MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

CRRP - HWY 97 CACHE CREEK REPLACEMENT BRIDGE

HYDROTECHNICAL DESIGN REPORT

SEPTEMBER 20, 2023 FINAL

CRRP - HWY 97 CACHE CREEK REPLACEMENT BRIDGE

HYDROTECHNICAL DESIGN REPORT

MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

HYDROTECHNICAL DESIGN REPORT (REVISION 0)
FINAL

PROJECT NO.: 221-11730-00.3680
CLIENT REF:3680
DATE: SEPTEMBER 20, 2023

WSP
SUITE 1000
840 HOWE STREET
VANCOUVER, BC, CANADA V6Z 2M1

T: +1 604 685-9381
F: +1 604 683-8655
WSP.COM

REVISION HISTORY

FIRST ISSUE

4 August 2023	Draft	
Prepared by	Reviewed by	Approved by
Adam Vaughan, BASc, EIT	Chris Coles, MASc, PEng	Chris Coles, MASc, PEng

SECOND ISSUE

20 September 2023	Final	
Prepared by	Reviewed by	Approved by
Adam Vaughan, BASc, EIT	Chris Coles, MASc, PEng	Chris Coles, MASc, PEng

SIGNATURES

PREPARED BY

September 20, 2023

Adam Vaughan, BASc, EIT
Water Resources Engineer

Date

September 20, 2023

Chris Coles, MASc, PEng
Senior Principal Hydrotechnical Engineer
Engineers & Geoscientists BC Permit #1000200

Date

APPROVED[1] BY

September 20, 2023

Chris Coles, MASc, PEng
Senior Principal Hydrotechnical Engineer

Date

WSP Canada Inc. prepared this report solely for the use of the intended recipient, MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE, in accordance with the professional services agreement. The intended recipient is solely responsible for the disclosure of any information contained in this report. The content and opinions contained in the present report are based on the observations and/or information available to WSP Canada Inc. at the time of preparation. If a third party makes use of, relies on, or makes decisions in accordance with this report, said third party is solely responsible for such use, reliance or decisions. WSP Canada Inc. does not accept responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken by said third party based on this report. This limitations statement is considered an integral part of this report.

The original of this digital file will be conserved by WSP Canada Inc. for a period of not less than 10 years. As the digital file transmitted to the intended recipient is no longer under the control of WSP Canada Inc., its integrity cannot be assured. As such, WSP Canada Inc. does not guarantee any modifications made to this digital file subsequent to its transmission to the intended recipient.

[1] Approval of this document is an administrative function indicating readiness for release and does not impart legal liability on to the Approver for any technical content contained herein. Technical accuracy and fit-for-purpose of this content is obtained through the review process. The Approver shall ensure the applicable review process has occurred prior to signing the document.

CONTRIBUTORS

WSP

Senior Principal Water Resources Engineer	Chris Coles, MASc, PEng
Water Resources Engineer	Adam Vaughan, BASc, EIT
Civil Consultant	Reza Alvankar

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

1 INTRODUCTION

WSP Canada Inc. (WSP) was retained by Urban Systems to provide hydrotechnical design services for the proposed replacement of the Highway 97 culvert crossing located along Cache Creek in the Village of Cache Creek, BC (the Site). The existing culvert is to be replaced with a clear span bridge. This report presents the hydrotechnical design parameters describing the opening geometry and erosion protection through the proposed replacement bridge.

The scope of work embodied in this report is limited to hydrotechnical aspects only and does not include any specific provisions for the investigation, testing, or assessment of the potential presence or impact of soil or groundwater contamination at the site, geotechnical analysis or investigations, First Nations consultation, archaeology, or bioscience services.

This report shall be read in conjunction with the Study Limitations which precede the text of this document. The reader's attention is specifically drawn to this information as it is essential that it is followed for the proper use and interpretation of this document.

2 BACKGROUND

The Highway 97 culvert crossing is located within the Village of Cache Creek, transporting runoff from the Cache Creek catchment area towards the Bonaparte River. The village has been subjected to several major flood events in recent years, including 2015, 2017, 2018, and now 2023. The 2017, 2018, and 2023 flood events overwhelmed the Quartz Road Culvert, which caused downstream flooding and property damage. Flooding in 2018 was exacerbated by the summer 2017 Elephant Hill Wildfire (True Consulting 2019).

Prior work on this project was previously completed as Golder Associates Ltd. (Golder, now a part of WSP) servicing a request from the Ministry of Transportation and Infrastructure (MOTI), considering a replacement culvert option. Based on the extensive damage caused by the 2023 flooding, the project was moved under the umbrella of the Cariboo Roads Recovery Project (CRRP) with Urban Systems as WSP's direct client. The decision was made to pursue a clear span bridge as the preferred replacement option.

3 SITE SETTING

Cache Creek is located within the Northern Thompson Plateau and Fraser Plateau hydrologic zones in an area which receives 360-390 mm of mean annual precipitation with about 95 mm falling as snow (UBC 2022), producing an estimated average annual runoff depth of about 50 mm to 100 mm (Province of British Columbia 2022). Based on regional data available, peak flows occur largely in May.

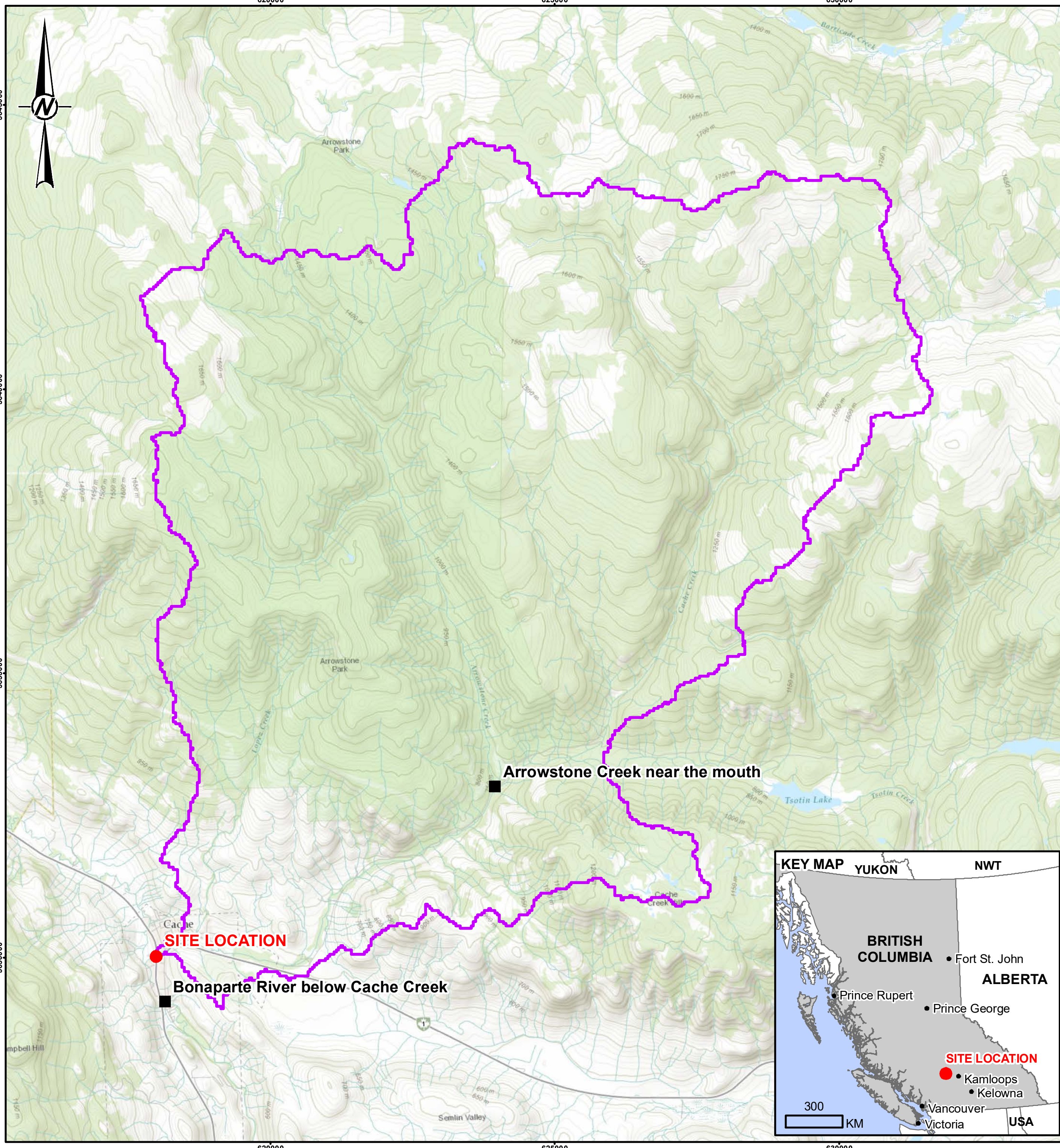
Based on terrain data from the Shuttle Radar Topography Mission (NASA 2013), the Site catchment area is approximately 136 km^2 (Figure 1), and ranges in elevation from about 460 m to 1,780 m. According to the provincial peak flow isolines provided in iMapBC (Province of British Columbia 2022), watersheds in this area yield a peak flow of about 5 m^3/s per 100 km^2 of catchment area during the 10-year peak flow event and about 10 m^3/s per 100 km^2 during the 100-year peak flow event.

The Highway 97 culvert is located downstream of two culverts owned by the Village of Cache Creek (Identified as Quartz Road Culvert and Motel Parking Lot Culvert on Figure 2). It is understood that these culverts are to be replaced in the near future.

The existing culvert on site is an approximately 35 m-long Corrugated Steel Pipe (CSP) pipe-arch culvert with a span of 2600 mm and rise of 1800 mm (KWL 2017). There is evidence of damage to the inlet of the culvert, an approximately 25-degree horizontal bend midway along the culvert, and visible deformation throughout its length. Culvert sections appear to have separated at the bend in the culvert.

The right bank of the upstream channel is characterized by a compound slope with two segments: a shallow-sloped area directly adjacent to the channel with a steeper-sloped section leading up to the neighbouring property. The combined width of the channel and shallow section is approximately 7.5 m; the top width of the channel and bank area is approximately 11 m. The area sees active use by the public. The left bank of the upstream channel consists of a vertical gabion wall.

At the time the culvert replacement project was initiated by MOTI in 2021, the outlet of the culvert was perched above the stream bed. Repair activities following the 2023 flood event included the installation of an extension of the existing culvert with an oversized sleeve which is at grade with the downstream creek bed. Downstream of the outlet, Cache Creek travels through a treed area towards Bonaparte River.



LEGEND

- SITE LOCATION
- WSC HYDROMETRIC STATION
- SITE CATCHMENT

0 2 4

1:100,000 KILOMETRES

REFERENCE(S)

1. TOPOGRAPHIC MAP © ESRI AND ITS LICENSORS. USED UNDER LICENSE, ALL RIGHTS RESERVED.
2. COORDINATE SYSTEM: NAD 1983 UTM ZONE 10N

CLIENT
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

PROJECT
HIGHWAY 97
CACHE CREEK, BC

TITLE
SITE LOCATION

CONSULTANT

wsp

YYYY-MM-DD	2023-08-03
DESIGNED	RC
PREPARED	CDB
REVIEWED	AV
APPROVED	CC

PROJECT NO.	PHASE	REV.	FIGURE
221-11730-00	3680	0	1

Figure 2: Site Setting

4 DESIGN BASIS

4.1 DESIGN CODES AND STANDARDS

The relevant hydrotechnical design codes and standards for the Hwy 97 Cache Creek replacement bridge are as follows:

— CHBDC S6:19 (CSA 2021)
— MOTI Supplement to the CHBDC S6:19 – Bridge Standards and Procedures Manual (MOTI 2022)
— Transportation Association of Canada (TAC) Guide to Bridge Hydraulics (TAC 2001)
— BC Supplement to TAC Geometry Design Guide (MOTI 2019a)
— MOTI Technical Circular T-04/19, Resilient Infrastructure Engineering Design - Adaptation to the Impacts of Climate Change and Weather Extremes (MOTI 2019b)

4.2 DESIGN CRITERIA

The following design criteria have been adopted to form the basis of the hydrotechnical components of this project, outlined in Table 1.

Table 1: Hydrotechnical Design Criteria

Parameter	Value
Design Flow	1:200-year climate change adjusted peak flow. (MOTI 2022)
Minimum Freeboard	Minimum 1.5 m freeboard between the peak design water level and the soffit of the bridge. (MOTI 2022)
Maximum Channel Side Slope	A maximum channel side slope of 1.5H:1V is acceptable, although a side slope of 2H:1V or shallower is preferred. (MOTI 2019a)

5 GEOMORPHOLOGICAL ASSESSMENT

Cache Creek flows southwest from upland headwaters, draining forests of Douglas Fir and Ponderosa Pine into a semi-arid bunchgrass ecosystem, flowing over a relic post-glacial alluvial fan. The watershed was harvested extensively between 1984 and the mid-2010s, and 81% of the area was burned in the 2017 Elephant Hill wildfire. Sediment loads higher than the long-term average might therefore occur.

A sediment-yield analysis was conducted using three methods:

- Graphical analysis of regional clastic sediment yield data.
- The empirical BQART sediment yield model.
- A modified Church et al. (1989) method using post-fire hillslope sediment yield rates from Jordan (2012).

Based on these three estimates, the long-term average annual sediment yield at Site is on the order of 2,000-7,000 m^3/yr. Over the next few years, the yield may increase to approximately 30,000 m^3/yr, depending on the effects of the Elephant Hill wildfire on sediment supply.

The existing culvert crossing of Hwy 97 artificially controls the channel gradient. It has raised and flattened the channel upstream from the crossing and the culvert outlet was perched above the downstream channel bed. In addition, two existing culverts immediately upstream from the Site also control the channel grade. With the replacement of the existing culvert with an open bottom structure, the potential for channel degradation was identified as it is anticipated that the channel will trend towards its natural grade. Mitigation for the potential channel degradation is discussed in Section 7.1.

The full geomorphological assessment has been included in Appendix A.

6 HYDROLOGIC ASSESSMENT

6.1 PEAK FLOW ASSESSMENT

Regional Water Survey of Canada (WSC) hydrometric data was acquired for nearby hydrometric stations, including both annual peak instantaneous flow and maximum daily flow datasets.

Where peak instantaneous flow datasets contained fewer years of data than maximum daily flow datasets, average peaking factors (the ratio between the peak flow and the maximum daily flow) were developed at each station for years where both flows were available. These peaking factors were used to estimate peak instantaneous flow values for years where only annual maximum daily flow data was available, thereby extending the peak flow series. An extreme value analysis was conducted on this extended peak flow dataset for each of the stations to establish 1:200-year peak flows.

Peak flows at the Site were estimated using two different methods. The first was a regional analysis using the established 1:200-year peak flows for nearby hydrometric stations. The second used an area-transfer scaling factor of peak flows of a single hydrometric station located within the Cache Creek watershed to the Site. This second approach was considered because it would more closely match the hydrologic response of the Site, which is known to be peaky, whereas other stations may not.

A review of regional WSC hydrometric data found 5 active hydrometric stations within 30 km of Site. These stations are noted in Table 2. The regional analysis compared drainage areas for each of the stations with the respective 1:200-year peak flow estimates. It is noted that there were a limited number of stations with comparable drainage areas (i.e., within one order of magnitude of the Cache Creek drainage area) from the pool of available hydrometric station data.

Table 2: Nearby Hydrometric Stations

Station		Years of Record		Location		Drainage Area
Number	**Name**	**Start**	**End**	**Latitude**	**Longitude**	**(km^2)**
08LF002	Bonaparte River below Cache Creek	1911	2019	50°48'10" N	121°19'24" W	5020
08LF007	Criss Creek near Savona	1912	2019	50°53'02" N	120°57'57" W	479
08LF027	Deadman River above Criss Creek	1913	2018	50°53'53" N	120°58'33" W	878
08LF099	Arrowstone Creek near the mouth	2001	2019	50°50'08" N	121°14'23" W	50.5
08LF100	Dairy Creek above Tsotin Lake	2001	2019	50°50'26" N	121°09'15" W	10.6

The regional analysis results found the relationship between catchment area and peak flow to be weak for the stations of interest (coefficient of determination, $R^2 = 0.64$) and therefore were not considered to be ideal for use in estimating a peak flow value at Cache Creek.

As an alternative approach, a single station area transfer analysis was completed using peak flow estimates for the 08LF099 station (Arrowstone Creek near the mouth) which is located within the watershed of the Site. This method was considered preferable as Arrowstone Creek is a tributary to Cache Creek and would better represent the flood response of the watershed as compared to the regional analysis. Stationarity of the historic peak flow data was performed using the Mann-Kendall test, and no trend was found. The stationarity test is discussed further in Section 6.2.

The area transfer method considered for establishing peak flows at Cache Creek was derived by Coulson (MOELP 1998). This method uses the ratio between the catchment areas of the subject site and a selected hydrometric station to scale flows:

$$Q_{site} = Q_{station}\left(\frac{A_{site}}{A_{station}}\right)^{0.785} \quad \text{(Equation 1) (MOELP 1998)}$$

The watershed area upstream of the Site was estimated to be 136 km^2, while the watershed area upstream of WSC station 08LF099 is 50.5 km^2 (Environment and Climate Change Canada 2022). A frequency analysis was performed on peak flow data from station 08LF099. 3 Parameter Log Normal, Extreme Value, Log Pearson III, and Weibull distributions were checked from the station data. The 3 Parameter Log Normal distribution provided the best statistical fit according to the Anderson-Darling goodness-of-fit test. Results of the frequency analysis of the station data, and estimated flows at the Site using Equation 1 are presented in Table 3.

Table 3: Historical peak flow estimates at the Site

Return Period (Years)	Historical Peak Flows at Station 08FL099 (m^3/s)	Historical Peak Flow at the Site (m^3/s)
2	1.1	2.4
5	2.4	5.3
10	3.7	8.1
20	5.2	11.4
25	5.8	12.6
50	7.7	16.9
100	10.1	21.9
200	12.8	27.8

The resulting 1:200-year peak instantaneous flow at site, not including estimated increases due to climate change, is estimated to be 27.8 m^3/s, based on the available historical data.

6.2 CLIMATE CHANGE ASSESSMENT

According to MOTI's Technical Circular T-04/19 (MOTI 2019a), it is required to consider climate change and extreme weather events for the design of infrastructure. This is a requirement for all new MOTI engineering design assignments and has been incorporated into the Cache Creek design flow analysis.

Stationarity of the historical peak flow data was checked using the Mann-Kendall test in order to assess if there was an observable trend due to the effects of climate change. The results of the Mann-Kendall test returned a p-value of 0.08, supporting the null hypothesis (as 0.08 is greater than the alpha value of 0.05). Therefore, no trend was observed in the historical data.

WSP used the PCIC Climate Explorer Tool (PCIC 2023) in order to estimate a climate change increase factor for extreme stream flows in the vicinity of Cache Creek. WSP adopted the maximum projected 1:200-year streamflow increase factor using the CanESM2 climate model under an RCP 8.5 emissions scenario and the percentile 97.5 rXi1p1 timeseries. The maximum scaling factor from the timeseries was a value of 1.66 and was adopted as the climate change scaling factor considered for the design flow.

6.3 DESIGN FLOW WITH CONSIDERATION OF CLIMATE CHANGE

As a result of the considered tool, a 66% increase to 1:200-year peak flows (estimated from the PCIC Climate Explorer Tool) was adopted as a climate change scaling factor for flows on Cache Creek at the Site. The climate change adjusted peak flows are presented in Table 4.

Table 4: Climate change adjusted peak flows at the Site

Return Period (Years)	Historical Peak Flow at the Site (m^3/s)	Climate Change Adjusted (+66%) Peak Flows at the Site (m^3/s)
2	2.4	4.0
5	5.3	8.8
10	8.1	13.4
20	11.4	18.9
25	12.6	20.9
50	16.9	28.0
100	21.9	36.3
200	27.8	46.2

The 1:200-year peak instantaneous discharge, without climate change considerations, was estimated to be 27.8 m^3/s. The recommended design flow for the Highway 97 Cache Creek culvert, considering potential increases due to climate change, is therefore 27.8 m^3/s + 66% = 46.2 m^3/s.

7 HYDRAULIC ASSESSMENT

The selected design concept for the Highway 97 crossing of Cache Creek was a single span bridge. WSP designed a riprap lined, trapezoidal channel to convey Cache Creek under the proposed bridge. WSP used HEC-RAS River Analysis System version 6.2 (USACE 2022) software to develop a one-dimensional hydraulic model of the channel. The HEC-RAS model was populated using data collected during the ground survey of the site (Binnie 2021). The model was run in steady state to simulate hydraulic conditions during the design event. Details of the HEC-RAS simulation are presented in Appendix C.

Modifications were made to the channel design grade in order to provide a smooth transition between the upstream and downstream reaches of the channel. Historically, the channel grade upstream from the crossing has been artificially controlled by the existing culvert. The channel design was regraded to a slope of 0.037 m/m upstream, through, and immediately downstream of the bridge opening. Further downstream, the slope was lowered to 0.01 m/m in order to tie-in to the existing creek. Additionally, the alignment of the channel was adjusted such that the bridge crossing was shifted to the north of the existing crossing in order to bypass the existing culvert. This was done to allow the existing culvert to maintain flow conveyance during the period of construction.

As a result of this realignment, several bends in the channel were introduced that required different treatment with respect to side slopes and riprap classes (discussed in Section 7.2). These reaches have been numbered as:

1. Reach 1 - The reach extending from the upstream terminus of the works approximately 40 m upstream from the existing culvert, through the bridge crossing to the downstream face of the proposed bridge;
2. Reach 2 - The reach extending downstream 32 m from the downstream face of the proposed bridge;
3. Reach 3 - The terminal reach, matching in with the natural channel.

A Manning's n value 0.035 was adopted for the channel roughness based on theoretical Manning's n values for natural mountain streams with cobbles and large boulders on their beds as well as trees and brush along steep banks (Chow 1959). The model upstream and downstream boundary conditions were set equal to the normal depth at the average channel longitudinal slope.

The proposed channel geometry was constrained by limitations imposed by adjacent property developments and the existing highway grades. The existing highway grades could not be significantly altered without impacting current driveway access on the adjacent properties. There were also limits on the depth to which the channel could be deepened in order to not compromise the foundation conditions of an existing gabion wall on the left bank of the channel in Reach 1. Channel base widths and side slopes were developed iteratively in tandem with bridge structure and riprap design constraints.

In general, channel side slopes of 1.5H:1V were selected in order to minimize the footprint of the channel as well as to reduce the span of the replacement bridge. The existing culvert is proposed to be retained in service during construction to provide conveyance of Cache Creek flows across Highway 97. This resulted in the introduction of several curves in the final channel alignment in order to bypass the existing culvert. At some locations on the outside bank within the curve, the side slope had to be shallowed to 2H:1V in order to achieve a stable design with the locally available riprap size. Channel velocity and flow depth during the design event were evaluated for the selected channel geometry.

Channel hydraulics input values are summarized in Table 5 below.

Table 5: HEC-RAS Model Configuration Parameters

Parameter	Value	Notes
Design Flow Rate	46.2 m^3/s	1:200-year climate change adjusted peak flow.
Channel Slope	0.037 m/m	At the location of the bridge.
Channel Manning's n	0.035	Estimated representative value (Chow 1959)
Channel Base Width	5.0 m	
<u>Reach 1</u> Reach Length Left side slope Right side slope Longitudinal slope Channel bend direction Channel bend radius	 75 m 1.5H:1V 1.5H:1V 0.037 m/m Right 58 m	
<u>Reach 2</u> Reach length Left side slope Right side slope Longitudinal slope Channel bend direction Channel bend radius	 42 m 1.5H:1V 2H:1V 0.037 m/m Left 34 m	Right side slope shallowed to 2H:1V in order to accommodate a feasible stable riprap size.
<u>Reach 3</u> Reach Length Left side slope Right side slope Longitudinal slope Channel bend direction Channel bend radius	 30 m 1.5H:1V 2H:1V 0.01 m/m Right 100 m	Shallowed right side slope carried down the channel from Reach 2. Longitudinal slope decreased to 0.01 m/m to tie-in to natural channel.

Results of the HEC-RAS simulation for the channel configuration at the upstream face of the bridge are provided below in Table 6.

Table 6: HEC-RAS Model Results

Parameter	Value	Results
Channel Bed Elevation	459.54 m	At the upstream face of the bridge, based on the regraded channel.
Maximum Water Depth	1.28 m	Average water depth during the design flood event, based on HEC-RAS model results.
Maximum Water Elevation	460.82 m	At the upstream face of the bridge, based on HEC-RAS model results.
Minimum Low Chord Elevation	462.32 m	At the upstream face of the bridge, based on the maximum water elevation plus 1.5 m minimum freeboard.
Minimum Revetment Height	1.6 m	Maximum water depth during design flood event plus 0.3 m freeboard.
Average Flow Velocity	5.2 m/s	During the design flood.

7.1 SCOUR ASSESSMENT

The effects and potential for scour were assessed at the Site. Natural scour (i.e., the scour that would occur in the channel even in the absence of the structure) was evaluated using the methods from Lacey (Mazumder 2007) and Blench (Lu et al 2012). The scour depth below the channel bed for each component was estimated by averaging the results after eliminating outliers. The calculations considered a D_{50} value of natural bed material of 60 mm, estimated from site visit observations. The scour estimate also took into account the effect of bends in the channel by considering a K factor of 1.5 as recommended in the Guide to Bridge Hydraulics (TAC 2001). The maximum natural scour depth was estimated to be 2.0 m.

Natural scour as estimated by the Lacey equation (Mazumder 2007) is presented below:

$$Y_{max} = KR \quad \text{(Equation 2) (Mazumder 2007)}$$

$$R = 0.473\left(\frac{Q}{f}\right)^{\frac{1}{3}} \quad \text{(Equation 3) (Mazumder 2007)}$$

$$f = 1.76(d_{50})^{1/2} \quad \text{(Equation 4) (Mazumder 2007)}$$

Natural scour as estimated by the modified Blench equation (Lu et al 2012) is presented below.

$$y_{ms} = 1.23\left[\frac{q^{\frac{2}{3}}}{D_{50}^{\frac{1}{12}}}\right] \quad \text{(Equation 5) (Lu et al 2012)}$$

The parameters and input values are presented in Table 7.

Table 7: Input Values Used in the Modified Lacey and Blench Equations (Mazumder 2007, Lu et al 2012)

Parameter	Description	Value
K	Maximum scour depth multiplier	1.5
R	Regime depth	2.3 m
Q	Design discharge	46.2 m^3/s
q	Discharge intensity under the bridge	6.7 m^2/s
f	Lacey's silt factor	0.43
d_{50}	Mean sediment diameter in the creek bed	60 mm

The applicable maximum scour depth multiplier (K) values (TAC 2001) are presented in Table 8.

Table 8: Maximum Scour Depth Multiplier (K) Values (TAC 2001)

Value	Application
1.25	Straight reach
1.5	Moderate bend
1.75	Severe bend
2.0	Abrupt right-angled turn

The results of the scour assessment are summarized in Table 9.

Table 9: Scour Assessment Results Summary

Scour Formula	Value
Natural Scour – modified Lacey (Mazumder 2007)	2.09 m
Natural Scour – modified Blench (Lu et al 2012)	1.82 m
Natural Scour – Average	2.0 m

With the removal of the existing culvert, there is a potential for the channel to headcut through the accumulated fills towards its natural grade. Based on the headcutting potential, estimated scour depth and geometric constraints, the design includes scour protection measures (i.e., riprap) across the entire width of the channel. Installing riprap across the entire channel base will mitigate potential for lowering of the channel bed and undermining of adjacent properties and infrastructure. It is recommended to install this scour protection throughout the entire length of the works, approximately 147 m in total (approximately 50 m upstream and 70 m downstream of the replacement bridge). As per the riprap assessment in Section 7.2, it is recommended to line the channel base with class 250 kg riprap.

7.2 RIPRAP ASSESSMENT

The minimum riprap class required for the channel armouring was assessed using both the Riprap Design Chart provided within the Supplement to TAC Geometric Design Guide (MOTI 2019b) and the HEC-15 method (FHWA 2005). The Riprap Design Chart was used to assess the straight portions of the design channel and the insides of the bends. However, this method does not consider the radius of the curves when evaluating the outsides of the channel bends and this resulted in unreasonably large classes of riprap for scenarios with "impinging flow against curved bank". The HEC-15 method considers the severity of the bend and was used for portions of the channel on the outsides of bends. The HEC-15 method is an iterative set of calculations based on the following formulae:

$$D_{50} \geq K_b \left(\frac{K_1}{K_2}\right) \left(\frac{SF\ d\ S_o}{F_*(SG-1)}\right) \quad \text{(Equation 6)}$$

$$K_1 = 0.066Z + 0.67 \ \ (1.5 < Z < 5) \quad \text{(Equation 7)}$$

$$K_2 = \sqrt{1 - \left(\frac{sin\theta}{sin\phi}\right)^2} \quad \text{(Equation 8)}$$

$$\theta = \tan^{-1}\left(\frac{1}{Z}\right) \quad \text{(Equation 9)}$$

The safety factor, SF, is defined by the following set of formulae and in Table 10:

$$R_e = \frac{V_* D_{50}}{\nu} \quad \text{(Equation 10)}$$

$$V_* = \sqrt{gdS_o} \quad \text{(Equation 11)}$$

Table 10: Selection of Shields' Parameter and Safety Factor based on Reynolds number for HEC-15

Reynolds number	**F_***	**SF**
$\leq 4x10^4$	0.047	1.0
$4x10^4 < R_e < 2x10^5$	Linear interpolation	Linear interpolation
$\geq 2x10^5$	0.15	1.5

K_b, the ratio of channel bend to bottom shear stress, is defined below:

$$K_b = 2.00 \qquad R_c/T \leq 2 \quad \text{(Equation 12)}$$

$$K_b = 2.38 - 0.206\left(\frac{R_c}{T}\right) + 0.0073\left(\frac{R_c}{T}\right)^2 \qquad 2 < R_c/T < 10 \quad \text{(Equation 13)}$$

$$K_b = 1.05 \qquad R_c/T \geq 10 \quad \text{(Equation 14)}$$

The parameters in the above formulae are defined in Table 11.

Table 11: Definition of parameters used in HEC-15

Parameter	Description
D_{50}	Minimum stable median rock size on a side slope (m)
K_1	Ratio of channel side shear stress to bottom shear stress
K_2	Tractive force ratio
SF	Safety factor (dimensionless)
d	Maximum flow depth in the channel (m)
S_o	Channel longitudinal slope (m/m)
F_*	Shields' parameter (dimensionless)
Z	Horizontal component of channel side slope
ϕ	Angle of repose of riprap (radians)
θ	Angle of channel side slope measured from horizontal (radians)
R_e	Reynolds number (dimensionless)
V_*	Shear velocity (m/s)
ν	Kinematic viscosity of water (m^2/s)
K_b	Ratio of channel bend to bottom shear stress
R_c	Radius of curvature of the bend to the channel centreline (m)
T	Channel top water surface width (m)

Based upon the hydraulic assessment results and channel geometry presented in Section 7, results of the erosion protection assessment are presented in Table 12. The HEC-15 calculation sheets have been included in Appendix B.

Table 12: Riprap Assessment Results

Location	Side Slope (h:v)	Riprap Class
Reach 1 Left Bank Right Bank	 1.5:1 1.5:1	 250 kg 100 kg
Reach 2 Left Bank Right Bank	 1.5:1 2:1	 100 kg 250 kg
Reach 3 Left Bank Right Bank	 1.5:1 1.5:1	 100 kg 100 kg

It is estimated that 400 m^3 of class 100 kg riprap and 1600 m^3 of class 250 kg riprap will be required for the design. In consultation with the project environmental team, the basic channel design was amended in order to improve fish habitat through the length of the works. Fish gravel will be washed into the voids of the riprap and several small riffle pools and large woody debris (LWD) have been added to the channel design.

8 CONCLUSIONS

WSP has summarized the hydrotechnical design recommendations for the conceptual bridge designs in Table 13. Hydrotechnical design drawings have been added in Appendix D.

Table 13: Summary of Hydrotechnical Design Recommendations

Parameter	**Value**	**Notes**
Design Flow (m^3/s)	46.2	1:200-year climate change adjusted peak flow.
Channel Bed Elevation	459.54 m	At the upstream face of the bridge, based on the regraded channel.
Maximum Water Depth	1.28 m	Average water depth during the design flood event, based on HEC-RAS model results.
Maximum Water Elevation	460.82 m	At the upstream face of the bridge, based on HEC-RAS model results.
Minimum Low Chord Elevation	462.32 m	At the upstream face of the bridge, based on the maximum water elevation plus 1.5 m minimum freeboard.
Minimum Hydraulic Opening Height	2.78 m	Clear opening height between the channel bed elevation and the minimum low chord elevation.
Minimum Span Between Bridge Abutments	12.87 m	Between outside edges of the top of the riprap at the bridge.
Channel Side Slope		
Reach 1 Left side slope Right side slope	 1.5H:1V 1.5H:1V	Right channel bend with a radius of 58 m and a longitudinal slope of 0.037 m/m.
Reach 2 Left side slope Right side slope	 1.5H:1V 2H:1V	Left channel bend with a radius of 34 m and a longitudinal slope of 0.037 m/m.
Reach 3 Left side slope Right side slope	 1.5H:1V 2H:1V	Right channel bend with a radius of 100 m and a longitudinal slope of 0.01 m/m.
Riprap Bank and Scour Protection		
Reach 1 Left side riprap class Right side riprap class	 250 kg 100 kg	Riprap layer thickness normal to the slope should be minimum 1000 mm on the left bank and 700 mm on the right bank (MOTI 2020).
Reach 2 Left side riprap class Right side riprap class	 100 kg 250 kg	Riprap layer thickness normal to the slope should be minimum 700 mm on the left bank and 1000 mm on the right bank (MOTI 2020).
Reach 3 Left side riprap class Right side riprap class	 100 kg 100 kg	Riprap layer thickness normal to the slope should be minimum 700 mm on both banks (MOTI 2020).

Parameter	Value	Notes
Additional Bank and Scour Protection Notes		Refer to MOTI 2020 Standard Specification for Highway Construction (MOTI 2020) for the recommended riprap dimensions and gradations. Riprap filter specifications to be determined by others. Bank protection work should provide a smooth transition to the existing banks and through the bridge waterway opening. Riprap scour protection should extend to 2.0 m below the finished channel bed elevation and should span the entire channel cross-section as per the maximum scour depth assessed in Section 7.1. According to typical practice for MOTI structures, potential natural scour depth was assessed in the absence of scour and erosion countermeasures.

BIBLIOGRAPHY

- Binnie (RF Binnie & Associates Ltd.). 2021. Survey Plan. Highway No. 1 & Highway No. 97. Cache Creek Topographic Survey. Binnie File Number 21-0820.
- FHWA (US Department of Transportation Federal Highway Administration). 2005. Hydraulic Engineering Circular No. 18 - Evaluating Scour at Bridges. 5th ed. Washington DC: Office of Bridge Technology. https://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=17&id=151
- KWL (Kerr Wood Leidal Associates Ltd.). 2017. Cache Creek Culvert Capacity Assessment. Prepared for Ministry of Transportation and Infrastructure. Vernon BC: Kerr Wood Leidal Associates Ltd.
- Lu et al. 2012. Prediction of Maximum General Scour Depth during a Flood for Intermittent Rivers. https://www.academia.edu/32193806/Prediction_of_Maximum_General_Scour_Depth_during_a_Flood_for_Intermittent_Rivers
- Mazumder SK. 2007. Limitations of Lacey's theory for estimation of bridge scour. In: Proceedings from ISCE6 Paris; 27-31 August 2012; Paris FR. http://www.profskmazumder.com/PDF/Ref_98.pdf
- MOELP (BC Ministry of Environment, Lands and Parks). 1998. British Columbia Streamflow Inventory. https://a100.gov.bc.ca/pub/acat/public/viewReport.do?reportId=2227
- MOTI (Ministry of Transportation and Infrastructure). 2019a. Technical Circular T-04/19, Resilient Infrastructure Engineering Design - Adaptation to the Impacts of Climate Change and Weather Extremes. March 2019. https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/engineering-standards-and-guidelines/technical-circulars/2019/t04-19.pdf
- MOTI. 2019b. BC Supplement to TAC Geometric Design Guide. 2019. 3rd Edition.
- MOTI. 2020. 2020 Standard Specification for Highway Construction. Volume 1.
- NASA (National Air and Space Administration Jet Propulsion Laboratory). 2013. NASA Shuttle Radar Topography Mission Global 1 arc second version 3 [data set]. https://www2.jpl.nasa.gov/srtm/
- Province of British Columbia. 2022. iMapBC. [accessed March 2022]. https://maps.gov.bc.ca/ess/hm/imap4m/
- TAC (Transportation Association of Canada). 2001. Guide to Bridge Hydraulics. Second Edition.
- True Consulting. 2019. Cache Creek Corridor Pre-Design. Report produced for the Village of Cache Creek. Project No. 310-261. October 2019.
- University of British Columbia (UBC). 2022. ClimateBC. Web-based version. Centre for Forest Conservation Genetics. [accessed 8 March 2022]. http://www.climatewna.com/ClimateBC_Map.aspx
- USACE (US Army Corps of Engineers). 2022. HEC-RAS version 6.2 [software]. Davis CA.

https://wsponlinecan.sharepoint.com/sites/CA-221-11730-003680/Shared Documents/05. Technical/200-Hydrotechnical/5-Deliverables/1-Working/1-Hydrotechnical Design Report/RevA_04AUG_23/26939_ht_rpt_draft-hydrotech-design-report 04AUG_23.docx

APPENDIX

A

GEOMORPHOLOGICAL ASSESSMENT

TECHNICAL MEMORANDUM

DATE 16 December 2022 **Reference No.** 21453571-001-TM-Rev0-5000

TO Mike Sullivan, PEng
Ministry of Transportation and Infrastructure

CC

FROM Kathryn Semiao, PhD **EMAIL Kathryn_DeRegoSemiao@golder.com**

25357 HWY 97 CACHE CREEK CULVERT REPLACEMENT PROJECT GEOMORPHOLOGICAL ASSESSMENT

Golder Associates Ltd. (Golder) was retained by the Ministry of Transportation and Infrastructure (MOTI) to provide preliminary and detailed hydrotechnical design services for the replacement of the Highway 97 culvert crossing located along Cache Creek in the Village of Cache Creek, BC (the Project). The Project is split into two phases: Phase 1 (Conceptual Hydrotechnical Design) and Phase 2 (Detailed Hydrotechnical Design and Tender Documentation). This memorandum describes the geomorphological setting of the Highway 97 culvert crossing (the Site) in contribution to the Phase 1 scope.

The Site is located within the Village of Cache Creek, transporting runoff from an upslope catchment towards the Bonaparte River. The village has been subject to several major flood events in recent years, including 2015, 2017, and 2018. The 2018 flood event clogged the Quartz Road Culvert, which caused downstream flooding and property damage. Flooding in 2018 was exacerbated by the spring 2018 Elephant Hill Wildfire.

The existing culvert on site is an approximately 35 m-long Corrugated Steel Pipe (CSP) pipe-arch culvert with a span of 2600 mm and rise of 1800 mm. There is an approximately 25-degree bend midway along the culvert, and there is significant scour at the downstream end. The culvert is in poor condition.

The Highway 97 culvert is located downstream of two culverts owned by the Village of Cache Creek. It is understood by Golder that both culverts will be replaced, and it has been assumed that they will be made sufficiently large to convey the design flow.

1.0 OBJECTIVES AND SCOPE

The objective of the geomorphologic assessment is to examine pertinent information on sediment supply and morphologic conditions upstream and downstream of the Site which may impact the culvert crossing. The scope of the assessment includes:

- Review of background reports, Google Earth™ imagery, site notes and photographs, and survey data.
- Sediment yield analysis.

2.0 BACKGROUND REVIEW

2.1 Watershed Characteristics

Cache Creek drains approximately 136 km^2 of hilly terrain on the Thompson Plateau. The channel flows southwest from upland headwaters draining forests within the Interior Douglas Fir and Ponderosa Pine biogeoclimatic zones into a semi-arid bunchgrass ecosystem (BC MFLNRORD, 2018). As the channel exits the uplands, it flows south over what appears to be a relic post-glacial alluvial fan (Church and Ryder, 1972) before turning west into the Village of Cache Creek, where it joins the Bonaparte River approximately 240 m downstream of the Site. Channel slope is approximately 3%.

The upper Cache Creek watershed has been harvested extensively (True Consulting, 2019). Based on available Google Earth™ imagery, approximately 10% of the watershed was cleared between 1984 and the mid-2010s. In addition, approximately 81% of the catchment was burned in 2017 during the Elephant Hill wildfire, with about 55% of the catchment experiencing moderate or severe burning (True Consulting, 2019). Loss of soil strength and increased runoff resulting from wildfire have been known to increase sediment loads to streams on timescales of several years in other catchments (Moody and Martin, 2009; Robinne et al., 2020). However, in south and central British Columbia, recent evidence suggests that the impact of wildfire on downstream sediment yields may be negligible in some cases (Eaton et al., 2010; Owens et al., 2012; Jordan, 2012). Peak precipitation events tend to occur in winter as snowfall in the BC Interior, reducing the chance of gully and bank erosion on burned hillslopes during the snow-free summer period (Jordan, 2012). In addition, hillslope-channel connectivity in the glacially-scoured BC landscape is low compared to fluvially-dominated landscapes because of the abundance of glacially widened valleys and underfit streams (Jordan, 2012). The degree to which burned watersheds experience increased sediment loading is also influenced by the magnitudes of peak flow events in the years immediately after the fire, as this determines whether hillslope or bank sediment can be mobilized before it is stabilized by vegetation growth (Eaton et al., 2010; Owens et al., 2012). Golder has assumed that sediment loads higher than the long-term average are possible over the next several years.

2.2 Channel Characteristics

The Cache Creek channel appears laterally confined upstream of Highway 97. The left bank consists of a concrete retaining wall and stone gabion, and the right bank is shallow-sloped and vegetated with mature riparian trees. Lateral sediment supply is low. Based on 2021 survey data (Binnie, 2021), channel slope is approximately 2%.

Downstream of Highway 97, the slope increases to approximately 4% (based on the 2021 survey data), and the channel is incised into an approximately 2-3 m deep ravine. Evidence of ravine erosion and bank undercutting suggest recent instability of the channel margins and increased local sediment supply.

Golder understands that the Quartz Road culvert is considered undersized. Much of the sediment supply entering the Cache Creek corridor is therefore likely sequestered upstream of Quartz Road. If the two culverts owned by the Village of Cache Creek are upgraded, then sediment supply to the Highway 97 culvert is likely to increase. In the short term (on the order to several years), much of the increase may be due to reactivation of the deposits upstream of the Quartz Road culvert.

3.0 SEDIMENT YIELD ASSESSMENT

An annual sediment yield was derived to estimate the amount of sediment that can be expected to pass through Cache Creek at Highway 97. The annual sediment yield represents a long-term average of the quantity of sediment exported by the watershed. In any given year, the yield may be higher or lower than the annual yield depending on the magnitude of high flow events and the availability of sediment. For example, the sediment yield in a year in which a major flood occurs can be expected to be many times greater than the average annual yield. Golder has not considered the annual yield of woody debris, which is not expected to be a major component of the total load at Highway 97.

Estimates of sediment yield are typically associated with high margins of error. To increase the reliability of the estimate, Golder compared the results from three methods of prediction:

1) Graphical analysis of regional clastic sediment yield data for British Columbia summarized by Church et al. (1989).
2) Analysis using BQART, an empirical sediment yield model developed by Syvitski et al. (2007).
3) A modification of the Church et al. (1989) yield to account for potential increases in sediment yield resulting from the Elephant Hill wildfire, using post-fire hillslope sediment yield rates from Jordan (2012).

Sediment yield is presented as a function of catchment area in Church et al. (1989). The dataset was developed using suspended sediment measurements collected at hydrometric stations throughout British Columbia. The sediment data do not include material transported as bedload; Golder has assumed that the bedload fraction is 10% of the total sediment load (Knighton, 1998). The annual sediment yield derived from the graphical analysis is in the range of approximately 400-3,100 m^3/yr.

Total clastic sediment yield is also estimated using the BQART model, which was developed using a global database of large rivers by Syvitski et al. (2007). The BQART model predicts long-term (~30-year timescale) sediment yield from watershed-wide variables including catchment area, average discharge, relief, and temperature, as well as metrics of glacier and lake cover, lithology, and anthropogenic influence. Average discharge was calculated using area transfer scaling from the Arrowstone Creek hydrometric station. Provincial, regional, and global datasets, including geologic maps (Ryder, 1972), publicly available Digital Elevation Models (NASA, 2013), and temperature modeled using regional stations (UBC, 2022) were used to meet the other data needs of the model (Table 1). The annual sediment yield estimated using the BQART model is approximately 6,500 m^3/yr.

Total clastic sediment yield that takes into account potentially increased soil erodibility as a result of the 2017 Elephant Hill wildfire was estimated by using the Church et al. (1989) graphical relation but modifying the sediment yield over the moderately and severely burned proportion of the catchment using values of hillslope sediment yield presented in Jordan (2012). Golder conservatively assumed that sediment storage within the watershed is negligible so that the hillslope sediment yield is representative of the Cache Creek sediment yield at Highway 97. The annual yield estimated from the work of Church et al. (1989) and Jordan (2012) is in the range of approximately 3,000-30,000 m^3/yr. This yield estimate is applicable for up to several years after the fire.

Table 1: Inputs used for the BQART model

Parameter	Value	Source	Notes
Mean annual discharge	0.24 m^3/s	Hydrological analysis	-
Watershed area	136 km^2	Hydrological analysis	-
Relief	1,320 m	NASA (2013), Hydrological analysis	Determined from catchment boundary and DEM using ArcMap™ software
Midpoint basin elevation	1358 m	NASA (2013), Hydrological analysis	Determined from catchment boundary and DEM using ArcMap™ software
Mean annual temperature at midpoint basin elevation	3.9 ^{o}C	UBC, 2022	2011-2040 climate projections derived from an ensemble of 13 GCM models incorporating RCP4.5 and RCP8.5 emissions scenarios (Wang et al., 2016)
Glaciation factor	0	Visual analysis of Google Earth™ imagery	Represents percent of watershed that is glaciated; parameter ranges from 0 (no glacial cover) to 10 (100% glacial cover)
Lithology index	2	Ryder (1972); Syvitski et al. (2007)	Represents metric of erodibility of surficial materials in the watershed; parameter ranges from 0.5 (low erodibility) to 3 (high erodibility). Value of 2 is typical for unconsolidated sediment (e.g., till).
Dam trapping efficiency	0	-	Value of 0 indicates no dams present in watershed
Anthropogenic factor	1.1	Syvitski et al. (2007)	Accounts for human related impacts on soil erosion, such as agriculture and urbanization, which higher values representing the prevalence of practices that increase sediment yield. The values typically range from 0.3-2 but can be higher. Assumed value slightly over 1 due to impacts of past forest harvesting.

Based on these estimates, Golder estimates that the long-term average annual sediment yield at Highway 97 is on the order of 2,000-7,000 m^3/yr. This represents the range between the average Church et al. (1989) estimate and the BQART estimate. Over the next few years, the yield may be up to approximately 30,000 m^3/yr, depending on the effect of the Elephant Hill wildfire on sediment supply to river channels.

4.0 CLOSURE

We trust that this information is sufficient for your requirements. Should you have any questions regarding the above, or if you require further information, please do not hesitate to contact our office.

Golder Associates Ltd.

Kathryn Semiao, PhD
Junior Ceomorphology Specialist

Phil Osborne, PhD, PGeo
Senior Geomorphologist

KS/PO/jts

https://golderassociates.sharepoint.com/sites/141430/project files/ph5000_warn-831cs1089-hwy 97 cache creek/6 deliverables/3.0_issued/21453571-001-tm-rev0/21453571-001-tm-rev0-5000-cache creek geomorphological assessment 16dec_22.docx

PERMIT TO PRACTICE #1003064
Engineers & Geoscientists BC

APPENDIX

B HEC-15 CALCULATION SHEETS

221-11730-00.3680
CRRP - Cache Creek at Hwy 97
Downstream Bend 250 kg stone at 2:1 solution
2023-07-26

HEC 15
Riprap Size Calculator for Mild Slopes With Bend

Normal Flow Depth:	1.255	m		
Superelevation	0.736	m	Only for crest calculations	
Design Depth at Bend	1.255	m		
Channel Slope:	0.037	m/m		
Side Slope:	2	:1 (H:V)		
Water Surface Top Width	9.39	m		
Radius of Curvature	34	m		
Unit Weight Water:	9800	N/m3		
SG Riprap	2.5			
Unit Weight Riprap:	24500	N/m3		
Angle Repose Riprap:	42.5	deg	(Fig 6-1)	
K1 Ratio of Side to Bottom Shear:	0.802	(eq 3.4 for 1.5<Z<5)		
Kinematic Viscosity	1.131E-06	m2/s		
Shear Velocity	0.675	m/s	(eq 6.10)	
Reynolds Number	3.199E+05			
Shields Parameter:	0.150	Table 6.1		
Factor of Safety:	1.5	Table 6.1		1.0
K_b	1.73		(eg 3.7)	
Bend Shear Stress	788	N/m^2	(eq 3.6)	
Angles in Radians				
Channel Slope:	0.0370	radians		
Theta:	0.4636	radians	(eq 6.17)	
Angle Repose Riprap:	0.7418	radians		
K_2	0.7495		(eq 6.16)	
Initial D50	0.536	m		
Iterative D50	0.536	m	(eq 6.8)+ Bend Shear Factor	
Base Final D50	0.535	m		
Side D50	**0.572**	m	(eq 6.15)	

RIPRAP

Table 205-B: Gradation of Rock by Class of Riprap

Class of Riprap (kg)	Rock Mass (kg)			
	Percentage Smaller Than Given Rock Mass			Max. Size
	15%	50%	85%	
10	1	10	30	50
25	2.5	25	75	125
50	5	50	150	250
100	10	100	300	500
250	25	250	750	1 250
500	50	500	1 500	2 500
1000	100	1 000	3 000	5 000
2000	200	2 000	6 000	10 000
4000	400	4 000	12 000	20 000

Table 205-C: Gradation and Intermediate Dimension of Rock by Class of Riprap

Class of Riprap (kg)	Intermediate Dimension (mm)			
	Percentage Smaller Than Intermediate Dimension			Max. Size
	15%	50%	85%	
10	90	200	285	350
25	125	270	385	450
50	155	340	485	600
100	200	425	610	750
250	270	575	830	1 000
500	340	725	1 050	1 250
1000	425	915	1 325	1 600
2000	535	1 150	1 650	2 000
4000	675	1 450	2 100	2 500

Note: Table 205-C shows the intermediate dimension as defined in the Wolman method as per FHWA FLH T 521 corresponding to the rock mass shown in Table 205-B, based on spherical volume, using Specific Gravity = 2.50. Regardless of actual source Specific Gravity, the dimensions indicated remain applicable (subject to the limits specified in Table 205-A*).*

RIPRAP

Table 205-D: Placement Dimensions by Class of Riprap

Class of Riprap (kg)	Nominal Thickness of Riprap* (mm)	Surface Width, W* (mm)	
		2H:1V Slope	1.5H:1V Slope
10	350	783	631
25	450	1006	811
50	550	1230	992
100	700	1566	1262
250	1000	2236	1803
500	1200	2684	2163
1000	1500	3355	2704
2000	2000	4473	3606
4000	2500	5591	4507

* See SS Drawing SP205-1 for the description of the Nominal Thickness and Surface Width dimension "W".

221-11730-00.3680
CRRP - Cache Creek at Hwy 97
Upstream Bend 250 kg stone solution
2023-07-26

HEC 15
Riprap Size Calculator for Mild Slopes With Bend

Normal Flow Depth:	1.282	m		
Superelevation	0.422	m	Only for crest calculations	
Design Depth at Bend	1.282	m		
Channel Slope:	0.037	m/m		
Side Slope:	1.5	:1 (H:V)		
Water Surface Top Width	8.85	m		
Radius of Curvature	58	m		
Unit Weight Water:	9800	N/m3		
SG Riprap	2.5			
Unit Weight Riprap:	24500	N/m3		
Angle Repose Riprap:	42.5	deg	(Fig 6-1)	
K1 Ratio of Side to Bottom Shear:	0.769	(eq 3.4 for 1.5<Z<5)		
Kinematic Viscosity	1.131E-06	m2/s		
Shear Velocity	0.682	m/s	(eq 6.10)	
Reynolds Number	2.557E+05			
Shields Parameter:	0.150	Table 6.1		
Factor of Safety:	1.5	Table 6.1		1.0
K_b	1.34		(eg 3.7)	
Bend Shear Stress	624	N/m^2	(eq 3.6)	
Angles in Radians				
Channel Slope:	0.0370	radians		
Theta:	0.5880	radians	(eq 6.17)	
Angle Repose Riprap:	0.7418	radians		
K_2	0.5708		(eq 6.16)	
Initial D50	0.424	m		
Iterative D50	0.425	m	(eq 6.8)+ Bend Shear Factc	
Base Final D50	0.425	m		
Side D50	**0.573**	m	(eq 6.15)	

RIPRAP

Table 205-B: Gradation of Rock by Class of Riprap

Class of Riprap (kg)	Rock Mass (kg)			
	Percentage Smaller Than Given Rock Mass			Max. Size
	15%	50%	85%	
10	1	10	30	50
25	2.5	25	75	125
50	5	50	150	250
100	10	100	300	500
250	25	250	750	1 250
500	50	500	1 500	2 500
1000	100	1 000	3 000	5 000
2000	200	2 000	6 000	10 000
4000	400	4 000	12 000	20 000

Table 205-C: Gradation and Intermediate Dimension of Rock by Class of Riprap

Class of Riprap (kg)	Intermediate Dimension (mm)			
	Percentage Smaller Than Intermediate Dimension			Max. Size
	15%	50%	85%	
10	90	200	285	350
25	125	270	385	450
50	155	340	485	600
100	200	425	610	750
250	270	575	830	1 000
500	340	725	1 050	1 250
1000	425	915	1 325	1 600
2000	535	1 150	1 650	2 000
4000	675	1 450	2 100	2 500

Note: Table 205-C shows the intermediate dimension as defined in the Wolman method as per FHWA FLH T 521 corresponding to the rock mass shown in Table 205-B, based on spherical volume, using Specific Gravity = 2.50. Regardless of actual source Specific Gravity, the dimensions indicated remain applicable (subject to the limits specified in Table 205-A*).*

RIPRAP

Table 205-D: Placement Dimensions by Class of Riprap

Class of Riprap (kg)	Nominal Thickness of Riprap* (mm)	Surface Width, W* (mm)	
		2H:1V Slope	1.5H:1V Slope
10	350	783	631
25	450	1006	811
50	550	1230	992
100	700	1566	1262
250	1000	2236	1803
500	1200	2684	2163
1000	1500	3355	2704
2000	2000	4473	3606
4000	2500	5591	4507

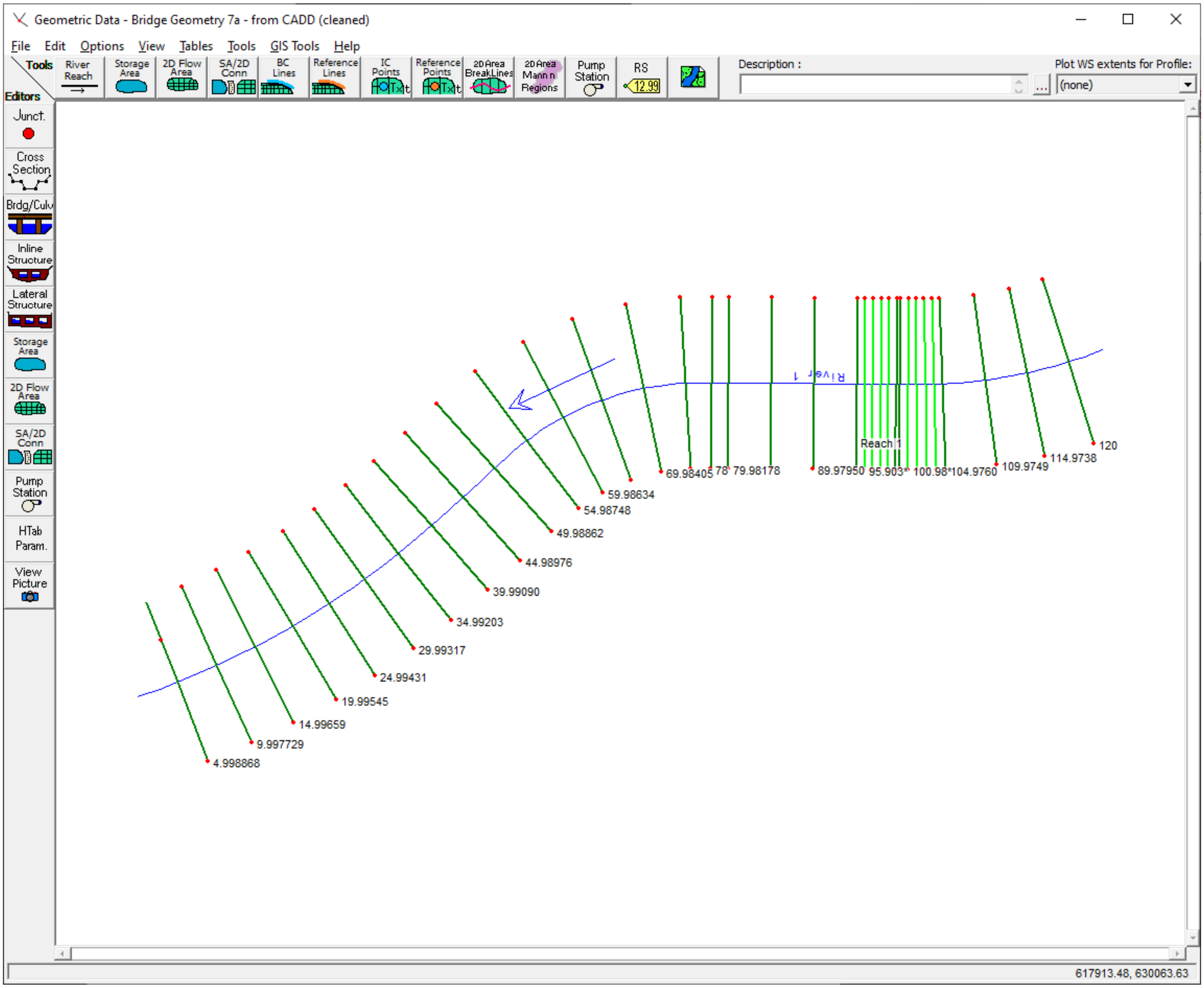
* See SS Drawing SP205-1 for the description of the Nominal Thickness and Surface Width dimension "W".

APPENDIX

C

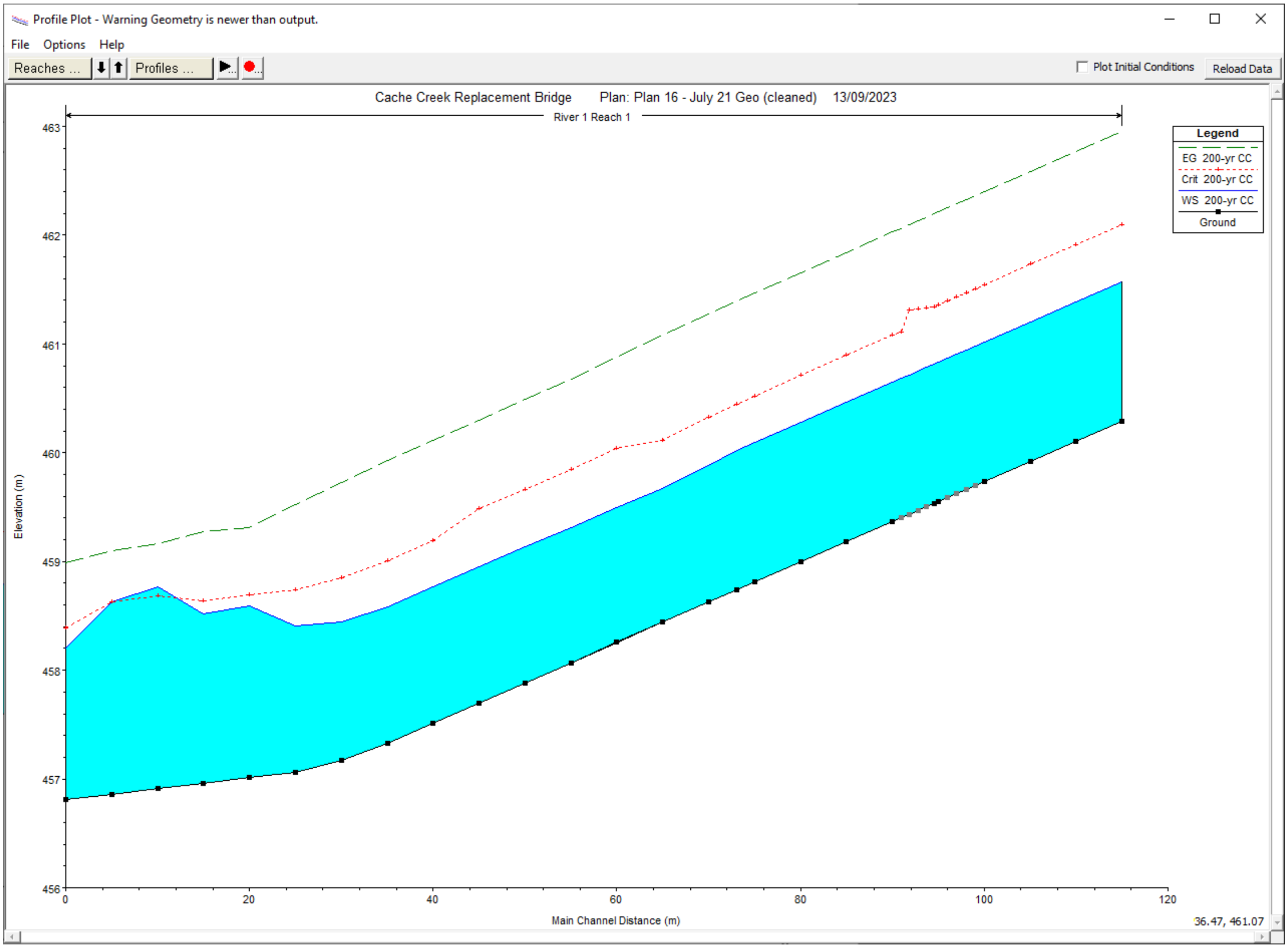
DETAILED HEC-RAS RESULTS

HEC-RAS PLAN

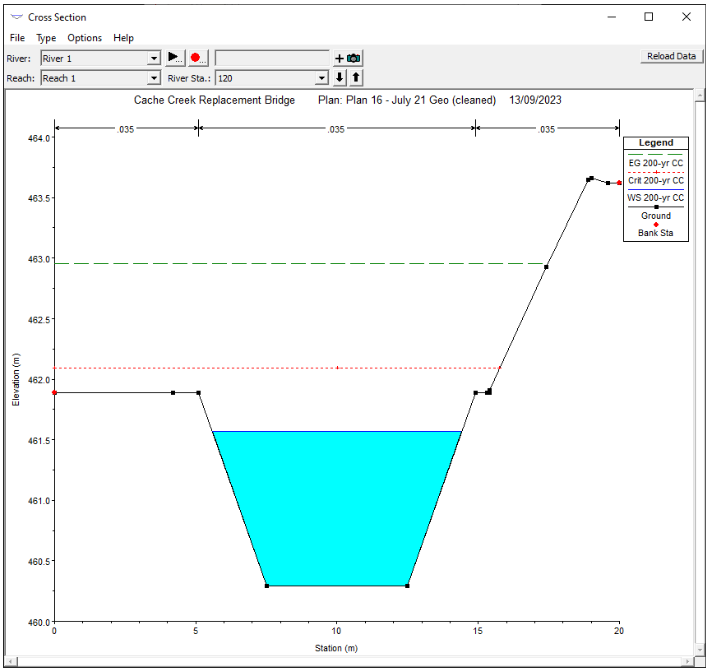


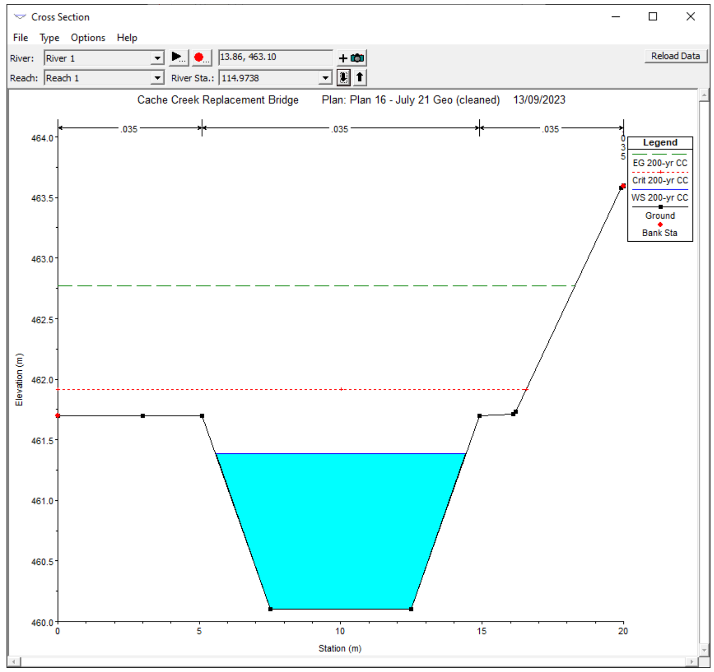
Geometric Data - Bridge Geometry 7a - from CADD (cleaned)
File Edit Options View Tables Tools GIS Tools Help
Tools
Editors
Description :
Plot WS extents for Profile:
(none)
Junct.
Cross Section
Brdg/Culv
Inline Structure
Lateral Structure
Storage Area
2D Flow Area
SA/2D Conn
Pump Station
HTab Param.
View Picture
River 1
Reach 1
120
114.9738
109.9749
100.98*104.9760
95.903*
89.97950
79.98178
69.98405
59.98634
54.98748
49.98862
44.98976
39.99090
34.99203
29.99317
24.99431
19.99545
14.99659
9.997729
4.998868
617913.48, 630063.63

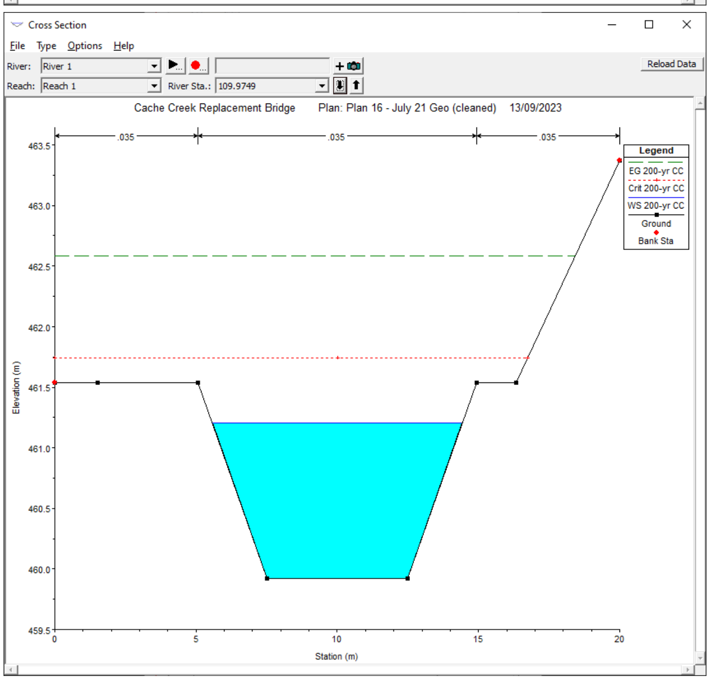
HEC-RAS PROFILE

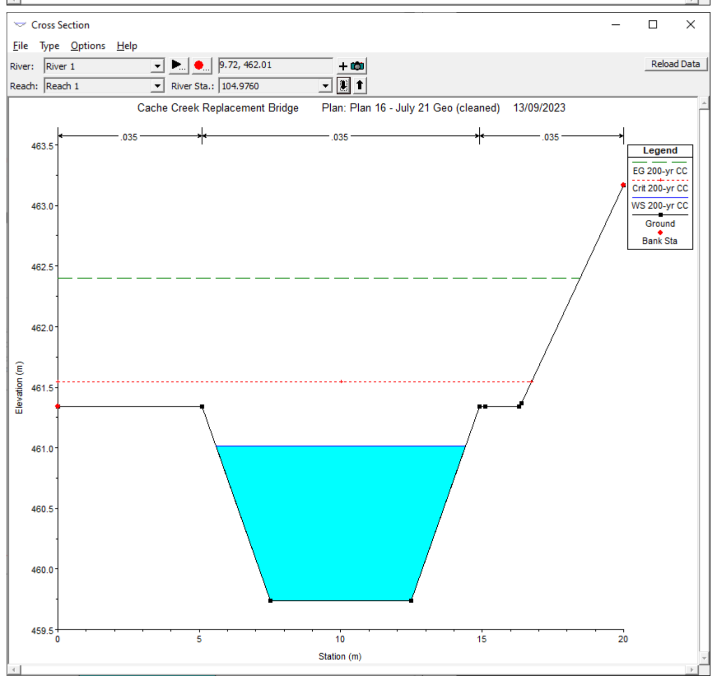


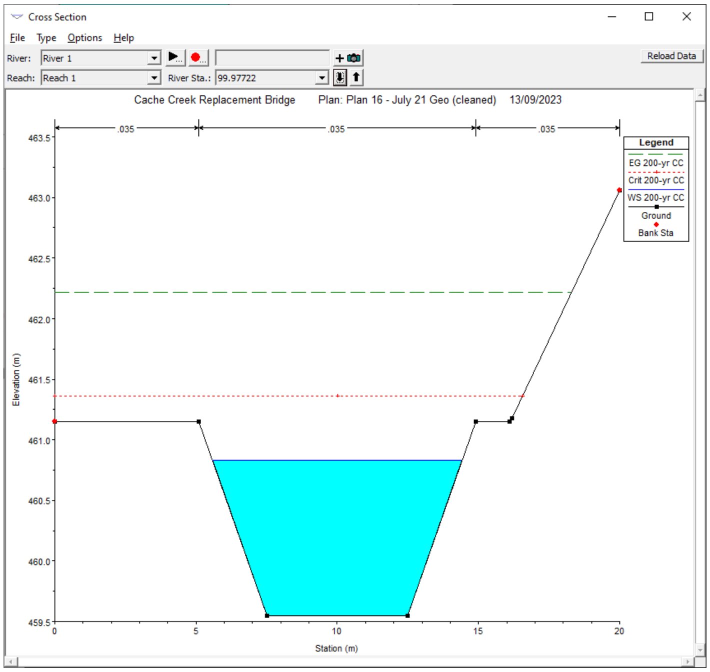
HEC-RAS CROSS-SECTIONS

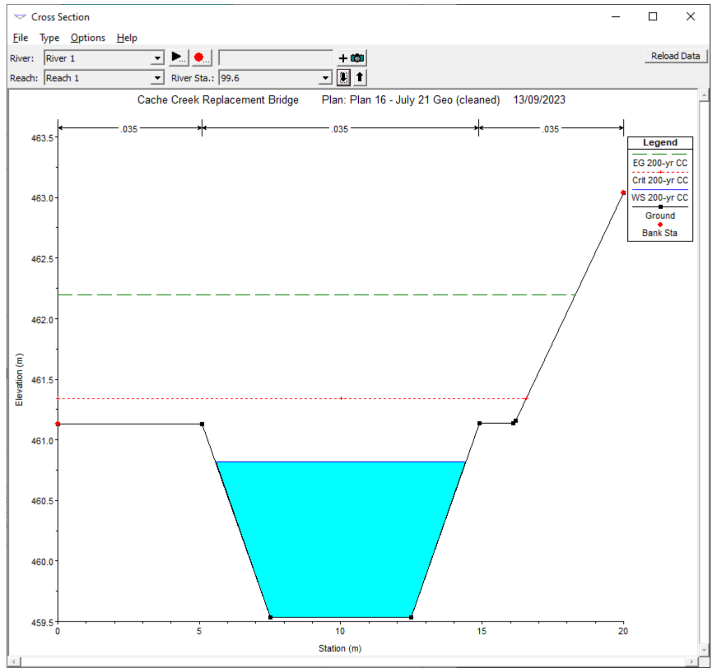


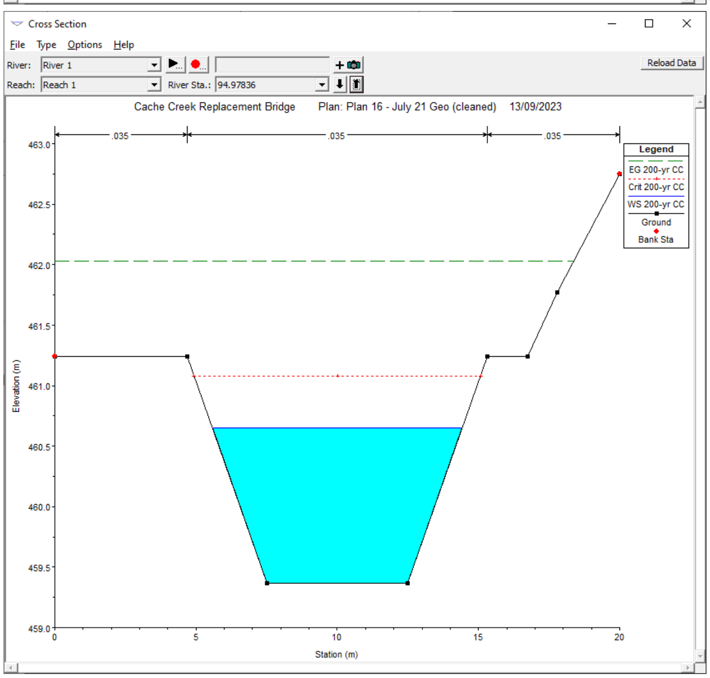


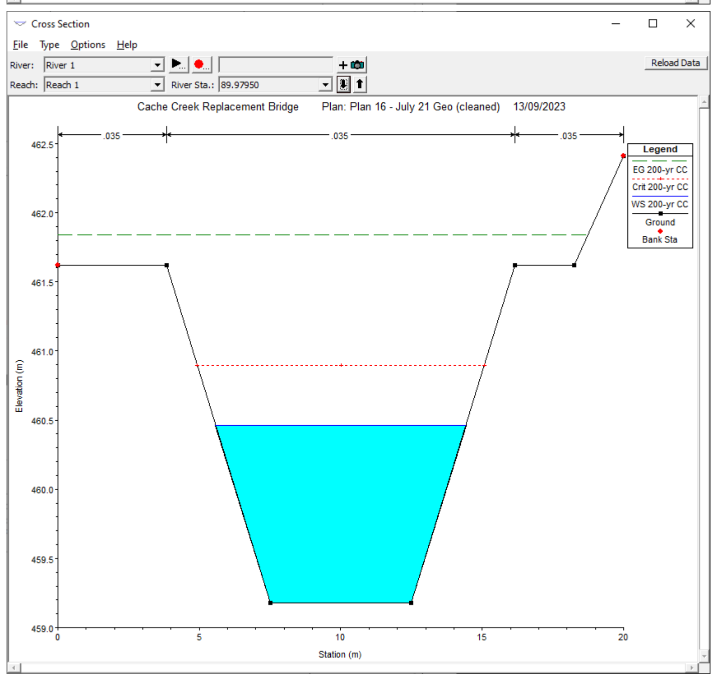


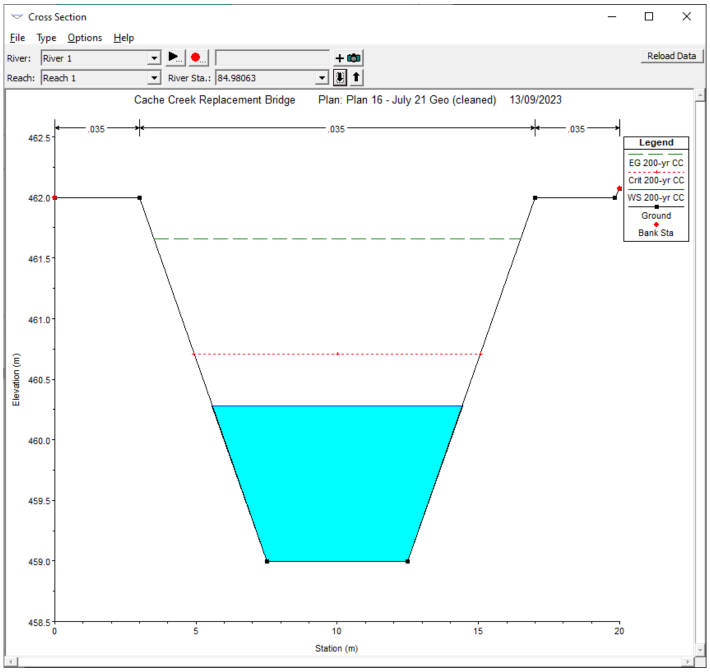


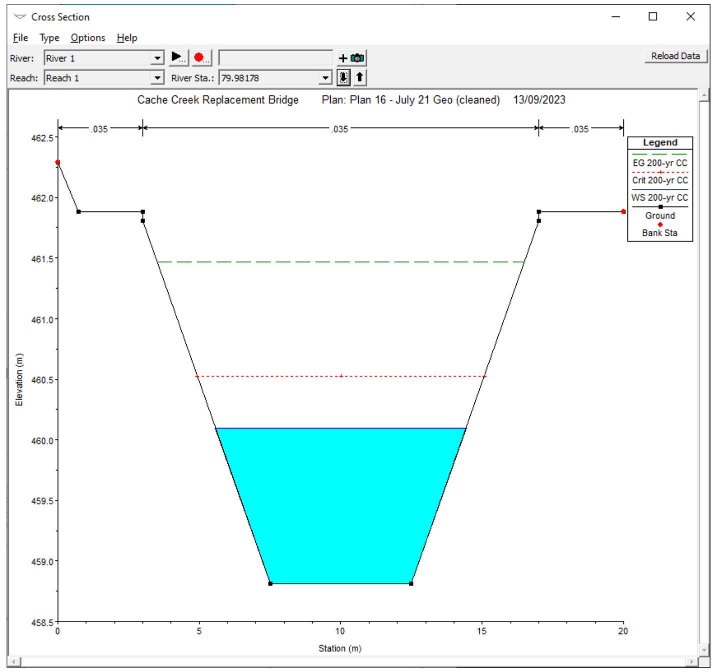

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 99.97722
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

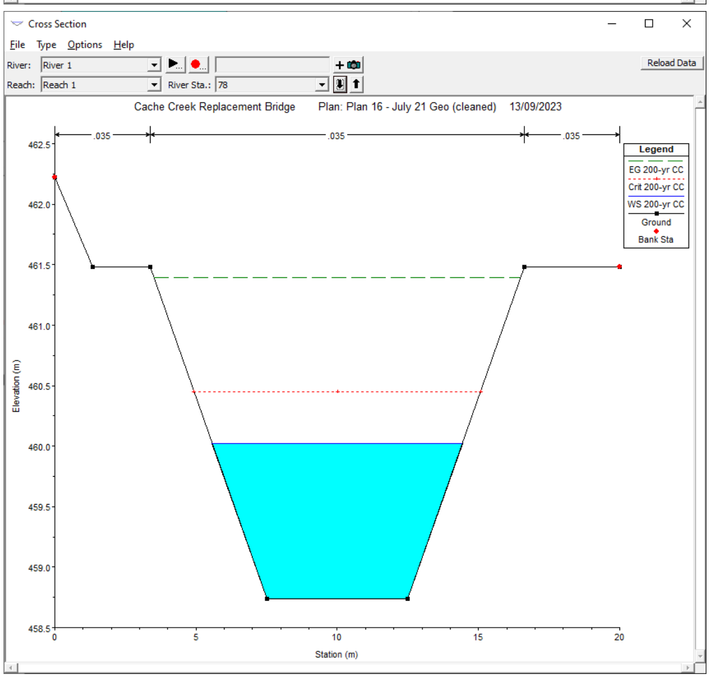

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 99.6
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

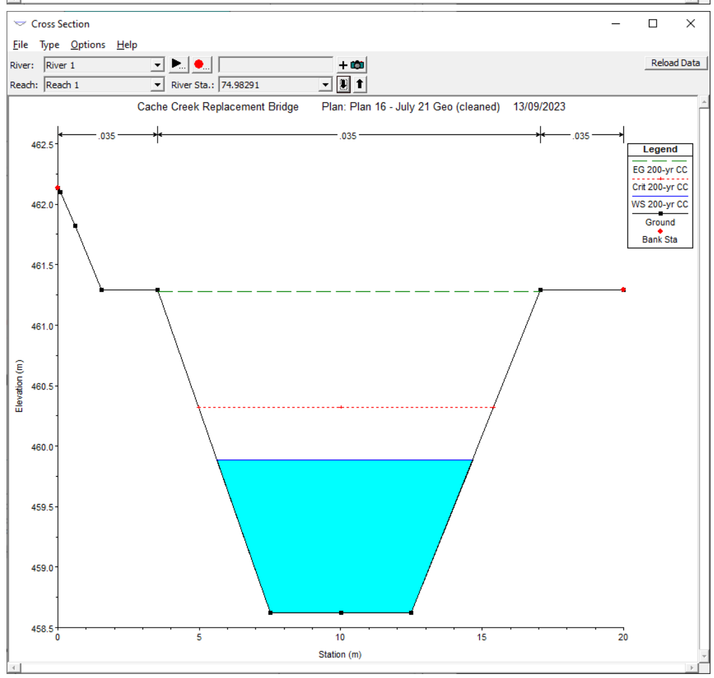

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 94.97836
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

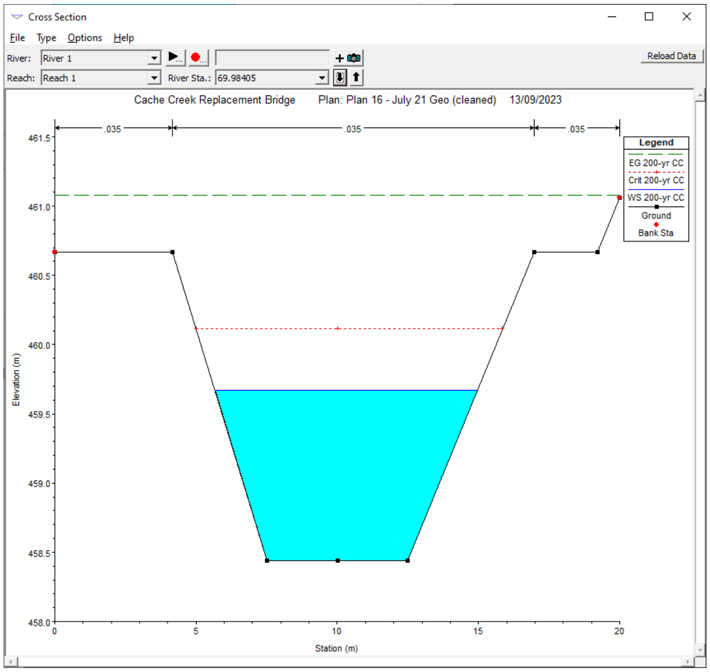

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 89.97950
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

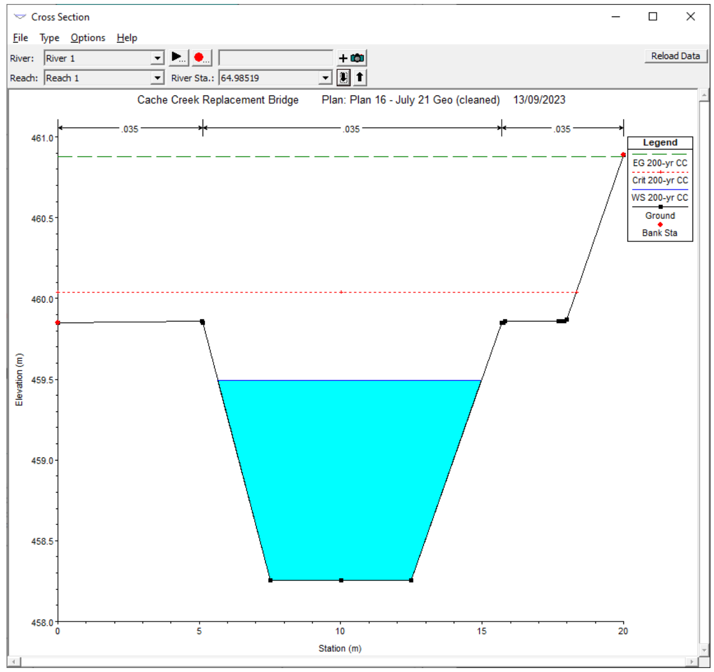

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 84.98063
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

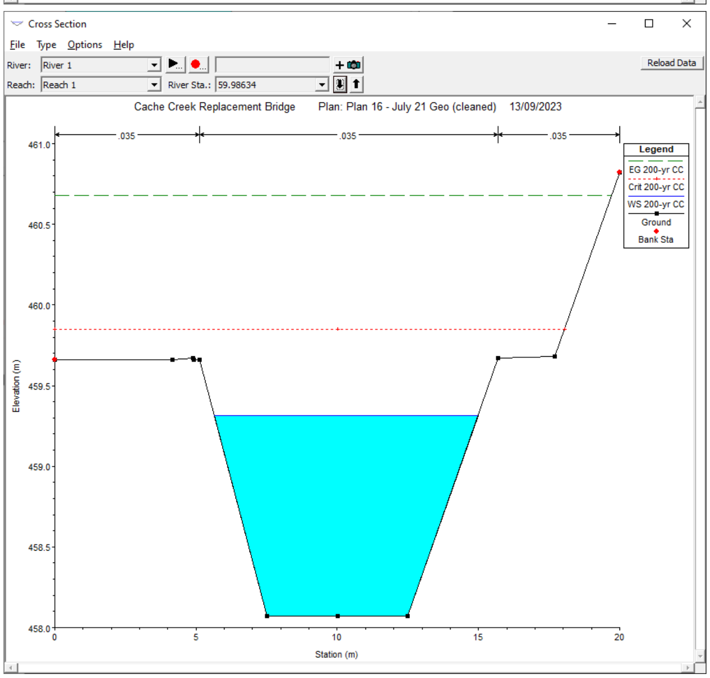

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 79.98178
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

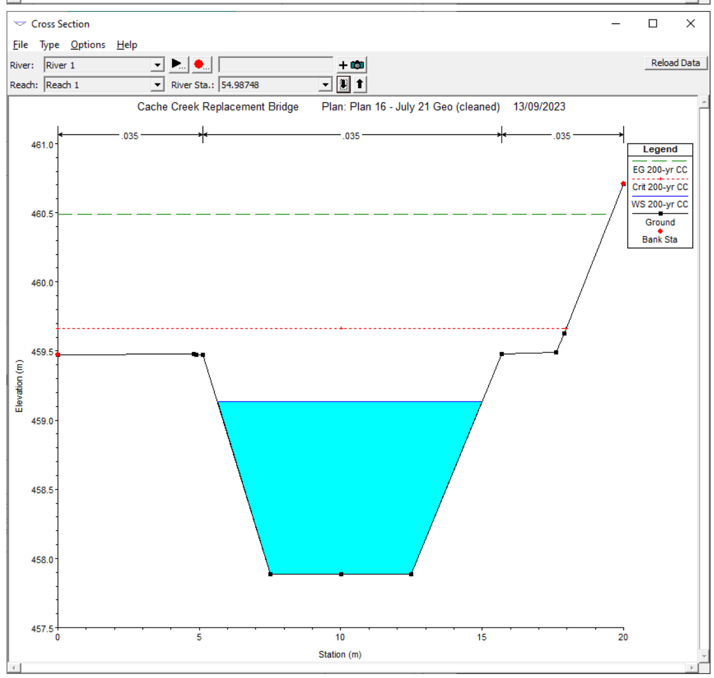

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 78
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

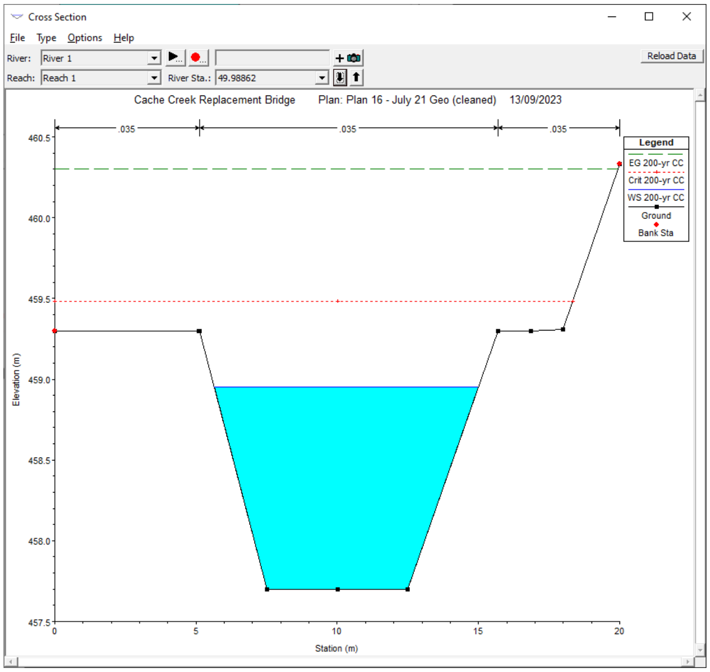

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 74.98291
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

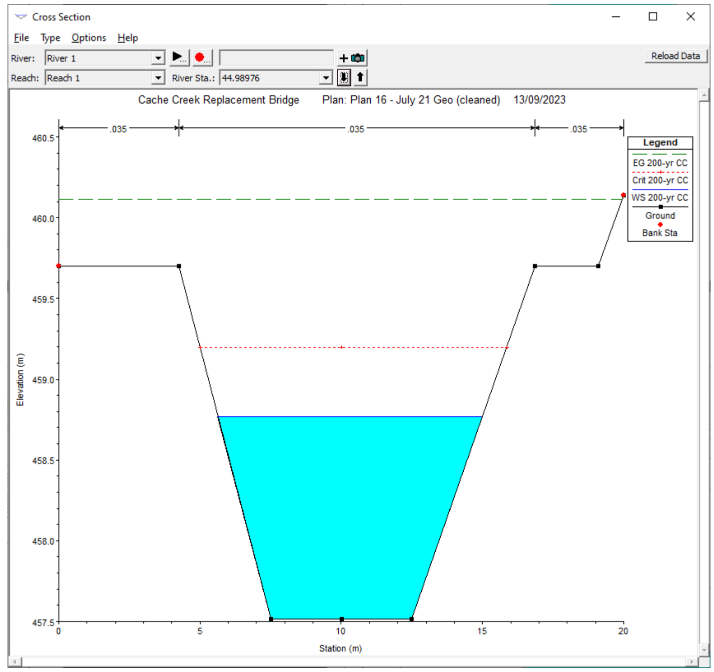

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 69.98405
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035 .035 .035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

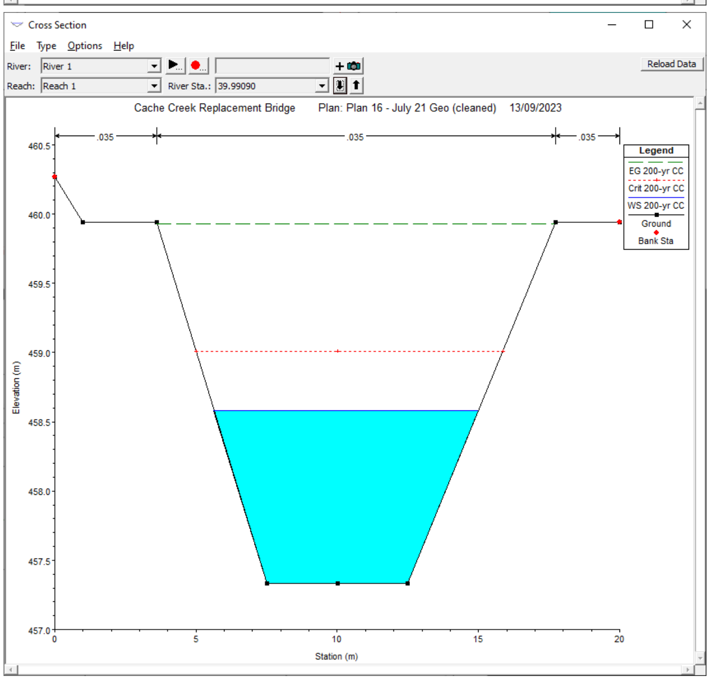

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 64.98519
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035 .035 .035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

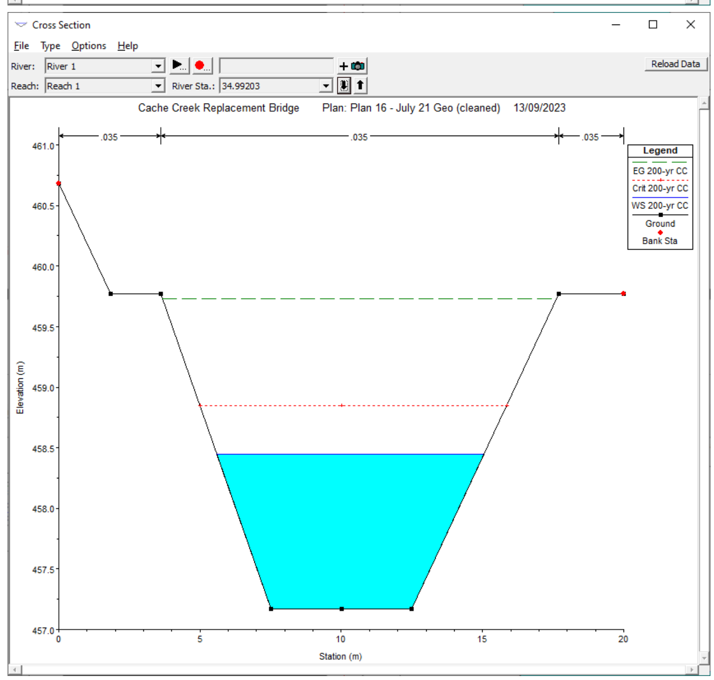

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 59.98634
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035 .035 .035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

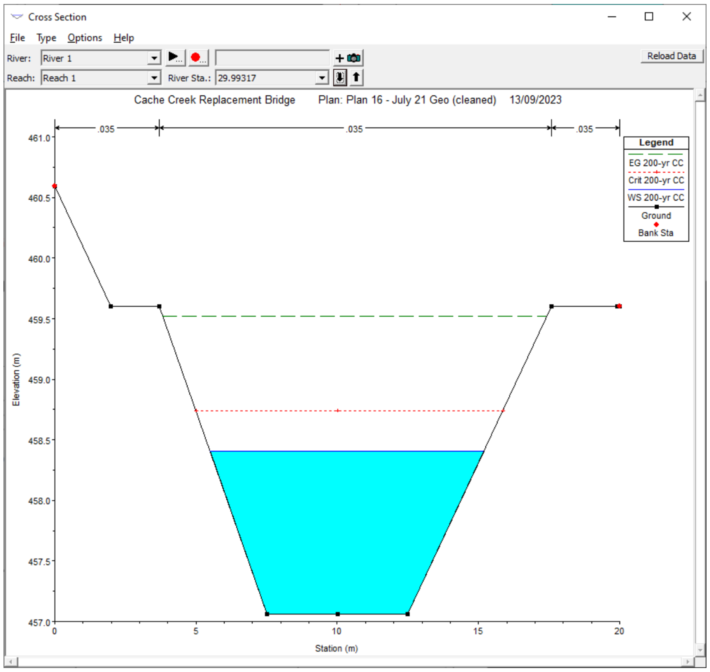

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 54.98748
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035 .035 .035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

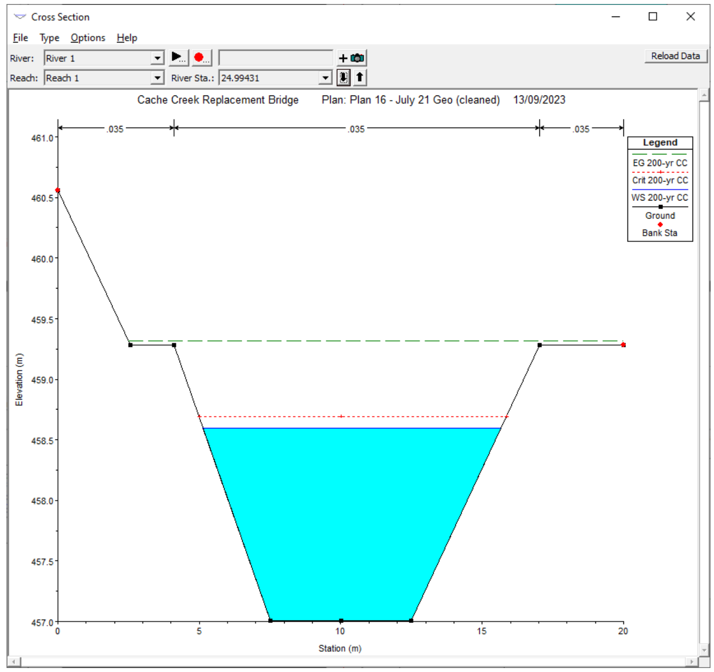

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 49.98862
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
.035
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

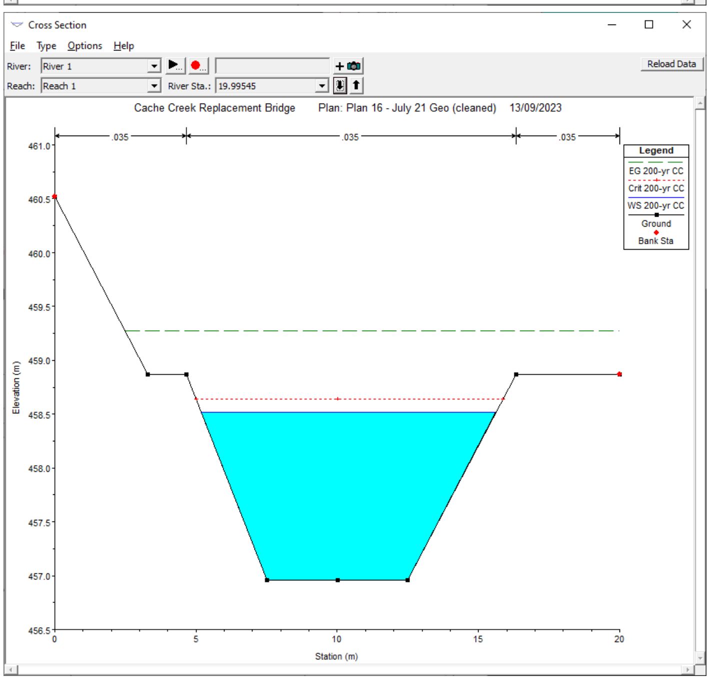

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 44.98976
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
.035
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

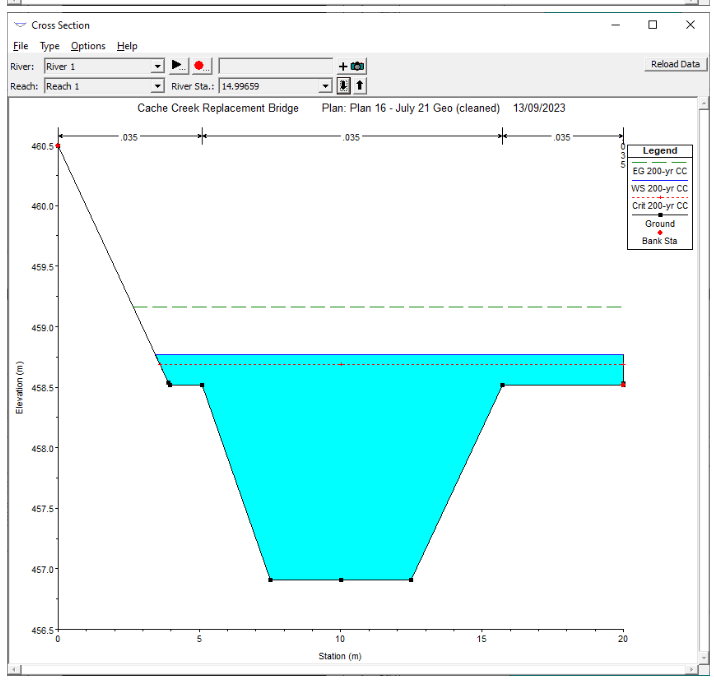

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 39.99090
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
.035
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

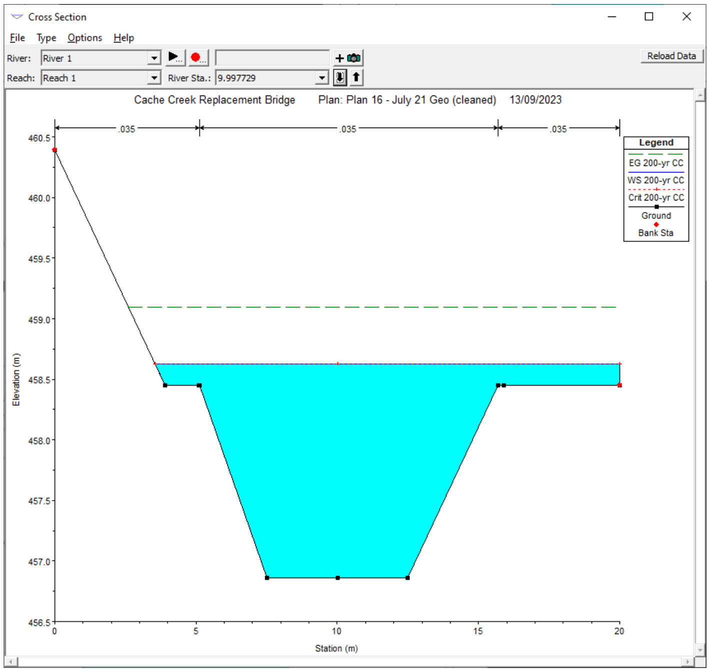

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 34.99203
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
.035
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

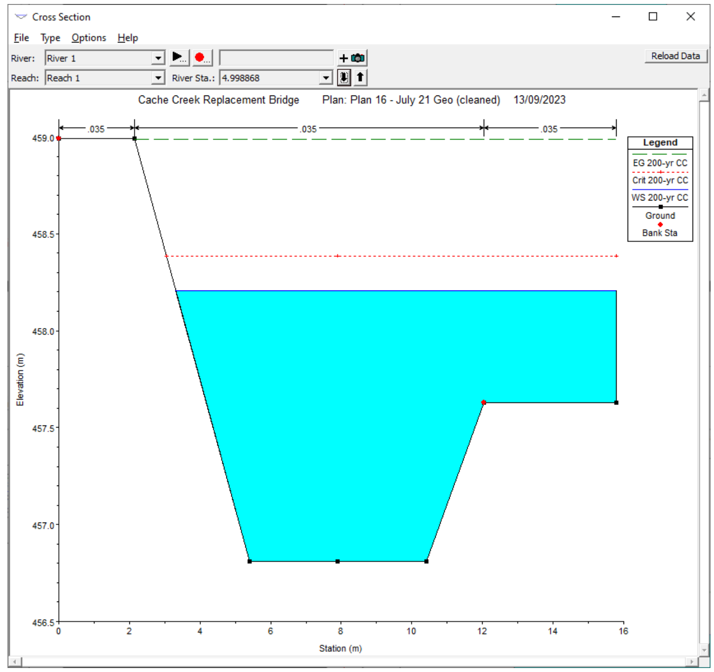

Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 29.99317
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
.035
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)


Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 24.99431
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
.035
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)


Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 19.99545
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
.035
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)


Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 14.99659
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
.035
.035
Legend
EG 200-yr CC
WS 200-yr CC
Crit 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)


Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 9.997729
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
WS 200-yr CC
Crit 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)


Cross Section
File Type Options Help
River: River 1
Reach: Reach 1
River Sta.: 4.998868
Reload Data
Cache Creek Replacement Bridge Plan: Plan 16 - July 21 Geo (cleaned) 13/09/2023
.035
Legend
EG 200-yr CC
Crit 200-yr CC
WS 200-yr CC
Ground
Bank Sta
Elevation (m)
Station (m)

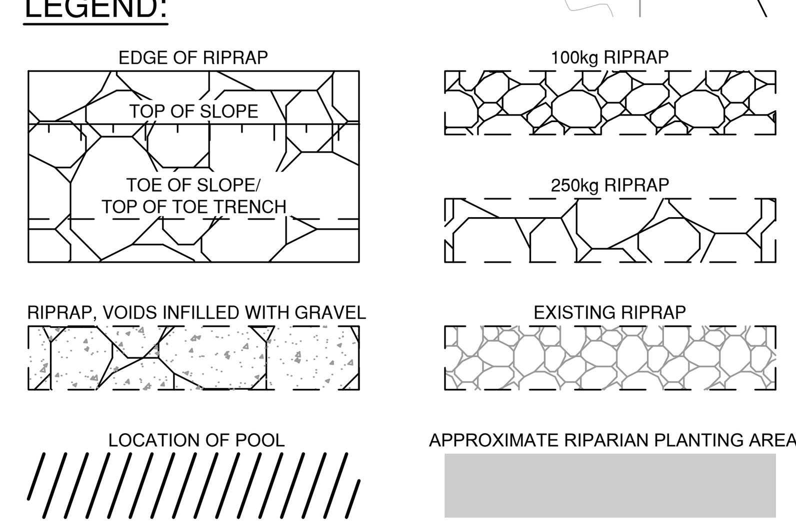
APPENDIX

D

HYDROTECHINCAL DESIGN DRAWINGS

CURVE DATA							
TAG	RADIUS	Δ	Tc	ARC LENGTH	Ec	P.I.	STATIONS
C1	58.000	026°46'50"	13.807	27.110	1.621	P.I. STA. 0+036.684 P.I. N. 630037.625 P.I. E. 618016.045	B.C. 0+022.876 E.C. 0+049.986
C2	34.000	042°46'37"	13.317	25.384	2.515	P.I. STA. 0+088.152 P.I. N. 630038.085 P.I. E. 617964.075	B.C. 0+074.835 E.C. 0+100.219
C3	100.000	021°57'54"	19.406	38.336	1.866	P.I. STA. 0+130.260 P.I. N. 630008.922 P.I. E. 617931.991	B.C. 0+110.854 E.C. 0+149.190

LEGEND:



wsp

Engineers & Geoscientists BC Permit #1000200

REV	DATE	REVISIONS	NAME

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — C. T. COLES # 28149 — 2023-09-20

BRITISH COLUMBIA

MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION
HIGHWAY ENGINEERING AND GEOMATICS

CAD FILENAME HYDR-CACHECREEK
FILE NUMBER 1961.0516.12
PLOT DATE 9/20/2023

DESIGNED C. COLES DATE 2023-09-01
QUALITY CONTROL M.GABELHEI DATE 2023-09-01
QUALITY ASSURANCE C. BAGG DATE 2023-09-01
DRAWN J. BRUINEMAN DATE 2023-09-01

STREAM CHANNEL PLAN

CACHE CREEK CULVERT REPLACEMENT

STA 0+05.476 TO STA 1+47.230

SCALE 0 2 1:250 12m

PROJECT NUMBER	REG	DRAWING NUMBER	REV
26239-0001	2	R2-1239-1111	

PLOT DATE : 2023/09/20 \\usl.urban-systems.com\projects\Projects_KEL\1961\0516\12\D-Design\CAD\DrawingProduction\1100_SubDisciplines\Hydrotechnical\HYDR-CacheCreek.dwg

PLOT DATE: 2023/09/20 \\usl.urban-systems.com\projects\Projects_KEL\1961\0516\12\D-Design\CAD\DrawingProduction\1100_SubDisciplines\Hydrotechnical\HYDR-CacheCreek.dwg

wsp

Engineers & Geoscientists BC Permit #1000200

REV	DATE	REVISIONS	NAME

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — C. T. COLES # 28149 — 2023-09-20

BRITISH COLUMBIA

MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

SOUTHERN INTERIOR REGION
HIGHWAY ENGINEERING AND GEOMATICS

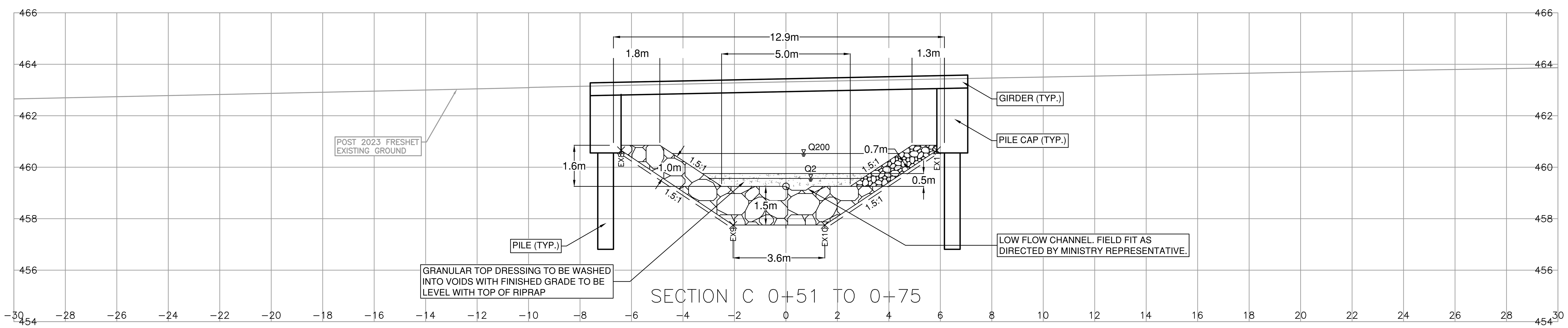
CAD FILENAME HYDR-CACHECREEK
FILE NUMBER 1961.0516.12
PLOT DATE 9/20/2023

DESIGNED	C. COLES	DATE	2023-09-01
QUALITY CONTROL	M.GABELHEI	DATE	2023-09-01
QUALITY ASSURANCE	C. BAGG	DATE	2023-09-01
DRAWN	J. BRUINEMAN	DATE	2023-09-01

STREAM CHANNEL PROFILE

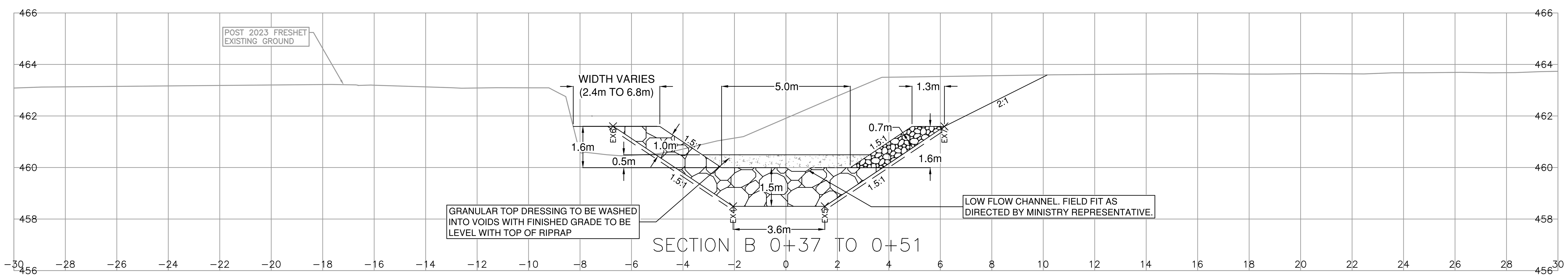
CACHE CREEK CULVERT REPLACEMENT

SCALE	PROJECT NUMBER	REG	DRAWING NUMBER	REV
0 2 H 1:250 10m / 0 0.25 V 1:25 1m	26239-0001	2	R2-1239-1112	



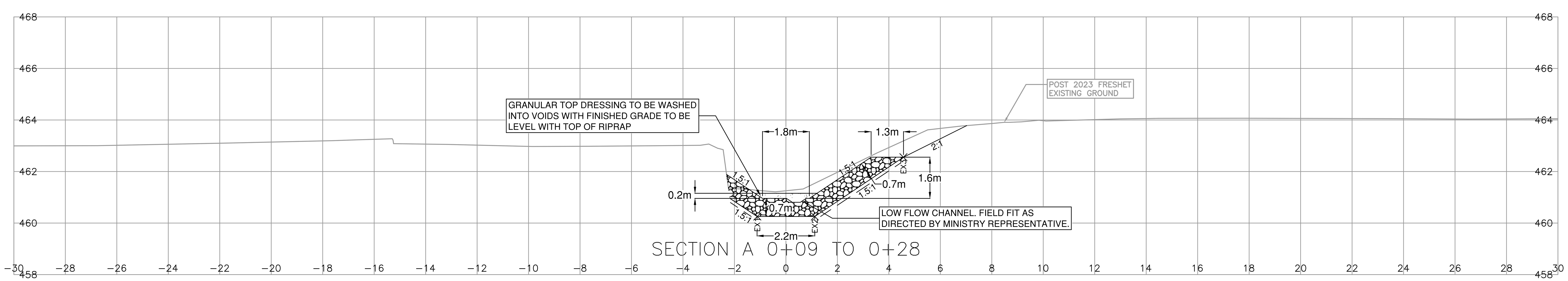
EXCAVATION SETOUT POINTS

ID	Elevation	Northing	Easting
EX8	460.65	630031.43	617992.17
EX9	457.75	630035.78	617992.21
EX10	457.75	630039.35	617992.24
EX11	460.65	630043.70	617992.28



EXCAVATION SETOUT POINTS

ID	Elevation	Northing	Easting
EX4	458.49	630036.49	618012.52
EX5	458.49	630040.01	618011.94
EX6	461.60	630031.89	618013.28
EX7	461.59	630044.59	618011.18



EXCAVATION SETOUT POINTS

ID	Elevation	Northing	Easting
EX1	460.26	630046.67	618036.88
EX2	460.26	630048.67	618035.89
EX3	462.56	630051.76	618034.36

LEGEND:

100kg RIPRAP
250kg RIPRAP
NON-WOVEN GEOTEXTILE
GRANULAR TOP DRESSING

NOTES:

1. ALL UNITS IN METERS UNLESS OTHERWISE NOTED
2. CHANNEL COMPLEXING DETAILS NOT SHOWN ON TYPICAL SECTIONS FOR CLARITY

REV	DATE	REVISIONS	NAME

Engineers & Geoscientists BC Permit #1000200

PROFESSIONAL ENGINEER PROVINCE OF BRITISH COLUMBIA C. T. COLES # 28149 2023-09-20

BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION
HIGHWAY ENGINEERING AND GEOMATICS

CAD FILENAME HYDR-CACHECREEK
FILE NUMBER 1961.0516.12
PLOT DATE 9/20/2023

DESIGNED C. COLES DATE 2023-09-01
QUALITY CONTROL M.GABELHEI DATE 2023-09-01
QUALITY ASSURANCE C. BAGG DATE 2023-09-01
DRAWN J. BRUINEMAN DATE 2023-09-01

wsp

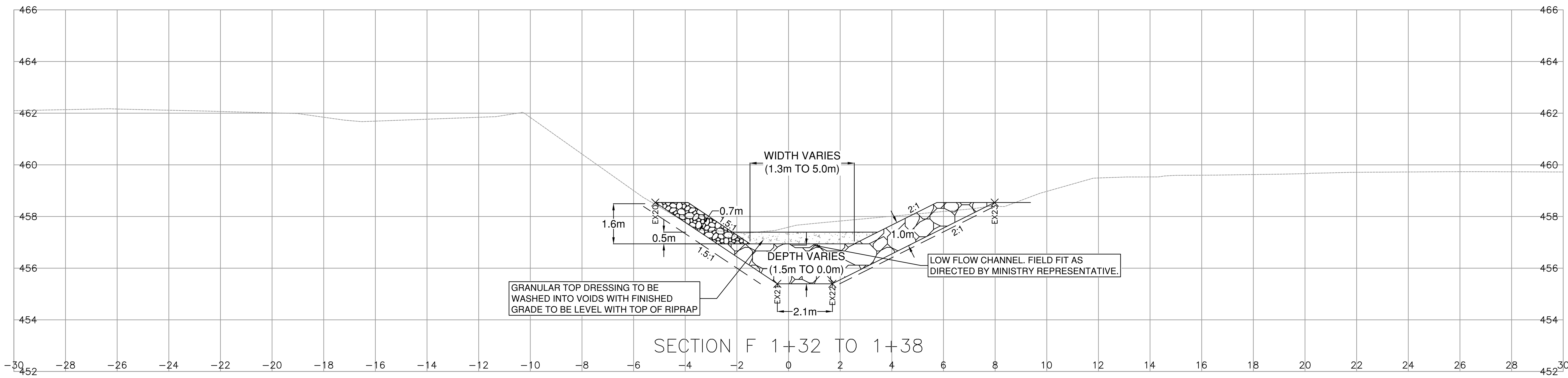
STREAM CHANNEL SECTIONS

CACHE CREEK CULVERT REPLACEMENT

SCALE 0 1 1:100 5m

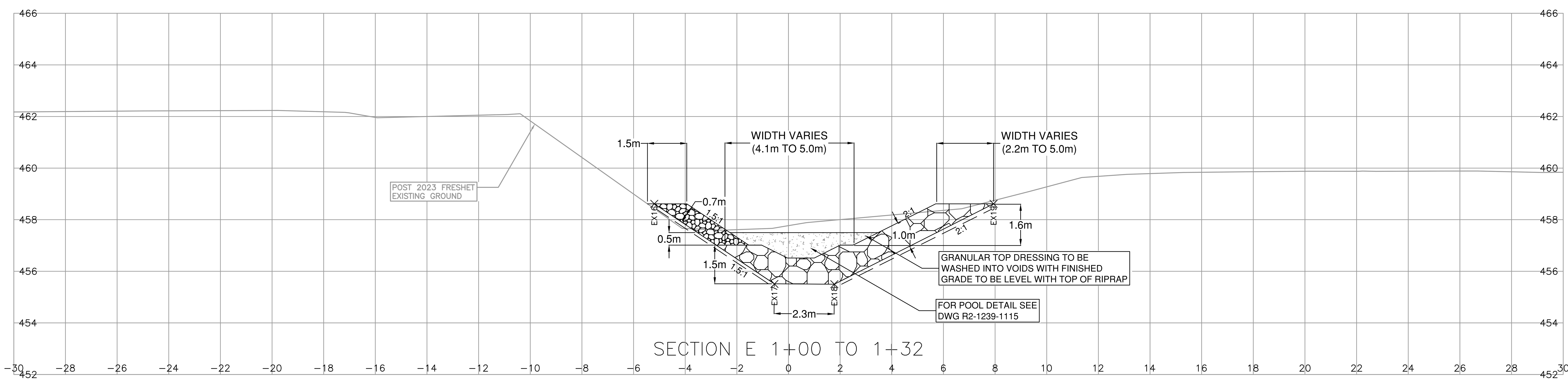
PROJECT NUMBER 26239-0001 | REG 2 | DRAWING NUMBER R2-1239-1113 | REV

PLOT DATE : 2023/09/20 \\usl.urban-systems.com\projects\Projects_KEL\1961\0516\12\D-Design\CAD\DrawingProduction\1100_SubDisciplines\Hydrotechnical\HYDR-CacheCreek.dwg



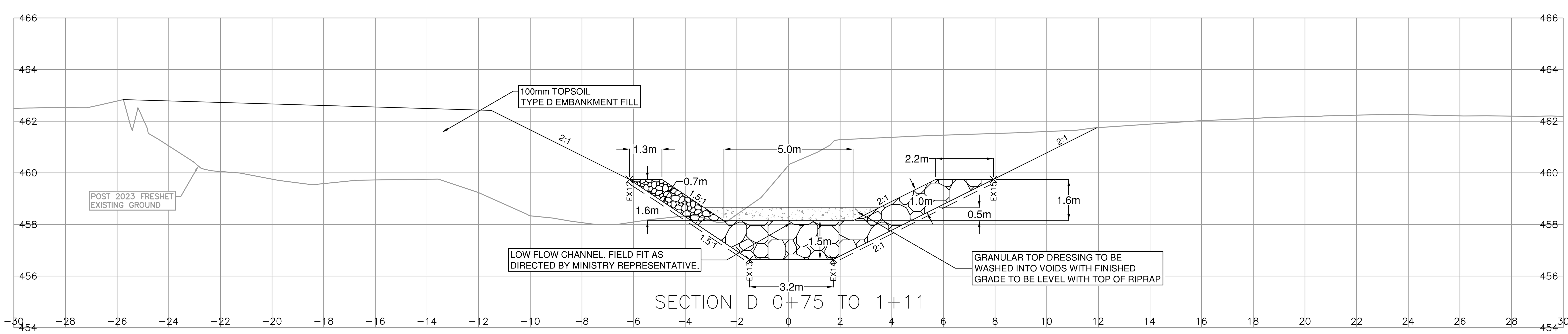
EXCAVATION SETOUT POINTS

ID	Elevation	Northing	Easting
EX20	458.54	630003.37	617928.92
EX21	455.39	630007.53	617926.68
EX22	455.39	630009.40	617925.66
EX23	458.54	630014.94	617922.69



EXCAVATION SETOUT POINTS

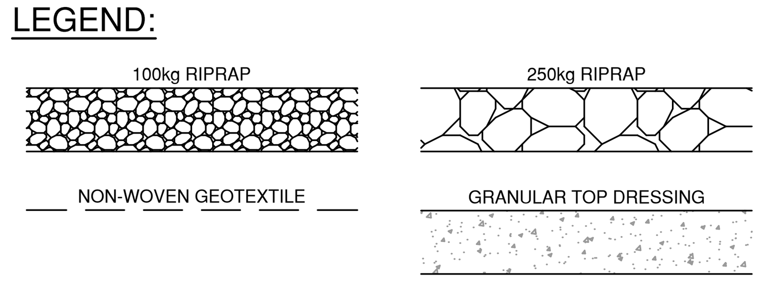
ID	Elevation	Northing	Easting
EX16	458.62	630007.20	617935.53
EX17	455.51	630011.12	617933.03
EX18	455.50	630013.08	617931.79
EX19	458.62	630018.28	617928.48



EXCAVATION SETOUT POINTS

ID	Elevation	Northing	Easting
EX12	459.74	630029.19	617965.30
EX13	456.64	630033.40	617963.34
EX14	456.64	630036.34	617961.96
EX15	459.74	630041.96	617959.33

LEGEND:



NOTES:

1. ALL UNITS IN METERS UNLESS OTHERWISE NOTED
2. CHANNEL COMPLEXING DETAILS NOT SHOWN ON TYPICAL SECTIONS FOR CLARITY

REV	DATE	REVISIONS	NAME

Engineers & Geoscientists BC Permit #1000200

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — C. T. COLES # 28149 — 2023-09-20

BRITISH COLUMBIA

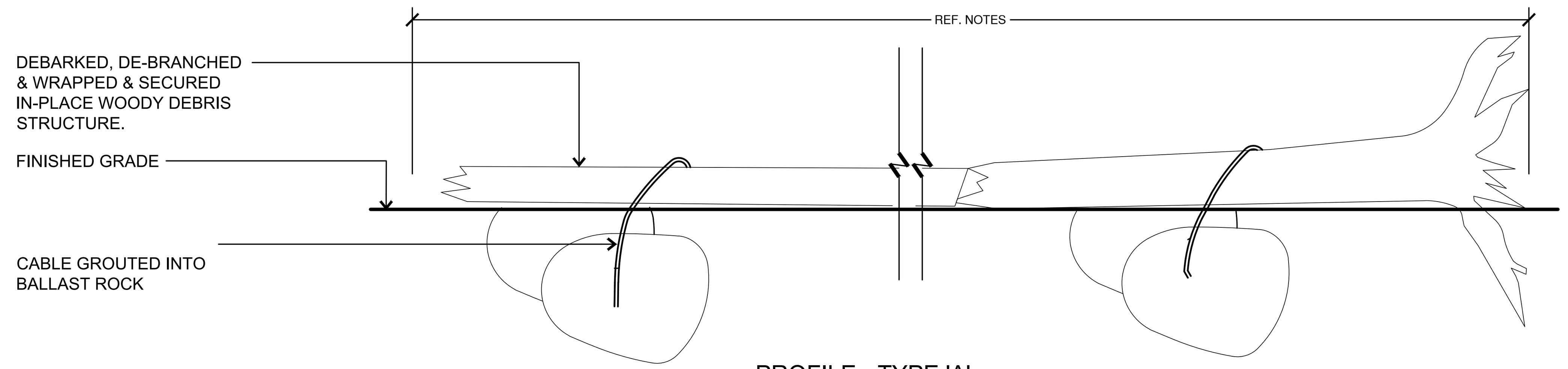
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION
HIGHWAY ENGINEERING AND GEOMATICS

CAD FILENAME	HYDR-CACHECREEK	DESIGNED	C. COLES	DATE	2023-09-01
		QUALITY CONTROL	M.GABELHEI	DATE	2023-09-01
FILE NUMBER	1961.0516.12	QUALITY ASSURANCE	C. BAGG	DATE	2023-09-01
PLOT DATE	9/20/2023	DRAWN	J. BRUINEMAN	DATE	2023-09-01

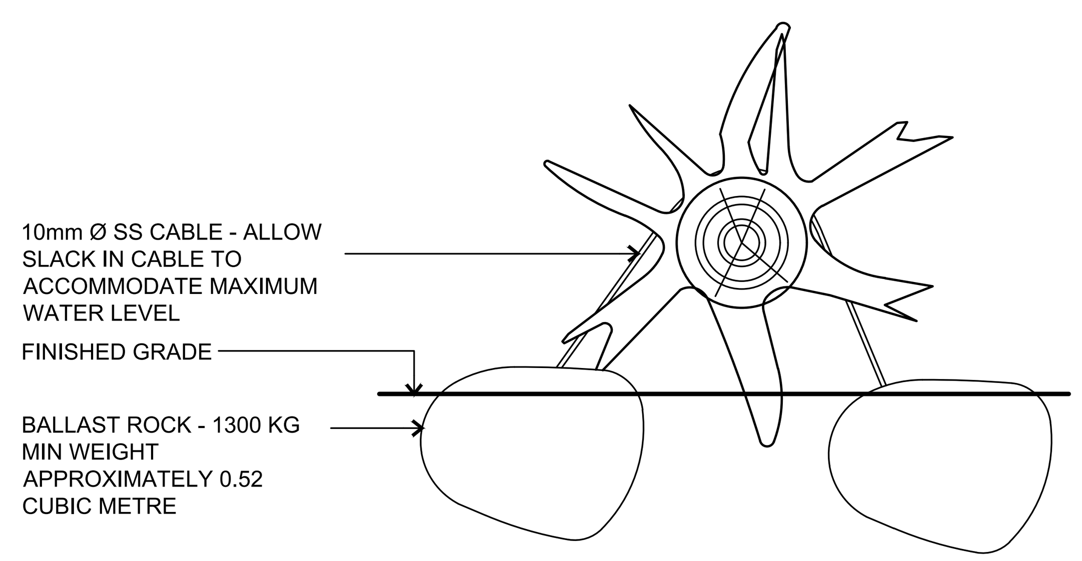
STREAM CHANNEL SECTIONS
CACHE CREEK CULVERT REPLACEMENT

SCALE	PROJECT NUMBER	REG	DRAWING NUMBER	REV
1:100 (0 1 5m)	26239-0001	2	R2-1239-1114	

PLOT DATE: 2023/09/20 \\usl.urban-systems.com\projects\Projects_KEL\1961\0516\12\D-Design\CAD\DrawingProduction\1100_SubDisciplines\Hydrotechnical\HYDR-CacheCreek.dwg



PROFILE - TYPE 'A'



CROSS-SECTION
TYPE 'A'

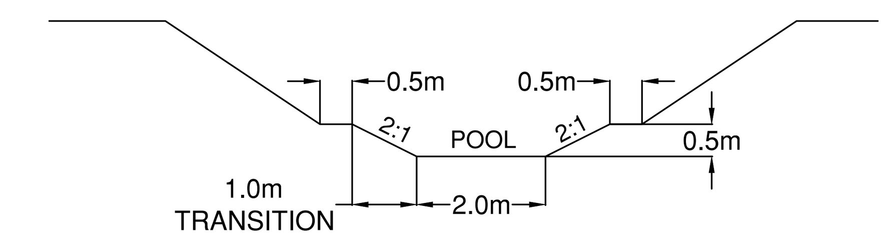
NOTES:

1. LOCATION OF BALLAST ROCK DETERMINED IN FIELD AND APPROVED BY MINISTRY REPRESENTATIVE.
2. LOCATION OF CABLE DETERMINED IN FIELD AND APPROVED BY MINISTRY REPRESENTATIVE.
3. EACH CONNECTED BOULDER SHALL CONSIST OF A 1300kg ROCK WITH AN APPROXIMATE AVERAGE DIMENSION OF 1000mm CONSISTENT WITH SS 205, TABLE 205-C.
4. WOODY DEBRIS SHALL BE CONSTRUCTED OF EXISTING COTTONWOOD LOG AND ROOT BALL REMOVED AS PART OF THE PROJECT OR DOUGLAS-FIR WITH AN AVERAGE TRUNK Ø OF 200mm MEASURED AT 1200mm ABOVE THE ROOT BALL, A ROOT BALL Ø OF 450mm, AND AN OVERALL LENGTH OF 2500mm.
5. CONTRACTOR TO PROVIDE SHOP DRAWINGS TO MINISTRY REPRESENTATIVE FOR REVIEW PRIOR TO INSTALL.

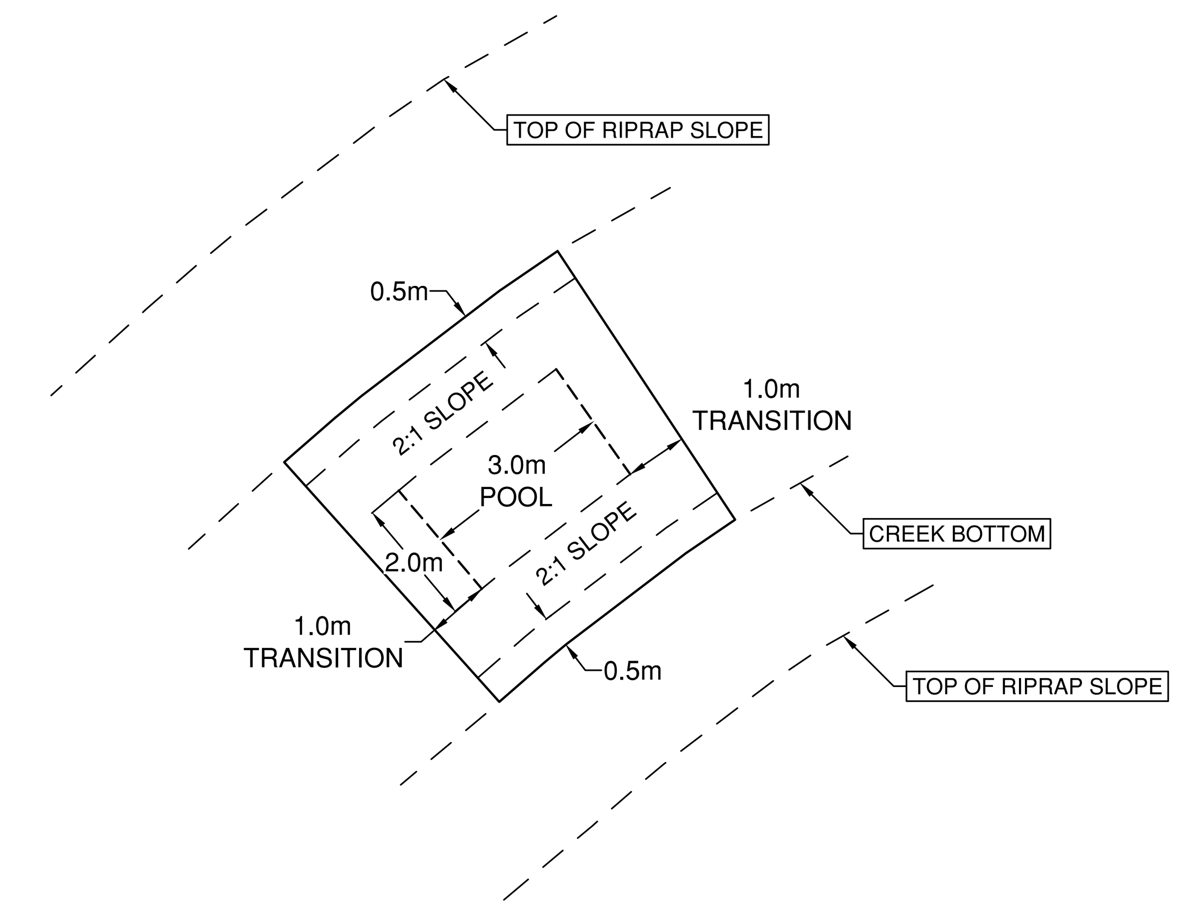
1 LARGE WOODY DEBRIS STRUCTURES

SCALE 1:25

P1-1961-0516-12-07



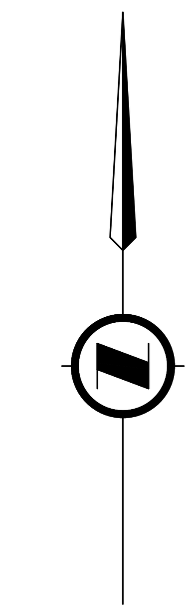
POOL CROSS-SECTION



POOL PLAN VIEW

02 POOL DETAIL

NOT TO SCALE



PLOT DATE: 2023/09/20 \\usl.urban-systems.com\projects\Projects_KEL\1961\0516\12\D-Design\CAD\DrawingProduction\1100_SubDisciplines\Hydrotechnical\HYDR-CacheCreek.dwg

wsp

Engineers & Geoscientists BC Permit #1000200

REV	DATE	REVISIONS	NAME

PROFESSIONAL ENGINEER — PROVINCE OF BRITISH COLUMBIA — C. T. COLES # 28149 — 2023-09-20

BRITISH COLUMBIA — MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION
HIGHWAY ENGINEERING AND GEOMATICS

CAD FILENAME HYDR-CACHECREEK
FILE NUMBER 1961.0516.12
PLOT DATE 9/20/2023

DESIGNED	C. COLES	DATE	2023-09-01
QUALITY CONTROL	M.GABELHEI	DATE	2023-09-01
QUALITY ASSURANCE	C. BAGG	DATE	2023-09-01
DRAWN	M.MENEZES	DATE	2023-09-01

CHANNEL DETAILS

CACHE CREEK CULVERT REPLACEMENT

SCALE	PROJECT NUMBER	REG	DRAWING NUMBER	REV
0 2 1:250 12m	26239-0001	2	R2-1239-1115	