used. This could help maintain more diverse physical habitat comprising slow and deep pools, and shallow and rapid riffles. It may also help maintain the topographic variability necessary to drive hyporheic exchanges between the stream the the river bed.

(4) Transitions from stable single-thread channels to multiple-thread braided channels during future rare floods will be less likely to occur. Braided streams are highly complex, but they often have little in the way of vegetative cover, and they may experience de-watering during low flows and/or elevated stream temperatures due to a lack of shade. Maintaining a single-thread channel reduces the potential magnitude of such impacts, even if some widening and channel modification does occur in the treated reach.

(5) Minor bank erosion may continue to occur within the treated reach, preventing a static channel bed from developing and maintaining the disturbance regime upon which the aquatic ecosystem depends.

(6) Stabilization of the channel bed (and in particular, of the riffles downstream of the treatment, where the treatment is installed on an active meander) could potentially modulate the amount of vertical scour that occurs, preventing the exposure of buried infrastructure. Where meander bends must be stabilized, it is often the case that the local reduction in sediment supply can cause the downstream riffle to degrade, steepening the gradient along the meander bend and possibly threatening the stabilization works. When the riffle degrades, the potential spawning habitat associated with the riffle is lost, and the riffle/pool morphology is replaced by a more uniform run or glide. Since the stabilizing sediment is mobile, it can be transported to the riffle, where it can potentially counter-balance the reduction in sediment supply due to meander stabilization.

3.2 stability seeding on channel banks

Where it is not feasible/desirable to stage the stabilizing sediment on the bank tops and to allow the river to recruit it when and where the banks experience migration, it is possible to add the stabilizing sediment as a facing on the toe of channel bank. Typically, such sediment additions will be placed upon an existing riprap installation where vertical degradation is a concern, or where the integrity of the riprap is compromised, but full-scale replacement is not feasible/necessary. This approach has not yet been tested experimentally (but will be soon). The benefits will be similar to those for the bank-top stability seeding approach, and it is likely that recruitment of the stabilizing sediment will require rare floods capable of eroding unprotected channel banks.

(1) The natural processes of erosion, transport and deposition will distribute the stabilizing grains within the channel when and where the channel becomes unstable.

(2) The addition of stabilizing grains to the face of a cut-bank along a meander bend will potentially off-set the sediment reduction associated with stabilizing the bend, and could help maintain the downstream riffle. This will likely help maintain diverse riffle /pool morphology and hyporheic exchange patterns while still preventing any lateral migration of the river from occurring.

(3) If stabilizing grains are introduced along the entire meander bend, then the stabilizing grains could reduce the potential for vertical incision along the channel, protecting buried infrastructure. The stabilizing grains could also help create complex sedimentary habitats by triggering the formation of stone lines, clusters and cells, which can provide important interstitial habitat for invertebrates and small/young fishes. The same features that reduce the potential for vertical incision create valuable benthic habitat.

3.3 stability seeding on the channel bed

In sections where vertical degradation of the channel is an imminent concern (e.g. at bridge crossings, or buried linear infrastructure crossings), it may be advantageous to place stabilizing sediment on the stream bed. The degree to which this (untested) stabilization approach will have the desired effect depends on how well the placements mimic the redistribution processes that have been produced in the laboratory experiments. Therefore the potential habitat benefits are less clear and are more likely to vary from site to site, depending on the details of the stabilization design.

(1) The stabilizing grains could potentially provide important interstitial habitat for invertebrates and small/young fishes by promoting the formation of stone lines, clusters and cells.

(2) Depending on the design, in-stream placement of stabilizing sediment could create/maintain sequences of bars, pools, and riffles. This could help maintain more diverse physical habitat and help promote hyporheic exchanges between the stream the the river bed.

4 monitoring

After implementing a stability seeding project, it is appropriate to conduct a monitoring program to document its effects. The stability seeding approach is relatively new, and post-implementation monitoring will yield important insights into its long-term effects. The precise nature of the monitoring will depend on the project design and the goals of the project, but overall, monitoring should seek to:

(1) collect annual or biannual (meaning every two years) aerial surveys of the project reach during low-flow conditions using an unmanned aerial vehicle (UAV) to document the post-implementation adjustment of the channel morphology, as well as the progressive re-vegetation of the channel where stability seeding has been combined with riparian planting;

(2) tag and trace a sample of boulder sized sediment used in the stability seeding to better understand where they are moving and how they are contributing to channel stability; and

(3) implement more detailed surveys, hydraulic modelling and sediment transport analysis following subsequent large floods that have the potential to mobilize and transport the stabilizing grains.

Because only floods with return periods of 10 years (or higher) will likely be capable of mobilizing and transporting the sediment grains used for stability seeding, the approach to monitoring needs to be opportunistic. That is, data should be collected regularly, while detailed analysis need only be conducted after a significant flood event has occurred. Fortunately, recent advances in data collection and analysis make this a cost-effective option. Nearly all the necessary data can be collected by conducting an aerial survey using a UAV.

4.1 Aerial surveys

Using UAVs, an aerial survey of a 500 m length of stream can be conducted in about the same amount of time as would be required to survey a single cross section using traditional methods. These surveys should be conducted during low flow conditions when as much of the channel as practical is exposed, and when the water turbidity is low.

Each survey will produce a high resolution orthophoto image of the study stream showing vegetation, large wood, bed sediment texture, and all other visible hydraulic and geomorphic features; and a geo-registered digital elevation model of the reach (including the topography of the submerged parts of the stream) with a positional accuracy of about 2 to 5 cm. Following some recently developed procedures (Tamminga et al. 2014; Tamminga, Eaton, and Hugenholtz 2015; Tamminga and Eaton 2018), a wide range of physical and ecological assessments can be made using the orthophoto image and DEM, including:

(1) mapping riparian vegetation (considering density, type, health), bed surface grain sizes, and accumulations of large wood;
(2) estimating the water depth and bathymetry of the river system using the ratio of the red and green colour channels on the orthophoto image (as described by Tamminga, Eaton, and Hugenholtz 2015) and some calibration depths measured in the field on the date of the aerial survey;
(3) modelling the flow conditions relevant to fish habitat; and
(4) documenting the geomorphic effects of extreme flood events on channel morphology.

While the data collection process is relatively straightforward and efficient, it takes a much greater investment of time to perform the analyses outlined above. Therefore, the recommended approach to monitoring involves:

(1) collecting baseline data annually/biannually, generating orthophoto images of the project reach, and calculating a few simple metrics of channel change (such as change in vegetated area, vegetation type, and bank erosion near the project), which requires about 3 days of work per year by a team of two; and
(2) triggering an in-depth analysis of the data only once a significant flood has occurred (including mapping sediment texture, large wood position and abundance, changes to the project area, and hydraulic modelling of the the project reach at several reference flow levels), which requires about 2 months of work by an intern such as a MITACS-funded graduate or undergraduate student under the supervision of senior geoscientist.

If a period of 5 years passes without the occurrence of a flood large enough to trigger an in-depth analysis of the data (e.g. a 10-year return period flood or higher), it may be worth conducting an in-depth analysis anyway, if only to refresh the baseline data and to identify any subtle changes that may have occurred.

4.2 sediment tracking

One thing that UAV surveys cannot tell us about is the typical transport distances for stabilizing sediment once it is eroded from the bed. A key scientific question relevant to the stability seeding approach is: “where do the stabilizing grains go, once they are eroded, and how do they help stabilize the channel morphology?” Tracking the movement of the stabilizing grains following a large flood will help answer these questions.

The best way to track the movement of the stabilizing grains is to tag them with passive integrated transponders. These are tracking tags that require no power source, which were originally developed to track the movements of anadromous fish such as salmon. The transponder is activated when it is in close proximity to a specialized antenna, at which point it broadcasts a unique identity code. These have been used to track the movement of sediment along a river system (Lamarre, MacVicar, and Roy 2005; Wilcock, Pitlick, and Cui 2009). A suitable approach would be to tag 50 to 100 boulders installed as part of the stability seeding project, and track their movement during periodic re-surveys.

Because the erosion and transport of stabilizing grains occurs only rarely, re-surveys of the boulder locations should be conducted once a detailed assessment of the UAV imagery has been triggered (either by a flood with a return period of 10 years or higher, or after a period of 5 years with no detailed analysis). The re-survey should be conducted during low flows when as much of the project reach as possible can be waded safely. These surveys can be time-consuming if the sediment has traveled a long way from where they were installed, and may take a week to complete for a team of two people in the field.

4.3 ground surveys

When a detailed analysis of the UAV survey data is triggered, it is worth considering a direct survey of the channel bathymetry and the water depths in the project reach. These data can be used to verify the water depth estimates based on UAV imagery. Such a survey could be combined with a survey of the stabilizing sediment movement during low flow conditions.

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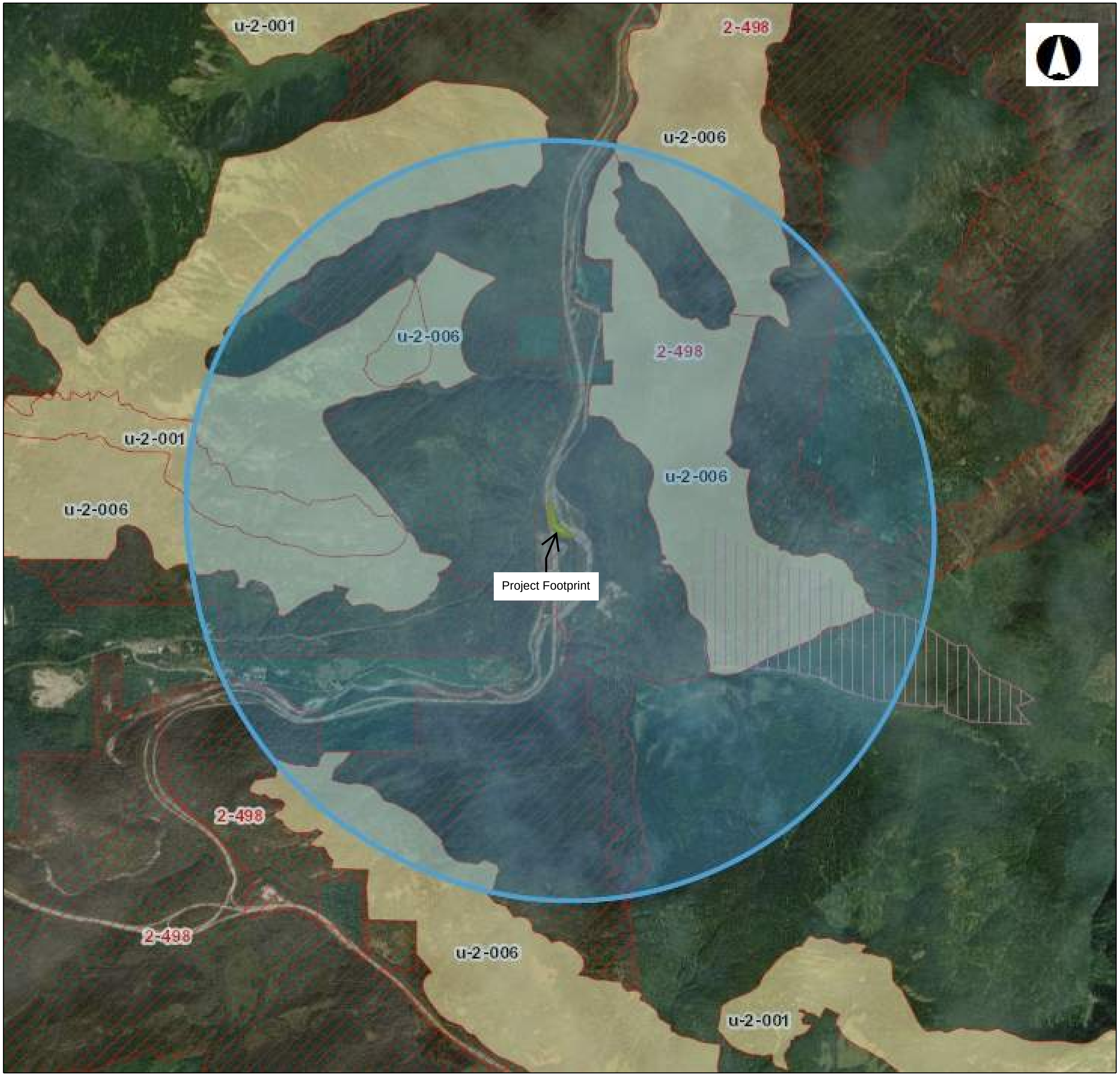
APPENDIX C – UNGULATE WINTER RANGE AND WILDLIFE HABITAT AREAS MAP



BRITISH COLUMBIA

WHA & UWR

Legend

- Wildlife Habitat Areas - Prop Themed
- ☐ Ungulate Winter Range - Ou
- Ungulate Winter Range - Co
  - FEATURE_CODE
  - 🟨 Ungulate Winter Range
  - 🟩 Specified Area for Ungulate Spe
- ☐ Wildlife Habitat Areas - Appr
- Wildlife Habitat Areas - Appr Themed
  - FEATURE_CODE
  - Wildlife Habitat Area - Buffer
  - Wildlife Habitat Area - Core
  - Specified Area - Species at Risk
- ☐ Wildlife Habitat Areas - Prop

0 1.47 2.94 km

1: 72,224

Copyright/Disclaimer

Datum: NAD83

Projection: WGS_1984_Web_Mercator_Auxiliary_Sphere

Key Map of British Columbia

APPENDIX D – PROVINCIAL SPECIES AT RISK DATABASE RESULTS

Scientific Name	English Name	BC List	COSEWIC	SARA	Probability	Rationale
Accipiter gentilis laingi	Northern Goshawk, *laingi* subspecies	Red	T	1-T (2003)	High	eBird data confirms presence within 5 km of footprint. WHA within 3 km. Nests in a variety of forest types, including deciduous, coniferous and mixed forests. Prefers mature or old-growth forest with high canopy closure (60-95%). Nest trees include Douglas fir, cedar, hemlock, spruce, willow and paper birch. Forages in both open and forested habitats. Nesting and foraging habitat are present in the forested area south of the footprint.
Contopus cooperi	Olive-sided Flycatcher	Yellow	SC	1-T (2010)	High	eBird data confirms presence within 5 km of footprint. Breeds in the region during the summer months. Occupies forested areas near wetlands, lakes and streams. Both nesting and foraging potential are present within the forested area south of footprint.
Aplodontia rufa	Mountain Beaver	Yellow	SC	1-SC (2003)	Moderate-High	Occurrence data in Hope, but >3 km from footprint. Has been associated with coniferous, mixed and red alder forests on moist slopes or hillsides near small streams or seeps. Requires deep soils for excavating burrows and tunnels.
Patagioenas fasciata	Band-tailed Pigeon	Blue	SC	1-SC (2011)	Moderate-High	Occurs in the southcoast year-round. Found in mixed forest and riparian habitat. EAA offers breeding and foraging potential.
Hirundo rustica	Barn Swallow	Yellow	SC	1-T (2017)	Moderate-High	eBird data confirms presence within 5 km of footprint. Barn swallows are typically found in open areas, often near water. They arrive to the region to breed in the spring and summer. They typically nest in old buildings and nest boxes, but may use caves and natural crevices. Foraging is on the
Chordeiles minor	Common Nighthawk	Blue	SC	1-T (2010)	Moderate-High	eBird data confirms presence within 5 km of footprint. Breeds in the region during the summer months. Nests in open areas such as grasslands, rocky outcrops, burns, gravel roads and recently logged areas. Breeding habitat within the footprint is likely restricted to the forested area south of the alignment.
Coccothraustes vespertinus	Evening Grosbeak	Yellow	SC	1-SC (2019)	Moderate-High	eBird data confirms presence within 5 km of footprint. Found in the region year-round. Nests in coniferous and mixed wood forests.
Ardea herodias fannini	Great Blue Heron, *fannini* subspecies	Blue	SC	1-SC (2010)	Moderate-High	Breeding extends from the coast to Hope; usually in colonies (which were not observed within the footprint). May forage along the Coquihalla River.
Falco rusticolus	Gyrfalcon	Blue	NAR		Moderate-High	Overwinters on the southcoast. Occassionally uses stream/river habitat. Occupies coniferous forest and mountainous regions.
Lasiurus cinereus	Hoary Bat	Blue			Moderate-High	Roosts in tree cavities. Active in the region from June to October.
Charadrius vociferus	Killdeer	Blue			Moderate-High	Nest on gravel substrates, typically near water, and in areas with sparse or low vegetation cover.
Myotis lucifugus	Little Brown Myotis	Blue	E	1-E (2014)	Moderate-High	Frequently use coniferous forest and occasionally use riparian habitat. Forage over water or in woodlands near water. Use caves and hollow trees for resting and maternity sites. Breeds September to October. May use the footprint for foraging, and possibly roosting in the forested area south of the footprint. Little is known about winter habitat use.
Mustela frenata altifrontalis	Long-tailed weasel, *altifrontalis* subspecies	Red			Moderate-High	Frequently use forest habitats and riparian areas. Usually found near water. Dens in abandoned burrows, rock crevices, brushpiles, stump hollows or amongst tree roots.
Rana aurora	Northern Red-legged Frog	Blue	SC	1-SC (2005)	Moderate-High	Preferred habitat and habitat features (e.g., leaf litter, permanent water body including slow moving portions of rivers) are present in the forested area south of the site. Use both aquatic and terrestrial habitats. Breeding occurs in permanent water with aquatic vegetation where eggs can be attached to submerged stems.
Sorex rohweri	Olympic Shrew	Red			Moderate-High	Limited data available on range east of Chilliwack. Associated with forest and riparian habitats. More commonly found amidst red alder, birch, Sitka spruce, western hemlock and lodgepole pine or in reed canarygrass, some of which occur within the forested area site.
Allogona townsendiana	Oregon Forestsnail	Red	E	1-E (2005)	Moderate-High	Project footprint is located in easternmost portion of range, but mostly observed west of Chilliwack. Occupy mixed and deciduous forest habitats, usually dominated by bigleaf maple, balsam poplar and scattered western redcedar. Correlated with stinging nettle presence, woody debris and significant leaf litter. Suitable habitat features are located within the forested area south of the footprint.
Pinicola enucleator carlottae	Pine Grosbeak, *carlottae* subspecies	Blue			Moderate-High	Species breeds in coniferous forest habitat in mountainous regions. Sometimes move to lower elevations during the winter months to take advantage of different food sources. Forested area south of the Project footprint may provide suitable foraging and nesting opportunity.

Scientific Name	English Name	BC List	COSEWIC	SARA	Probability	Rationale
Lepus americanus washingtonii	Snowshoe Hare, *washingtonii* subspecies	Red			Moderate-High	Occupies mixed forest habitat and riparian areas. Prefers dense shrub layer 1-3 m tall. May occur in the forested area south of the footprint.
Strix occidentalis	Spotted Owl	Red	E	1-E (2003)	Moderate-High	Footprint occurs in a Wildlife Habitat Area for spotted owl recovery. Species is extremely rare, but management recommendations have been provided in response to WHA.
Corynorhinus townsendii	Townsend's Big-eared Bat	Blue			Moderate-High	Occupy forested regions, caves, cultivated valleys, and hills with mixed vegetation. Foraging habitat often occurs along the edges of riparian areas in the mid- to upper-canopy of trees. Maternity and hibernation colonies typically occur in caves and mine tunnels. Sometimes tree hollows are used for roosting.
Sorex trowbridgii	Trowbridge's Shrew	Blue			Moderate-High	Occupies mature forest with abundant ground litter, forested canyons and ravines, and swampy woods, deep rank grass near salmonberry thickets, and riparian fringe areas (but not streamside).
Megascops kennicottii kennicottii	Western Screech-Owl, *kennicottii* subspecies	Blue	T	1-T (2005)	Moderate-High	Occupies mature lowland coniferous and mixed forests below 600 m elevation.
Carychium occidentale	Western Thorn	Blue			Moderate-High	Occurs in low elevation (<80 m above sea level) deciduous and mixed forests, often with bigleaf maple. Colonies occur in leaf litter, moist hollows and along riparian zones. Suitable habitat is present in the forested area south of the footprint.
Falco peregrinus anatum	Peregrine Falcon, *anatum* subspecies	Red	NAR	1-SC (2012)	Moderate-High (foraging)	eBird data confirms peregrine falcon presence within 5 km of the footprint (it is not subspecies specific). May use the area as foraging habitat. Suitable nesting features, including cliff ledges and largescale infrastructure, do not exist within project footprint.
Falco peregrinus pealei	Peregrine Falcon, *pealei* subspecies	Blue	SC	1-SC (2003)	Moderate-High (foraging)	eBird data confirms peregrine falcon presence within 5 km of the footprint (it is not subspecies specific). May use the area as foraging habitat. Suitable nesting features, including cliff ledges and largescale infrastructure, do not exist within project footprint.
Anaxyrus boreas	Western Toad	Yellow	SC	1-SC (2018)	Moderate-High (post-breeding)	Occurs in young seral and managed second-growth forests and riparian areas. Breeding habitat (i.e., shallow waterbodies with sandy substrate) are not present within the Project alignment. Adults disperse to terrestrial habitat such as forests after breeding. May roam from standing water, but prefer damp conditions.
Tanypteryx hageni	Black Petaltail	Blue			Moderate-Low	Documented at various locations on the southcoast, with the nearest occurrences in Harrison Lake area and the Chilliwack River Valley. Adults use tree trunks, logs, rocks and the ground around hillside seeps, wet meadows and bogs for perching and basking. Larvae burrow in mud, moss and low sedge communities saturated by seeps or springs, often near stream edges or bogs. Some of habitat requirements are present on site.
Ascaphus truei	Coastal Tailed Frog	Yellow	SC	1-SC (2003)	Moderate-Low	Provincial data confirms presence within 3 km of footprint. Generally found in cold, clear, fast-moving streams (<10 m wide) adjacent to old growth and mature coniferous, deciduous and mixed forest. Associated with steep gradient, non-fish bearing waters. Adults rarely travel far from stream banks but have been found under logs and other suitable cover in forests adjacent to streams up to 40 m. Several important habitat factors are present, but the wide river and fish presence makes it unlikely the frogs are breeding in within the footprint.
Butorides virescens	Green Heron	Blue			Moderate-Low	Largely restricted to the Georgia Depression Ecoprovince, but may occur outside this range. Typically breeds along riparian edges of slow moving rivers in stands of red alder.
Botaurus lentiginosus	American Bittern	Blue			Low	Bitterns are obligate users of wetland and marsh habitats. They nest in large wetlands with abundant vegetation, which is used as cover.
Sympetrum vicinum	Autumn Meadowhawk	Blue			Low	Obligate user of lakes and ponds. Uses slow streams with dense emergent vegetation.
Tyto alba	Barn Owl	Blue	T	1-T (2018)	Low	Core breeding range extends east to Hope. Typically occurs in open habitats such as old fields, pastures and grassy marshes. Nests in old buildings, barns, nest boxes or tree cavities.
Melanitta americana	Black Scoter	Blue			Low	Overwinters along the BC coast.
Cypseloides niger	Black Swift	Blue	E	1-E (2019)	Low	Occurrence likely to only consist of foraging well above canopy during the summer months. Breeding habitat occurs behind waterfalls on cliff ledges, which do not occur within the site.
Pachydiplax longipennis	Blue Dasher	Blue			Low	Dashers use vegetation along the shoreline and within the water of ponds and lakes between June to mid-September. More common on southern Vancouver Island and the Gulf Islands.

Scientific Name	English Name	BC List	COSEWIC	SARA	Probability	Rationale
Larus californicus	California Gull	Red			Low	Winters along the coast and interior. Potential breeding habitat occurs on Lillooet and Harrison lakes. Gull is an obligate user of lakes and ponds, but only occasionally uses riparian and stream habitat.
Nannopterum auritum	Double-crested Cormorant	Blue	NAR		Low	Mostly a coastal species found along the Strait of Georgia. Interior population breeding site is located in the Chilcotin.
Rubus lasiococcus	dwarf bramble	Blue			Low	Obligate user of coniferous forest habitat but is only found in elevations 1300 - 1720 m.
Argia emma	Emma's Dancer	Blue			Low	A population occurs in Kawkawa Lake, Hope >3 km from the footprint. Adults often found with riffle areas of flowing waters. Breeds along lakeshores associated with streams.
Ursus arctos	Grizzly Bear	Blue	SC	1-SC (2018)	Low	Rare in southwest BC. If present, may use the site to access the river for hunting fish. No bear dens were identified within the footprint.
Chlosyne hoffmanni	Hoffman's Checkerspot	Red			Low	Restricted to Manning Provincial Park.
Callophrys johnsoni	Johnson's Hairstreak	Red	SC		Low	Occurs within dwarf-mistletoe-infected forests (typically low elevation, structurally diverse, old growth/mature forests). Adults frequent forest openings, riparian areas and forest edges with abundant wildflowers. Larvae require hemlock dwarf mistletoe, which is not present on site, to complete their lifecycle.
Mitellastra caulescens	leafy mitrewort	Blue			Low	Occupies wet to moist meadows and woodlands. Closest records occur in Skagit Valley Provincial Park.
Melanerpes lewis	Lewis's Woodpecker	Blue	T	1-T (2012)	Low	Mostly occurs in the interior in PP, IDF and BG biogeoclimatic zones. Favours open ponderosa pine woodlands, which are not present in the footprint.
Brachyramphus marmoratus	Marbled Murrelet	Blue	T	1-T (2003)	Low	Typically breeds up to 50 km inland from the coast.
Claytonia perfoliata ssp. intermontana	miner's-lettuce	Blue			Low	Only one occurrence in BC located 2.2 km east of the Yale Tunnel at the Highway 1 pullover.
Charina bottae	Northern Rubber Boa	Yellow	SC	1-SC (2005)	Low	Occurs in humid mountainous regions and dry lowland areas, usually around rock outcrops, piles, bluffs or talus slopes, which are not present on site. Can be found beneath rocks and woody debris in forested habitats. Hibernacula were not detected during site assessment.
Sorex bendirii	Pacific Water Shrew	Red	E	1-E (2003)	Low	Range in the coast mountains is unknown, but occurrence data is only confirmed as east as Harrison Lake. There are unconfirmed sightings from the Skagit River Valley.
Chrysemys picta	Painted Turtle	No Status	T/SC	1-T/SC (2021)	Low	Inhabit slow-moving, shallow waters with soft bottoms. Conditions on site are not appropriate to support this species.
Chrysemys picta pop. 1	Painted Turtle - Pacific Coast Population	Red	T	1-T (2021)	Low	Inhabit slow-moving, shallow waters with soft bottoms. Conditions on site are not appropriate to support this species.
Cervus elaphus roosevelti	Roosevelt Elk	Blue			Low	Considered rare or absent in the area.
Buteo lagopus	Rough-legged Hawk	Blue	NAR		Low	Overwinters in the area, but occupies open grassland and field habitats.
Antigone canadensis	Sandhill Crane	Yellow	NAR		Low	May be observed during migration in spring and fall, but the species is not known to breed around the Hope area.
Asio flammeus	Short-eared Owl	Blue	T	1-SC (2012)	Low	Primary habitat includes grasslands, meadows in early succession, and marshlands, which are not present in the project alignment. Frequent riparian areas and broad expanses of open land with low vegetation, which are limited within the site. Attracted to areas with an abundance of food (e.g., rodents and small birds). Typically roost on the ground in dry upland areas with low, dense shrub. Rarely breed outside the Lower Mainland.
Ophiogomphus occidentis	Sinuous Snaketail	Blue			Low	Occupies stream and lake habitats. Little information available, No known records in the Hope area.
Muhlenbergia filiformis	slender muhly	Blue			Low	Only known to occur in Chilliwack Lake and Dewar Hot Springs.
Myodes gapperi occidentalis	Southern Red-backed Vole, *occidentalis* subspecies	Red			Low	Occurs in select areas of the lower mainland, which are outside the footprint.
Argia vivida	Vivid Dancer	Blue	SC	1-SC (2019)	Low	Associated with cool or hot springs.
Acipenser transmontanus	White Sturgeon	No Status	E/T	1-E	Low	Barriers to passage present downstream of footprint.
Acipenser transmontanus pop. 4	White Sturgeon (Lower Fraser River Population)	Red	T		Low	Barriers to passage present downstream of footprint.
Pinus albicaulis	whitebark pine	Blue	E	1-E (2012)	Low	Typically occupies upper subalpine forests. Almost exclusively occurs in the Englemann Spruce - Subalpine Fir and the Alpine Tundra biogeoclimatic zones.

Scientific Name	English Name	BC List	COSEWIC	SARA	Probability	Rationale
Aeronautes saxatalis	White-throated Swift	Blue			Low	Nests on rock and silt cliffs with crevices. May forage over the site by flying-over, but is unlikely to be impacted by the Project works.
Gulo gulo luscus	Wolverine, *luscus* subspecies	Blue	SC	1-SC (2018)	Low	Typically found in remote wilderness areas away from human activity. Known to avoid crossing active transportation cooridors.
Icteria virens	Yellow-breasted Chat	Red	E	1-E (2003)	Low	Have been documented breeding in Hope, but this is a rare occurrence as they are mostly restricted to the Okanagan Valley and lower Similkameen Valley. Breeds in riparian thickets of wild rose, willow, hawthorn, trembling aspen, black cottonwood and water birch.
Speyeria zerene bremnerii	Zerene Fritillary, *bremnerii* subspecies	Red			Low	Mostly occurs on Vancouver Island and Saltspring Island. Occupies mesic meadows in Douglas-fir habitat and Garry oak and associated habitats.
Oreamnos americanus	Mountain Goat	Blue			Low	Ungulate Winter Range area for mountain goat occurs within 3 km of footprint. Obligate users of rock / cliff / talus habitats, which are not present on site. Feeds on spruce or hemlock during winter, which are not present on site.
Pelecanus erythrorhynchos	American White Pelican	Red	NAR		Unlikely	Only known to breed in the Central Interior Ecoprovince.
Synthliboramphus antiquus	Ancient Murrelet	Blue	SC	1-SC (2006)	Unlikely	Restricted to Haida Gwaii.
Setophaga castanea	Bay-breasted Warbler	Red			Unlikely	Breeds in NE BC. May pass through on migration.
Nycticorax nycticorax	Black-crowned Night-heron	Red			Unlikely	Only breeds at Reifel Island. Nonbreeders have been observed in the Fraser Lowlands east to Chilliwack, and in the interior, from Osoyoos Lake and Creston north to Clearwater Lake.
Setophaga virens	Black-throated Green Warbler	Blue			Unlikely	Breeds in NE BC.
Prophysaon coeruleum	Blue-grey Taildropper	Blue	T	1-T (2019)	Unlikely	Restricted to Vancouver Island.
Pristiloma johnsoni	Broadwhorl Tightcoil	Blue			Unlikely	Only occurs in subalpine habitat.
Cardellina canadensis	Canada Warbler	Blue	SC	1-T (2010)	Unlikely	Breeds in NE BC.
Hydroprogne caspia	Caspian Tern	Blue	NAR		Unlikely	Site does not occur within a known breeding location. Species may pass through the area on migration.
Montia chamissoi	Chamisso's montia	Blue			Unlikely	Occurs between 1100 - 1220 m elevation.
Dicamptodon tenebrosus	Coastal Giant Salamander	Blue	T	1-T (2003)	Unlikely	Distribution limited to the Chilliwack River Valley and nearby tributaries south of the Fraser River.
Coenonympha california insulana	Common Ringlet, *insulana* subspecies	Red			Unlikely	Occurs on Vancouver Island and Gulf Islands.
Contia tenuis	Common Sharp-tailed Snake	Red	E/T	1-E (2003)	Unlikely	Rare occurrence in dry woodlands in the Gulf Islands and SE Vancouver Island.
Cercyonis pegala incana	Common Wood-nymph, *incana* subspecies	Red			Unlikely	Restricted to southern Vancouver Island and Gulf Islands, with rare occurrences on the Sunshine Coast.
Oporornis agilis	Connecticut Warbler	Blue			Unlikely	Breeds in NE BC.
Daltonia splachnoides	Dalton's moss	Red	E		Unlikely	Only found on Haida Gwaii.
Hemphillia dromedarius	Dromedary Jumping-slug	Red	T	1-T (2005)	Unlikely	Restricted to Vancouver Island.
Mustela richardsonii anguinae	Ermine, *anguinae* subspecies	Blue			Unlikely	Restricted to Vancouver Island and Saltspring Island.
Deroceras hesperium	Evening Fieldslug	Red	DD		Unlikely	Believed to be extirpated in the region.
Pekania pennanti	Fisher	No Status			Unlikely	Project footprint is located outside range.
Sterna forsteri	Forster's Tern	Red	DD		Unlikely	Breeding restricted a single site in SE BC.
Octogomphus specularis	Grappletail	Red	SC		Unlikely	Easternmost occurrence documented in the Harrison watershed. Prefers small, swift flowing streams.
Icaricia saepiolus insulanus	Greenish Blue, *insulanus* subspecies	Red	E	1-E (2003)	Unlikely	Endemic to Vancouver Island.
Mustela haidarum	Haida Ermine	Red	T	1-T (2003)	Unlikely	Endemic to Haida Gwaii.
Staala gwaii	Haida Gwaii Slug	Red	SC	1-SC (2018)	Unlikely	Endemic to Haida Gwaii and northern Vancouver Island.
Dryobates villosus picoideus	Hairy Woodpecker, *picoideus* subspecies	Yellow			Unlikely	Endemic to Haida Gwaii.
Limosa haemastica	Hudsonian Godwit	Red	T		Unlikely	Breeds in NW BC.
Euchloe ausonides insulanus	Large Marble, *insulanus* subspecies	Red	XT	1-XT (2003)	Unlikely	Extirpated from area.
Pieris marginalis guppyi	Margined White, *guppyi* subspecies	Blue			Unlikely	Occurs in NW BC.

Scientific Name	English Name	BC List	COSEWIC	SARA	Probability	Rationale
Callophrys mossii mossii	Moss' Elfin, *mossii* subspecies	Red			Unlikely	Occurs in Garry oak ecosystems on southern Vancouver Island and the Gulf Islands.
Ammospiza nelsoni	Nelson's Sparrow	Red	NAR		Unlikely	Breeds in NE BC.
Glaucidium gnoma swarthi	Northern Pygmy-owl, *swarthi* subspecies	Blue			Unlikely	Restricted to Vancouver Island and Gulf Islands.
Aegolius acadicus brooksi	Northern Saw-whet Owl, *brooksi* subspecies	Blue	T	1-T (2007)	Unlikely	Endemic to Haida Gwaii.
Actinemys marmorata	Northwestern Pond Turtle	Red	XT	1-XT (2005)	Unlikely	Extirpated from area.
Rana pretiosa	Oregon Spotted Frog	Red	E	1-E (2003)	Unlikely	Only occurs in the Fraser River Basin.
Hemphillia camelus	Pale Jumping-slug	Blue			Unlikely	Occurs in SE BC.
Erynnis propertius	Propertius Duskywing	Red			Unlikely	Restricted to garry oak ecosystems on Vancouver Island and Gulf Islands.
Cryptomastix devia	Puget Oregonian	Red	XT	1-XT (2005)	Unlikely	Extirpated from area.
Progne subis	Purple Martin	Blue			Unlikely	Restricted to coastal BC.
Sphaerium patella	Rocky Mountain Fingernailclam	Red			Unlikely	Last reports occur in Burnaby Lake in 1961 and Abbotsford Lake in 1949.
Euphagus carolinus	Rusty Blackbird	Blue	SC	1-SC (2009)	Unlikely	Does not occur in the area.
Epargyreus clarus	Silver-spotted Skipper	Blue			Unlikely	Occurs in lower mainland, Gulf Islands and southern Kootenays. Project footprint located outside range.
Cyanocitta stelleri carlottae	Steller's Jay, *carlottae* subspecies	Blue			Unlikely	Endemic to Haida Gwaii.
Melanitta perspicillata	Surf Scoter	Blue			Unlikely	Breeds in the Peace River district and overwinters off the coast.
Musculium partumeium	Swamp Fingernailclam	Blue			Unlikely	Only recorded in Kootenay Lake in 1969 and Salt Spring Island in 2014.
Nearctula sp. 1	Threaded Vertigo	Blue	SC	1-SC (2012)	Unlikely	Restricted to Vancouver Island, Gulf Islands, Sunshine Coast
Scapanus townsendii	Townsend's Mole	Red	E	1-E (2005)	Unlikely	Restricted to Abbotsford and Huntingdon.
Aneides vagrans	Wandering Salamander	Blue	SC	1-SC (2018)	Unlikely	Only found on Vancouver Island, adjacent small islands and one location on the Sunshine Coast.
Tringa incana	Wandering Tattler	Blue			Unlikely	Breeding range restricted to the St. Elias Mountains in extreme NW BC, but likely extends south to at least Gnat Pass near Dease Lake.
Hemphillia glandulosa	Warty Jumping-slug	Red	SC	1-SC (2005)	Unlikely	Restricted to southern Vancouver Island.
Hesperia colorado oregonia	Western Branded Skipper, *oregonia* subspecies	Red	E		Unlikely	Restricted to Vancouver Island and the Gulf Islands.
Sorex navigator brooksi	Western Water Shrew, *brooksi* subspecies	Blue			Unlikely	Restricted to Vancouver Island.
Gulo gulo vancouverensis	Wolverine, *vancouverensis* subspecies	Red	SC	1-SC (2018)	Unlikely	Restricted to Vancouver Island.
Coccyzus americanus	Yellow-billed Cuckoo	Red			Unlikely	Does not occur in the region.

APPENDIX E – BGC BOULDER SEEDING MEMO

TECHNICAL MEMORANDUM

Date March 13, 2023 **Project** 0272097

To Dickson Chung, Senior Engineering Manager
BC Ministry of Transportation and Infrastructure

From Sarah Davidson, Ph.D., P.Geo.

Stability Seeding at Peers Creek Frontage Road

1.0 INTRODUCTION

BGC Engineering Inc. (BGC) is pleased to provide the BC Ministry of Transportation and Infrastructure (MoTI) with this memo detailing the potential habitat benefits of using a ‘Stability Seeding’ approach at Peers Creek Frontage Road. The memo was requested in a meeting on February 28th, 2023 to support MoTI with presenting the proposed approach to Fisheries and Oceans Canada (DFO).

This memo provides a high-level overview of the experimental background of the Stability Seeding approach, as well as the potential habitat benefits. Appendix A provides a more detailed explanation of the approach, its hydraulic and morphologic impacts, and the observed habitat benefits from laboratory experiments completed at the University of British Columbia (UBC). Appendix A was written by Dr. Brett Eaton, a professor in the Department of Geography at UBC, and the principal investigator in the laboratory experiments.

2.0 EXPERIMENTAL BACKGROUND

The Stability Seeding approach has emerged from a series of laboratory experiments conducted by Dr. Brett Eaton and others at UBC. Experiments by Mackenzie and Eaton (2017) and Booker and Eaton (2020) first showed that the addition of a small amount of coarse sediment drastically reduced bank erosion, changing the modelled stream from laterally active to stable. Based on these findings, Eaton, Mackenzie, and Tatham (2022) devised an alternative approach to typical riprap armouring: lining the floodplain with a layer of sediment similar in size to the coarse tail of the sediment observed on the riverbed (i.e., D_{84} to D_{90}, or the 84th to 90th percentile of the grain size distribution).

The experiments conducted by Eaton, Mackenzie, and Tatham (2022) and subsequent unpublished experiments show that the Stability Seeding approach limits bank erosion compared to an unarmoured control reach, while allowing for more lateral movement than with riprap. To date experiments have focused on applying the Stability Seeding to the channel floodplain, but Dr. Eaton also outlines two other potential application methods in Appendix A that have yet to be tested in the laboratory. The first approach (i.e., applying Stability Seeding on the floodplain) is most relevant to Peers Creek Frontage Road.

3.0 HABITAT BENEFITS

Experiments show that the Stability Seeding approach reduces bank erosion in the laboratory setting, while still allowing for minor widening and recruitment of sediment from the river banks. Dr. Eaton outlines the following potential habitat benefits of the approach:

- The approach reduces or eliminates the need for in-stream work, as material can be applied to areas that are outside of the main channel and excavation is not needed to ‘key’ material in.
- If combined with riparian planting, the stability offered by the coarse material may support the re-growth of the riparian forest by limiting erosion while vegetation establishes. Rooting strength will then enhance the bank stability in the future.
- Minor bank erosion is likely to continue with this approach, recruiting the “seeded” coarse material into the river. This will allow for the maintenance of bars, pools, and riffles better than might be expected with riprap – which is shown in the experiments to produce high shear stresses and bed scour – and prevent the development of a static riverbed.
- Improved variability in depth and bed topography may promote hyporheic exchange between the stream and riverbed.
- Transitions from a single-thread to braided channel are less likely to occur. This may reduce the likelihood of dewatering during low flows which often happens in the shallow and wide conditions typical of braided rivers.

Appendix A provides additional details on the hydraulic and morphologic changes observed in laboratory experiments. The habitat benefits outlined above have been observed in the laboratory setting; as the approach has not yet been tested in the field, the extent to which these habitat benefits will be realized in a field setting is not yet clear.

4.0 CLOSURE

We trust the above satisfies your requirements. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC Engineering Inc.
per:

Sarah Davidson, Ph.D., P.Geo. (BC, AB, SK)
Senior Geoscientist

Reviewed by:

Evan Shih, M.Eng., P.Eng. (BC)
Senior Hydrotechnical Engineer

EGBC Permit to Practice, BGC Engineering Inc. 1000944

ES/mjp

Attachment(s): Appendix A

LIMITATIONS

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APPENDIX A

STABILITY SEEDING MEMO FROM DR. BRETT EATON

Habitat benefits of using a stability seeding approach to channel stabilization

Brett Eaton

2023-03-08

1 executive summary

New proof-of-concept experiments demonstrate the potential impact of the "stability seeding" approach to channel stabilization. This approach involves introducing sediment (typically in the boulder size class range) that is consistent with the largest sediment transported by the river at the site requiring stabilization. This stabilizing sediment includes sediment ranging from 50% to 100% of the largest mobile particle at the site. This size of sediment has been shown to control the stability of the banks, bars, pools and riffles in gravel bed streams by controlling the deposition of the rest of the sediment found in the bed of the river.

There are a range of methods for implementing stability seeding, including: positioning the stabilizing sediment on the floodplain surface adjacent to the channel banks and relying on bank erosion to recruit them; placing stabilizing sediment directly on the channel banks (either on top of existing riprap or on top of an eroding cut-bank) so that high flows can recruit the sediment before bank erosion occurs; and placing the stabilizing sediment on the channel bed at key locations to mimic the redistribution of these sediments that naturally occur during high flows. While the nature of the potential habitat impacts produced by stability seeding are well defined, the degree to which they can be realized in a real-world implementation depends on how well the stabilizing sediment can be recruited by the river and transported to key locations that control the channel morphology. Therefore, it is important to remember that the extent of the habitat improvement that will result remains to be demonstrated in the field.

Relative to standard riprap designs, channel rehabilitation using stability seeding approaches has the potential to retain a diverse set of physical habitats (including riffles, pools and bars) within the stabilized reach, and to maintain the exchange of water between the stream and the river bed (which is key to maintaining potential spawning habitat quality associated with riffles).

When used to stabilize actively retreating meander bends, the stability seeding approach will help offset the reduction in bed sediment supply associated with stabilizing the bank, thereby reducing the potential for degradation of the riffles downstream of the bend. This should reduce the potential for the bank stabilization activities to have negative impacts on downstream habitat quality.

Stability seeding also limits the potential for vertical bed scour, which not only simplifies the channel morphology and degrades the physical habitat, but can expose and damage buried infrastructure (which can obviously have negative effects on the local riverine ecology). The degree to which this effect can be realized depends on how much of the stabilizing sediment can be entrained by the flow and transported to key locations (such as riffles) that control the stability of the stream bed. In situations where vertical scour is an imminent threat to infrastructure and physical habitat, direct placement of stabilizing sediment in the stream channel may be preferable to a standard riprap installation.

2 stability seeding overview

The gravel bed streams found in mountainous regions like British Columbia are commonly referred to as threshold streams (Church 2006) because they seldom experience flows that are much more powerful than those capable of eroding and transporting the median sized sediment particle on the surface of the river bed (called D_{50}).

The relative strength of a flow can be indexed using the average shear stress, which is the force per unit area exerted on the channel bed (τ). It depends primarily on the water depth, d, and the water surface gradient, S. Relative flow strength is also often indexed using the average flow velocity (U), which depends on d, S, and the roughness of the channel boundary. The key equations used to analyse sediment transport are most often constructed using τ. To more explicitly link channel stability to the hydrological events that produce channel change, specific discharge, q, (or discharge divided by the width of the river at that discharge) is used in this memo to represent the power of the river to erode and transport sediment. The threshold specific discharge, q_{c50}, is the discharge at which the median sized sediment on bed surface (D_{50}) is first entrained, and significant transport of the sediment found in the river channel begins. This typically occurs at flows less than the bank-full flow; experience in BC at Fishtrap Creek suggests that q_{c50} is about half the bank-full flow (Eaton et al. 2010).

The reason that gravel bed streams typically never experience flows that exceed q_{c50} by more than a factor of about 3 is that their banks are weak compared to the stream bed. Shortly after flows exceed q_{c50}, an unarmoured gravel bank is subject to forces capable of eroding it. While riparian vegetation can delay the onset of bank erosion in smaller rivers, the effect of riparian vegetation on bank strength disappears for rivers much deeper than 2 m at their bank-full flood stage (Eaton and Giles 2009), making large gravel bed streams particularly prone to hazardous lateral migration. Once bank erosion is initiated, gravel bed streams will widen, spreading the total flow over a greater area and maintaining specific discharge values close to about 3 times q_{c50}. This negative feedback between bank erosion and specific discharge is an important mechanism by which these systems maintain their relative stability.

Because gravel bed streams tend to respond to rare flood events by rapid bank erosion and channel widening, they often are transformed from single-threaded channels into multi-threaded (or braided) channels. In contrast, the larger sand bed streams found further downstream where valley gradients are lower typically have banks that are relatively strong due the the cohesive sediment found in them, which means they can (and do) sustain specific discharges much greater than 3 times q_{c50} (Church 2006). As a result, they are far less likely to experience extensive channel migration and seldom are transformed from single-thread to braided morphologies.

Recent research has demonstrated that, in threshold gravel bed streams, the stability of the channel is not controlled by the median sized sediment on the bed surface as has long been assumed; it is controlled by the largest grains on the bed surface, which most likely form a stable skeletal structure that traps and stores the smaller material found on the bed surface. Experiments by Eaton and Church (2004) and Eaton, MacKenzie, and Booker (2020) showed that gravel bed streams could not establish a stable, single-thread channel morphology for flow conditions during which the coarsest sediment in the stream was eroded and transported. Subsequent research demonstrated that the addition of a small quantity of sediment from the coarse tail of the bed surface grain size distribution was sufficient to prevent significant lateral migration of an experimental stream channel during bank-full flows (MacKenzie and Eaton 2017); the channels with and without the additional stabilizing sediment are shown in Fig. 1. Booker and Eaton (2020) similarly showed that the coarse tail of the bed sediment distribution controlled the stable gradient for in-channel sediment deposits at near-threshold flow conditions.

These findings indicate that there is the potential to modulate erosion and transport in gravel bed streams with only minor additions of stabilizing coarse sediment to the system. Eaton, MacKenzie, and Tatham (2022) tested one possible means of implementing a stability seeding approach that relies on bank erosion to recruit stabilizing sediment from the floodplain and high flows to redistribute the material within the channel. The stabilizing sediment used in these proof-of-concept experiments is close to the 90th percentile of the bed surface sediment size distribution, as shown in Fig. 2. The stabilizing sediments are mobilized during the highest flows but they are entrained less frequently and move shorter distances than do the majority of the sediment sizes on the bed surface.

More generally, sediment ranging from 50% to 100% of the largest mobilized particle in the stream can be used as stabilizing sediment. This corresponds approximately to sediment coarser than the 84th percentile of

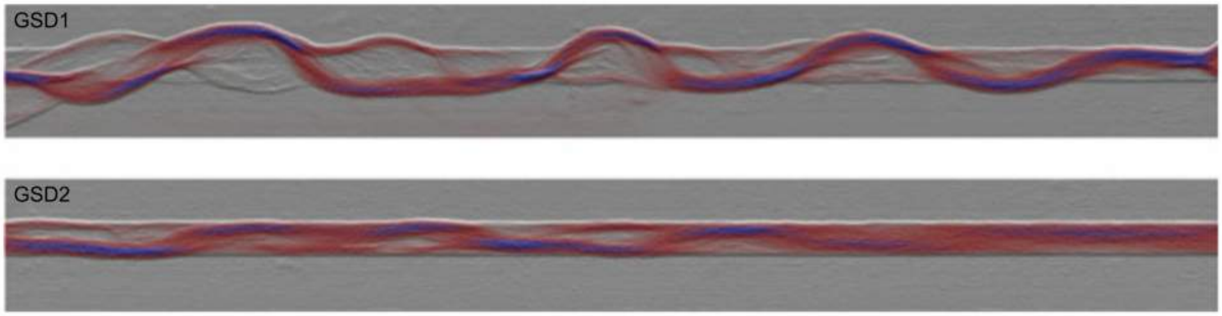

Figure 1: Maps of specific discharge are presented for two channels with nearly identical bed sediment distributions. The upper panel shows the channel pattern formed in the original bed material. The lower panel shows the morphology of a stream with a small addition of coarse sediment to the bed material. Figure taken from MacKenzie and Eaton, 2017.

the bed surface grain size distribution. Ideally, it should be rounded to sub-rounded in shape, consistent with sediment naturally found within the river. In most gravel bed streams, this will include sediment in the boulder size range, though some large cobbles will also act as stabilizing sediment in some gravel bed rivers.

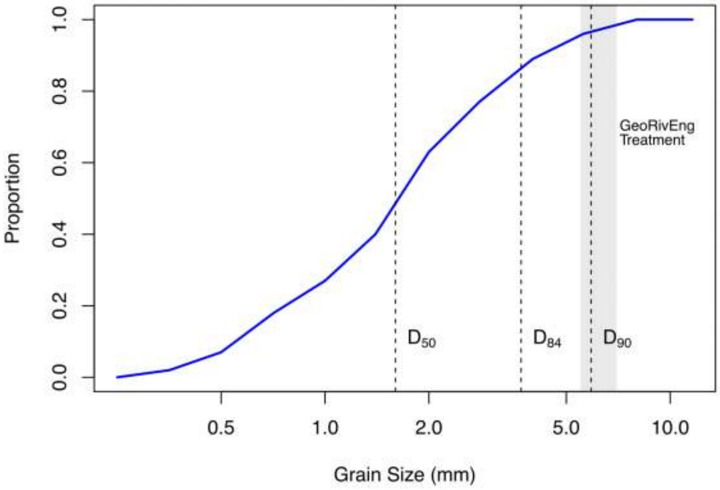

Figure 2: Experimental sediment size distribution and stabilizing sediment size range (GeoRivEng Treatment) for the proof-of-concept experiments by Eaton, MacKenzie and Tatham, 2022.

The treatment using this size of sediment will be referred to as the “stability seeding” experiments. Fig. 3. shows the channel morphology at the beginning of each experiment (top panel), the morphology after three floods of increasing magnitude (the largest of which is 3 times larger than the bank-full flood) for an untreated reach (second panel), the morphology after three floods for the reach with stability seeding (third panel), and the morphology for a reach with standard class 3 riprap (bottom panel).

The detailed post-flood morphology of the stability seeding treatment reach is shown in Fig. 4. The treatment involved placing a layer of stabilizing sediment one grain diameter thick on the bank top, right up to the edge of the channel but not within the channel. Fig. 5 presents the same information for the riprap treatment. Riprap was installed following the conventional design, including toeing the installation into the channel bed.

Briefly, the stability seeding treatment was able to modulate the rate of bank erosion during a range of flood events. As a result, the natural channel morphology comprising cut-banks, bars, pools and riffles was maintained throughout the experiment, although the channel was prevented from widening so much

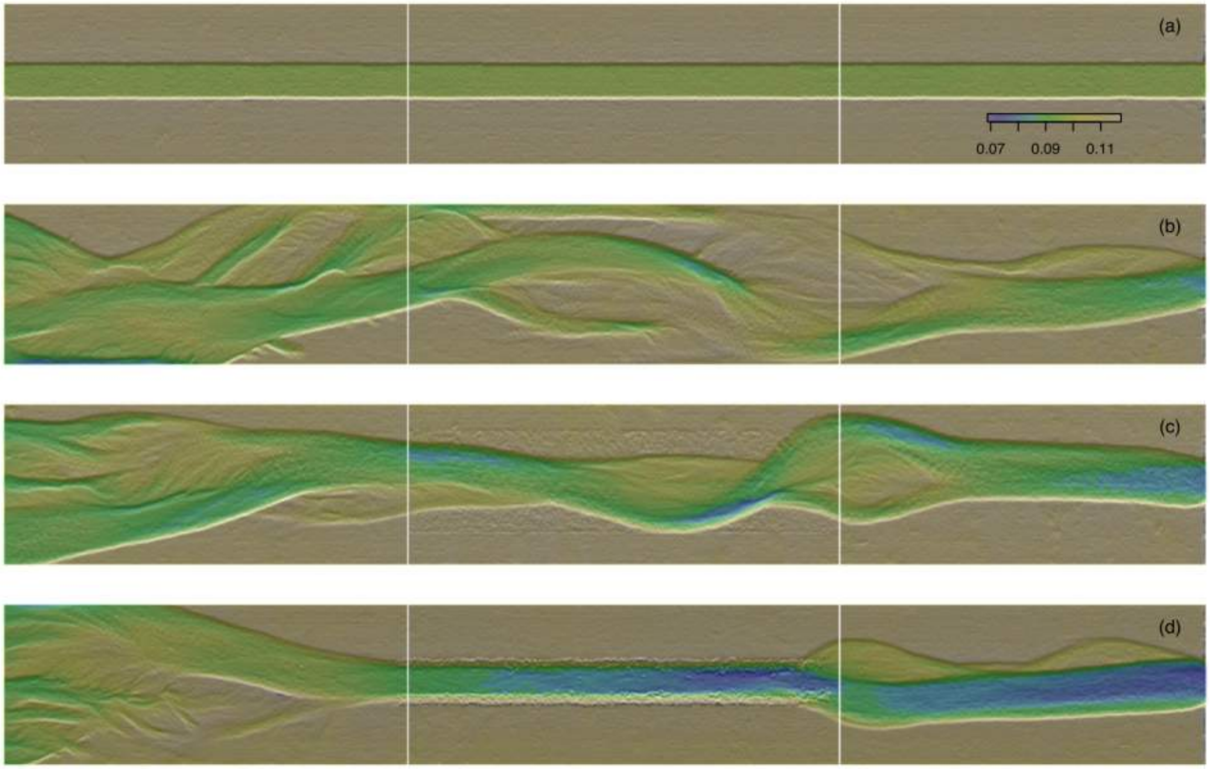

Figure 3: Hillshade images of channel morphology (a) at the beginning of each run; (b) with no stabilizing treatment; (c) with stability seeding treatment; and (d) with standard class 3 riprap treatment. Each experiment involved three floods of increasing magnitude, with the largest flood reaching 3 times the size of the bankful flood. Flow direction is from right to left. Only the middle sections of the experimental channels were stabilized; the upstream and downstream sections were left unprotected.

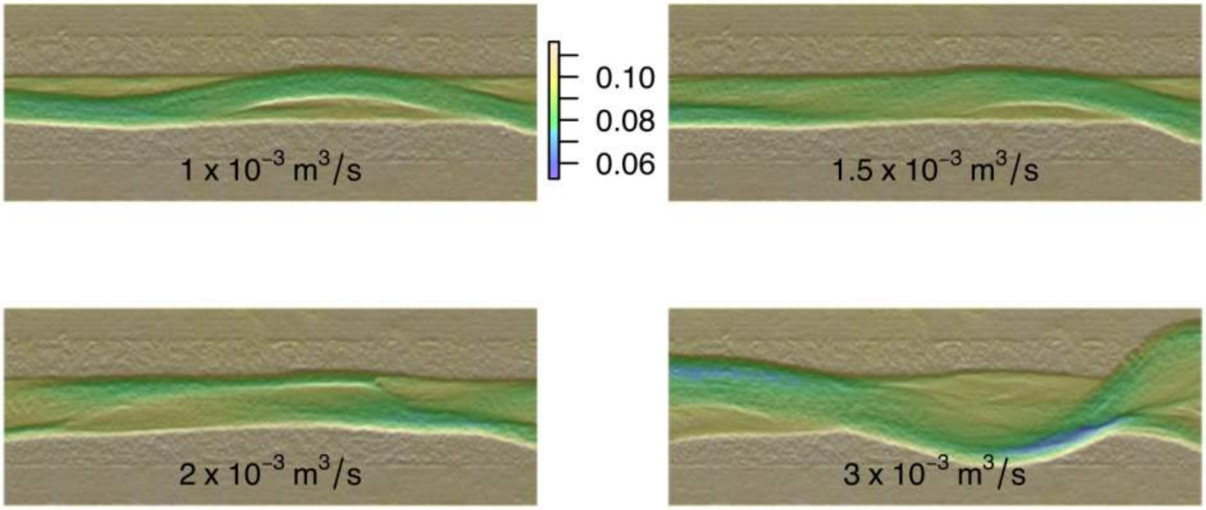

Figure 4: Morphology of the treated reach with stability seeding after four floods, ranging from the bankfull flow to 3 times the bankfull flow.

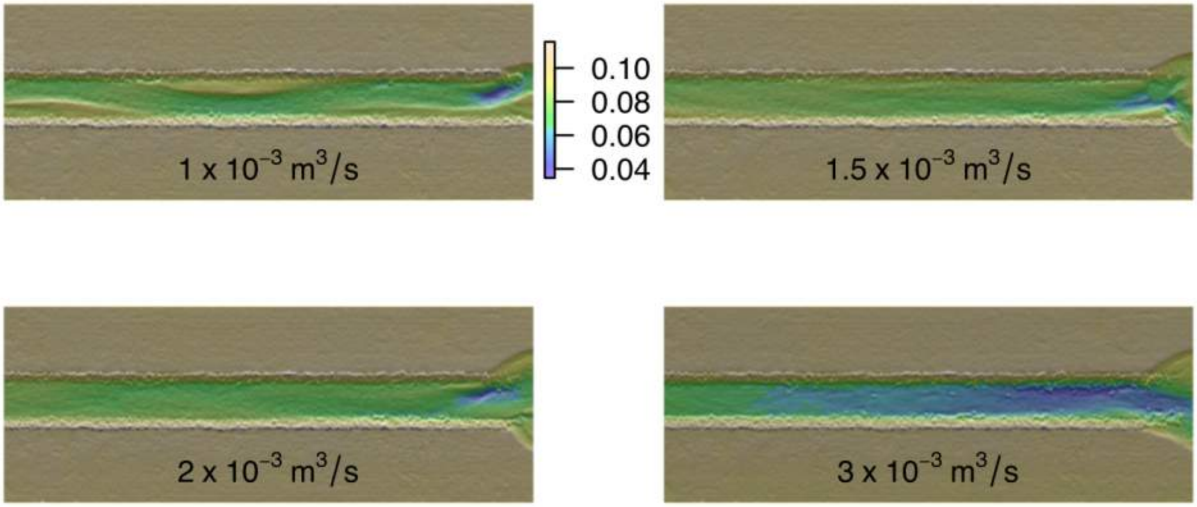

Figure 5: Morphology of the treated reach with class 3 riprap after four floods, ranging from the bankfull flow to 3 times the bankfull flow.

that it would transition to a braided channel pattern. As a result, a diverse suite of physical habitats was maintained, and the topographic variations responsible for generating flow into and out of the stream bed were maintained, thereby maintaining the quality of the potential spawning habitat associated with these hyporheic exchange patterns.

In contrast, standard riprap prevented any lateral channel migration, and prevented the stabilizing feedback between channel widening and specific discharge reduction from occurring. As a consequence, the riprap reach was subject to excessively high shear stresses and high rates of sediment transport, which produced significant vertical bed degradation, and the loss of channel complexity; by the end of the last flood, no bars, pools or riffles remained in the riprap reach. Over 75% of the channel bed in the riprap reach experienced net vertical bed scour that exceeded the mean bank-full water depth, which could pose a significant risk to buried linear infrastructure beneath the stream bed.

3 geomorphic effects and habitat benefits

There are several ways in which the stabilizing sediment could be delivered to the stream channel. The potential habitat benefits of each approach are slightly different and are described separately below. The actual habitat benefits of stability seeding in the field have not yet been studied, so the discussion below is speculative. The actual benefits that will occur in the field will depend largely on (a) how much of the stabilizing sediment is recruited by the river; and (b) where on the river bed it is deposited. Furthermore, the recruitment and redistribution of these stabilizing sediments only happens during floods capable of producing wide-spread bank erosion and channel widening (e.g. 50-year return period floods), so they would have no direct (negative or positive) effects on river habitat until after a rare flood event occurred.

3.1 stability seeding on the channel floodplain

The placement of a layer of stabilizing sediment on the floodplain adjacent to the channel banks has been tested experimentally (Eaton, MacKenzie, and Tatham 2022) and the potential benefits of this approach are reasonably well documented. It can be applied to both banks and in straight reaches where a straight channel alignment needs to be maintained (as in Figs 3, 4 and 5), to both banks of a sinuous, meandering channel (tested by Eaton, MacKenzie, and Tatham 2022 but not shown), or along a single eroding meander bend (tested in the lab, but not yet published).

(1) The first benefit of this approach is that it involves the minimum possible disturbance to the treated reach. No sediment is placed directly on the stream bed or banks, and sediment only enters the channel when it is recruited by bank erosion. In addition, the added material is indistinguishable from the bed material in terms of size and roundness. As a result, the effects on bed surface structure and porosity would be analogous to those that occur naturally.

(2) This approach could also be combined with riparian planting in and around the stabilizing grains, which would increase the likelihood that the plantings would remain undisturbed for long enough to establish a mature forest cover capable of moderating bank erosion rates on its own. This combination of stabilization and revegetation would help restore the natural linkages between the river and the rehabilitated riparian forest. This approach is likely to be particularly successful on streams with average bank heights of 1 m or less, since root reinforcement can be moderately to highly effective in streams of this size (Eaton 2006).

(3) If/when stabilizing sediments are introduced to the treated reach via bank erosion, it is likely that the natural sequences of bars, pools, and riffles will be maintained to a greater degree than if traditional riprap were used. This could help maintain more diverse physical habitat comprising slow and deep pools, and shallow and rapid riffles. It may also help maintain the topographic variability necessary to drive hyporheic exchanges between the stream the the river bed.

(4) Transitions from stable single-thread channels to multiple-thread braided channels during future rare floods will be less likely to occur. Braided streams are highly complex, but they often have little in the way of vegetative cover, and they may experience de-watering during low flows and/or elevated stream temperatures due to a lack of shade. Maintaining a single-thread channel reduces the potential magnitude of such impacts, even if some widening and channel modification does occur in the treated reach.

(5) Minor bank erosion may continue to occur within the treated reach, preventing a static channel bed from developing and maintaining the disturbance regime upon which the aquatic ecosystem depends.

(6) Stabilization of the channel bed (and in particular, of the riffles downstream of the treatment, where the treatment is installed on an active meander) could potentially modulate the amount of vertical scour that occurs, preventing the exposure of buried infrastructure. Where meander bends must be stabilized, it is often the case that the local reduction in sediment supply can cause the downstream riffle to degrade, steepening the gradient along the meander bend and possibly threatening the stabilization works. When the riffle degrades, the potential spawning habitat associated with the riffle is lost, and the riffle/pool morphology is replaced by a more uniform run or glide. Since the stabilizing sediment is mobile, it can be transported to the riffle, where it can potentially counter-balance the reduction in sediment supply due to meander stabilization.

3.2 stability seeding on channel banks

Where it is not feasible/desirable to stage the stabilizing sediment on the bank tops and to allow the river to recruit it when and where the banks experience migration, it is possible to add the stabilizing sediment as a facing on the toe of channel bank. Typically, such sediment additions will be placed upon an existing riprap installation where vertical degradation is a concern, or where the integrity of the riprap is compromised, but full-scale replacement is not feasible/necessary. This approach has not yet been tested experimentally (but will be soon). The benefits will be similar to those for the bank-top stability seeding approach, and it is likely that recruitment of the stabilizing sediment will require rare floods capable of eroding unprotected channel banks.

(1) The natural processes of erosion, transport and deposition will distribute the stabilizing grains within the channel when and where the channel becomes unstable.

(2) The addition of stabilizing grains to the face of a cut-bank along a meander bend will potentially off-set the sediment reduction associated with stabilizing the bend, and could help maintain the downstream riffle. This will likely help maintain diverse riffle /pool morphology and hyporheic exchange patterns while still preventing any lateral migration of the river from occurring.

(3) If stabilizing grains are introduced along the entire meander bend, then the stabilizing grains could reduce the potential for vertical incision along the channel, protecting buried infrastructure. The stabilizing grains could also help create complex sedimentary habitats by triggering the formation of stone lines, clusters and cells, which can provide important interstitial habitat for invertebrates and small/young fishes. The same features that reduce the potential for vertical incision create valuable benthic habitat.

3.3 stability seeding on the channel bed

In sections where vertical degradation of the channel is an imminent concern (e.g. at bridge crossings, or buried linear infrastructure crossings), it may be advantageous to place stabilizing sediment on the stream bed. The degree to which this (untested) stabilization approach will have the desired effect depends on how well the placements mimic the redistribution processes that have been produced in the laboratory experiments. Therefore the potential habitat benefits are less clear and are more likely to vary from site to site, depending on the details of the stabilization design.

(1) The stabilizing grains could potentially provide important interstitial habitat for invertebrates and small/young fishes by promoting the formation of stone lines, clusters and cells.

(2) Depending on the design, in-stream placement of stabilizing sediment could create/maintain sequences of bars, pools, and riffles. This could help maintain more diverse physical habitat and help promote hyporheic exchanges between the stream the the river bed.

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