Associated Engineering

GLOBAL PERSPECTIVE.
LOCAL FOCUS.

REPORT

BC Ministry of Transportation and Transit

Cooper's Corner Culvert (St. No. 10567) Hydrotechnical Detailed Design Summary Report for Culvert Replacement

JANUARY 2025

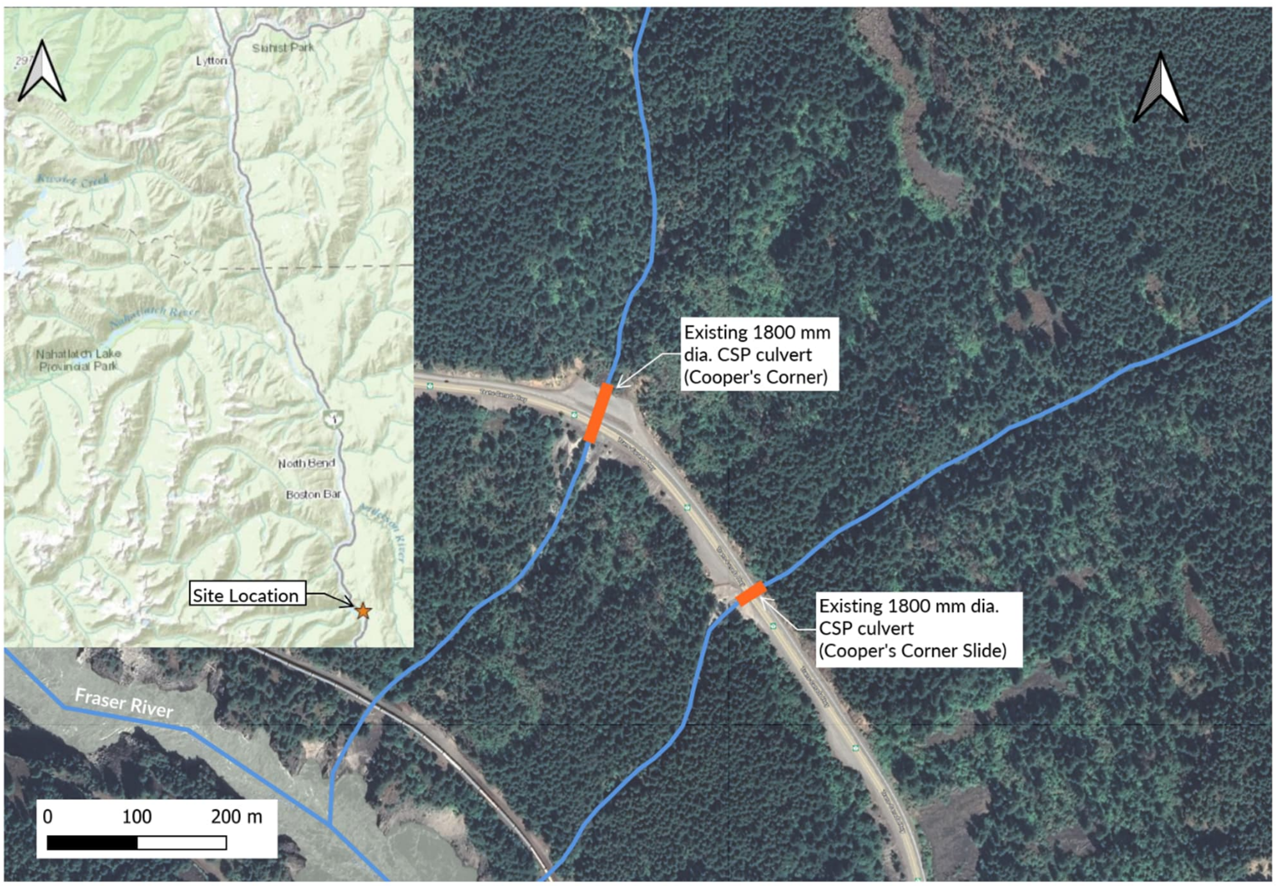
TABLE OF CONTENTS

LIST OF TABLES

1 INTRODUCTION

Cooper's Corner is located on Highway 1, near Hells Gate, BC. During the November 2021 Atmospheric River Event (ARE), sediment/debris blocked the existing culvert at the highway pullout (CHIRS ID #1865331 – Cooper's Corner Crossing). The combined blockage and high streamflow resulted in water overtopping the highway and running down the embankment slope, as well as flowing through the southeast highway ditch. The uncontrolled flows caused severe erosion and damage to the asphalt shoulder, the nearby highway pullout, and the highway embankment in the surrounding area. Additionally, the 2021 ARE resulted in significant worsening of a local highway embankment slope failure at the southern culvert's outlet (CHRIS ID #1865333 – Cooper's Corner Slide Crossing). **Figure 1-1** depicts the site location.

Figure 1-1 Coopers Corner Culvert Crossing Location



Associated Engineering (B.C.) Ltd. (Associated) was retained by the BC Ministry of Transportation and Transit (MoTT, the Ministry) to complete the design of the culvert replacement and associated highway and drainage works at Cooper's Corner. This report includes hydrotechnical details for the IFT Detailed Design Submission for Cooper's Corner. Design details for the Cooper's Corner Slide site can be found in the Cooper's Corner Slide (St. No. 10568) - Hydrotechnical IFT Design Summary Report for Culvert Replacement.

2 BACKGROUND

Subsequent to the ARE, debris consisting of sediments and woody material was cleared from the upstream channel at Cooper's Corner Crossing on October 25, 2022 by Emil Anderson Maintenance Co. Ltd. In May 2023, Associated completed a *Hydrotechnical Design Report for Cooper's Corner*. This report focussed on addressing the local drainage problems along the southward flowing ditch and the spill over the highway shoulder resulting in embankment damage. This report did not recommend improvements to the culvert crossing under the highway and pullout area, as the Ministry had previously planned to keep the existing culvert.

In parallel to the *Hydrotechnical Design Report for Cooper's Corner*, Associated conducted a high-level culvert assessment study (*Highway 1 Culvert Assessment – Asset Management Report*, *April 2024*) along Highway 1 in the Fraser Canyon between October 2022 to April 2024. Associated performed a field review (November 2, 2022) and analysis at the Cooper's Corner culvert site as part of this study. This assessment identified the Cooper's Corner crossing as a culvert that may have insufficient capacity to convey high flow events.

As re-directed by the Ministry, more recent efforts were focused on replacement assessment and options analysis at the culvert crossing under the highway at the pullout area (Cooper's Corner crossing). This assessment focused on the mitigation of risk of future blockage of the culverts and included reviewing capacity deficiencies as well as management options for sediment and debris transport and deposition. Associated performed a field review on February 7, 2023 in support of this study. Recommendations from this study concluded that the combination of a sediment basin and box culvert was the most suitable solution for the highway crossing. Further details are included in the *Cooper's Corner Final Hydrotechnical Assessment and Options Analysis Report*.

Detailed design to improve the crossing through the Cooper's Corner area was initiated based on the recommendations from this above report. It has been refined to the point of this final design report, which is being submitted with the Issued for Tender (FT) drawing package.

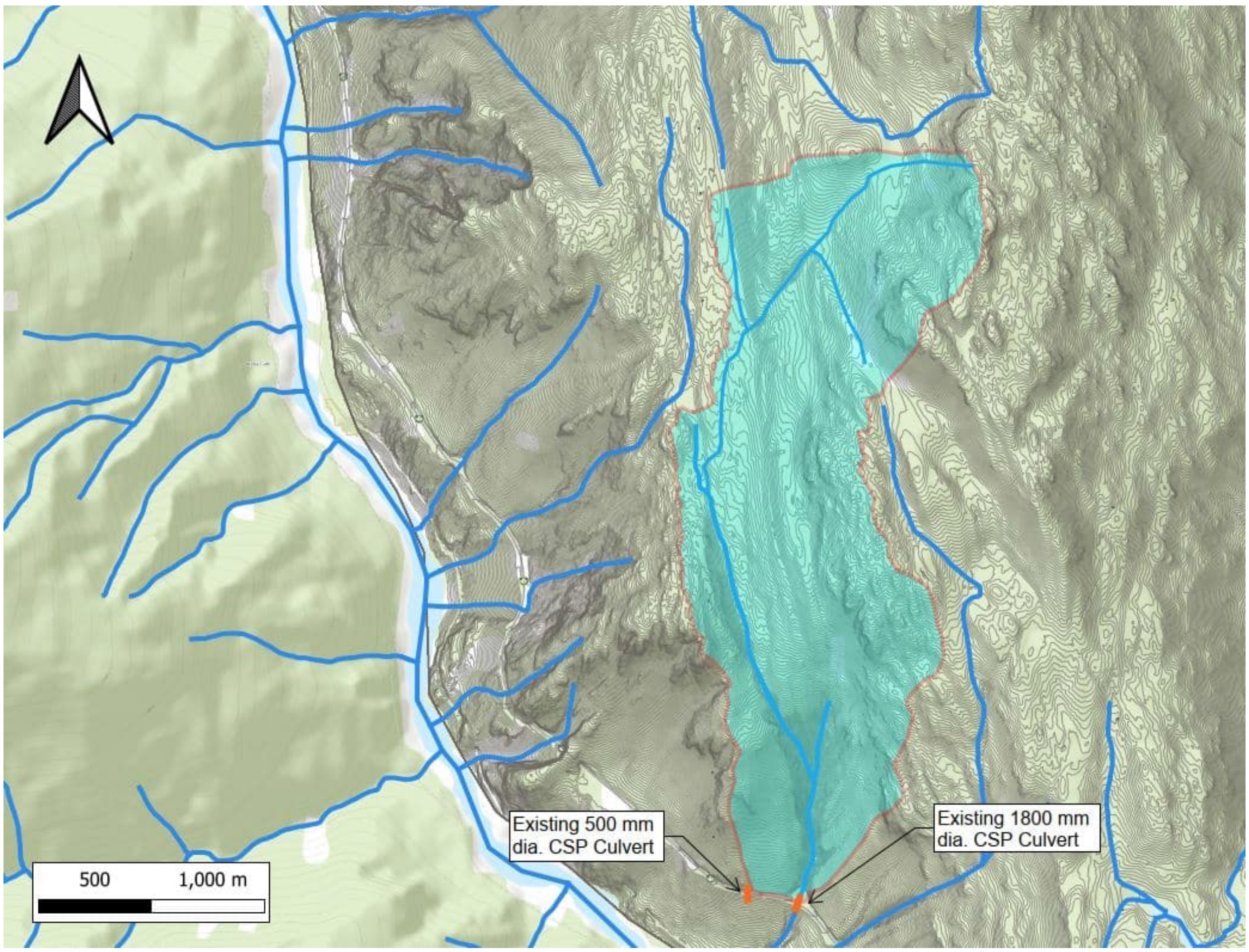
2.1 Field Review During Detailed Design

A field review prior to design finalization was conducted by two key hydrotechnical staff members, Noah Fanos, EIT and Andromeda MacIsaac, P.Eng., the Engineer of Record. This field review took place on January 14, 2025 and confirmed current site conditions and was used to develop minor design changes.

3 HYDROLOGICAL ANALYSIS

The watershed above Cooper's Corner crossing is an ungauged, coastal mountain catchment, and subject to rainfall and seasonal snowfall, with an estimated area of 2.87 km^2. **Figure 3-1** provides an overview of the watershed. We assessed flow conditions under both present-day and climate change impacted conditions. The 200-year return period was selected for the design event based on the guidance from *Guide to Bridge Hydraulics, Second Edition (2001)* and CSA-S6:19 Canadian Highway Bridge Design Code (CHBDC) with the concurrence of the Ministry.

Figure 3-1 Cooper's Corner Watershed



3.1 Hydrologic Model

We completed the hydrologic analysis with PCSWMM software. Details can be found in the *Cooper's Corner Final Hydrotechnical Assessment and Options Analysis Report*; however, a summary is provided herein.

Rainfall inputs for the PCSWMM hydrologic model were estimated using data from the Hope Airport climate station (ID: 1113543), and a 24-hour SCS Type 1A storm was selected as the representative hyetograph for simulation. Model parameters were set to represent saturated ground conditions typical of sandy clay loam soil.

We estimated potential increases in precipitation due to climate change effects using the temperature scaling Clausius Clapeyron Method. To determine input data, we used the Climate Data Canada web-based portal to estimate the predicted mean annual temperature increase for the year 2100, based on CMIP6 SSP5-8.5 climate model scenario. The resulting increase to rainfall intensity for the year 2100 was calculated to be 45%. Based on the 45% increase applied to rainfall intensity, the resulting design flow rate (200-year return period) is estimated to increase by 73%.

3.2 Design Flows

Table 3-4 summarizes the clear water flow estimates for Cooper's Corner crossing. These values are based on the methodology described in the sections above. For comparative purposes, both historical and climate change influenced design flows are shown. The 200-year peak flow with climate change is used for design purposes.

Table 3-1 Flow Rates

Return Period	Historical Peak Flow (m^3/s)	Peak Flow with Climate Change (m^3/s)
200-year	10.3	17.8
100-year	8.8	15.4
50-year	7.6	13.3
2-year	2.0	4.0

In addition to the clear water flows shown in **Table 3-4**, we have addressed the potential bulking effects of sediment and debris transport (i.e. a debris flood) for our design based on recommendations provided in the *Preliminary Debris Flow Hazard Assessment Draft Report* by Thurber Engineering Ltd. (Thurber, 2024b). Thurber has estimated bulking factors that can be applied to clear water flows to account for these effects. Thurber has estimated a debris flood to be a potential risk for any event equal to or larger than the 50-year return period clear water flow.

Table 3-5 displays the final selected design flow rates. Both clear water and debris flood design flow rates were considered for design of hydrotechnical components at the Cooper's Corner crossing. Additional information on how these different flow rates were used is discussed in **Section 4**.

Table 3-2 Selected Design Flows

Return Period	Clear Water Design Flow (m^3/s)	Estimated Bulking Factor	Debris Flood Design Flow (m^3/s)
200-year	17.8	1.15	20.5

4 HYDRAULIC MODELLING

We completed the hydraulic assessments for existing conditions and proposed designs with the HEC-RAS (Version 6.5) software developed by the U.S. Army Corps of Engineers (USACE). We developed 1D hydraulic models using site observations, photos, and measurements collected from the site reconnaissance, as well as LiDAR, and topographic survey data provided by the Ministry. The models were used to assess the capacity of the existing culverts under current and projected future design flows and to evaluate proposed improvements. Hydrologic flow inputs used in our hydraulic analysis are described in **Section 3**.

4.1 Existing Conditions Analysis

We modelled existing hydraulic conditions at Cooper's Corner culvert crossing and detailed the analysis in the following previously submitted report: *Cooper's Corner Final Hydrotechnical Assessment and Options Analysis Report*.

A summary of the existing conditions analysis for Cooper's Corner crossing is included in **Table 4-1** below. The existing culvert is inadequately sized for 200-year flow events under historic and future climate conditions. Based on the design criteria discussed in **Section 5**, the culvert must be capable of conveying this flow. As the current culvert does not meet these criteria, an upgrade is necessary to ensure compliance and proper flow capacity.

Table 4-1 Existing Condition Culvert Analysis

Location	Condition	Flow Rate (m^3/s)	HW/D Ratio	Overtopping Roadway
Cooper's Corner Crossing	200-year Flow Historical	10.3	1.9	No
	200-year Flow with Climate Change	17.8	2.4	Yes

4.2 Proposed Design Analysis

We modelled our proposed design at Cooper Corner crossing, including improvements to the channel and culvert crossing. The hydraulic model results serve as the foundation for designing the structures and features related to the crossing improvements. The model includes a total structure reach length of approximately 300 meters. We set the boundary conditions at the upstream and downstream boundaries to normal depth for the model, assigning them based on the average channel slope at the point where the model terminates. **Table 4-2** below summarizes the hydraulic inputs utilized, selected based on publications, standards, and engineering judgement. **Table 4-3** summarizes the Manning's "n" roughness coefficients applicable to the design models.

Table 4-2 Hydraulic Model Inputs

Model Parameter	Value / Source	
Surface Geometry	Survey provided by Stantec from August 9, 2022 and October 24, 2022. Field observations of channel cross-sectional geometry.[1] Proposed channel design modifications.	
Manning's "n" Roughness Values	Based on field observations, HEC-RAS manual guidance and standard literature (TAC, 1982 and US FHA, 2005b). See **Table 4-3**.	
Contraction and Expansion Coefficients	Gradual expansion: 0.3 Abrupt expansion: 0.8	Gradual contraction: 0.1 Abrupt contraction: 0.6

Notes:
[1]Existing channel geometry utilized a combination of survey collected by Stantec and field measurements collected by Associated, due to additional channel excavation being completed after Stantec's survey was complete.

Table 4-3 Hydraulic Model Manning's "n" Coefficients

Description	"n" Value
Channel	
Riprap Channel (500 kg Class)[1]	0.085
Riprap Channel (50 kg Class)[1]	0.08
Steep Bedrock Natural Channel	0.06
Floodplain	
Heavy stand of timber, moderate undergrowth	0.12
Heavy stand of timber, little undergrowth	0.1
Light brush and trees	0.06
Pavement	0.013

Notes:
[1] Roughness values applicable for steep riprap channels, based on guidance from US FHA, 2005b.

Proposed Design Results

Table 4-4 summarizes the model outputs from HEC-RAS software for the proposed hydrotechnical design.

Table 4-4 Hydraulic Design HEC-RAS Model Outputs

Hydrotechnical Design Component	Max Velocity (m/s)	Max Depth (m)
Upstream Armoured Channel – 20% Gradient Channel Section	7.3	0.9
Upstream Transition Channel – 3.7% Gradient Channel Section	0.9	2.3
Sediment Basin	1.0	2.6
Culvert Inlet	3.9	2.6
Culvert Outlet	4.6	1.29

It should be noted that the HEC-RAS model results and hydraulic modelling analysis were supplemented by additional calculations to better analyse and design the proposed culvert outlet treatment, a baffled concrete apron. These calculations are discussed under **Section 6.4** of this report and are based on the US FHA HEC-14 Section 7 specifications for a USBR Type IX Baffled Apron.

5 DESIGN CRITERIA

Table 5-1 summarizes the hydrotechnical design criteria for Cooper's Corner culvert crossing. The overarching design criteria for buried structures (i.e., culverts exceeding 3 m diameter or width) is the Bridge Standards and Procedures Manual – Volume 1 – Supplement to CHBDC S6:19 (BC MoTI, 2022).

Table 5-1 Hydrotechnical Design Criteria

Criteria	Value	Basis for Criteria Value
Design Return Period for Hydraulic Structure	200-year	Bridge-sized buried structure, highway road classification, and discussion with the Ministry (BC MoTI, 2022).
Climate Change Adaptation	73% increase to 200-year return period flow rate	Refer to **Section 3.1.1**.
Design Flow Rate	Clear water: 17.8 m^3/s Debris flood: 20.5 m^3/s	200-year peak flow rate, including a 73% increase to 200-year peak flow rates for climate change adaptation. Additional consideration of debris flood flow rate for portions of the channel expected to carry significant bedload.
Design Scenario	• Culvert: Clear water event • Culvert outlet treatment: Clear water event • Sediment basin: Debris flood event • Upstream riprap channel: Debris flood event	Debris floods are considered the most likely steep creek hazard to affect Cooper's Corner crossing, based on study results from Thurber Engineering Ltd. (Thurber, 2024b). Debris flows are not expected to impact the lower reaches of the watershed (Thurber, 2024b) and we have not designed to protect against them. Our design will mitigate the impact against debris floods in the upstream channel through the use of a sediment basin and an armoured channel and berm. The culvert and culvert outlet treatment are designed to protect against clear water flood events.

Criteria	Value	Basis for Criteria Value
Culvert Hydraulic Capacity	The culvert crossing shall be designed to pass the anticipated ice flows and floating debris as well as accommodating sediment bed load at the site for the Q200 design flood.	Based on anecdotal evidence from the 2021 ARE and geotechnical input (Thurber, 2024b), floating debris is not anticipated to be a likely hazard at Cooper's Corner crossing. As confirmed with the Ministry, the proposed sediment interception design provides sufficient risk mitigation to negate the need for additional freeboard to pass sediment.
Design Channel Freeboard	≥ 300 mm	Bridge Standards and Procedures Manual (BC MoTI, 2022) recommends a minimum of 300 mm freeboard above the design high-water level.

6 PROPOSED HYDROTECHNICAL DESIGN

The following section includes a summary of each hydrotechnical design component, specifically:

- Channel improvements within the upstream creek channel;
- Sediment and debris control measures (i.e. a sediment basin) between the upstream channel and the inlet to the proposed box culvert structure;
- The proposed box culvert structure at the highway crossing, and
- Culvert outlet treatment (a concrete baffled apron).

6.1 Channel Improvements

The existing channel upstream from the culvert is characterized by steep mountainous terrain with slopes ranging from 3.7% to 20% at the Cooper's Corner crossing. Our improved channel design at Cooper's Corner crossing includes the following:

- Increasing the channel cross sectional area and removing "pinch points" to improve hydraulic capacity,
- Creating a more consistent channel gradient to improve hydraulic capacity, minimize local backwater effects and encourage sediment conveyance through the channel to the sediment interception basin.

The channel is designed with a minimum freeboard height of 300 mm based on guidance from the *Bridge Standards and Procedures Manual* (BC MoTI, 2022). As this reach of the channel is expected to experience debris floods, we have designed the channel and calculated freeboard using the debris flood flow of 20.5 m^3/s.

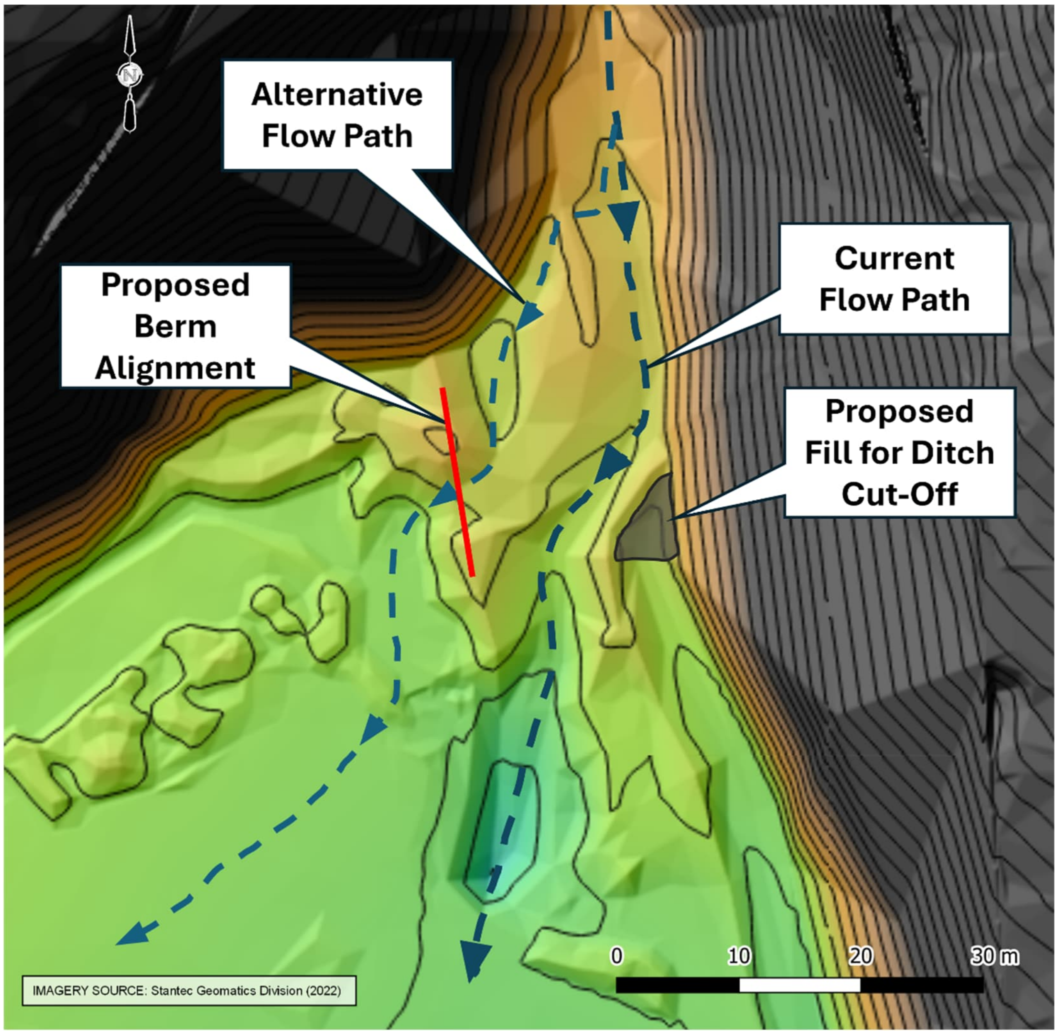
It should be noted that construction of the riprap channel will require a field-fit solution from the contractor to ensure a smooth tie-in with the existing channel at the upstream boundary of project works. This is due to the uncertainty in the current channel topography. While existing channel survey was collected by Stantec in August and October of 2022, additional channel excavation was completed afterwards to clear sediment. Associated then collected field measurements in November 2022 to estimate the updated existing channel geometry. As a result, there is uncertainty in exact channel tie-in elevations at the upstream extent of the proposed riprap channel. The creek has a high sediment load and is relatively morphologically active; we expect that further sediment deposition has taken place in the past two years. Construction of the riprap channel can be field-fit by adjusting the channel gradient of the upper 10 m of the design channel to ensure a smooth tie-in with the existing channel.

To reduce the risk of channel avulsion over the right channel bank and preserve the existing flow path to the culvert crossing, we propose the construction of a berm adjacent to the upstream channel. Approximately 40 m upstream from the existing culvert inlet, there is risk of water entering a low-lying area over the right bank of the main channel during high flows, redirecting flow away from the culvert. We propose constructing a berm at least 2 m higher than the existing terrain in this area and armouring the berm slope facing the channel with 500 kg class riprap to reduce channel avulsion risk. To allow for construction and maintenance of the berm and allow access to maintaining the adjacent channel, we propose a 3.5 m top width and 2:1 bank slopes. The berm is intended to be constructed using the material excavated during construction of the sediment basin. Further design details are provided in the *Coopers Corner Culvert Replacements – IFT Detailed Design Submission (#14054)*.

Figure 6-1 provides a visualization of the proposed berm location and the intention to cut-off the alternative flow paths. It should be noted that this figure shows the site terrain as surveyed by Stantec in 2022 following the atmospheric river event; this surface has been intentionally included to illustrate the tendency for avulsions and deposits on the alluvial fan. Subsequently, the site has been altered by the removal of deposited material.

Figure 6-1 also provides a visualization of a proposed area of fill behind the left channel bank which is intended to improve the ditch cut off east of the creek. Our proposed channel improvements also raise the left bank through this section to reduce the risk of flow redirecting away from the culvert and ensure sufficient channel freeboard. This area is intended to be filled with material excavated during the construction of the sediment basin.

Figure 6-1 Proposed Berm and Ditch Fill Locations



Erosion Protection

The estimated flow velocities are relatively high due to the steep channel slopes; a maximum velocity of 7.3 m/s is estimated to occur along the 20 percent channel slopes. However, the flow is expected to be parallel to the channel banks, such that significant impingement is not expected.

For riprap design, we consider numerous factors in the sizing recommendations; the 20% channel slope occurs over approximately a 35 m reach, such that the gravitational forces acting on the riprap coincide with the drag forces of the flowing water, and contribute to instability of the riprap revetment. A hydraulic jump is expected to occur due to the transition of 20% to the 1% channel slope in the sediment basin downstream. Larger riprap gradations, particularly Class 250 kg and above, contain significant voids allowing for flow within the riprap blanket (interstitial flow). We have reviewed several riprap sizing methods, particularly those suited to riprap sizing on spillway faces and/or steep rock chutes. The reviewed methodologies and estimated riprap sizes are listed below.

Table 6-1 Riprap Design Summary – Upstream Channel

Riprap Sizing Method	Upstream Channel – Recommended D_{50} w/ Debris Flood Design Flow (mm)
ARS Rock Chutes, 1998; Robinson, Rice, and Kadavy	620
Catchments & Creeks, Version 1, 2010 & Version 2, 2014	720
HEC-23 - Design of Riprap for Overtopping Flow, 2009	560
Selected D_{50}	**725 (Class 500 kg)**

We considered the guidance and methods identified in the above table to determine the required riprap class for erosion protection. We recommend 500 kg class riprap for the channel upstream of the sediment basin. This riprap class meets or exceeds the required sizes estimated by the methods identified in **Table 6-1**. Additional considerations for constructability, maintenance, and robustness of design were considered in selection of the required riprap class. Further details of the riprap calculations can be found in **Appendix A**.

6.2 Upstream Sediment and Debris Control Measures (Sediment Basin)

We propose extending the upstream channel to the highway, excavation approximately 24 m of new channel and shortening the length of the proposed culvert crossing. Instead, this area will be constructed at a gentle slope and very wide channel cross section relative to the upstream channel sections, forming a sediment settling basin. This sediment basin will be excavated in a portion of the current highway pullout.

Subsequent to the November 2021 ARE, debris consisting of sediments and woody material was cleared on October 25, 2022. The construction report by Emil Anderson Maintenance Co. Ltd. states that approximately 50 truckloads of debris was cleared. Assuming 8 m^3 of debris volume loaded per truck, the total debris volume cleared is estimated to be 400 m^3. Our proposed sediment basin is designed to meet this target sediment deposition volume. The design channel depth in the basin allows for approximately 500 m^3 of sediment deposition while still providing at least 1 m of freeboard under the debris flood design flow, which is consistent with guidance from the *Bridge Standards and Procedures Manual* (BC MoTI, 2022) and recommendations from geotechnical analysis (Thurber, 2024b).

The sediment basin will be constructed with a longitudinal slope of 1% to promote sediment deposition upstream of the culvert inlet. It is intended to have a sediment interception capacity of approximately 500 m^3, before removal effort is required. As deposited sediment will form a fan shape in the basin, the full excavated volume of the basin (1,240 m^3) will not actually be utilized for sediment interception and storage. A stage-volume table is provided below to illustrate the approximate design capacity of the sediment basin.

We have designed the transition from upstream channel to sediment basin to provide a rapid transition from a high velocity, high sediment transport capacity condition to a low velocity and low sediment transport capacity condition. Sediment transport mechanisms within the creek will include traction and saltation in addition to suspension, and extreme events the creek may experience debris floods (Thurber, 2024b). Through this transition point, design velocities reduce from 7 m/s to 1 m/s. This rapid loss of kinetic energy should correspond to rapid settlement of material at the entrance to the sediment basin. Based on observation of previous events on site, we believe that the combination of a 20% slope and 7 m/s velocities is likely to maintain transport of both a suspended sediment load and bed load arriving from the natural channel upstream. The 1% slope and 1 m/s design velocity for the sediment basin are low enough to promote sediment deposition even for relatively fine material.

Table 6-2 Sediment Basin Stage-Volume Relationship

Stage (m)	Volume (m^3)
278.6	0
279.0	15
279.5	95
280.0	210
281.0	555
282.0	1,060
283.0	1,145

The addition of a sediment interception basin directly upstream of the Cooper's Corner culvert crossing will protect the culvert and reduce the potential for blockage or conveyance of sediment through the culvert onto the steep embankment slope. The basin provides the following functions:

- Promotes debris interception, reducing the risk of culvert blockage or damage.
- Provide a runout zone to partially mitigate a debris flood or debris flow (depending on magnitude).
- Limits the risk of larger sediment and debris impacting the culvert outlet treatment and energy dissipation baffle design.
- Reduce the likelihood of sediment transiting through the culvert and impacting the CN rail line below the highway.

Erosion Protection

Erosion protection is required for bank protection, similar to the discussion in **Section 6.1**. As with the upstream channel, the flow is expected to be parallel to the channel banks, such that significant impingement is not expected. Direct flow impingement may occur surrounding the culvert inlet; however, the streamflow velocities are expected to be notably lower given the channel configuration and slopes through the sediment basin.

For riprap design, we consider several factors in the sizing recommendations, including the hydraulic jump expected to occur in the transition from the upstream channel to the sediment basin. Although HEC-RAS modelling suggests that this hydraulic jump is likely to take place within the upstream slope, this is a highly complex hydraulic process and the effects of the hydraulic jump may impact erosive forces at the transition from steep channel to sediment basin. For this reason, we recommend extending the same riprap protection used in the upstream channel into the most upstream 5 m of the sediment basin.

As discussed in **Section 6.1**, we have reviewed several riprap sizing methods, particularly those suited to riprap sizing on spillway faces and/or steep rock chutes. Riprap sizing within the main portion of the sediment basin used the more typical USACE method. The reviewed methodologies and estimated riprap sizes are listed below. Given the gentle slope through the sediment basin, velocities are much lower through this channel section and the required erosion protection to reduce erosion/scour risk is determined to be 50 kg class riprap. Although this is a larger class than was calculated with the USACE method, it represents a minimum practical size, given the variability and high energy of flow at this site. Additional considerations for constructability, maintenance, and robustness of design were considered in selection of required riprap class. Further design details are provided in the *Coopers Corner Culvert Replacements – IFT Detailed Design Submission (#14054)*. Further details for riprap calculations can be found in **Appendix A**.

Table 6-3 Riprap Design Summary – Sediment Basin

Riprap Sizing Method	Sediment Basin – Recommended D_{50} w/ Clear Water Design Flow (mm)	Sediment Basin Inlet – Recommended D_{50} w/ Debris Flood Design Flow (mm)
USACE, 1991	20	-
ARS Rock Chutes, 1998; Robinson, Rice, and Kadavy	-	620
Catchments & Creeks, Version 1, 2010 & Version 2, 2014	-	720
HEC-23 - Design of Riprap for Overtopping Flow, 2009	-	560
Selected D_{50}	**340 (Class 50 kg)**	**725 (Class 500 kg)**

Recommendations for sediment basin maintenance are included in **Section 7**. Geotechnical investigation is required to identify whether there is a potential for additional infiltration to the embankment fill due to retention of water in the sediment basin, potentially impacting embankment stability.

6.3 Box Culvert

Based on the design criteria summarized in **Table 5-1**, the required replacement culvert is a 3.0 m wide x 2.7 m high (nominal dimensions) concrete box culvert. As discussed in **Section 6.1**, the longer approach channel through the pullout area will reduce the culvert length to approximately 16 m. The replacement culvert has a slope of 1% to match the upstream channel slope and reduce the discharge velocity at the culvert outlet. Velocity reduction within the culvert is critical to downstream erosion protection and outlet treatment design; it is discussed further in **Section 6.3**.

Advantages for selecting a box culvert as the Cooper's Corner crossing structure are outlined below:

- Box culverts are more hydraulically efficient for the same overall dimensions, and less susceptible to blockage.
- They have a lower height relative to a round culvert with comparable capacity, therefore making it easier to achieve cover requirements.
- A solid bottom alleviates concerns with channel downcutting as may exist with a free span bridge.

- The concrete culvert bottom is more robust, and less susceptible to abrasion than a corrugated steel pipe culvert.

6.4 Culvert Outlet Treatment

The Cooper's Corner culvert crossing is located on top of highly erodible slopes that provide unique design challenges. A summary of the site challenges and considerations impacting outlet treatment design are listed below:

- Extreme downstream slopes (70% slopes or greater).
- Extreme downstream slopes continue to the CN Rail line; there is no secure toe in which to key the outlet treatment and risk to downstream infrastructure should the slope or outlet treatment mobilize.
- The site has existing erosion concerns and histories of mass wasting or slide events.
- The site is constructed on colluvium deposits, which are not stable and may allow for groundwater seepage (Thurber, 2024a).
- Erosion risk at the site includes the possibility of undermining the highway, should the risk not be properly managed.

These challenges raise a number of concerns with typical erosion protection design options. We have addressed the most common options below.

Loose Riprap

Due to the high velocities and extreme slopes, typical riprap design would require extremely large rock (e.g. Class 4000 kg or greater). There are a number of concerns with sourcing and installing material of this size as well as long term stability issues. There is a significant risk that the rock would mobilize on the slope, posing a risk to the CN railway. We do not consider the risk presented by the use of very large, loose riprap acceptable at the Cooper's Corner site.

Grouted Riprap

Grouted riprap is often considered as an alternative method on slopes where loose riprap stability is a concern. However, site specific challenges preclude its use. These include the risk of fragmentation of the grouted mass due to pore pressures and a lack of toe support on the long, steep slope to prevent tensile forces from forming in the grouted riprap. Specific guidance from the BC Ministry of Environment, Lands and Parks *Riprap Design and Construction Guide* (NHC, 2000) states:

"Grouted rock is rigid, but not very strong, and the underlying bank supports it. Careful attention is required to bank preparation, often with bank materials filled and compacted, a sub-base or foundation layer placed beneath the rock, a permeable filter layer, and pressure relief or drainage pipes provided through the grout." – Section 3.14 Grouted Riprap

"Grouted riprap must be securely protected against toe scour or undermining (see previous sections). It will not self-repair like ordinary riprap." – Section 3.14 Grouted Riprap

Outlet Treatment Design

We propose the installation of an 18 m long concrete baffled apron as the outlet treatment for Cooper's Corner Crossing. The concrete baffled apron will be installed at a 72% slope and based on the US FHA HEC-14 Section 7 specifications for a USBR Type IX Baffled Apron.

Advantages for selecting a baffled apron energy dissipator as the Cooper's Corner crossing outlet treatment are outlined below:

- Energy dissipation, reducing the velocities on the downstream slope to subcritical.
- Apron baffles divided the culvert flow into multiple paths, preventing a single, concentrated high velocity stream (or jet) from eroding the downstream slope.
- The outlet treatment can be successfully anchored on existing slope, reducing the risk of slope instability and impacts to the CN Rail line downslope.
- The concrete apron design can successfully resist pore pressure in the downstream slope and prevent groundwater seepage through the structure.

Figure 6-2 shows the typical design dimensions for a USBR Type IX Baffled Apron. Specific design dimensions and hydraulics are summarized in **Table 6-4**. All design dimensions, flow calculations and analysis used for the USBR Type IX Baffled Apron are as per the directions of the US FHA HEC-14 Section 7. It should be noted that the design slope of 72% exceeds the normally recommended maximum slope of 50% provided by HEC-14. Extra provisions, in the form of increased apron length with additional baffle rows are incorporated in the design. We have performed calculations against the likelihood of excessive splashing and overshooting of the baffles to adapt this design to the needs of the project site. Further details for riprap calculations can be found in **Appendix B**.

Figure 6-2 USBR Type IX Baffled Apron (HEC-14)

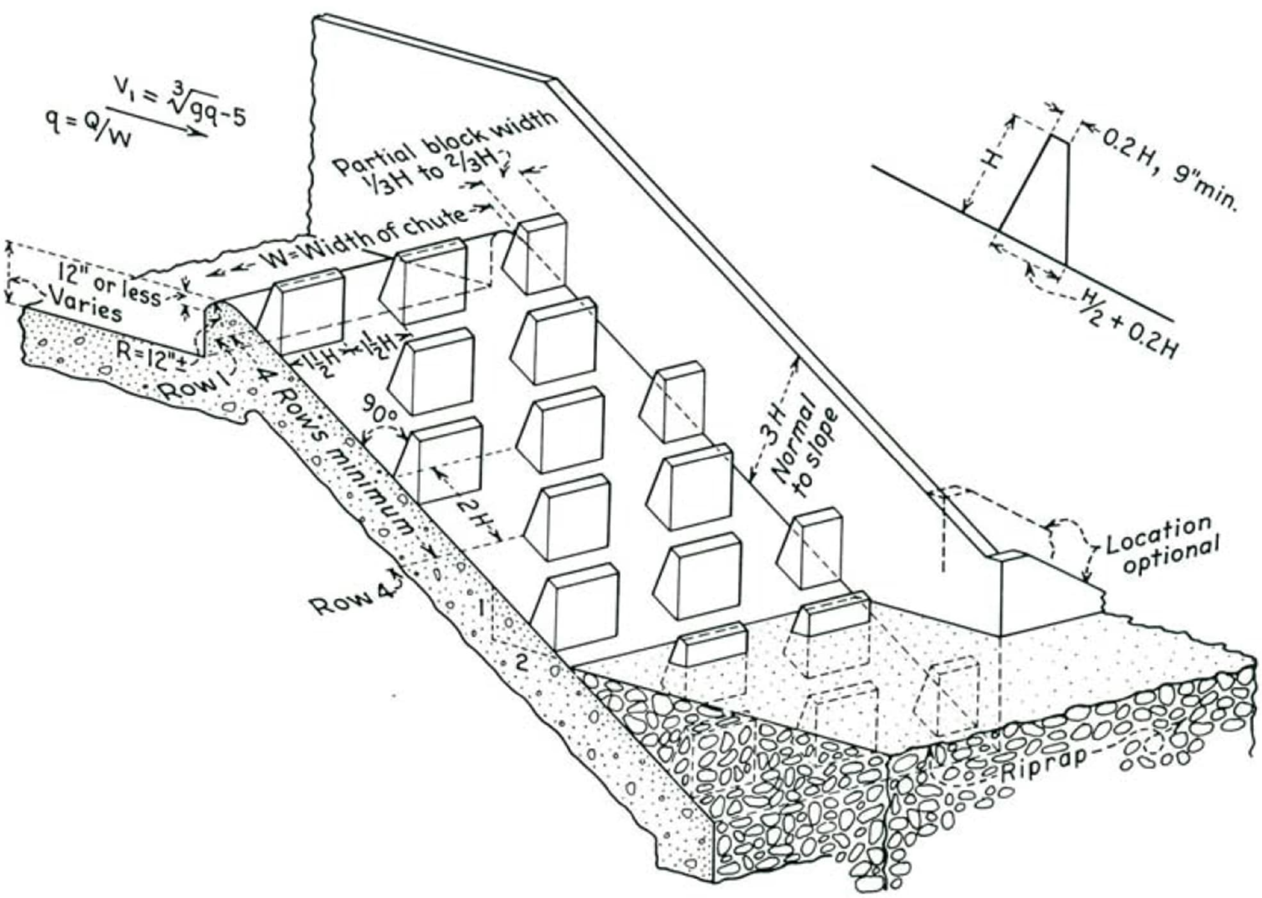


Table 6-4 USBR Type IX Baffled Apron Design Specifications

Criteria	Value
Apron Dimensions	18 m length 9 m maximum width 4.2 m height of side walls
Baffle Height	0.9 m
Baffle Width	1.8 m
Number of Rows of Baffles	9 rows
Discharge Velocity from Baffled Apron	1.09 m/s
Critical Flow Depth	1.1 m

7 MAINTENANCE PLANNING

Maintenance planning is crucial for culverts and channels to ensure they function as designed, preventing risk of blockages and potential flooding. Regular maintenance helps proactively identify and address sediment buildup, wear/damage, or debris hazards that could compromise performance, ultimately reducing repair costs and extending the lifespan of these critical infrastructure components. The following sections provide additional details on maintenance activity for hydrotechnical design components at Cooper's Corner Crossing.

7.1 Inspection and Maintenance Plan Recommendations

As discussed in **Section 6.2**, the sediment basin is designed to intercept bedload transport of a similar magnitude to the deposition volume experienced during the 2021 ARE upstream from the highway culvert crossing. The sediment basin has been designed with sufficient capacity to accommodate an anticipated sediment deposition of approximately 400 cubic meters. This design approach ensures that, even as sediment accumulates, the basin will maintain adequate volume to allow for the continued conveyance of the design flow through the channel and culvert. Notably, the full volume capacity of the sediment basin is not intended for active use, but rather serves as a safeguard to manage sediment build-up without compromising flow capacity.

As sediment accumulates in the sediment basin over time, maintenance will be required to clean and excavate the basin so that it can continue to accommodate the design target volume of sediment deposition. Sediment maintenance recommendations and maximum sediment deposit thresholds have been selected to ensure that even at its most full, the sediment basin and upstream channel should be able to convey the design clearwater flow event with 1 m freeboard.

As discussed in **Section 5** and **Section 6**, the culvert at Cooper's Corner box culvert is designed to convey the design clear water flow; however, it is still likely that sediment accumulates in the culvert barrel over time, particularly as the sediment basin fills with sediment.

Strategies for maintenance are identified below.

Inspection Intervals

We recommend regular inspection program to ensure effective function of the sediment basin. This should include visual inspection during regular annual highway maintenance inspections at minimum. Ideally, these regular annual inspections will be timed to occur in the late-summer or fall to identify any concerns prior to large winter rainfall events. Additional inspections should occur after major rainfall events, specifically any event where a rainfall warning is released by Environment and Climate Change Canada for the area. The majority of these events are anticipated to occur during the winter months.

Inspection Activities

Typical hydrotechnical inspections should include the following items:

- Inspection of the upstream channel for identification of large woody debris and sediment build-up.
- Inspection of the sediment basin for identification of large woody debris and sediment build-up, including measurement of the depth from the top of sediment basin bank to the bottom of the channel.
- Inspection of the culvert barrel for identification of large woody debris and sediment build-up.

Additional maintenance inspection items such as structural, highways, and utilities should be confirmed with the appropriate professionals.

Maintenance Activities and Indicators for Clearing Sediment

Cleaning and clearing (excavating) the sediment basin should occur if any of the following are observed during inspection:

- Deposited sediment exceeds a maximum elevation of 282.1 m Canadian Geodetic Vertical Datum 2013 anywhere within the sediment basin or upstream channel;
- Depth of the channel or sediment basin are reduced to 2m or less anywhere within the sediment basin or upstream channel, or
- Sediment deposition *of any depth* is observed within 5 m of the culvert inlet.

Appendix C includes a sediment basin maintenance drawing which illustrates the likely deposition pattern for sediment within the basin as well as the maximum allowable deposition elevation. It should be referred to during inspections and maintenance activities.

Cleaning and clearing the box culvert should occur if sediment accumulates within the culvert.

We also recommend that any coarse/large woody debris that is identified during inspections be cleaned or cleared if possible.

7.2 Sediment Basin and Upstream Channel Maintenance Activities

Sediment basin and upstream channel maintenance efforts should aim to re-establish the design cross-sectional shape and elevations of the sediment basin. Maintenance can be performed via the remaining pullout area and proposed gravel maintenance access path along the east overbank of the basin. Additional access is provided at the west overbank of the basin if necessary for maintenance efforts.

During regular maintenance activities, coarse woody debris in the channel at and upstream of the sediment basin should be cut into lengths that can be pass through the culvert (thus reducing the risk of logjams) or directly removed. This effort should extend above the construction extents as far as practical to address coarse woody material that will migrate down to the culvert over time.

7.3 Culvert Maintenance Activities

Box culvert maintenance efforts should aim to clear all sediment and other debris from the culvert barrel. This may be accomplished through the use of a typical skid-steer or track loader to “sweep” sediment from the culvert barrel and collect in an area accessible for removal by excavator. Extreme precaution should be exercised during culvert maintenance to avoid any damage to the culvert structure.

BIBLIOGRAPHY

Associated Engineering (B.C.) Ltd. 2024. Cooper's Corner Final Hydrotechnical Assessment and Options Analysis Report.

Associated Engineering (B.C.) Ltd. 2024. Highway 1 Culvert Assessment – Asset Management Report.

Associated Engineering (B.C.) Ltd. 2023. Hydrotechnical Design Report for Cooper's Corner.BC Ministry of Transportation and Infrastructure (BC MoTI). 2019. Supplement to TAC Geometric Design Guide. 3rd Edition.

BC Ministry of Transportation and Infrastructure (BC MoTI). 2022. Bridge Standards and Procedures Manual – Volume 1. Supplement to CHBDC S6:19.

Catchments & Creeks Pty Ltd. 2014. Rock Sizing for Small Dam Spillways – Stormwater Management Practices.

Catchments & Creeks Pty Ltd. 2010. Gully Erosion, Part 3 – Design of Rock Chutes for Gully Stabilisation.

CSA Group (CSA). 2019. CSA S6:19 – Canadian Highway Bridge Design Code, Twelfth Edition.

Northwest Hydraulic Consultants (NHC). 2000. BC Ministry of Environment, Lands and Parks – Riprap Design and Construction Guide.

Thurber Engineering Ltd. (Thurber). 2024a. HWY 1 Lower Fraser Canyon Flood Recovery: CPS Project No. 14054, SA07-1-12 Corridor SA07 Hope To Jackass Cooper's Corner Culvert Upsizing – 50% Detailed Design.

Thurber Engineering Ltd. (Thurber). 2024b. Highway 1 Lower Fraser Canyon Flood Recovery - Cooper's Corner Preliminary Debris Flow Hazard Assessment Draft Report.

Transportation Association of Canada (TAC). 1982. Drainage Manual – Volume I.

Transportation Association of Canada (TAC). 2001. Guide to Bridge Hydraulics, Second Edition.

United States Army Core of Engineers (USACE) Hydrologic Engineering Center. Accessed online: March 2024. HEC-RAS User's Manual – Version 6.5.

United States Army Core of Engineers (USACE) Hydrologic Engineering Center. 1991. Hydraulic Design of Flood Control Channels.

United States Department of Agriculture – Natural Resources Conservation Service. 2007. National Engineering Handbook Part 654 – Technical Supplement 14G: Grade Stabilization Techniques.

United States Department of Transportation – Federal Highway Administration (US FHA, 2005a). 2005. Hydraulic Engineering Circular No. 9, Third Edition – Debris Control Structures Evaluation and Countermeasures.

United States Department of Transportation – Federal Highway Administration (US FHA). 2006. Hydraulic Engineering Circular No. 14, Third Edition – Hydraulic Design of Energy Dissipators for Culverts and Channels.

United States Department of Transportation – Federal Highway Administration (US FHA, 2005b). 2005. Hydraulic Engineering Circular No. 15, Third Edition – Design of Roadside Channels with Flexible Linings.

United States Department of Transportation – Federal Highway Administration (US FHA). 2009. Hydraulic Engineering Circular No. 23 – Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance – Third Edition.

W. James, L. A. Rossman, and W. R. C. James. 2010. User's Guide to SWMM5 – 13th Edition.

CERTIFICATION PAGE

This report was prepared for the BC Ministry of Transportation and Transit to summarize the hydrotechnical detailed design methodology for the Cooper's Corner Culvert (St. No. 10567) Hydrotechnical Detailed Design.

The services provided by Associated Engineering (B.C.) Ltd. in the preparation of this report were conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions. No other warranty expressed or implied is made.

Respectfully submitted,

Associated Engineering (B.C.) Ltd.
Engineers & Geoscientists BC Permit Number 1000163

Prepared by:

Noah Fanos, E.I.T.
Hydrotechnical Engineer

Prepared by:

PROFESSIONAL
PROVINCE OF
A. C. MacISAAC
60158
BRITISH COLUMBIA
ENGINEER
2025-01-31

Andromeda MacIsaac, P.Eng.
Hydrotechnical Engineer (EOR)

Reviewed by:

Michael MacLatchy, Ph.D., P.Eng.
Specialist – Hydrotechnical

NF/AM/MM/nhd

APPENDIX A - RIPRAP CALCULATIONS

Project Nam	Cooper's Corner Detailed Design - Pullout Culvert
Subject:	RIP-RAP calculations
Project Num	2022-2604
Prepared:	Noah Fanos
Checked:	Andromeda MacIsaac
File:	
Date:	2024-11-04

Summary

The purpose of this spreadsheet is to size riprap for the design channel upstream from the sediment basin at Cooper's Corner Crossing. This Channel is designed to range from 12 to 20%.
It is possible the channel may need to be steeper than 20%, as we expect some contractor field-fit of the upper 10 m of this channel to tie-in to existing ground (which is unknown due to old survey). A check for expected upper range is copied at the bottom of this page.

General Rip Rap Inputs

Source of inputs:
Most conservative channel cross section output taken from HECRAS Model for design flow.
Q200 + Climate Change + 15% bulking factor (20.5 cms)

	Metric		Imperial	
Slope	0.26	m/m	0.26	ft/ft
Design Discharge	20.5	m^3/s	724.0	ft^3/sec
Width of Channel (at mid depth for trapezoid)	5.1225	m	16.9	ft
Unit Discharge	4.0	m^3/s/m	42.8	Ft^3/sec/ft
Depth of Flow	0.4	m		

Method	D50 (m)	Comment
C&C1	0.72	max slope of 50%
C&C2	0.82	max slope of 50%
ARS (robinson 1998)	0.68	max 40%
HEC-23	0.69	flow over embankments

Design Check

Copy of 26% channel slope tested (below). We expect 26% slope to be the upper range for possible field-fit slope by contractor, based on approx tie-in to the elevation of Historic 2022 Channel survey (which has since been excavated to clear debris/sediment and no updated survey was provided).

General Rip Rap Inputs

Source of inputs:
Most conservative channel cross section output taken from HECRAS Model for design flow.
Q200 + Climate Change + 15% bulking factor (20.5 cms)

	Metric		Imperial	
Slope	0.26	m/m	0.26	ft/ft
Design Discharge	20.5	m^3/s	724.0	ft^3/sec
Width of Channel (at mid depth for trapezoid)	5.1225	m	16.9	ft
Unit Discharge	4.0	m^3/s/m	42.8	Ft^3/sec/ft
Depth of Flow	0.4	m		

Method	D50 (m)	Comment
C&C1	0.72	max slope of 50%
C&C2	0.82	max slope of 50%
ARS (robinson 1998)	0.68	max 40%
HEC-23	0.69	flow over embankments

Catchments and Creeks Method - Climate Change

K1 (assume fractured)	1	
K2 (assume well graded)	1.05	
Unit Discharge	4.0	m^3/s/m
Specific gravity (Granite)	2.5	
Bed Slope	0.26	m/m
Factor of Safety	1	
Depth of Flow	0.4	m
D50	**0.72**	**m**

Equation 1 represents the recommended design formula for sizing rock on the bed and banks of chutes. Tables 6 and 7 provide mean rock size (based on Equation 1 and rounded up to the next 0.1m unit) for safety factors of 1.2 and 1.5 respectively.

$$d_{50} = \frac{1.27 . SF . K_1 . K_2 . S_o^{0.5} . q^{0.5} . y^{0.25}}{(s_r - 1)} \qquad \text{(Eqn 1)}$$

where:

d_{50} = nominal rock size (diameter) of which 50% of the rocks are smaller [m]

K_1 = correction factor for rock shape

= 1.0 for angular (fractured) rock, 1.36 for rounded rock (i.e. smooth, spherical rock)

K_2 = correction factor for rock grading

= 0.95 for poorly graded rock ($C_u = d_{60}/d_{10} < 1.5$), 1.05 for well graded rock ($C_u > 2.5$), otherwise $K_2 = 1.0$ ($1.5 < C_u < 2.5$)

q = flow per unit width down the embankment [m^3/s/m]

s_r = specific gravity of rock

S_o = bed slope = tan(θ) [m/m]

SF = factor of safety (refer to Table 1)

y = depth of flow at a given location [m]

Wherever practical, the unit flow rate 'q' (m^3/s/m), flow velocity 'V' (m/s), and flow depth 'y' (m) used to determine rock size should be based on 'local' flow conditions (i.e. unit flow rate, flow depth and flow velocity at the location of the rock), rather than values averaged over the full cross-section.

Catchments and Creeks 2 - Climate Change

For Slopes < 50%

SF	1
K1	1
K2	0.95
Slope	0.26
q	4.001952
y	0.4
sr	2.5

Equation 1		
D50	0.65	m

Equation2 (not dependent on velocity)		
D50	0.82	m

Table 3 – Flow depth [1], y (m) and mean rock size, d_{50} (m) for SF = 1.2

Safety factor, SF = 1.2			Specific gravity, s_r = 2.4		Size distribution, d_{50}/d_{90} = 0.5			
Unit flow rate (m^3/s/m)	Bed slope = 1:2		Bed slope = 1:3		Bed slope = 1:4		Bed slope = 1:6	
	y (m)	d_{50}	y (m)	d_{50}	y (m)	d_{50}	y (m)	d_{50}
0.1	0.09	**0.20**	0.09	**0.20**	0.09	**0.10**	0.09	**0.10**
0.2	0.14	**0.30**	0.14	**0.20**	0.14	**0.20**	0.15	**0.20**
0.3	0.18	**0.30**	0.19	**0.30**	0.19	**0.20**	0.20	**0.20**
0.4	0.22	**0.40**	0.23	**0.30**	0.23	**0.30**	0.24	**0.20**
0.5	0.26	**0.40**	0.26	**0.40**	0.27	**0.30**	0.27	**0.30**
0.6	0.29	**0.50**	0.30	**0.40**	0.30	**0.40**	0.31	**0.30**
0.8	0.35	**0.60**	0.36	**0.50**	0.37	**0.40**	0.37	**0.40**
1.0	0.41	**0.70**	0.42	**0.60**	0.42	**0.50**	0.44	**0.40**
1.2	0.46	**0.70**	0.47	**0.60**	0.48	**0.50**	0.49	**0.50**
1.4	0.51	**0.80**	0.52	**0.70**	0.53	**0.60**	0.54	**0.50**
1.6	0.56	**0.90**	0.57	**0.70**	0.58	**0.70**	0.60	**0.50**
1.8	0.60	**1.00**	0.62	**0.80**	0.63	**0.70**	0.64	**0.60**
2.0	0.65	**1.00**	0.66	**0.90**	0.67	**0.70**	0.69	**0.60**
3.0	0.85	**1.30**	0.87	**1.10**	0.88	**1.00**	0.90	**0.80**
4.0	1.02	**1.60**	1.05	**1.30**	1.07	**1.20**	1.10	**1.00**
5.0	1.19	**1.80**	1.22	**1.50**	1.24	**1.30**	1.27	**1.10**

[1] Flow depth is expected to be highly variable due to whitewater (turbulent) flow conditions.

Table 1 – Recommended rock sizing equations for small dam spillways [1]

Bed slope (%)	Design equations
Preferred equation: $S_o < 50\%$	Uniform flow conditions only, $S_e = S_o$ $$d_{50} = \frac{1.27.SF.K_1.K_2.S_o^{0.5}.q^{0.5}.y^{0.25}}{(s_r - 1)} \quad (1)$$
A simplified equation independent of flow depth: $S_o < 50\%$	Uniform flow conditions only, $S_e = S_o$ $$d_{50} = \frac{SF.K_1.K_2.S_o^{0.47}.q^{0.64}}{(s_r - 1)} \quad (2)$$
A simplified, velocity-based equation: $S_o < 33\%$	Uniform flow conditions only, $S_e = S_o$ $$d_{50} = \frac{SF.K_1.K_2.V^2}{(A - B.\ln(S_o)).(s_r - 1)} \quad (3)$$ For SF = 1.2: A = 3.95, B = 4.97 For SF = 1.5: A = 2.44, B = 4.60
Partially drowned spillway chutes: $S_o < 50\%$	Steep gradient, non-uniform flow conditions, $S_e \neq S_o$ $$d_{50} = \frac{1.27.SF.K_1.K_2.S_o^{0.5}.V^{2.5}.y^{0.75}}{V_o^{2.0}(s_r - 1)} \quad (4)$$

[1] The above equations, with the exception of Equation 2, are based on the Manning's 'n' roughness for rock-lined surfaced determined from Equation 5.

The Manning's roughness of rock-lined surfaces used in the development of Equations 1, 3 & 4 was based on Equation 5, which was specifically developed for application in both shallow-water and deep-water flow conditions. Rock roughness values are also presented in Table 7.

$$n = \frac{d_{90}^{1/6}}{26(1 - 0.3593^{(X)^{0.7}})} \quad (5)$$

ARS Rock Chutes - Climate Change

Limitations:
Applies to bed slopes of 40 percent and less, ours is 40 percent - upper limit

0.1< S <0.4

Slope	S	0.26 ft/ft
Unit Discharge	q	42.8 ft^3/s/ft
Median Rock Size (inches)	**D50**	26.8 in
		2.2 ft
		0.7 m

developed as a function of median stone size, unit discharge, and embankment slope. The equation is:

$$D_{50} = \left(q_{design}\right)^{0.56} \times S^{0.43} \times 5.23 \qquad \text{(eq. TS14C–14)}$$

where:
D_{50} = stone size in inches; m percent finer by weight
q_{design} = unit discharge ($ft^3/s/ft$)
S = channel slope (ft/ft) and S between 0.02 and 0.20 ft/ft

$$\left(q_{design}\right) = \frac{\left(q_{failure}\right)}{0.74} = 1.35 q_{failure} \qquad \text{(eq. TS14C–15)}$$

Stone movement occurred at approximately 74 percent of the flow, causing layer failure. It was determined from testing that rounded stone should be oversized by approximately 40 percent to provide the same protection as angular stone.

ARS rock chutes

This design technique (Robinson, Rice, and Kadavy 1998) is primarily targeted at high-energy applications. Loose riprap with a 2 D_{50} blanket thickness composed of relatively uniform, angular riprap was tested to overtopping failure in models and field scale structures. This method applies to bed slopes of 40 percent and less. This technique can be used for low slope, and thus, low-energy applications, but it is particularly useful for slopes greater than 2 percent. A factor of safety appropriate for the project should be applied to the predicted rock size. The equations are:

for S <0.1

$$D_{50} = 12\left(1.923 q S^{1.5}\right)^{0.529} \qquad \text{(eq. TS14C–16)}$$

0.10<S<0.40

$$D_{50} = 12\left(0.233 q S^{0.58}\right)^{0.529} \qquad \text{(eq. TS14C–17)}$$

where:
D_{50} = median stone size (in)
q = highest stable unit discharge ($ft^3/s/ft$)
S = channel slope (ft/ft)

A spreadsheet program (Lorenz, Lobrecht, and Robinson 2000) is available to assist in sizing riprap on steep slopes. A screen capture of this spreadsheet program is shown in figure TS14C–7.

This method is best used in steep slopes for grade control, embankment overtopping, or on side inlets from fields to a major drainage outlet. The spreadsheet provides much additional information related to rock chutes such as guidance on inlet and outlet conditions, quantity estimates, and hydrology.

California Department of Transportation RSP

This technique was developed by the California Department of Transportation (CALTRANS) for designing rock slope protection (RSP) for streams and riverbanks. Unlike most of the other available techniques, it results in a recommended minimum weight of the stone. The equation is:

$$W = \frac{0.00002}{\left(G_s - 1\right)^3} \times \frac{VM \times V^6 \times G_s}{\sin^3\left(r - a\right)} \qquad \text{(eq. TS14C–18)}$$

where:
W = minimum rock weight (lb)
V = velocity (ft/s)
VM = 0.67 if parallel flow
VM = 1.33 if impinging flow
G_s = specific gravity of rock (typically 2.65)
r = angle of repose (70° for randomly placed rock)
a = outside slope face angle to the horizontal (typically a maximum of 33°)

The weight indicated by this method should be used in conjunction with standard CALTRANS specifications and gradations.

Far West states (FWS)—Lane's Method

Vito A. Vanoni worked with the Northwest E&WP Unit to develop the procedure from the ASCE paper entitled "Design of Stable Alluvial Channels" (Lane 1955a). The equation is:

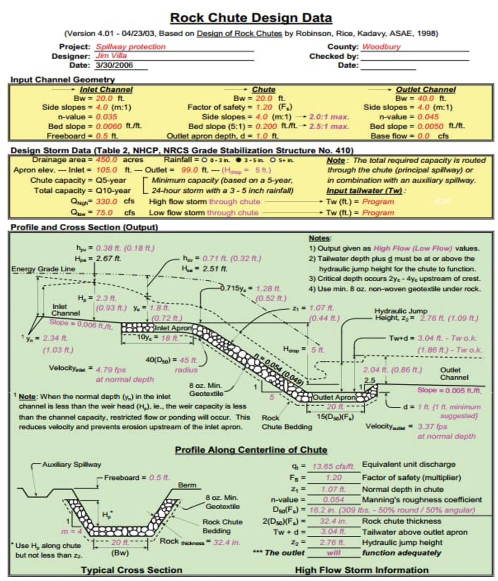
$$D_{75} = \frac{3.5}{C \times K} \times \gamma_w \times D \times S_f \qquad \text{(eq. TS14C–19)}$$

where:
D_{75} = stone size, (in)
C = correction for channel curvature
K = correction for side slope
S_f = channel friction slope (ft/ft)
d = depth of flow (ft)
γ_w = density of water

This is generally considered to be a conservative technique. It assumed that the stress on the sides of the channel were 1.4 times that of the bottom. This

TS14C–8 (210–VI–NEH, August 2007)

Figure TS14C–7 Rock chute spreadsheet



HEC-23 - Climate Change

Only valid for steep slopes greater than 1:4 if flow is contained within thickness of rip rap layer (intertitila flow)

Ku	0.55		
q	4.00	m^3/s/m	
Cu	1.55		not sensitive parameter
S	0.26		
Sg	2.5		
Slope	0.3	RAD	
Angle of Repose	0.73	RAD	
D50	0.69	m	

Table 5.1. Riprap Failure Characteristics.

Year	d_{50} ft (mm)	Coefficient of Uniformity, C_u (d_{60}/d_{10})	Failure Discharge $ft^3/s/ft$ ($m^3/s/m$)
1994	1.27 (386)	1.90	2.4 (0.223)
1995	2.15 (655)	1.55	10 (0.929)
1997	0.89 (271)	1.81	2.2 (0.204)

When flow overtops an embankment, spur, or guide bank, locally high velocities occur at the downstream shoulder of the structure. When tailwater is low relative to the crest of the structure, the flow will continue to accelerate along the downstream slope. Guidance for riprap stability under these conditions was developed from the laboratory testing described in Section 5.3 (Mishra 1998). For slopes steeper than 1V:4H, the method requires that all the flow is contained within the thickness of the riprap layer (interstitial flow). For milder slopes, a portion of the total discharge can be carried over the top of the riprap layer. The three equations necessary to assess the stability of rock riprap in overtopping flow are given below. The design procedure is illustrated by examples in Sections 5.5.2 and 5.5.3.

$$V_i = 2.48\sqrt{gd_{50}}\left(\frac{S^{0.58}}{C_u^{2.22}}\right) \tag{5.1}$$

where:
- V_i = Interstitial velocity, ft/s (m/s)
- g = Acceleration due to gravity, 32.2 ft/s^2 (9.81 m/s^2)
- d_{50} = Particle size for which 50% is finer by weight, ft (m)
- C_u = Coefficient of uniformity of the riprap, d_{60}/d_{10}
- S = Slope of the embankment, ft/ft (m/m)

$$d_{50} = \frac{K_u q_f^{0.52}}{C_u^{0.25} S^{0.75}}\left(\frac{\sin\alpha}{(S_g\cos\alpha - 1)(\cos\alpha\tan\phi - \sin\alpha)}\right)^{1.11} \tag{5.2}$$

where:
- d_{50} = Particle size for which 50% is finer by weight, ft (m)
- K_u = 0.525 for English units
  0.55 for SI units
- q_f = Unit discharge at failure, ft^3/s/ft (m^3/s/m)
- C_u = Coefficient of uniformity of the riprap, d_{60}/d_{10}
- S = Slope of the embankment, ft/ft (m/m)
- S_g = Specific gravity of the riprap
- α = Slope of the embankment, degrees
- φ = Angle of repose of the riprap, degrees

When the embankment slope is less than 1V:4H (25%), the allowable depth of flow (h) over the riprap is given by:

$$h = \frac{0.06(S_g - 1)d_{50}\tan\phi}{0.97(S)} \tag{5.3}$$

Project Name: Cooper's Corner Detailed Design
Subject: RIP-RAP calculations - pullout culvert
Project Number: 2022-2604
Prepared: NF
Checked: ACM
Date: 20224-06-04
Summary: The purpose of this spreadsheet is to size riprap class for the sediment basin at cooper's corner crossing.

Riprap Revetment Design Tool per USACE 1991

Parameter	Description	Unit	Value	Assumption	Value	Assumption	Value	Assumption		
		Scenario:		1 - Upstream (US) Channel from Sediment Basin CS 104 in 100% Design HECRAS Model		2 - Sediment Basin CS 114 in 100% Des HECRAS Model		3 - Sediment Basin CS 124 in 100% Des HECRAS Model		
		Scenario Description:		Q200 w/ CC		Q200 w/ CC		Q200 w/ CC		
y	Local Depth of Flow	m	2.58	From 100% Design HECRAS Model	2.49	From 100% Design HECRAS Model	2.4	From 100% Design HECRAS Model		
S_f	Safety Factor	-	1.10		1.10		1.10			
C_s	Stability Coefficient	-	0.30		0.30		0.30			
C_v	Velocity Distribution Coefficient	-	1.00		1.00		1.00			
C_T	Blanket Thickness Coefficient	-	1.00		1.00		1.00			
V_{avg}	Channel Cross-Section Average Velocity	m/s	0.68	From 100% Design HECRAS Model	0.99	From 100% Design HECRAS Model	0.87	From 100% Design HECRAS Model		
V_{des}	Characteristic Velocity for Design	m/s	0.68		0.99		0.87			
K_1	Side Slope Correction Factor	-	0.718		0.718		0.871			
SS	Side Slope (H:V)	H:1V	1.5	Design Slope	1.5	Design Slope	2	Design Slope		
θ	Side Slope (Degrees)	°	33.7		33.7		26.6			
R_c	Centerline Radius of Curvature of Channel Bend	m	500	Assume straight	500	Assume straight	500	Assume straight		
W	Width of Water Surface at Upstream End of Bend	m	14.6	From 100% Design HECRAS Model	11.04	From 100% Design HECRAS Model	13.32	From 100% Design HECRAS Model		
R_c/W	Ratio of Curvature to Width	-	34.2		45.3		37.5			
S_g	Specific Gravity of Riprap	-	2.5		2.5		2.5			
g	Gravitational Acceleration	m/s^2	9.81		9.81		9.81			
D_{30}	30% Finer by Weight	m	0.005		0.013		0.008			
D_{50}/D_{30}			1.45		1.45		1.45			
D_{50}	50% Finer by Weight	m	0.008		0.020		0.011			
Results:	**Minimum Acceptable Riprap Class**	**kg**	**10**		**10**		**10**			
	MoTI Riprap D_{50}	**m**	**0.2**		**0.2**		**0.2**			
	MoTI Nominal Thickness	**mm**	**350**		**350**		**350**			

References:
Primary: based on guidance in HEC-23 Volume 2 (2009) Design Guideline 4 - Riprap Revetment.
Secondary: supplemental information can be found in TAC Guide to Bridge Hydraulics
Basis of the above references: USACE EM-1601

$$D_{30} = y(S_f C_S C_V C_T)\left[\frac{(V_{des})}{\sqrt{K_1(S_g-1)gy}}\right]^{2.5}$$

APPENDIX B - DESIGN CALCULATIONS FOR BAFFLED APRON

Appendix B - Coopers Corner Culvert - Design Calculations for Baffled Apron

Reference: HEC-14 Ch 7.3 - USBR Type IX Baffled Apron

Purpose: Development of a USBR Type IX Baffled Apron to Reduce Velocities and Flow Concentration.

Step 1 - Compute Normal Flow Conditions Upstream of Baffles on Baffled Apron

Step 1A - Calculation of Normal Flow Conditions at Culvert Outlet (Normal Velocity in Culvert)

Design Flow	17.8 **m^3/s**	
Manning's Roughness	0.012	
Width of Culvert	3.02 **m**	
Slope	0.01 **m/m**	
Calculated Normal Depth	1.000 **m**	**<< Calculated depth using Eqtn. 1 and adjusted until the Normal Flow Calculation matched the Design Flow value.**
Area (Width x Depth)	3.02 **m^2**	
Wetted Perimeter (Width+2*Depth)	5.02 **m**	**Eqtn. 1**
Hydraulic Radius (Area / Wetted Perimeter)	0.60 **m**	$Q = VA = \left(\frac{1.00}{n}\right) A R^{\frac{2}{3}} \sqrt{S}$ [SI]
Normal Flow Calc (see Eqtn 1)	17.93 **m^3/s**	
Normal Velocity Vn (Flow / Area)	5.89 **m/s**	**<< Confirmed the Calculated Normal Flow within the culvert.**

Step 1B - Calculation of Normal Flow Conditions at Top of Apron (Normal Velocity In Apron Entrance)

Design Flow	17.8 **m^3/s**	
Manning's Roughness	0.012	
Width of Top of Apron	5 **m**	
Slope	0.0001 **m/m**	
Calculated Normal Depth	3.300 **m**	**<< Calculated depth using Eqtn. 1 and adjusted until the Normal Flow Calculation matched the Design Flow value.**
Area (Width x Depth)	16.50 **m^2**	
Wetted Perimeter (Width+2*Depth)	11.60 **m**	
Hydraulic Radius (Area / Wetted Perimeter)	1.42 **m**	
Normal Flow Calc (as per Eqtn 1)	17.39 **m^3/s**	
Normal Velocity Vn (Flow / Area)	1.08 **m/s**	**<< Confirmed the Calculated Normal Flow at the Apron Inlet.**

Step 2 - Verify Approach Flow Conditions are Acceptable

Use design flow and calculate the Critical Velocity (Vc) at the top of the apron.

Apron Width - B	5.00 **m**	**Eqtn. 2**
Discharge per Unit Width (Flow/Width), i.e. "q"	3.56 **m^3/s/m**	
Critical Velocity Vc (as per Eqtn 2)	3.27 **m/s**	

$$V_c = (qg)^{1/3}$$

Checks from this Step: Vn at the apron inlet is less than Vc at the apron inlet. This is appropriate for baffled apron design.
Disharge per unit length is less than 5 m^3/s/m. This is appropriate for baffled aprong design.
However, Vn at the culvert exit is much higher than Vc at the apron. There is therefore some risk of flow overshooting at the first row of baffles.

Engineering Adjustment and Further Checks: Check that the apron is long enough to compensate for any risk of overshooting. (See "overshooting" arc calculation, use unlikely but worst case scenario of 5.89
Ensure that there are a sufficient number of baffle rows (i.e. 4 rows) downstream of the maximum overshooting risk.

Step 3 - Baffled Apron Discharge Velocity Calculation and Criteria Check

Calculate the Discharge Velocity from the Baffled Apron. Confirm that it is low enough for the USBR Type IX baffled aprong design to be used.

Baffled Apron Discharge Velocity (Vc/3)	1.089561495 **m/s**	**<<Defined as 1/3 of Vc within the HEC-14 document.**

Checks from this Step Baffled apron discharge velocity is less than 3 m/s; this meetings the USBR Type IX criteria.

Step 4 - Baffled Apron and Baffle Design

Calculate critical depthfor the baffled apron. Set baffle dimensions and baffled apron dimensions based on guidance from document and guidance figure.

Critical Depth Yc (q / Vc) as per Eqtn. 3	**1.09 m**	**Eqtn. 3**

$$y_c = q/V_c$$

Step 4B - Calculated Baffle and Apron Dimensions (First Round Via Equations)

		Calculated Dimension (from HEC-14)>> See figure below for illustration.
Baffle Height (H)	0.87 m	H = 0.8*Yc
Baffle Width	1.31 m	W = 1.5*H
Baffle Spacing - Horizontal	1.31 m	1.5*H
Baffle Thickness	0.61 m	H/2+0.2H
Baffled Spacing (Along Apron)	1.74 m	2*H
Minimum Apron Wall Height	3.27 m	Wall Height = 3*Yc
Minimum Number of Baffle Rows	8 rows	*Design Note: Minimum of 4 rows required by HEC-14. Jet arc worst scenario calculation suggests addition of 4 rows*
Minimum Length (Baffle Spacing x Number of Rows)	13.94 m	*after 5.5 m horizontal distance along the apron.*

Step 4C - Final Design Baffle and Apron Dimensions (Final Values Adjusted for Constructability and Overshooting Jet Arc)

Baffle Height	0.90 m	
Baffle Width	1.80 m	
Baffle Spacing - Horizontal	1.80 m	
Baffle Thickness	0.70 m	
Baffled Spacing (Along Apron)	1.80 m	
Apron Wall Height (Min)	4.20 m	
Number of Baffle Rows	9 rows	*Design Note: Minimum of 4 rows required by HEC-14. Jet arc worst scenario calculation suggests addition of 4 rows*
Length	16.00 m	*after 5.5 m horizontal distance along the apron.*

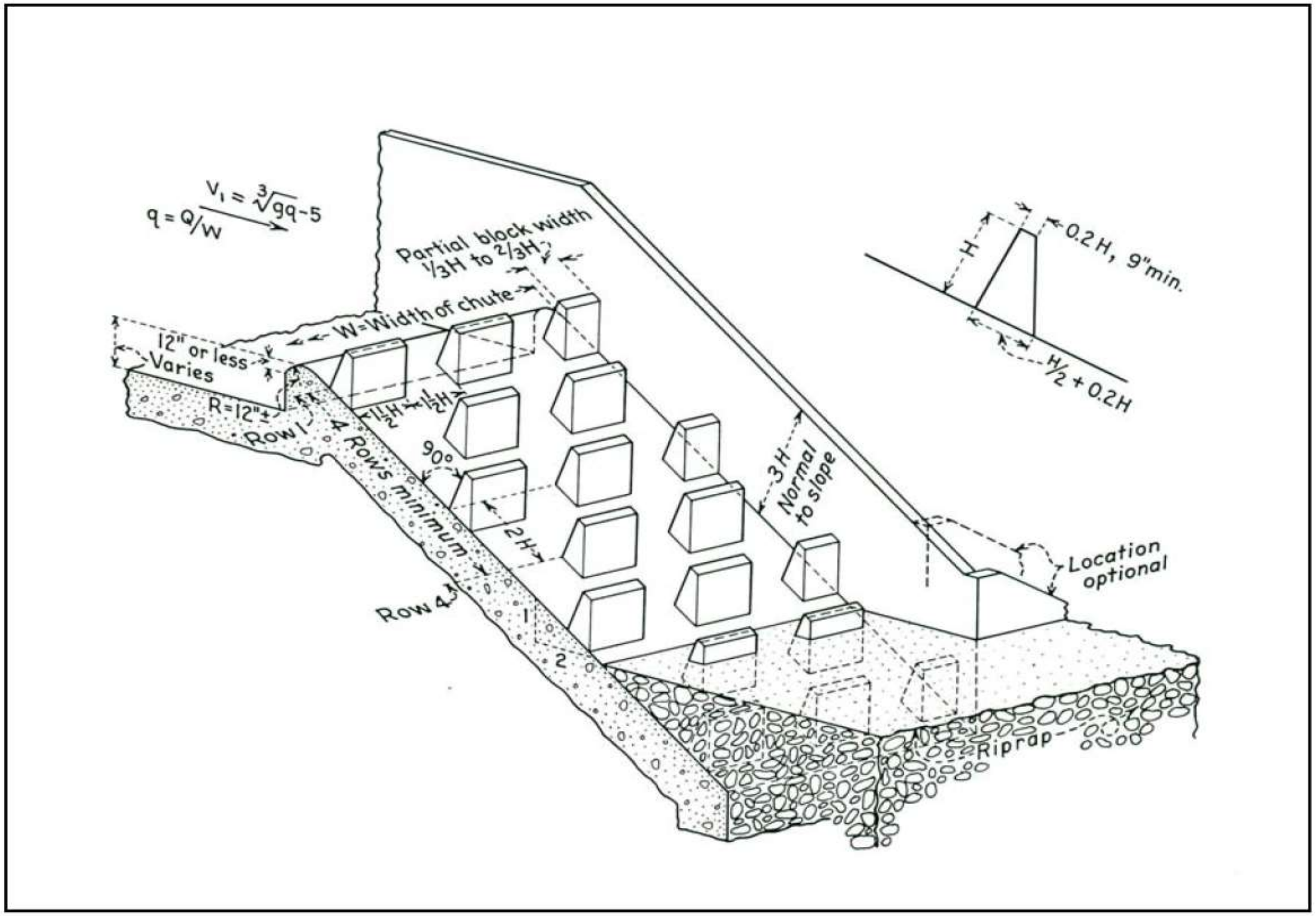


Figure 7.9. USBR Type IX Baffled Apron (Peterka, 1978)

Appendix B - Coopers Corner Culvert

Overshooting jet of water arc check.

Purpose:

Check that the apron is long enough to compensate for any risk of overshooting. (Use unlikely but worst case scenar

Ensure that there are a sufficient number of baffle rows (i.e. 4 rows) downstream of the maximum overshooting risk.

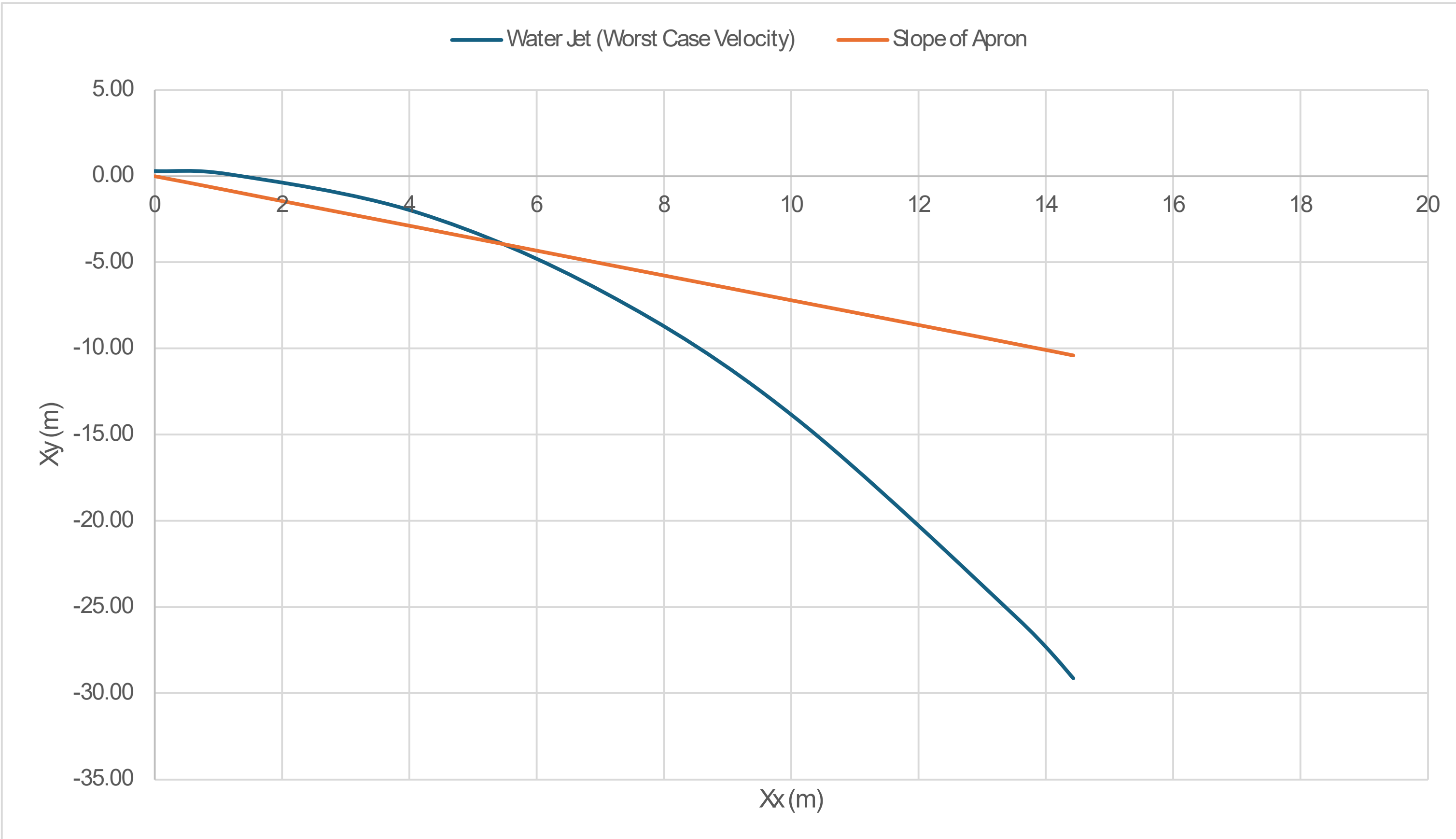
Arc from Top of Apron: Worst Case Scenario

Plot distance travelled bywater jet vs. time against the length of the apron slope. Determine point of intersection.

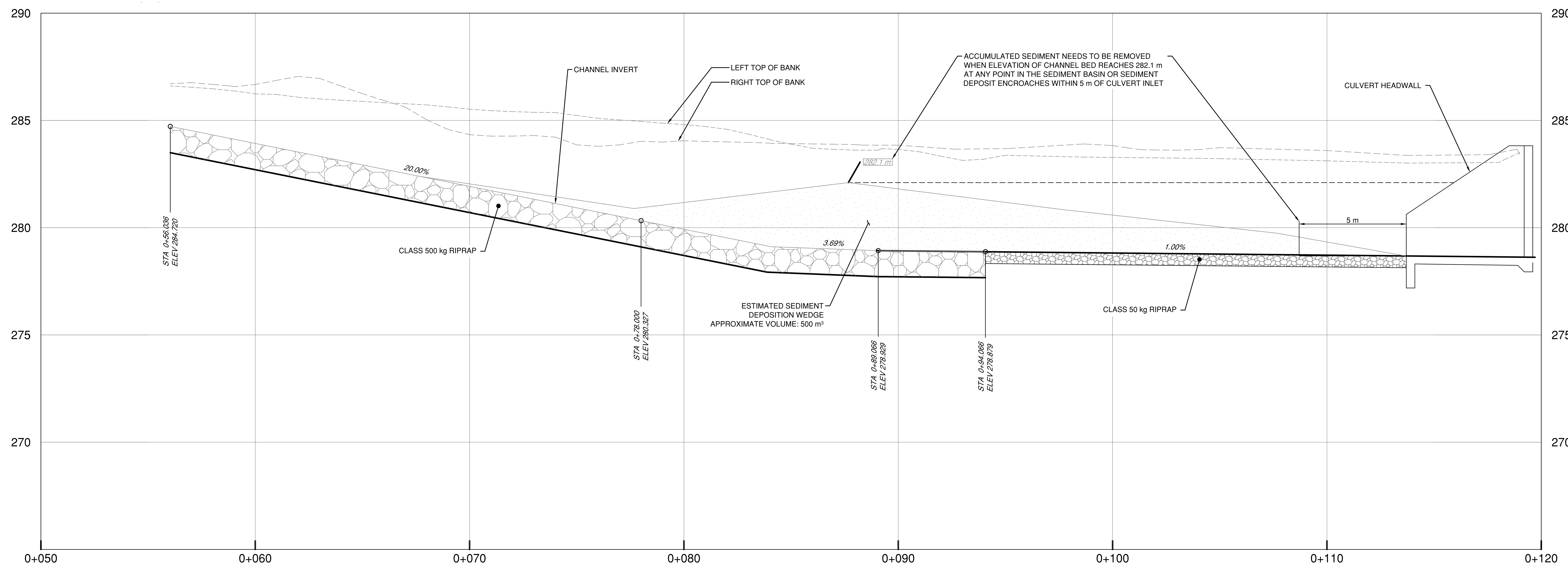
Max. Horizontal Velocity (Vx max)	5.89	**m/s**	
Slope of Apron	0.72	**m/m**	
First Baffle Height (H) Above Apron	0.3	**m**	
Time	0.58	**s**	Adjust by hand (incremental).
Vertical Distance of Jet (Xy (t))	1.64	**m**	= 0.5* g*t^2
Horizontal Distance of Jet (Xx (t))	3.40	**m**	= Vx max*t
Slope Intersect with Apron	2.90	**m**	= Xx(t)*Slope

Time	**Arc**		**Slope Intersection on Apron**	
T (s)	**Xx (t)**	**Xy (t)**	**Xx**	**Xy**
0	0	0.30	0	0
0.2	1.178	0.10	1.178	-0.85
0.7	4.123	-2.10	4.123	-2.97
1.2	7.068	-6.76	7.068	-5.09
1.7	10.013	-13.87	10.013	-7.21
2.3	13.547	-25.64	13.547	-9.75
2.45	14.4305	-29.13	14.4305	-10.39

Results: Intersection at approximately 5.5 m along apron slope (measued horizontally).
Recommend an additional 4 rows after intersection point.


Water Jet (Worst Case Velocity)
Slope of Apron
5.00
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
0
2
4
6
8
10
12
14
16
18
20
Xy (m)
Xx (m)

APPENDIX C - CHANNEL AND SEDIMENT BASIN MAINTENANCE



PROFILE 1:100

SEDIMENT BASIN

PLOT DATE: 2025/01/30 Q:\2022-2604-00\civ\model\MoTI_Working_Drawings\DrawingProduction\700_DrainageUtilities\R1-10567-C-1.dwg

Associated Engineering

SCALE AS SHOWN	CAD FILENAME R1-10567-C-1 FILE NUMBER PLOT DATE 2025-01-31

REV	DATE	REVISIONS	NAME
A	2025-01-31	ISSUED FOR DETAILED DESIGN REPORT	ACM

BRITISH COLUMBIA

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

COOPER'S CORNER CULVERT - CHANNEL AND SEDIMENT BASIN MAINTENANCE

COOPER'S CORNER CULVERT No. 10567
HYDROTECHNICAL DETAILED DESIGN SUMMARY REPORT FOR CULVERT REPLACEMENT

ASSOCIATED ENGINEERING (B.C.) LTD.
PERMIT TO PRACTICE 1000163

DESIGNED	N. FANOS	DATE 2025-01-31
QUALITY CONTROL	A. MACISAAC	DATE 2025-01-31
QUALITY ASSURANCE	M. MACLATCHY	DATE 2025-01-31
DRAWN	B. SYKES	DATE 2025-01-31

PROJECT NUMBER	REG	DRAWING NUMBER	REV
14054-0000	1	C-1	