Cottonwood Hill Slope Stabilization Project – Drainage Report

Final Submission

March 13, 2024

Submitted to: BC Ministry of Transportation and Infrastructure
Prepared by McElhanney

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Our file: 2121-00924-00

Your Challenge.
Our Passion.

Our File: 2121-00924-00

March 13, 2024

R.F. Binnie and Associates Ltd
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Burnaby, BC V5G 4K6

Attention: Maurizio Ponzini, P.Eng. – Design Manager, Cariboo Road Recovery Project

Cottonwood Hill Slope Stabilization Project – Drainage Report

The Cottonwood River/Hwy 97 geotechnical instability is located approx. 14 km north of Quesnel, BC. The instability is impacting Hwy 97, which transects the upper portion of the slide. A section of the highway is being relocated to the east, which is expected to improve the stability of the slide mass.

McElhanney was engaged by Binnie and Associates Ltd. (Binnie) to provide drainage analysis and detailed design of drainage infrastructure changes and upgrades for the site.

The following report summarizes the completed analyses and general drainage recommendations for the Issued for Tender (IFT) submission for the proposed highway realignment.

We trust this report meets the requirements of Binnie and the Ministry of Transportation and Infrastructure. Please do not hesitate to contact the undersigned with any questions or concerns.

Sincerely,
McElhanney Ltd.

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

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1. Introduction

Ministry of Transportation and Infrastructure (MoTI) retained McElhanney Ltd. (McElhanney) to provide design information on proposed drainage infrastructure for a proposed highway realignment through the Cottonwood Hill Slope Stabilization project site, located along Hwy 97 approximately 14 km north of Quesnel, B.C. This area contains a geotechnical instability adjacent to the highway, and as a result, the highway alignment is being altered to run further east of the river. The southern extent of the project is located around N53° 6' 10.2594", E-122° 21' 17.352" and extends north to N53° 6' 42, E-122° 21' 16"". Most of the surface water draining to this area comes from the hillslope located east of the site. This report presents the drainage analysis and design recommendations for the drainage infrastructure for the proposed highway realignment.

To estimate the flows and size of the culverts and ditches required to service the catchment, a hydrologic / hydraulic model was developed in PCSWMM (v7.5). The proposed highway design primarily conveys flows down the eastern ditches along the highway. Some flows from the western side of the highway near the highway crest are conveyed to the main east ditch. The main east ditch conveys water via a 1200 mm culvert, west where it discharges into a natural sag ponds/wetland. North of the highway crest, surface water is conveyed north via existing ditches. Three culverts were sized to convey flows away from the site. Additional information regarding riprap requirements in the ditches and the areas surrounding the culverts is supplied.

1.1. BACKGROUND DATA

McElhanney has gathered and reviewed background material relevant to the drainage area, climate, drawings, and GIS information to understand site constraints and design criteria comprehensively. Information relevant to drainage design was gathered from a number of sources including:

- Government of Canada historical rainfall data,
- Climatedata.ca,
- BC Ministry of Agriculture and BC Ministry of Environment and Climate Change Strategy Soil Information Finder Tool,
- LiDAR data collected as part of the Cariboo Rd Recover Project,
- Government of Canada topographic data,
- BC Supplement to TAC Geometric Design Guide, 2019 3rd edition,
- BC Water Resources Atlas
- iMapBC hydrologic zone data; and,
- Site visits and anecdotal information.
- Binnie's Draft 100% Detailed Design Drainage Drawings, dated Jan. 2024

1.2. RAINFALL DATA

The catchment area is located in the Fraser Plateau hydrologic zone. Rainfall data was gathered from Climatedata.ca, a collaborative project between Environment and Climate Change Canada, and several other institutions aiming to supply climate data for various climate change scenarios for different weather stations across Canada. Data was gathered from the nearby climate station of Quesnel Airport Auto (Station ID 1096631) located approximately 15km southwest of the site. This provides rainfall intensity-duration-frequency (IDF) curves for the site.

1.3. SOIL MAPS

Soil data was gathered using the BC Soil Information Finder Tool, which is a platform produced through a collaboration between the BC Ministry of Agriculture and the BC Ministry of Environment. The Tool was used to investigate what types of surficial soils are present within the catchment area that drains to the project site. This information was used to determine the infiltration properties of the watershed sub-catchments.

1.4. LIDAR AND TOPOGRAPHIC MAPS

McElhanney received detailed LiDAR data acquired from 2021 to 2023 as part of the project. It covered most of the catchment area that reports to the project site. A DEM of the proposed road realignment, merged with the existing LiDAR, was also provided. The surfaces were used to discern flow patterns in the highway's proximity, delineate sub-catchments within the project area, and assign properties to those sub-catchments (i.e. flow path length and slope).

Additional information on catchment boundaries was collected from the BC Freshwater Atlas, which delineates 1st order catchments and streams across the province. This information was used to assist in the delineation of the drainage catchment boundaries.

1.5. SITE VISIT AND ANECDOTAL INFORMATION

A site visit to assess existing drainage conditions was conducted on October 13th, 2023. Doug Johnston and Luc Harvey of McElhanney walked the lower 700m length of the project site. Stops were made at known culvert locations so that condition assessments and measurements could be taken. Observations from the site visit are as follows:

- Existing culvert crossings within the active portion of the geotechnical instability have been temporarily blocked to redirect collected runoff above the highway to a location to the south of the active instability.
- A construction access road has been constructed down to the Cottonwood River with its connection to the highway located just south of the active portion of the instability.
- The existing ditch on the highway's east shoulder is vegetated and has no riprap lining. Riprap ditch blocks have been installed at intermittent spacing along the existing ditch.

- The west side of the highway slopes down at approximately 2H:1V to the lower vegetated bench below. There is no existing ditches along this side of the highway and grass extends from the edge of the gravel shoulder to the toe of the embankment slope.

1.6. DESIGN CRITERIA

The BC Supplement to TAC Geometric Design Guide, 2019, 3rd edition, provided the primary design criteria for this project. Key guidelines are listed in Table 1. The return period utilized for analysis was selected in accordance with Section 1010, the hydrologic analysis of the catchment region was completed using methodology specified in Section 1020 Hydrology. Ditch and culvert design (refer to Section 3) complied with Sections 1030 and 1040, respectively.

We have designed ditches for a 100-year return period storm event as there is no safe overland flow path across the highway, other than through the proposed culverts without impacting the geotechnical instability. However, the extent of the ditch riprap lining was designed for the 25-year event to limit the required ditch depth.

Table 1: BC MoTI Design Guidelines

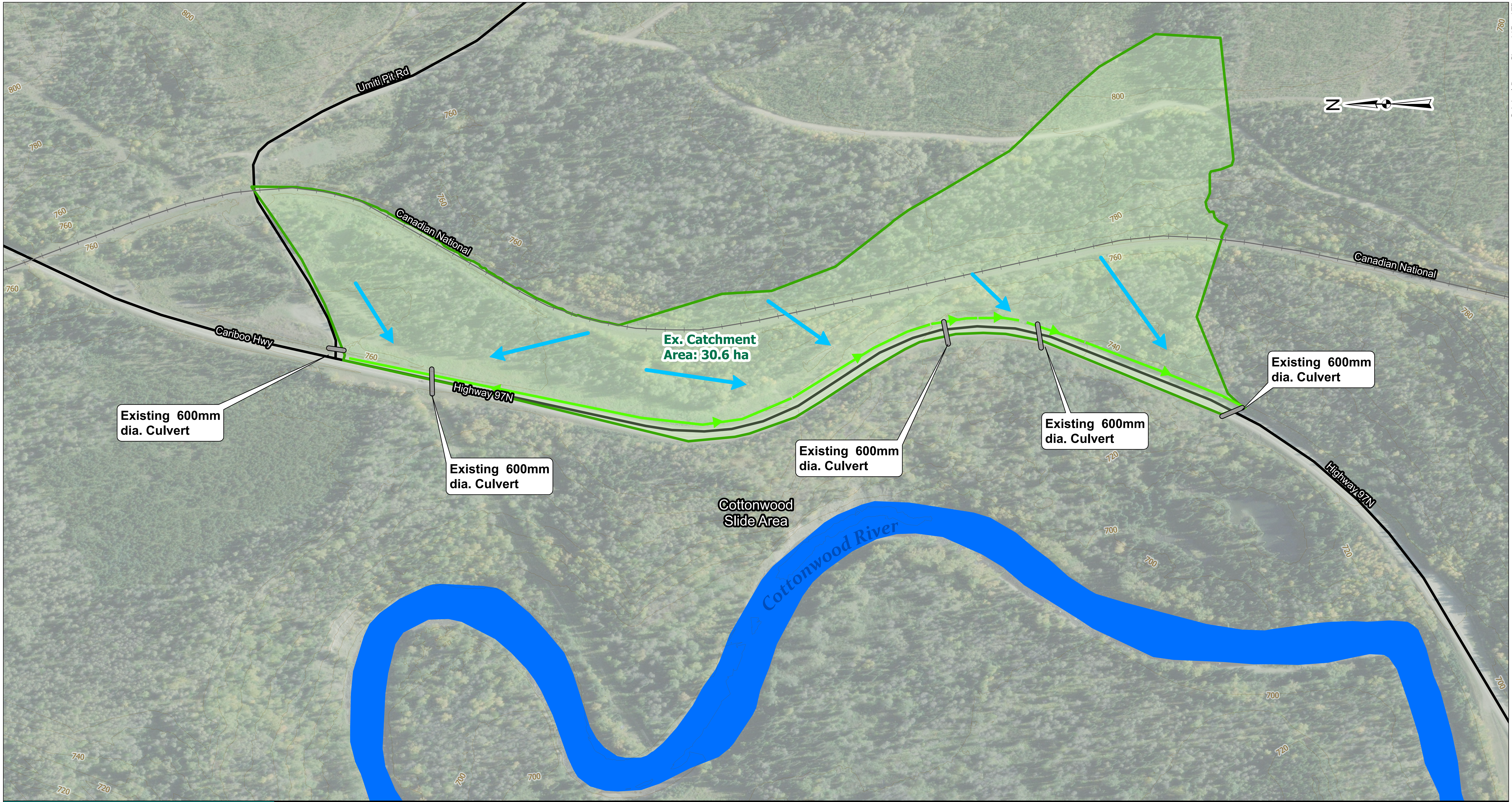
MoTI Section	Criteria	Value
1010 – General Design Guidelines	Design Return Period (Freeway) • Highway Ditches • Culverts < 3m Span • Storm Water Inlets	 100-year conveyance capacity, 25-year height of ditch riprap lining 100-year 5-year
1030 – Open Channel Design	Longitudinal Slope • Minimum • Recommended Channel Depth to Invert • Minimum Minimum Freeboard Minimum Channel Bottom Width Channel Side Slopes (H:V) • Minimum • Recommended Minimum • Maximum	 0.3% 0.5% 0.30m below SGSB layer 0.3m 1m 1.5:1 2:1 4:1
1040 – Culvert Design	Minimum Culvert Size • Under highway or main road • Driveway culvert Longitudinal Slope • Minimum • Maximum Roughness Coefficients • CSP Hydraulics • Inlet Control HW/D • Outlet Control Headloss Erosion Protection • Culvert Inlet Apron • Culvert Outlet Apron Culvert position • Length of Culvert extension • Protrusion	 600mm 400mm 0.5% 20% (CSP) 0.024 Shall not exceed 1.0 Shall not exceed 0.3m Shall be at least twice the culvert rise Shall be at least four times the culvert rise Typically extend 0.5m to 0.7m beyond the slope Shall not exceed 0.150m

MoTI Section	Criteria	Value
1050 – Pavement Drainage and Storm Sewers	Pavement Runoff • Runoff Coefficient • Time of Concentration • Minimum Pavement Grade • Maximum Ponding Width Grates / Spillway Spacing: • Depressed Bicycle Safe Grate Inlet Width • Spillway Width • Maximum Catchbasin / Spillway Spacing • Minimum Catchbasin / Spillway Spacing	0.95 5 minutes 0.3% Maximum of 65% of paved shoulder or 1.2m 0.625m 0.600m 150m 20m

2. Drainage Design Development

2.1. EXISTING CONDITIONS

The existing highway traverses the geotechnical instability between the Cottonwood River to the west and the railway to the east, and crests at approximately the centre of the north-most horizontal bend within the project site. South of the crest (high point), flow is conveyed south via the east ditch. This water is conveyed west across the highway via three culverts. There are two culverts north of the highway crest: one conveys water across the highway from the east highway ditch; the other conveys water flowing north across Umiti Pit Road at its junction with Highway 97. There are currently no ditches present on the west side of the highway through the geotechnical instability. There is a short section of ditch north of the instability on the west shoulder. Existing culverts and approximate drainage paths are shown in Figure 1.



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Projection:
NAD 1983 CSRS UTM Zone 10N

TITLE

Figure 1. Existing Culverts and Drainage Paths

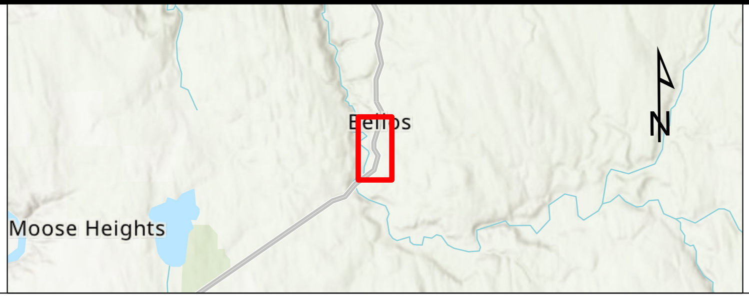
Project: Cottonwood Hill Slope Stabilization

Location: Hwy 97 Near Cottonwood River, BC

Scale 1:5,000

0 300 Meters

INSET



LEGEND

- Existing Road
- Railway
- Contour (10m Interval)
- Existing Ditch
- Existing Catchment
- Cottonwood River
- Existing Culvert
- Overland Flow Direction

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Author: JAlmeida

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2.2. PROPOSED DRAINAGE DESIGN

The 100% drainage drawings provide details on the proposed drainage design. The limits of construction for the proposed highway modifications extend from station 198+68 (N 883612.979, E 543110.239) to station 212+41 (N 884933.180, E 543209.252), a total distance of 1.37km. The modifications include a horizontal realignment to shift a portion of the highway to the east by a short distance to reduce its impacts on the geotechnical instability. The highway length that is modified as part of this project will also be widened to improve safety.

Figure 2 shows the proposed drainage system layout and associated catchment areas for the project.

2.2.1. Culverts

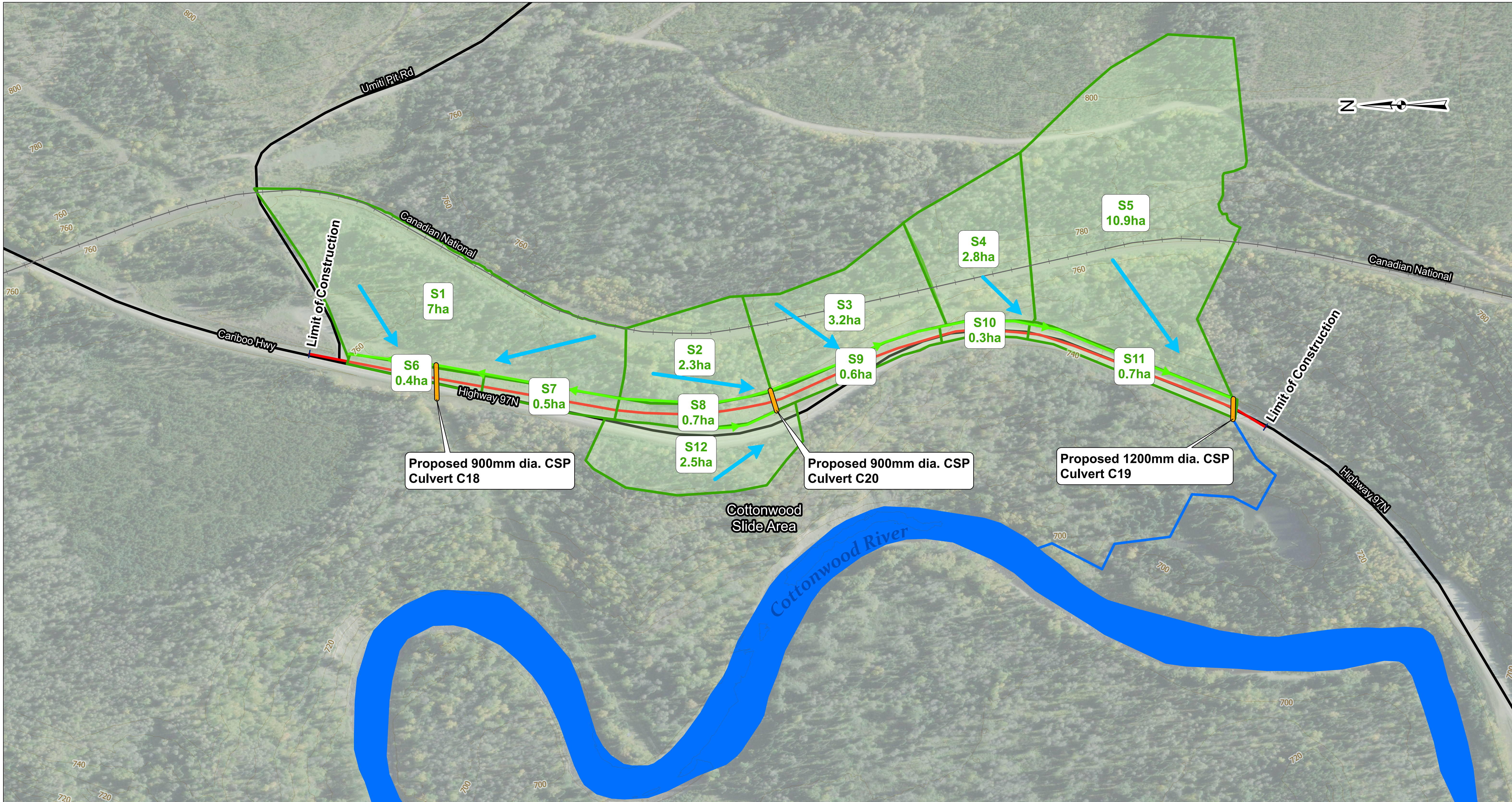
Two new culverts are required to convey surface water south. A 1200 mm diameter CSP is specified at the southern project limit (Sta. 199+01). It will convey runoff from the east ditch west through the highway, eventually discharging it to the existing sag pond. A new culvert is also specified at Sta. 205+90. It conveys flow collected in the west ditch near the highway crest to the main east ditch.

The existing culvert at the north end of the project site south of Umiti road requires replacement. The existing culvert at Sta. 210+61, which conveys flow from the east ditch across the highway to a natural drainage path to the west, will be replaced to accommodate an increase in design flow and lengthened to accommodate the new highway width.

2.2.2. Ditches

All ditches along the modified highway length will have a bottom width of 1.0m with 2H:1V side slopes. Similar to the existing conditions, a ditch is present on the east side for the entire 1.37km modified highway. The portion of the realigned highway near the existing highway crest will require significant cutting, creating an upslope catchment on both sides of the roadway. A ditch will be present on the west side through this section to collect runoff and convey it to the culvert located at Sta. 205+90. A ditch will also be provided on the west shoulder of the highway from approximately Sta. 204+40 to Sta. 203+33 and will discharge to a riprap spillway at the southern end.

Ditches south of Sta. 205+45 will be at a longitudinal grade of 4.5% towards the south, matching the highway slope except for special ditching. There are several areas along the highway where special ditching will be required to create a continuous ditch along the east side of the highway. These grades range from 1.2% to 7.5%. The ditch slope will gradually flatten north of Sta. 205+45 until it crests and begins to slope to the north.



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Projection:
NAD 1983 CSRS UTM Zone 10N

TITLE

Figure 2. Proposed Culverts and Drainage Paths

Project: Cottonwood Hill Slope Stabilization
Location: Hwy 97 Near Cottonwood River, BC

Scale 1:5,000
0 — 300 Meters

INSET

LEGEND

- Subcatchments
- Proposed Highway Realignment
- Existing Road
- Railway
- Proposed Ditch
- Proposed Culvert
- Overland Flow Direction
- Drainage Path
- Contour (10m Interval)
- Cottonwood River

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3. Hydrology

3.1. HISTORIC RAINFALL DATA

Rainfall data was obtained from ClimateData.ca for the Quesnel Airport Auto station. Table 2 below provides historic rainfall IDF data for the site.

Table 2: Present-day rainfall IDF information based on historical data.

Duration (hr)	2-year (mm/h)	5-year (mm/h)	10-year (mm/h)	25-year (mm/h)	50-year (mm/h)	100-year (mm/h)
0.083	51.8	66.1	75.6	87.5	96.4	105.2
0.167	36.1	45.6	51.8	59.8	65.6	71.5
0.25	28.1	36.3	41.8	48.7	53.8	58.9
0.5	16.8	23.6	28.1	33.8	38	42.2
1	10.2	14.5	17.4	21.1	23.8	26.5
2	6.1	8.3	9.7	11.5	12.9	14.2
6	2.9	3.6	4.1	4.7	5.1	5.6
12	1.9	2.4	2.8	3.2	3.5	3.8
24	1.1	1.4	1.5	1.7	1.9	2

Single-event design storms used in the hydrologic model were created using the IDF data from Climatedata.ca.

3.2. CLIMATE CHANGE

The effect of climate change on rainfall data was assessed using the information provided by ClimateData.ca. The data supplied by the site uses the Clausius Clapeyron relation to estimate the projected increase in rainfall volume due to projected temperature increases into the future and the resulting increase in the air's moisture-holding capacity. The worst-case emission scenario SSP5-8.5, representing the upper boundary range of emissions by 2100 (similar to RCP 8.5), was utilized to generate the projected IDF curve. The climate data used a period of 2070 to 2100 to represent the future climate scenario for this project. Table 3 provides rainfall intensities for various return periods and durations for the future period.

Table 3: Rainfall intensity and duration data for the SSP5-8.5 climate scenario for the future period of 2070-2100.

Duration (hr)	2-year (mm/h)	5-year (mm/h)	10-year (mm/h)	25-year (mm/h)	50-year (mm/h)	100-year (mm/h)
0.083	73	93	106	123	136	148
0.167	51	64	73	84	92	101
0.25	40	51	59	68	76	83
0.5	24	33	40	48	53	59
1	14	20	24	30	33	37
2	8.6	12	14	16	18	20
6	4.1	5.1	5.8	6.6	7.2	7.9
12	2.7	3.4	3.9	4.5	4.9	5.3
24	1.5	2	2.1	2.4	2.7	2.8

4. Hydrologic and Hydraulic Modelling

MoTI design standards allow designers to use several methods to estimate peak discharge rates for sizing drainage infrastructure. For this project, hydrologic / hydraulic computational modelling was selected to estimate flows from the study area sub-catchments to assess the existing crossings' capacity and to size infrastructure upgrades.

Single-event computational modeling was undertaken to determine peak flows during design storm conditions. The hydrologic / hydraulic model was developed in PCSWMM version 7.5., a computational hydraulic modeling software that relies on the well-known and widely used United States Environmental Protection Agency's (USEPA) Stormwater Management Model (SWMM) version 5.1. engine. PCSWMM was developed by Computational Hydraulics International (CHI) as a combined hydrology-hydraulic modeling package.

4.1. MODEL BUILD

Hydrologic / hydraulic modelling requires various input parameters to simulate the rainfall-to-runoff and routing processes. Some key input parameters required for hydrologic / hydraulic simulation of catchment areas and conduits are presented in Table 4.

Table 4: Catchment Parameters and Conduit Roughness Coefficients

Parameter	Value
Overland Impervious Manning's n	0.011
Overland Pervious Manning's n	Forested Catchments - 0.4 Road Catchments – 0.1
Catchment Slope	Forested Catchments - 5% to 23% Road Catchments – 0% to 4.5%
Impervious Depression Storage (mm)	1
Pervious Depression Storage (mm)	5
Conduit Roughness Coefficients	CSP – 0.024 Ditches – 0.025

The catchment area for the project site is undeveloped, with only the railway and highway running through it. As a conservative measure, a minimum of 2% impervious area was selected for these forested sub-catchments to account for potential unseen rock outcrops that could contribute to impervious area. The percent impervious area based on land type is presented in Table 5.

Table 5: Percent Impervious of Land Covers Present in Drainage Area

Catchment Land Cover	Percent Impervious
Forest	2 (minimum)
Road	95

Infiltration losses for this analysis were calculated using the Soil Conservations Service (SCS) curve number (CN) method. Infiltration parameters were assumed to be universal for the catchment area. Soil drainage rates in the region were identified as primarily Well Drained to Moderately Well drained, which corresponded to soil groups B and C. Soil group C was selected as a conservative estimate for the catchment area. Saturated soil conditions following the spring melt or continuous rainfall events were assumed for the design events corresponding to antecedent moisture condition (AMC) III. These conditions result in a curve number of 80.

4.2. DESIGN STORMS

Synthetic design storms that account for climate change were simulated to estimate design flows for the culverts and ditches. The Soil Conservation Service (SCS) Type II distribution was used to generate the synthetic design storms for a 24-hour event. The events were then scaled for varying peak intensities from the design IDF curves to confirm the catchment's time of concentration. Design storms were then generated for each design return period event for the catchment's associated time of concentration. A summary of the climate change-adjusted design storms used for the drainage analysis are presented in Table 6.

Table 6: Design Storm Characteristics

Event	Total Design Storm Rainfall Based on Historical Data (mm)	Total Design Storm Rainfall Adjusted for Climate Change (mm)
SCS Type II 100-Year, 24-Hour	58.4	81.6
SCS Type II 25-Year, 24-Hour	46.5	66.1

The historical and climate change-adjusted design storms were applied to the PCSWMM model and the resulting design flows for the proposed culverts were compared between the two scenarios. The change in flow was found to be disproportionately larger than the change in rainfall intensity for the various return periods modelled (approximately 40% increase in rainfall results in an average of 120% increase in design flow). This occurs because as the rainfall intensity increases, the soil infiltration rate in the model remains the same, leading to all of the excess precipitation contributing to runoff. The model is likely overestimating the runoff volumes and would lead to conservative design flow estimates. However, given the small catchments in this drainage and the fact that some infrastructure is being sized for additional resilience, we have adopted the conservative increase for this particular assignment.

The resulting runoff coefficients from the hydrologic / hydraulic model for the climate change scenarios averaged 0.48 for forested areas and 0.96 for roadways for the 100-year design storm. The storm events were applied to the entire site area equally.

5. Drainage Infrastructure Sizing

5.1. CULVERT PERFORMANCE

The proposed culvert performances were assessed under the 100-year design storms (per the supplement to TAC) and the results are summarized in Table 7.

Table 7: Proposed Culvert Sizes and Performance

Proposed Culvert	Culvert Status	100-Year Design Flow with Climate Change (m^3/s)	Culvert Diameter (mm)	Slope (%)	HW/D	Outlet Control Headloss (m)	Outlet Velocity (m/s)
C18	Replacement	0.435	900	0.9	0.62	0.12	1.42
C19	New	1.415	1200	5.0	0.82	0.25	3.67
C20	New	0.227	900	1.5	0.40	~0.00	1.49

Culvert C18 is replacing a culvert that currently occupies the same location. C19 and C20 will be installed in locations where there are currently no culverts. All culverts should be aluminized Type II coated, corrugated steel pipe (CSP). The minimum pipe wall thickness should be 2.8mm for culvert C19 and 2.0mm for culverts C18 and C20.

Each culvert was assessed to determine whether it operated in inlet or outlet control. Due to the steep hillslope gradients and the lack of water depth at the outlet, inlet control was found to govern the sizing of all culverts.

The culvert diameters above are shown to meet the MoTI design criteria. A minimum cover of 0.45m should be provided above all culverts per the Supplement to TAC. All culvert inlets should be mitered to the slope to reduce the risk of debris blockages and improve the flow from the ditch into the culvert inlet. Headwalls are not recommended for any of the culvert installations.

Culvert hydraulic calculations are included in Appendix B.

5.2. CULVERT RIPRAP SIZING

The area around the culvert inlets should be lined with Class 50kg riprap. Ditch blocks should be installed immediately downstream of the culvert inlets with a crest elevation that matches the culvert inlet crown elevation to help ensure that surface water flow is properly routed into the culvert and does not bypass the culvert entrance.

Splash pads are required at the outlet of all culverts to mitigate erosion and scour at the culvert outlet. Class 50kg riprap is required for the splash pads at the outlets of culverts C18 and C20.

Class 250kg riprap is required for the splash pad at the outlet of culvert C19. Splash pad dimensions should generally conform to the following:

- Horizontal extents relative to the culvert outlet should be 3 times the pipe diameter centered around the pipe outlet.
- The coverage should extend a distance of at least 4 times the pipe diameter past the culvert outlet.
- Riprap should extend a minimum of 300mm above the crown of the pipe.
- The top of riprap at the culvert outlet should be at the same elevation as the outlet invert.

For culvert C19 a riprap channel should be provided down the proposed road embankment and terminate at a point where the slope becomes less steep (approximately 35m downstream of the culvert outlet) in the direction of the natural sag ponds/wetland. This channel should be constructed with a base width of 1m and a minimum riprap height of 0.55m

Culvert outlet velocity and riprap sizing calculations are included in Appendix B.

5.3. DITCH LINING

Based on calculated channel velocities, ditches with a slope steeper than 3.5% and up to 7.5% should be lined with a minimum of Class 10kg riprap to prevent erosion up to the 25-year design flow. This excludes the ditch on the west side of the highway south of the instability which is expected to convey very little flow. Riprap should extend to the base of the SGSB layer per Supplement to TAC design criteria. Ditches will be capable of conveying the 100-year design flows to the culverts but may experience minor erosion due to the limited vertical extent of the rock.

Riprap rock quality and gradation, placement, thickness, geotextile and base preparation should meet the MoTI 2020 Standard Specifications for Highway Construction requirements for the culvert and ditch riprap lining and splash pads.

5.4. CONCRETE DRAINAGE BARRIER AND SPILLWAY LOCATIONS

Asphalt spillways and/or concrete drainage barriers (CDB) have been included in the proposed drainage design along the new section of the highway due to the proposed highway superelevation, widening, fill height and/or addition of concrete barriers. Concrete roadside barriers have been placed along the east and west sides of the highway, starting at around Sta.198+80. The barriers on the west side terminate around Sta.208+24. The barriers on the east side terminate at Sta. 205+65, where they transition to an asphalt curb extending north until Sta.211+00. The proposed highway geometry was used to calculate the required locations and spacing of the asphalt spillways and CDBs. A summary of the proposed spillway and CDB locations is included in Table 8.

Detailed spillway spacing calculations are also included in Appendix D.

Table 8: Concrete Drainage Barrier and Spillway Locations

Spillway ID	Station	Side of Road	Type	Maximum Spacing (m)	Actual Spacing (m)	Notes
1	198+80	West	CDB + Spillway	142	145	Construction access road reduces contributing road length to 142m
2	200+25	West	CDB + Spillway	80	80	
3	201+05	West	CDB + Spillway	80	80	
4	201+85	West	CDB + Spillway	297	138	
5	203+23	West	CDB + Spillway	188	150	
6	204+73	East	CDB + Spillway	26	20	
7	204+93	East	CDB + Spillway	130	77	
8	205+70	East	Asphalt Curb + Spillway	200	150	
9	207+20	East	Asphalt Curb + Spillway	99	63	
10	207+83	East	Asphalt Curb + Spillway	20	20	Minimum spacing is 20m as per Supplement to TAC
11	208+03	East	Asphalt Curb + Spillway	4	20	Highway Crest
12	208+23	East	Asphalt Curb + Spillway	3	20	Minimum spacing is 20m as per Supplement to TAC
13	208+43	East	Asphalt Curb + Spillway	16	20	Minimum spacing is 20m as per Supplement to TAC
14	208+72	East	Asphalt Curb + Spillway	29	29	
15	209+02	East	Asphalt Curb + Spillway	30	30	
16	209+32	East	Asphalt Curb + Spillway	30	30	
17	209+62	East	Asphalt Curb + Spillway	30	30	
18	209+92	East	Asphalt Curb + Spillway	30	30	

19	210+22	East	Asphalt Curb + Spillway	30	30	
20	210+52	East	Asphalt Curb + Spillway	30	30	
21	210+76	East	Asphalt Curb + Spillway	30	24	
22	210+99	East	Asphalt Curb + Spillway	30	23	Spillway is located at end of asphalt curb.

6. Conclusion

MoTI engaged McElhanney to provide drainage analysis and design for the Cottonwood Hill Slope Stabilization Project. This project involves a realignment of an existing section of Highway 97, approximately 14 km north of Quesnel, BC, to reduce its impacts on the active geotechnical instability in the area. This realignment work will include modifications to the existing drainage system to convey upslope catchment and highway runoff away from the active geotechnical instability.

Much of the surface water draining to this area comes from the hillslope east of the site. A computational model was developed to determine peak runoff flows generated from the catchments contained in the project area. The capacity of the proposed culverts to convey the 100-yr runoff generated by the Highway 97 catchments was evaluated with a hydrologic / hydraulic model created in PCSWMM. Runoff from these catchments is conveyed along the highway ditch system, and through the proposed culverts to be discharged on the west side of the highway, at locations outside the extents of the active portion of the geotechnical instability.

The resulting flows and velocities from the model were used to confirm the required culvert and ditch sizing, associated riprap requirements, and asphalt spillway / CDB locations for the new highway design. These are summarized in Section 5.

APPENDIX A

Design Criteria Sheet for Climate Change Resilience.

Design Criteria Sheet for Climate Change Resilience

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

Project: *Caribou Road Recovery Projects – Cottonwood Hill Slope Stabilization Project*
Type of work: *Highway 97 Culvert Replacement*
Location: *Highway 97, 19.2km north of Quesnel*
Discipline: *Hydrotechnical*

Design Component	Design Life or Return Period	Design Criteria + (Units)	Design Value Without Climate Change	Change in Design Value from Future Climate	Design Value Including Climate Change	Adaptation Cost Estimate ($)	Comments / Notes / Deviations / Variances
Culvert C18 <3m	100-yr RP	Peak Flow Rate (m^3/s)	0.209	0.226 m^3/s (108% increase)	0.435	$5,900	The CSP size required to accommodate the design flow without climate change is 600 mm. The CSP culvert must be sized up to 900 mm to accommodate the design flow with climate change. The increased size improves system resiliency from debris and sedimentation, and improves access for maintenance purposes.
Culvert C19 < 3m	100-yr RP	Peak Flow Rate (m^3/s)	0.669	0.746 m^3/s (112% increase)	1.415	$9,300	The CSP size required to accommodate the design flow without climate change is 900 mm. The CSP culvert must be sized up to 1200 mm to accommodate the design flow with climate change. The increased size improves system resiliency from debris, sedimentation, and improves access for maintenance purposes.
Culvert C20 < 3m	100-yr RP	Peak Flow Rate (m^3/s)	0.085	0.142 m^3/s (167% increase)	0.227	$3,800	The CSP size required to accommodate the design flow without climate change is 600 mm. The CSP culvert must be sized up to

							900 mm to accommodate the design flow with climate change. design flow with climate change. The increased size improves system resiliency from debris and sedimentation, and improves access for maintenance purposes.
Concrete Drainage Barriers and Spillways	5-yr RP	Number of spillways	18	4 (22% increase)	22	$10,000	Increased rainfall intensity reduced the spillway spacing in areas where the calculated spillway spacing for historical climate conditions was between the minimum and maximum spacing specified in the supplement to TAC.

Explanatory Notes / Discussion:

The proposed drainage infrastructure described in this document forms the drainage system for the proposed highway realignment, which will be completed as part of Phase 2 of the Cottonwood Hill Slope Stabilization project. The drainage system design criteria, hydrologic analysis, and hydraulic calculations for the highway realignment are summarized in the Drainage Report (Final), dated February 23, 2024.

The proposed major drainage infrastructure for the highway realignment includes two new culvert installations (C19 and C20) and one culvert replacement (C18). To limit the runoff that flows onto the active slide area below the highway, fewer culverts are proposed to convey larger portions of the upslope catchment and discharge to areas on the outer extents of the slide.

The proposed culverts were sized to convey the climate change-adjusted flows from the revised catchment areas. The climate change analysis was performed using the climatedata.ca climate change-adjusted IDF curves provided by Environment and Climate Change Canada (ECCC). Climate change adjusted IDF curves were selected for the SSP5-8.5 scenario under the CMIP6 climate model. These IDF curves show an increase in the 100-year rainfall intensity of approximately 40% between historical and future scenarios. This results in an average modelled increase in the 100-year design flow of 120%. A comparison of the pre- and post-climate change pipe diameters and design HW/D values for the proposed culverts is given below.

Culvert ID	***100-yr design flow without climate change***		***100-yr design flow with climate change***	
	Pipe Diameter (mm)	*HW/D*	*Pipe Diameter (mm)*	*HW/D*
C18	600	0.61	900	0.58
C19	900	0.8	1200	0.82
C20	600	0.42	900	0.38

PCSWMM model results show a disproportionately large change in the culvert design flows compared to the change in rainfall intensity for the various return periods modelled. The model likely overestimates the runoff values under climate change scenarios and leads to conservative design flow estimates. However, given the small catchments in this drainage and the fact that some infrastructure is being sized for additional resilience, we have adopted the conservative increase for this assignment.

Spillway spacing for the proposed highway realignment ranges from a minimum of 20m at the north end of the project (flatter areas) to a maximum of 150m in areas with the highest crossfall and longitudinal slope (at the sharpest bend). The calculated spillway spacing for historical climate conditions at the north end of the project were generally above the minimum spacing requirement, so the increased rainfall intensity due to climate change had a larger effect on the number of spillways in this area. In comparison, calculated spillway spacing for historical climate conditions for the southern half of the site were typically greater than the maximum allowable spacing of 150m (Supplement to TAC) and were therefore less affected by climate change. Four additional spillways were found to be required to account for climate change.

Recommended by: Engineer of Record: Luc Harvey, P.Eng
(Print Name / Provide Seal & Signature)

Final Document

PROFESSIONAL
PROVINCE OF
L. C. HARVEY
56602
BRITISH COLUMBIA
ENGINEER

2024-03-14

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

Date: ______March 13, 2024______

Engineering Firm: ____McElhanney Ltd.______

Accepted by BCMoTI Consultant Liaison: ______
(For External Design)

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

APPENDIX B

Culvert Hydraulic Calculations

McElhanney

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project No.:	**2121-00924-00**
Purpose:	**Sizing of culvert C18 to convey 100-year climate change-adjusted peak flow**
Location:	
Equation Type:	
Case:	

Inputs	Description		Value	Units	Notes/Source
Flows					
Q_{design}	Design Flow	=	0.435	m^3/s	See 'Design Flows' tab
Elevations					
EL_i	Culvert Inlet Elevation	=	758.66	m geo.	input
EL_o	Culvert Outlet Elevation	=	758.28	m geo.	input
Hydraulic Parameters					
K_U	Friction loss coefficient	=	19.63	unitless (SI)	Hydraulic Design of Highway Culverts, culvert design form
n	Manning's roughness	=	0.024	unitless	standard value for CSP
k_e	Entrance loss coefficient	=	0.9	unitless	Hydraulic Design of Highway Culverts: Projecting from fill slope
k_o	Exit loss coefficient	=	1.0	unitless	standard
$TW_{channel}$	Normal flow tailwater in outlet channel	=	0.00	m	
Culvert Dimensions					
D	Pipe Diameter	=	0.9	m	input
L	Pipe length	=	44	m	input
N	Number of Barrels	=	1		input
s	Slope	=	0.9%		

Legend
Input
Output

Outputs	Equation		Value	Units	Notes
Flows					
Flow per Barrel, Q	Q_{design}/N	=	0.435	m^3/s	
Inlet Control					
HW_i/D	From nomograph, 2A	=	0.62	unitless	
Inlet Control Headwater Depth, HW_i/D	$HW_i/D \times D$	=	0.56	m	
Elevation of Inlet Headwater, EL_{hi}	$EL_i + HW_i$	=	**759.22**	m geo.	
Outlet Velocity					
Critical depth for CSP pipe arch, d_c	From nomograph, 4A	=	0.40	m	Hydraulic Design of Highway Culverts: Projecting from fill slope
Critical tailwater, TW_{crit}	$(d_c + D)/2$	=	0.65	m	
Controlling tailwater depth, h_0	greater of $TW_{channel}$ and TW_{crit}	=	0.65	m	
Headloss, H	From nomograph, 6A	=	0.12	m	Hydraulic Design of Highway Culverts
Outlet Control Headwater Depth, HW_o	$H+h_o$	=	0.77	m	Hydraulic Design of Highway Culverts
Outlet Control Headwater Elevation, EL_{ho}	EL_o+HW_o	=	**759.05**	m geo.	
Design Checks					
Is Culvert in Inlet Control	if $EL_{ho} \leq EL_{hi}$: TRUE, else: FALSE)		**TRUE**		
Controlling Inlet Headwater Elevation, HW_0	max of EL_{ho} and EL_{hi}	=	**759.2**	m	

McElhanney

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project No.:	**2121-00924-00**
Purpose:	**Sizing of culvert C19 to convey 100-year climate change-adjusted peak flow**
Location:	
Equation Type:	
Case:	

Inputs	Description		Value	Units	Notes/Source
Flows					
Q_{design}	Design Flow		1.415	m^3/s	See 'Design Flows' tab
Elevations					
EL_i	Culvert Inlet Elevation		730.47	m geo.	input
EL_o	Culvert Outlet Elevation		729.05	m geo.	input
Hydraulic Parameters					
K_U	Friction loss coefficient		19.63	unitless (SI)	Hydraulic Design of Highway Culverts, culvert design form
n	Manning's roughness		0.024	unitless	standard value for CSP
k_e	Entrance loss coefficient		0.9	unitless	Hydraulic Design of Highway Culverts: Projecting from fill slope
k_o	Exit loss coefficient		1.0	unitless	standard
$TW_{channel}$	Normal flow tailwater in outlet channel		0.00	m	
Culvert Dimensions					
D	Pipe Diameter	=	1.2	m	input
L	Pipe Length	=	28.5	m	input
N	Number of Barrels	=	1		input
s	Slope	=	5.0%		

Outputs	Equation		Value	Units	Notes
Flows					
Flow per Barrel, Q	Q_{design}/N	=	1.415	m^3/s	
Inlet Control					
HW_i/D	From nomograph, 2A	=	0.82	unitless	
Inlet Control Headwater Depth, HW_i/D	$HW_i/D \times D$	=	0.98	m	
Elevation of Inlet Headwater, EL_{hi}	$EL_i + HW_i$	=	**731.45**	m geo.	
Outlet Velocity					
Critical depth for CSP pipe arch, d_c	From nomograph, 4A	=	0.63	m	Hydraulic Design of Highway Culverts: Projecting from fill slope
Critical tailwater, TW_{crit}	$(d_c + D)/2$	=	0.92	m	
Controlling tailwater depth, h_o	greater of $TW_{channel}$ and TW_{crit}	=	0.92	m	
Headloss, H	From nomograph, 6A	=	0.25	m	Hydraulic Design of Highway Culverts
Outlet Control Headwater Depth, HW_o	$H+h_o$	=	1.17	m	Hydraulic Design of Highway Culverts
Outlet Control Headwater Elevation, EL_{ho}	EL_o+HW_o	=	**730.21**	m geo	
Design Checks					
Is Culvert in Inlet Control	if $EL_{ho} \le EL_{hi}$: TRUE, else: FALSE)		**TRUE**		
Controlling Inlet Headwater Elevation, HW_0	max of EL_{ho} and EL_{hi}	=	**731.5**	m	

Legend
Input
Output

McElhanney

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project No.:	**2121-00924-00**
Purpose:	**Sizing of culvert C20 to convey 100-year climate change-adjusted peak flow**
Location:	
Equation Type:	
Case:	

Inputs	Description		Value	Units	Notes/Source
Flows					
Q_{design}	Design Flow	=	0.227	m^3/s	See 'Design Flows' tab
Elevations					
EL_i	Culvert Inlet Elevation	=	759.30	m geo.	input
EL_o	Culvert Outlet Elevation	=	758.84	m geo.	input
Hydraulic Parameters					
K_U	Friction loss coefficient	=	19.63	unitless (SI)	Hydraulic Design of Highway Culverts, culvert design form
n	Manning's roughness	=	0.024	unitless	standard value for CSP
k_e	Entrance loss coefficient	=	0.9	unitless	Hydraulic Design of Highway Culverts: Projecting from fill slope
k_o	Exit loss coefficient	=	1.0	unitless	standard
$TW_{channel}$	Normal flow tailwater in outlet channel	=	0.00	m	
Culvert Dimensions					
D	Pipe Diameter	=	0.9	m	input
L	Pipe length	=	29.5	m	input
N	Number of Barrels	=	1		input
s	Slope	=	1.6%		

Legend
Input
Output

Outputs	Equation		Value	Units	Notes
Flows					
Flow per Barrel, Q	Q_{design}/N	=	0.227	m^3/s	
Inlet Control					
HW_i/D	From nomograph, 2A	=	0.40	unitless	
Inlet Control Headwater Depth, HW_i/D	$HW_i/D \times D$	=	0.36	m	
Elevation of Inlet Headwater, EL_{hi}	$EL_i + HW_i$	=	**759.66**	m geo.	
Outlet Velocity					
Critical depth for CSP pipe arch, d_c	From nomograph, 4A	=	0.25	m	Hydraulic Design of Highway Culverts: Projecting from fill slope
Critical tailwater, TW_{crit}	$(d_c + D)/2$	=	0.58	m	
Controlling tailwater depth, h_0	greater of $TW_{channel}$ and TW_{crit}	=	0.58	m	
Headloss, H	From nomograph, 6A	=	0.05	m	Hydraulic Design of Highway Culverts
Outlet Control Headwater Depth, HW_o	$H+h_o$	=	0.63	m	Hydraulic Design of Highway Culverts
Outlet Control Headwater Elevation, EL_{ho}	EL_o+HW_o	=	**759.47**	m geo.	
Design Checks					
Is Culvert in Inlet Control	if $EL_{ho} \leq EL_{hi}$: TRUE, else: FALSE)		**TRUE**		
Controlling Inlet Headwater Elevation, HW_0	max of EL_{ho} and EL_{hi}	=	**759.7**	m	

McElhanney

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project No.:	**2121-00924-00**
Purpose:	**Manning's calculation for culvert C18 discharge velocity and outlet riprap size**
Location:	
Equation Type:	
Case:	

Symbol	Description		Value	Units	Notes/Source
Q_{design}	Design Flow	=	0.44	m^3/s	
n	Manning's n	=	0.024		standard value for CSP pipes from https://www.engineeringtoolbox.com/mannings-roughness-
s	Slope (%)	=	0.9%		Design pipe slope
D	Diameter	=	900	mm	900mm dia. CSP pipe
C	Pipe full ratio (d/D)	=	49%		Adjust to match design flow
A	Pipe Flow Area	=	309987	mm^2	
R	Hydraulic Radius	=	222	mm	
v	Velocity	=	1.42	m/s	
Q	Flow at 'C'% Full	=	0.44	m^3/s	Q > Q_{design}, maintain existing pipe diameter and slope
S	Specific gravity of rock	=	2.65		
D_{50}	Median diameter of riprap for outlet splash pad	=	0.08	m	Ishbash Equation; results in Class 10kg

Legend
Input
Output

McElhanney

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project No.:	**2121-00924-00**
Purpose:	**Manning's calculation for culvert C19 discharge velocity and outlet riprap size**
Location:	
Equation Type:	
Case:	

Legend
Input
Output

Symbol	Description		Value	Units	Notes/Source
Q_{design}	Design Flow	=	1.42	m^3/s	
n	Manning's n	=	0.024		standard value for CSP pipes from https://www.engineeringtoolbox.com/mannings-roughness-d_799.html
s	Slope (%)	=	5.0%		Design pipe slope
D	Diameter	=	1200	mm	1200mm dia. CSP
C	Pipe full ratio	=	38%		Adjust to match design flow
A	Pipe Area	=	394360	mm^2	
R	Hydraulic Radius	=	247	mm	
v	Velocity	=	3.67	m/s	
Q	Flow at 'C'% Full	=	1.45	m^3/s	$Q > Q_{design}$, maintain existing pipe diameter and slope
S	Specific gravity of rock	=	2.65		
D_{50}	Median diameter of riprap for outlet splash pad	=	0.56	m	Ishbash Equation; results in Class 250kg

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project No.:	**2121-00924-00**
Purpose:	**Manning's calculation for culvert C20 discharge velocity and outlet riprap size**
Location:	
Equation Type:	
Case:	

Symbol	Description		Value	Units	Notes/Source
Q_{design}	Design Flow	=	0.23	m^3/s	
n	Manning's n	=	0.024		https://www.engineeringtoolbox.com/mannings-roughness-d_799.html
s	Slope (%)	=	1.6%		Design pipe slope
D	Diameter	=	900	mm	900mm dia. CSP
C	Pipe full ratio	=	30%		Adjust to match design flow
A	Pipe Area	=	160516	mm^2	
R	Hydraulic Radius	=	154	mm	
v	Velocity	=	1.49	m/s	
Q	Flow at 'C'% Full	=	0.24	m^3/s	$Q > Q_{design}$, maintain existing pipe diameter and slope
S	Specific gravity of rock	=	2.65		
D_{50}	Median diameter of riprap for outlet splash pad	=	0.09	m	Ishbash Equation; results in Class 10kg

Legend
Input
Output

APPENDIX C

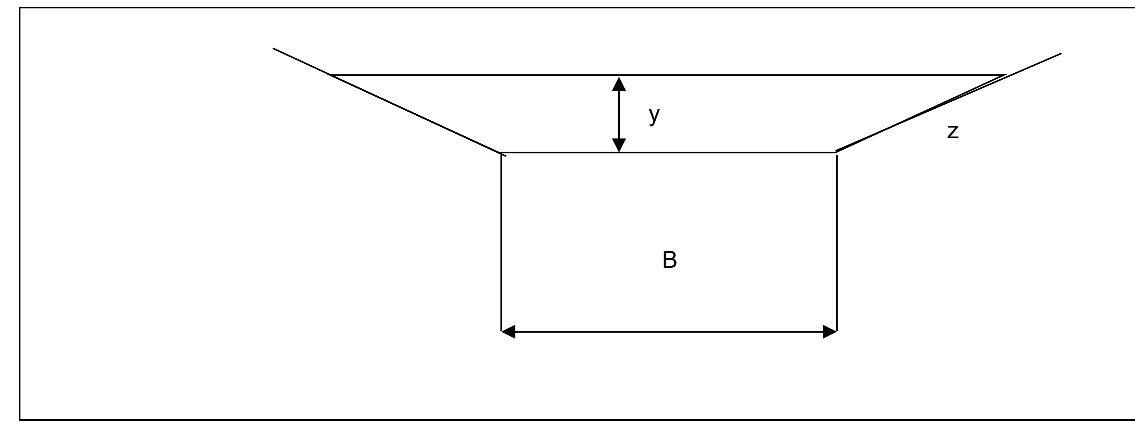
Ditch Hydraulic Calculations

McElhanney

Project Title:	Caribou Road Recover Projects - Cottonwood River Slide
Project No.:	2121-00924-00
Purpose:	Manning's calculation for unlined ditch velocities and water depths (no riprap lining); ditch sizing for 100 year design flow. Valid from the highway crest to culvert C20 inlet and outlet

Legend
Input
Output

Symbol	Description		Value	Unit	Notes/Source
S	Channel Slope	=	3.7%	percent	Proposed inlet channel slope
B	Base Width	=	1.0	m	Design channel width (CAD)
z	Side Slope	=	2.0	H/V	Proposed inlet side slope
Q	Design Flow - target value	=	0.3	m3/s	Refer to 'Design Flows' tab
n	Manning's n	=	0.025	unitless	Max Manning's n value - assumed for no riprap lining
y	Water Depth	=	calculated		
Formulas					
A =	Water Area	=	$y^2 \cdot z+By$		
P =	Wetted Perimeter	=	$B+2[(y \cdot z)^2+y^2)]^{1/2}$		
R =	Hydraulic Radius	=	A/P		
n =	Manning's n	=	$0.319*y^{1/6} / (2.25+5.23\log(y/D_{50})$ HEC-15, p. 6-1 Blodgett, 1986a		
V =	Velocity	=	$(1/n) \cdot R^{2/3}S^{1/2}$		



Water Depth Iterative Calculation (Blodgett, 1986a)

y (m)	A (m2)	P (m)	R (m)			V (m/s)	Q (m3/s)
0.12	0.14	1.52	0.09			1.59	0.23
0.20	0.28	1.89	0.15			2.15	0.60
0.145	**0.19**	**1.65**	**0.11**			**1.80**	**0.34**

NOTES: Class 50kg at culvert inlet and at the ditch block
Specify minimum depth of ditch allowable
Tabulate minimum depths and velocities for different channel base widths
Design channels to 100-year flow as overland flow path would end up on slide area otherwise

Table 2. Values of Manning's roughness coefficient for natural channels

[Modified from Chow (1959, table 5–6), published with permission of McGraw-Hill]

Type of channel and description	Roughness coefficient Minimum	Normal	Maximum
A. Minor streams (top width at flood stage less than 100 ft)			
1. Streams on plain:			
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	.030	.035	.040
c. Clean, winding, some pools and shoals	.033	.040	.045
d. Same as above, but some weeds and stones	.035	.045	.050
e. Same as above, lower stages more ineffective slopes and sections	.040	.048	.055
f. Same as type d, but more stones	.045	.050	.060
g. Sluggish reaches, weedy, deep pools	.050	.070	.080
h. Very weedy reaches, deep pools or floodways with heavy stand of timber and underbrush	.075	.100	.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages:			
a. Bottom: gravels, cobbles, and few boulders	.030	.040	.050
b. Bottom: cobbles and large boulders	.040	.050	.070
B. Major streams (top width at flood stage greater than 100 ft). The *n* value is less than that for minor streams of similar description because banks offer less effective resistance			
1. Regular section with no boulders or brush	.025	—	.060
2. Irregular and rough section	.035	—	.100

McElhanney

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project No.:	**2121-00924-00**
Purpose:	**Manning's calculation for riprap lined ditch velocities and water depths; ditch sizing for 100 year design flow.**

Legend
Input
Output

Symbol	Description		Value	Unit	Notes/Source
S	Channel Slope	=	4.5%	percent	Proposed inlet channel slope
B	Base Width	=	1.0	m	Design channel width (CAD)
z	Side Slope	=	2.0	H/V	Proposed inlet side slope
Q	Design Flow - target value	=	1.499	m3/s	Refer to 'Design Flows' tab
D_{50}	Riprap 50% passing size	=	0.195	m	Assume Class 10kg is required
n	Manning's n	=	0.05	unitless	Max Manning's n value - assumed for continuous riprap lining
y	Water Depth	=	calculated		
Formulas					
A =	Water Area	=	$y^2 \cdot z + By$		
P =	Wetted Perimeter	=	$B+2[(y \cdot z)^2+y^2)]^{1/2}$		
R =	Hydraulic Radius	=	A/P		
n =	Manning's n	=	$0.319*y^{1/6}$ / $(2.25+5.23\log(y/D_{50})$ HEC-15, p. 6-1 Blodgett, 1986a		
V =	Velocity	=	$(1/n) \cdot R^{2/3}S^{1/2}$		

Water Depth Iterative Calculation (Blodgett, 1986a)

y (m)	A (m2)	P (m)	R (m)	n (unitless)	y/D_{50}	V (m/s)	Q (m3/s)
0.43	0.80	2.92	0.27	0.050	2.21	1.79	1.43
0.45	0.86	3.01	0.28	0.050	2.31	1.83	1.57
0.440	**0.83**	**2.97**	**0.28**	0.050	**2.26**	**1.81**	**1.50**

NOTES: Class 50kg at culvert inlet and at the ditch block
Specify minimum depth of ditch allowable
Tabulate minimum depths and velocities for different channel base widths
Design channels to 100-year flow as overland flow path would end up on slide area otherwise

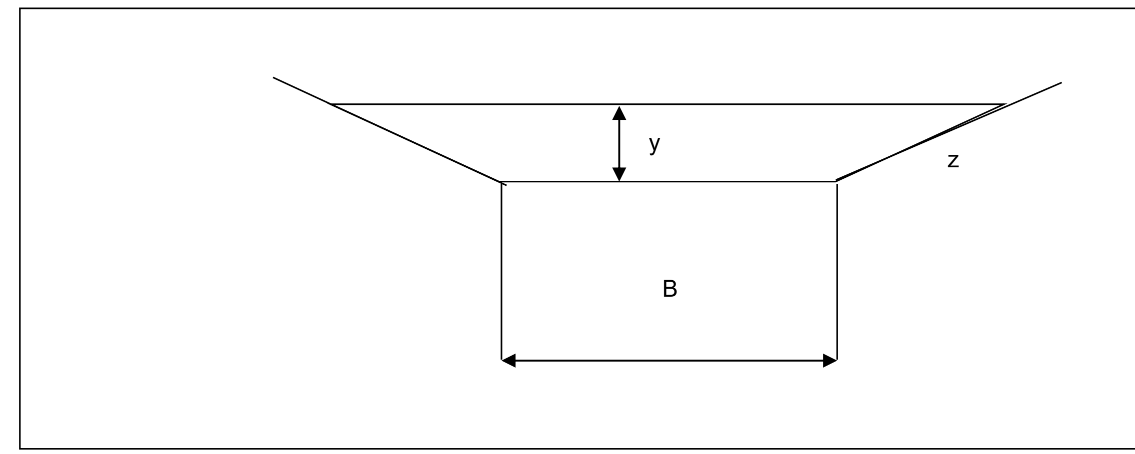


Table 2. Values of Manning's roughness coefficient for natural channels
[Modified from Chow (1959, table 5–6), published with permission of McGraw-Hill]

Type of channel and description	Roughness coefficient		
	Minimum	Normal	Maximum
A. Minor streams (top width at flood stage less than 100 ft)			
1. Streams on plain:			
a. Clean, straight, full stage, no rifts or deep pools..........	0.025	0.030	0.033
b. Same as above, but more stones and weeds................	.030	.035	.040
c. Clean, winding, some pools and shoals	.033	.040	.045
d. Same as above, but some weeds and stones................	.035	.045	.050
e. Same as above, lower stages more ineffective slopes and sections	.040	.048	.055
f. Same as type d, but more stones	.045	.050	.060
g. Sluggish reaches, weedy, deep pools	.050	.070	.080
h. Very weedy reaches, deep pools or floodways with heavy stand of timber and underbrush	.075	.100	.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages:			
a. Bottom: gravels, cobbles, and few boulders	.030	.040	.050
b. Bottom: cobbles and large boulders...........................	.040	.050	.070
B. Major streams (top width at flood stage greater than 100 ft). The *n* value is less than that for minor streams of similar description because banks offer less effective resistance			
1. Regular section with no boulders or brush	.025	—	.060
2. Irregular and rough section..	.035	—	.100

McElhanney

Riprap (USACE 1991) Ditch

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project #:	**2121-00924-00**
Purpose:	**USACE, 1991 riprap sizing calculation for 100-year climate-change-adjusted design flow and velocities in east highway ditch**
Channel Location	**At the end of the failure slope**

Legend: Input / Output

Riprap Calculation for Weir Berm			
Inputs	**Value**	**Units**	**Source**
Design Flood	100-year		
Design Flow	1.499	m^3/s	100-year climate-change-adjusted design flow from report
V_{avg}, Average Channel Velocity	1.81	m/s	Channel velocity based on Manning's calculation for lined ditch
Flow Depth, d	0.44	m	Water depth based on HECRAS Model, existing scenario
Bend Radius, R	N/A	m	
Water Surface Width at upstream of bend, W	N/A	m	
Side slope with horizontal	2	H:1V	

Calculation Method (D_{30})		
USACE (1994) for reference only	$$D_{30} = S_f C_s C_v C_T d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5} \quad (3\text{-}3)$$	
USCAE (1991) Presented in MOE	.... Eq. [2A-1] $$\frac{D}{y} = S_f C_s C_v C_T \left[\frac{V^2}{(s-1)K_1(gy)} \right]^{1.25}$$	This method has been superceded by the 1994 method but provides more reasonable side slope correction factor values
HEC23. For reference only - These are functionally the same	$$d_{30} = y(S_f C_S C_V C_T)\left[\frac{(V_{des})}{\sqrt{K_1(S_g - 1)gy}} \right]^{2.5} \quad (4.1)$$	

USCAE (1991) - Method				
Variable	**Parameter Description**	**Value**		**Comments**
y	Local flow depth near bank at 20% up slope	0.35	m	Used Design Max Flow Depth from Hydraulic Inputs. depth taken at 20% up sloped bank to calculate height. Depth does not change values significantly but a shallower depth increases rock size
S_f	Safety Factor	1.10		1.1 minimum, increase for uncertainties, extreme freeze thaw etc..
C_s	Stability Coefficient	0.30		for angular rock
C_v	velocity distribution coefficient	1.00		1.0 for straight channels
C_t	Thickness coefficient	1.00		1.0 for normal blanket thickness either D100 or 1.5 X D50
R/W	Ratio of radius of curvature to water surface width	N/A		
V_{ss}/V_{avg}	Velocity scaling factor	0.80		From graph for R/W >15; assumed for straight channels
V_{ss}	Local (depth-averaged) flow velocity	1.45	m/s	Vss = Vavg * (Vss/Vavg)
g_w	Unit weight of water	1000	kg/m3	
g_s	Unit weight of stone	2640	kg/m3	Lafarge riprap spec - see reference material
K_1	Side slope correction factor	0.90	see chart	empirical

Calculation	Formula			Comments
	$y S_f C_s C_v C_T$	0.1162		
	$\left[\frac{V^2}{(s-1)K_1(gy)} \right]^{1.25}$	0.3296		
	$D = y S_f C_s C_v C_T \left[\frac{V^2}{(s-1)K_1(gy)} \right]^{1.25}$	0.038	m	For D30
	Riprap D_{50} = 1.25 x D30	0.048	m	
	Riprap class	**Class 10kg**		Automatically selects min class category for calculated D50
	Riprap Thickness	0.35	m	per MoTI Standard Specifications (2019)

McElhanney

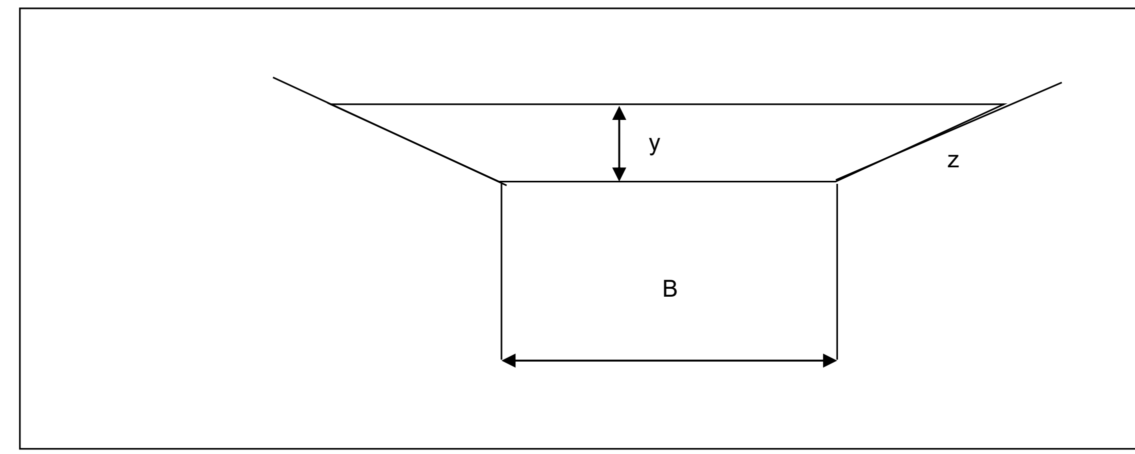
Project Title:	Caribou Road Recover Projects - Cottonwood River Slide
Project No.:	2121-00924-00
Purpose:	Manning's calculation for riprap lined ditch velocities and water depths; ditch sizing for 100 year design flow.
	Testing 10kg riprap with the steepest special slopes on the main drainage channel.

Legend
Input
Output

Symbol	Description		Value	Unit	Notes/Source
S	Channel Slope	=	7.5%	percent	Proposed inlet channel slope
B	Base Width	=	1.0	m	Design channel width (CAD)
z	Side Slope	=	2.0	H/V	Proposed inlet side slope
Q	Design Flow - target value	=	1.499	m3/s	Refer to 'Design Flows' tab
D_{50}	Riprap 50% passing size	=	0.195	m	Assume Class 10kg is required
n	Manning's n	=	0.05	unitless	Max Manning's n value - assumed for continuous riprap lining
y	Water Depth	=	calculated		

Formulas

A =	Water Area	=	$y^2 \cdot z + By$
P =	Wetted Perimeter	=	$B+2[(y \cdot z)^2+y^2)]^{1/2}$
R =	Hydraulic Radius	=	A/P
n =	Manning's n	=	$0.319*y^{1/6}$ / $(2.25+5.23\log(y/D_{50})$ HEC-15, p. 6-1 Blodgett, 1986a
V =	Velocity	=	$(1/n) \cdot R^{2/3} S^{1/2}$



Water Depth Iterative Calculation (Blodgett, 1986a)

y (m)	A (m2)	P (m)	R (m)	n (unitless)	y/D_{50}	V (m/s)	Q (m3/s)
0.38	0.67	2.70	0.25	0.050	1.95	2.16	1.45
0.40	0.72	2.79	0.26	0.050	2.05	2.22	1.60
0.387	**0.69**	**2.73**	**0.25**	0.050	**1.98**	**2.18**	**1.50**

NOTES: Class 50kg at culvert inlet and at the ditch block
Specify minimum depth of ditch allowable
Tabulate minimum depths and velocities for different channel base widths
Design channels to 100-year flow as overland flow path would end up on slide area otherwise

Table 2. Values of Manning's roughness coefficient for natural channels
[Modified from Chow (1959, table 5–6), published with permission of McGraw-Hill]

Type of channel and description	Roughness coefficient		
	Minimum	Normal	Maximum
A. Minor streams (top width at flood stage less than 100 ft)			
1. Streams on plain:			
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	.030	.035	.040
c. Clean, winding, some pools and shoals	.033	.040	.045
d. Same as above, but some weeds and stones	.035	.045	.050
e. Same as above, lower stages more ineffective slopes and sections	.040	.048	.055
f. Same as type d, but more stones	.045	.050	.060
g. Sluggish reaches, weedy, deep pools	.050	.070	.080
h. Very weedy reaches, deep pools or floodways with heavy stand of timber and underbrush	.075	.100	.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages:			
a. Bottom: gravels, cobbles, and few boulders	.030	.040	.050
b. Bottom: cobbles and large boulders	.040	.050	.070
B. Major streams (top width at flood stage greater than 100 ft). The *n* value is less than that for minor streams of similar description because banks offer less effective resistance			
1. Regular section with no boulders or brush	.025	—	.060
2. Irregular and rough section	.035	—	.100

McElhanney

Riprap (USACE 1991) Ditch

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project #:	**2121-00924-00**
Purpose:	**USACE, 1991 riprap sizing calculation for 100-year climate-change-adjusted design flow and velocities in east highway ditch. Testing 10kg riprap with the steepest ditch slopes on site.**
Channel Location	

Legend
Input
Output

Riprap Calculation for Weir Berm			
Inputs	**Value**	**Units**	**Source**
Design Flood	100-year		
Design Flow	1.499	m^3/s	100-year climate-change-adjusted design flow from report
V_{avg}, Average Channel Velocity	2.18	m/s	Channel velocity based on Manning's calculation for lined ditch
Flow Depth, d	0.39	m	Water depth based on HECRAS Model, existing scenario
Bend Radius, R	N/A	m	
Water Surface Width at upstream of bend, W	N/A	m	
Side slope with horizontal	2	H:1V	

Calculation Method (D_{30})		
USACE (1994) for reference only	$D_{30} = S_f C_s C_v C_T d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{1/2} \frac{V}{\sqrt{K_1 g d}}\right]^{2.5}$ (3-3)	
USCAE (1991) Presented in MOE	.... Eq. [2A-1] $\frac{D}{y} = S_f C_s C_v C_T \left[\frac{V^2}{(s-1)K_1(gy)}\right]^{1.25}$	This method has been superceded by the 1994 method but provides more reasonable side slope correction factor values
HEC23. For reference only - These are functionally the same	$d_{30} = y(S_f C_s C_v C_T)\left[\frac{(V_{des})}{\sqrt{K_1(S_g-1)gy}}\right]^{2.5}$	(4.1)

USCAE (1991) - Method				
Variable	**Parameter Description**	**Value**		**Comments**
y	Local flow depth near bank at 20% up slope	0.31	m	Used Design Max Flow Depth from Hydraulic Inputs. depth taken at 20% up sloped bank to calculate height. Depth does not change values significantly but a shallower depth increases rock size
S_f	Safety Factor	1.10		1.1 minimum, increase for uncertainties, extreme freeze thaw etc..
C_s	Stability Coefficient	0.30		for angular rock
C_v	velocity distribution coefficient	1.00		1.0 for straight channels
C_t	Thickness coefficient	1.00		1.0 for normal blanket thickness either D100 or 1.5 X D50
R/W	Ratio of radius of curvature to water surface width	N/A		
V_{ss}/V_{avg}	Velocity scaling factor	0.80		From graph for R/W >15; assumed for straight channels
V_{ss}	Local (depth-averaged) flow velocity	1.75	m/s	Vss = Vavg * (Vss/Vavg)
g_w	Unit weight of water	1000	kg/m3	
g_s	Unit weight of stone	2640	kg/m3	Lafarge riprap spec - see reference material
K_1	Side slope correction factor	0.90	see chart	empirical

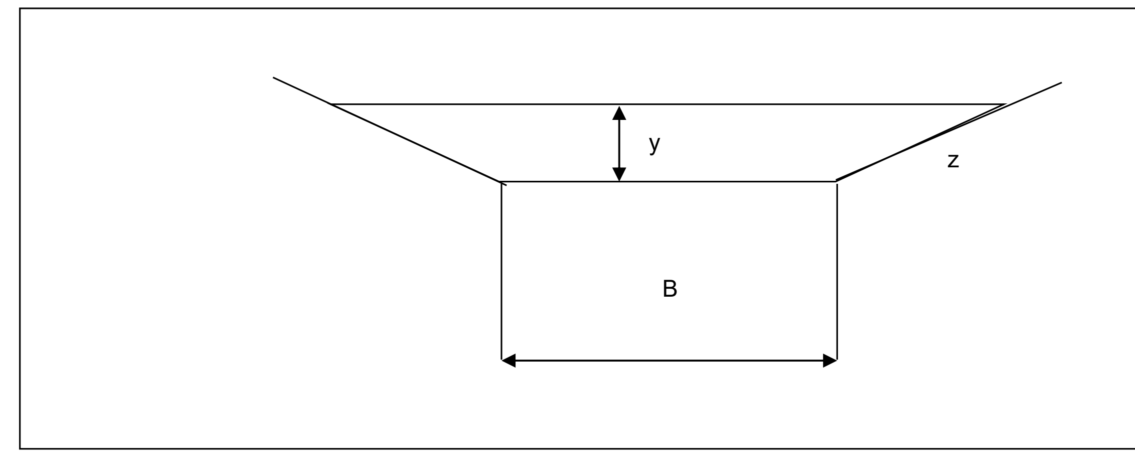
Calculation	Formula			Comments
	$y S_f C_s C_v C_T$	0.1022		
	$\left[\frac{V^2}{(s-1)K_1(gy)}\right]^{1.25}$	0.6171		
	$D = y S_f C_s C_v C_T \left[\frac{V^2}{(s-1)K_1(gy)}\right]^{1.25}$	0.063	m	For D30
	Riprap D_{50} = 1.25 x D30	0.079	m	
	Riprap class	**Class 10kg**		Automatically selects min class category for calculated D50
	Riprap Thickness	0.35	m	per MoTI Standard Specifications (2019)

McElhanney

Project Title:	Caribou Road Recover Projects - Cottonwood River Slide
Project No.:	2121-00924-00
Purpose:	Manning's calculation for riprap lined ditch velocities and water depths; ditch sizing for 100 year design flow.

Legend
Input
Output

Symbol	Description		Value	Unit	Notes/Source
S	Channel Slope	=	25.0%	percent	Proposed inlet channel slope
B	Base Width	=	1.0	m	Design channel width (CAD)
z	Side Slope	=	2.0	H/V	Proposed inlet side slope
Q	Design Flow - target value	=	1.415	m3/s	Refer to 'Design Flows' tab
D_{50}	Riprap 50% passing size	=	0.195	m	Assume Class 10kg is required
n	Manning's n	=	0.05	unitless	Max Manning's n value - assumed for continuous riprap lining
y	Water Depth	=	calculated		
Formulas					
A =	Water Area	=	$y^2 \cdot z + By$		
P =	Wetted Perimeter	=	$B+2[(y \cdot z)^2+y^2)]^{1/2}$		
R =	Hydraulic Radius	=	A/P		
n =	Manning's n	=	$0.319 * y^{1/6} / (2.25+5.23\log(y/D_{50})$ HEC-15, p. 6-1 Blodgett, 1986a		
V =	Velocity	=	$(1/n) \cdot R^{2/3} S^{1/2}$		



Water Depth Iterative Calculation (Blodgett, 1986a)							
y (m)	A (m2)	P (m)	R (m)	n (unitless)	y/D_{50}	V (m/s)	Q (m3/s)
0.25	0.38	2.12	0.18	0.050	1.28	3.15	1.18
0.30	0.48	2.34	0.20	0.050	1.54	3.48	1.67
0.276	**0.43**	**2.23**	**0.19**	0.050	**1.42**	**3.32**	**1.42**

NOTES: Class 50kg at culvert inlet and at the ditch block
Specify minimum depth of ditch allowable
Tabulate minimum depths and velocities for different channel base widths
Design channels to 100-year flow as overland flow path would end up on slide area otherwise

Table 2. Values of Manning's roughness coefficient for natural channels
[Modified from Chow (1959, table 5–6), published with permission of McGraw-Hill]

Type of channel and description	Roughness coefficient Minimum	Normal	Maximum
A. Minor streams (top width at flood stage less than 100 ft)			
1. Streams on plain:			
a. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	.030	.035	.040
c. Clean, winding, some pools and shoals	.033	.040	.045
d. Same as above, but some weeds and stones	.035	.045	.050
e. Same as above, lower stages more ineffective slopes and sections	.040	.048	.055
f. Same as type d, but more stones	.045	.050	.060
g. Sluggish reaches, weedy, deep pools	.050	.070	.080
h. Very weedy reaches, deep pools or floodways with heavy stand of timber and underbrush	.075	.100	.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages:			
a. Bottom: gravels, cobbles, and few boulders	.030	.040	.050
b. Bottom: cobbles and large boulders	.040	.050	.070
B. Major streams (top width at flood stage greater than 100 ft). The *n* value is less than that for minor streams of similar description because banks offer less effective resistance			
1. Regular section with no boulders or brush	.025	—	.060
2. Irregular and rough section	.035	—	.100

Riprap (USACE 1991) Ditch

McElhanney

Project Title:	**Caribou Road Recover Projects - Cottonwood River Slide**
Project #:	**2121-00924-00**
Purpose:	**USACE, 1991 riprap sizing calculation for 100-year climate-change-adjusted design flow and velocities in east highway ditch**
Channel Location	**At the end of the failure slope**

Legend
Input
Output

Riprap Calculation for Weir Berm

Inputs	Value	Units	Source
Design Flood	100-year		
Design Flow	1.415	m^3/s	100-year climate-change-adjusted design flow from report
V_{avg}, Average Channel Velocity	3.32	m/s	Channel velocity based on Manning's calculation for lined ditch
Flow Depth, d	0.28	m	Water depth based on HECRAS Model, existing scenario
Bend Radius, R	N/A	m	
Water Surface Width at upstream of bend, W	N/A	m	
Side slope with horizontal	2	H:1V	

Calculation Method (D_{30})			
USACE (1994) for reference only	$D_{30} = S_f C_s C_V C_T d \left[\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{1/2} \frac{V}{\sqrt{K_1 g d}} \right]^{2.5}$	(3-3)	
USCAE (1991) Presented in MOE	$\frac{D}{y} = S_f C_s C_v C_T \left[\frac{V^2}{(s-1) K_1 (gy)} \right]^{1.25}$ .... Eq. [2A-1]		This method has been superceded by the 1994 method but provides more reasonable side slope correction factor values
HEC23. For reference only - These are functionally the same	$d_{30} = y(S_f C_S C_V C_T) \left[\frac{(V_{des})}{\sqrt{K_1 (S_g - 1) g y}} \right]^{2.5}$	(4.1)	

USCAE (1991) - Method

Variable	Parameter Description	Value		Comments
y	Local flow depth near bank at 20% up slope	0.22	m	Used Design Max Flow Depth from Hydraulic Inputs. depth taken at 20% up sloped bank to calculate height. Depth does not change values significantly but a shallower depth increases rock size
S_f	Safety Factor	1.10		1.1 minimum, increase for uncertainties, extreme freeze thaw etc..
C_s	Stability Coefficient	0.30		for angular rock
C_v	velocity distribution coefficient	1.00		1.0 for straight channels
C_t	Thickness coefficient	1.00		1.0 for normal blanket thickness either D100 or 1.5 X D50
R/W	Ratio of radius of curvature to water surface width	N/A		
V_{ss}/V_{avg}	Velocity scaling factor	1.00		From graph for R/W >15; assumed for straight channels
V_{ss}	Local (depth-averaged) flow velocity	3.32	m/s	Vss = Vavg * (Vss/Vavg)
g_w	Unit weight of water	1000	kg/m3	
g_s	Unit weight of stone	2640	kg/m3	Lafarge riprap spec - see reference material
θ	Angle of side slope with horizontal	0.46	radians	2H:1V
		27	degrees	
φ	Angle of repose of riprap material	40.00	degrees	
		0.70	radians	normally 40 degrees
K_1	Side slope correction factor	0.90	see chart	empirical

Calculation	Formula			Comments
	$y S_f C_s C_v C_T$	0.0729		
	$\left[\frac{V^2}{(s-1) K_1 (gy)} \right]^{1.25}$	4.7150		
	$D = y S_f C_s C_v C_T \left[\frac{V^2}{(s-1) K_1 (gy)} \right]^{1.25}$	0.344	m	For D30
	Riprap D_{50} = 1.25 x D30	0.429	m	
	Riprap class	**Class 250kg**		Automatically selects min class category for calculated D50
	Riprap Thickness	1.00	m	per MoTI Standard Specifications (2019)

APPENDIX D

Concrete Drainage Barrier and Spillway Spacing Calculations

CDB / Spillway Spacing Calculations

Notes:

NOTE: CDB STATIONS REPRESENT THE RECOMMENDED STATIONS IN THE 100% DESIGN

CDB spacing is based on Figure 1050.I in Section 1050 of the MoTI Supplement to TAC Geometric Design Guide

Design Inputs are from **100% DD Drawings R2-1249-100, -200, -300, -400, -XS**

Inlet width (w) based on typical spillway width

Longitudinal grade based on grades within segement station range from R2-1249-200

Shoulder and contrib. width based on R2-1249-300 and -400

Catchment Parameters							
CDB / Spillway ID		1	2	3	4	5	6
Side of Road		West	West	West	West	West	East
Start Station		**198+80**	**200+25**	**201+05**	**201+85**	**203+23**	**204+73**
Design Inputs							
Shoulder Width (SW)	[m]	2.5	2.5	2.5	2.5	2.5	N/A
Longit. Grade (s_y)	[m/m]	0.045	0.045	0.045	0.045	0.045	N/A
Crossfall (s_x)	[m/m]	0.038375	0.03	0.03	0.06	0.042	N/A
Manning's n (n)		0.020	0.020	0.020	0.020	0.020	N/A
Rainfall Intesity (i)	[mm/hr]	93.2	93.2	93.2	93.2	93.2	N/A
Contrib. Width	[m]	18	15.8	15.8	15.8	15.8	N/A
Runoff Coeff. (C_w)		0.95	0.95	0.95	0.95	0.95	N/A
Inlet Width (w)	[m]	0.6	0.6	0.6	0.6	0.6	N/A
Calculated Design Gutter Flow							
Pond Width (PW)	[m]	**1.6**	**1.6**	**1.6**	**1.6**	**1.6**	**N/A**
Max Gutter Depth (y_0)	[m]	**0.062**	**0.049**	**0.049**	**0.098**	**0.068**	**N/A**
R_s		**0.85**	**0.67**	**0.67**	**1.33**	**0.93**	**N/A**
w_eff	[m]	**0.660**	**0.660**	**0.660**	**0.660**	**0.660**	**N/A**
v	[m/s]	**1.65**	**1.40**	**1.40**	**2.23**	**1.76**	**N/A**
Gutter Flow (Q_0)	[m3/s]	**0.0628**	**0.0416**	**0.0416**	**0.1325**	**0.0730**	**N/A**
Max Depth outside w (y_over)	[m]	**0.037**	**0.029**	**0.029**	**0.058**	**0.041**	**N/A**
Overflow (Q_over)	[m3/s]	**0.0156**	**0.0104**	**0.0104**	**0.0329**	**0.0182**	**N/A**
Intercepted flow (Q_int)	[m3/s]	**0.0472**	**0.0313**	**0.0313**	**0.0962**	**0.0549**	**N/A**
Eff	[%]	**75.1**	**75.1**	**75.1**	**72.6**	**75.1**	**N/A**
CDB / Spillway Spacing							
Initial CDB Spacing	[m]	**141.8**	**107.1**	**107.1**	**409.1**	**187.9**	**N/A**
Consecutive CDB Spacing	[m]	**106.6**	**80.5**	**80.5**	**297.1**	**141.2**	**N/A**
CDB / Spillway Location							
Catchbasin Catchment		**1**	**2**	**3**	**4**	**5**	**6**
Side of Road		**West**	**West**	**West**	**West**	**West**	**East**
Actual Distance between CBs		**145**	**80**	**80**	**138**	**150**	**N/A**

CDB / Spillway Spacing Calculations

Notes:

NOTE: CDB STATIONS REPRESENT THE RECOMMENDED STATIONS IN THE 100% DESIGN

CDB spacing is based on Figure 1050.I in Section 1050 of the MoTI Supplement to TAC Geometric Design Guide

Design Inputs are from **100% DD Drawings R2-1249-100, -200, -300, -400, -XS**

Inlet width (w) based on typical spillway width

Longitudinal grade based on grades within segement station range from R2-1249-200

Shoulder and contrib. width based on R2-1249-300 and -400

Catchbasin Catchment Parameters																		
CDB Catchment		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Side of Road		East	East	East	East	East	East	East	East	East	East	East	East	East	East	East	East	East
Start Station		204+73	204+93	205+70	207+20	207+83	208+03	208+23	208+43	208+72	209+02	209+32	209+62	209+92	210+22	210+52	210+76	210+99
Design Inputs																		
Shoulder Width (SW)	[m]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Longit. Grade (s_y)	[m/m]	0.045	0.045	0.028	0.008	0.003	0.003	0.003	0.005	0.0086	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
Crossfall (s_x)	[m/m]	0.01	0.04	0.06	0.055	0.028	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Manning's n (n)		0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Rainfall Intesity (i)	[mm/hr]	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2	93.2
Contrib. Width	[m]	7.9	15.8	15.8	15.8	15.8	15.8	15.8	13.055	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7	9.7
Runoff Coeff. (C_w)		0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Inlet Width (w)	[m]	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Calculated Design Gutter Flow																		
Pond Width (PW)	[m]	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Max Gutter Depth (y_0)	[m]	0.016	0.065	0.098	0.089	0.046	0.016	0.016	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
R_s		0.22	0.90	2.18	6.62	9.33	3.33	3.33	4.00	2.33	2.22	2.22	2.22	2.22	2.22	2.22	2.22	2.22
w_eff	[m]	0.660	0.660	0.660	0.720	0.720	0.660	0.660	0.660	0.660	0.660	0.660	0.660	0.660	0.660	0.660	0.660	0.660
v	[m/s]	0.67	1.69	1.74	0.90	0.35	0.17	0.17	0.36	0.47	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Gutter Flow (Q_0)	[m3/s]	0.0066	0.0670	0.1037	0.0485	0.0096	0.0017	0.0017	0.0070	0.0092	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095	0.0095
Max Depth outside w (y_over)	[m]	0.010	0.039	0.058	0.049	0.025	0.010	0.010	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Overflow (Q_over)	[m3/s]	0.0017	0.0167	0.0258	0.0102	0.0020	0.0004	0.0004	0.0018	0.0023	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024	0.0024
Intercepted flow (Q_int)	[m3/s]	0.0050	0.0504	0.0779	0.0383	0.0076	0.0013	0.0013	0.0053	0.0069	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071	0.0071
Eff	[%]	75.1	75.1	75.1	79.0	79.0	75.1	75.1	75.1	75.1	75.1	75.1	75.1	75.1	75.1	75.1	75.1	75.1
Catchbasin Spacing																		
Initial CDB Spacing	[m]	34.2	172.5	266.8	124.8	24.6	4.4	4.4	22.0	38.8	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6
Consecutive CB Spacing	[m]	25.7	129.6	200.4	98.7	19.5	3.3	3.3	16.5	29.1	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8
Catchbasin Location																		
Catchbasin Catchment		6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Side of Road		East	East	East	East	East	East	East	East	East	East	East	East	East	East	East	East	East
Actual Distance between CBs		20	77	150	63	20	20	20	20	29	30	30	30	30	30	30	24	23

APPENDIX E

Statement of Limitations

Statement of Limitations

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