To	Basir Saleh, Siddhwartha Mandal	Page	1 of 21
CC	Laura Boone, Gord Geoffrey, Justin Hanisch		
Subject	Fish Passage Design for Sinclair Culvert at Parks Gate, Kootenay National Park, BC		
From	Jagadish Kayastha		
Date	December 18, 2017	Project Number	60547362

1. Introduction

Parks Canada Agency (PCA) is planning to rehabilitate or replace the existing Sinclair culvert using a suitable culvert option with a sufficient hydraulic capacity for the 1:200 year design flow. PCA retained AECOM Canada Ltd. (AECOM) to assess the different crossing options and provide preliminary recommendations for a suitable option to replace the existing culvert. The existing culvert was not designed as a fish bearing culvert. However, according to the aquatics team at Parks Canada, the fish species that has been observed along Sinclair Creek and has the potential of occurrences at this culvert location is Brook Trout (Salvelinus fontinalis). So, it is suggested that the new culvert to be designed with an appropriate fish passage as the culvert is within the reach known to support Brook Trout.

Sinclair Culvert is located at the Parks Gate (latitude 50^0 38' 07.16"N and longitude 116^0 01' 57.49"W) across Kootenay HWY 93S at the Sinclair creek, is 102.03 km south of the Intersection of HWY 93S and the Trans-Canada Highway as shown in **Figure 1**.

The existing culvert is a corrugated structural plate pipe arch section of 3840 mm span and 2210 mm rise with a longitudinal slope of 4.13%. The culvert was built in 1962. Based on the existing inspection reports dated October 02, 2006; October 03, 2012 and October 13, 2016 the culvert is in poor condition with through corrosion and distorted ribs in the culvert and multiple sections with cracked bolt seams. The culvert site location and the creek catchment are shown on **Figures 1 and 2** respectively.

AECOM carried out Hydrologic and hydraulic analysis (H&H) for assessment of the existing culvert and designing new culvert crossing options. Concrete box section of 3.0 m span and 2.2 m rise was chosen for a detailed design with the 1:200 year design flow of 14.0 m^3/s based on H&H analysis and this technical memo on fish passage design have been prepared to be consistent with guidelines for the collection and analysis of fish and fish habitat data for the purpose of designing fish bearing culvert in British Columbia. Since the proposed culvert was also designed for 4.13% longitudinal slope the flow velocities are too high through the length of the concrete box section, baffles or weirs need to be installed to create small pools for increasing flow depth during low fish passage flow conditions and reducing velocities under high flow conditions.

The primary purpose of this memo is to estimate (i) the fish spawning migration period (number of days), (ii) maximum flow velocity fish can tackle during migration time for high fish passage flows, and (iii) minimum flow depth requirement at low fish passage flows during migration time for a particular fish available in the creek. The 1:200 year return period flow was used to design structures to withstand appropriate levels of flooding during both construction and operations. In order to provide an appropriate fish passage, the design of new baffled concrete box culvert needs to meet the following criteria.

- The bed material in the culvert area should be stable for the 1:200 year peak design flow.
- The streambed should be in dynamic equilibrium for the peak discharge.
- Sediment inflow to culvert equals sediment outflow for the fish passage design flow.
- Design of baffled culvert should not be based on the same average velocity criteria as for open barrel culvert, as the fish movement occurs in zones of much lower velocity within the pool area.
- Hydraulic drop at the outfall of the culvert should be eliminated by providing tailwater control weirs and energy dissipation pool to increase flow depths in the culvert during periods of low fish passage flows.

2. Fish Passage Design Discharge

2.1 General

The total drainage area contributing flow to the Sinclair creek draining through the Sinclair culvert consists of catchment areas of 91.7 km^2. There is no representative reference hydrometric station with a catchment area similar to the project catchment in the vicinity of the site. Gauging stations in the project area either show a large catchment area or very small catchment area. Gauging station 08NA020 was considered as the most appropriate for determining the relevant Fish Passage Design Discharge (FPDD) in the vicinity of the proposed culvert location and the basin transfer method was used to estimate the fish passage design flows as described in the following sections.

ANSI A 215.9mm x 279.4mm

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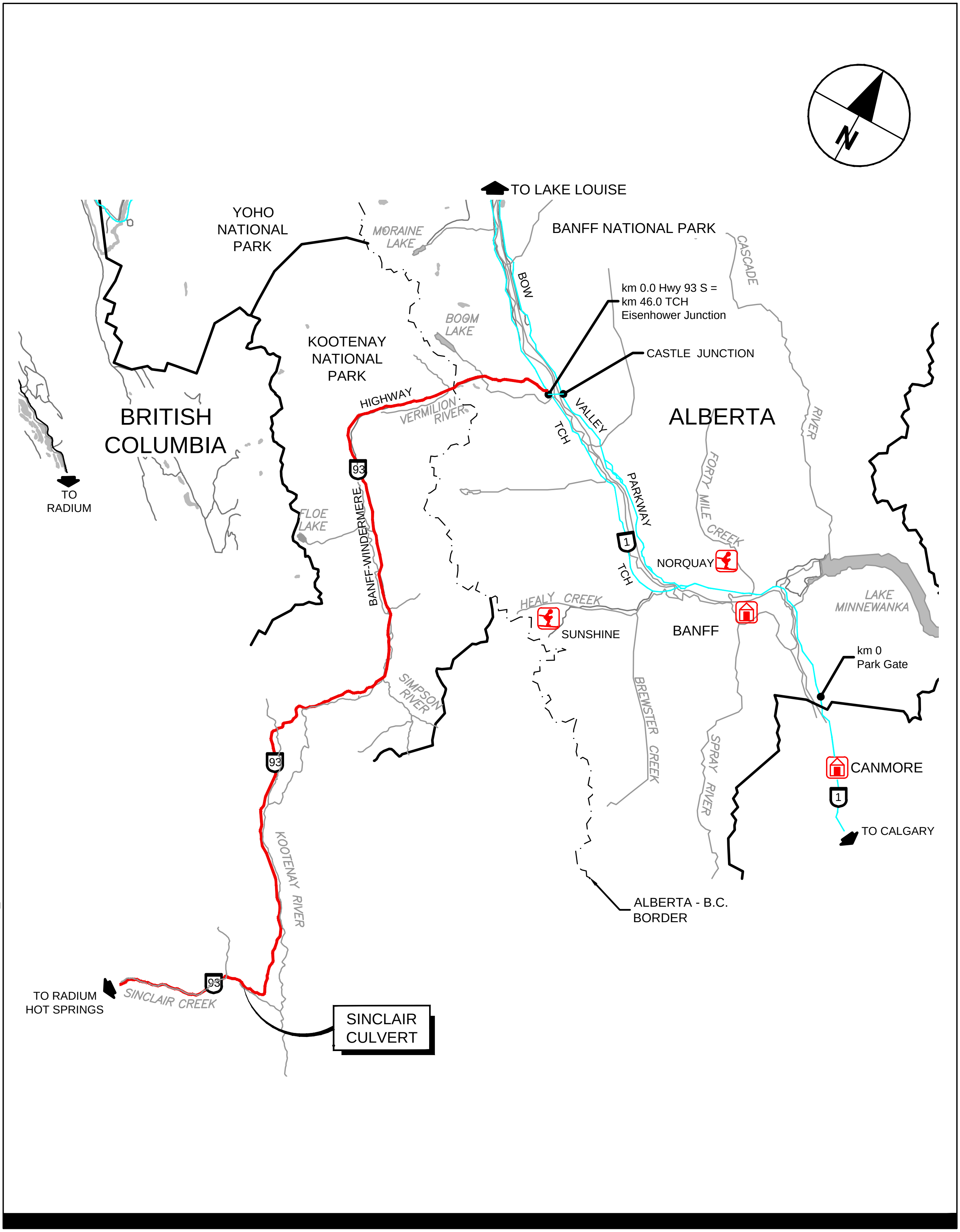
Filename: \\CACGY5FS001\PROD\PROJECTS\60547362\900-CAD_GIS\910-CAD\25-SKETCHES\CW01 SINCLAIR CREEK CULVERT KM102.03 HWT 93S\60547362-FIG-01-CWF01.DWG



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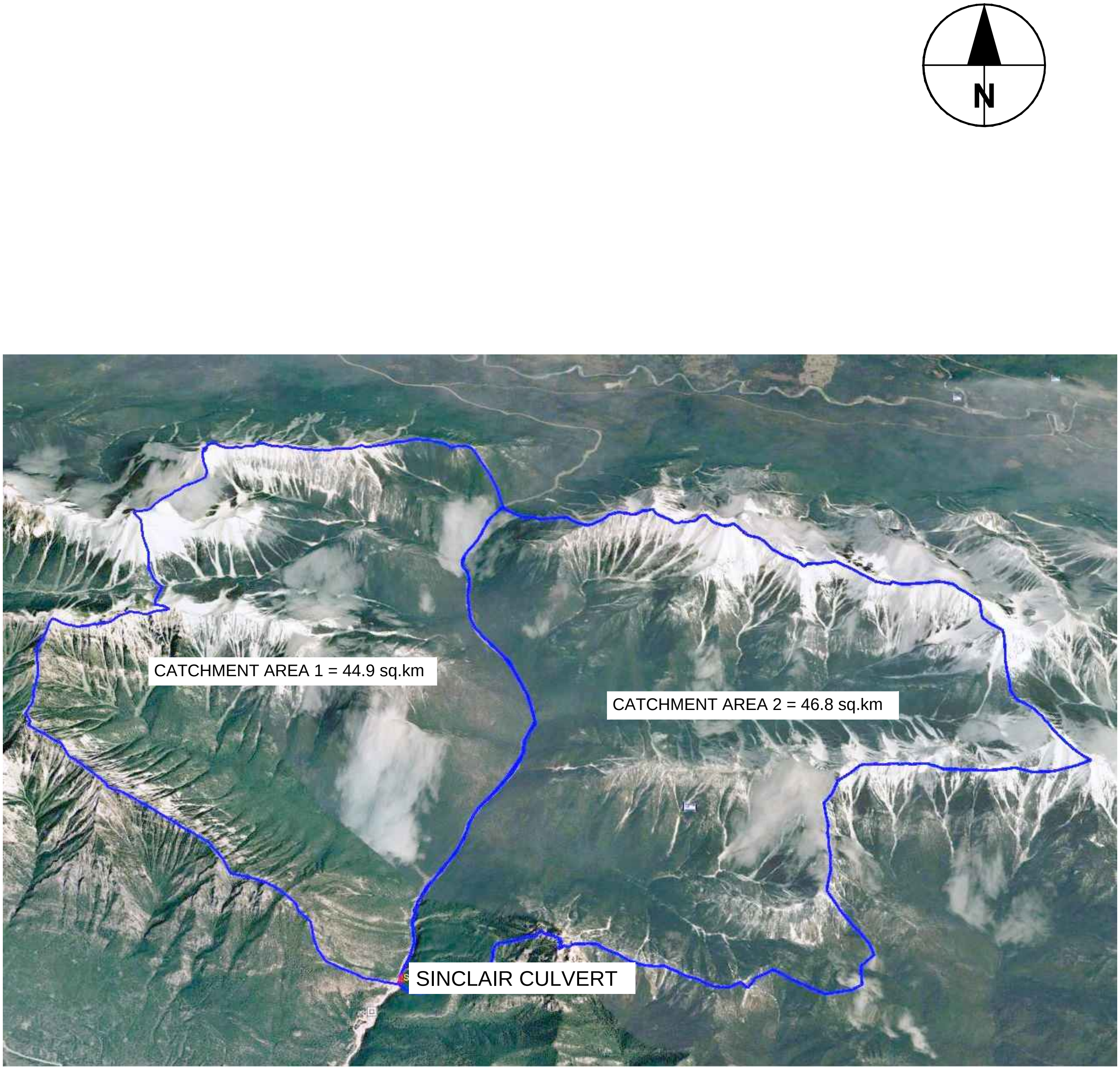
LOCATION PLAN

PARKS - KOOTENAY NATIONAL PARK

Project No.: 60547362 Date: 2017-09-08

AECOM

Figure: 1



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Filename: P:\60547362\900-CAD_GIS\910-CAD\25-SKETCHES\CW01 SINCLAIR CREEK CULVERT KM102.03 HWT 93S\60547362-FIG-01-CWF02.DWG

ANSI A 215.9mm x 279.4mm

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SINCLAIR CULVERT (REDWALL/PARKS GATE)
CATCHMENT AREAS

PARKS - KOOTENAY NATIONAL PARK
Project No.: 60547362 Date: 2017-11-28

AECOM

Figure: 2

2.2 Methodology for Hydrologic Analysis

A fish passage design discharge (FPDD) is required to assess the proposed culvert structure's performance and evaluate fish passage through the structure. Since the proposed culvert for the given creek does not have historical hydrological information and the available gauging stations in the vicinity of the culvert location do not represent similar catchment area as that of the proposed culvert catchment area of 91.7 ha there is difficulty of estimating an appropriate maximum fish passage discharge for the culvert.

Gauging station 08NA020 was considered as the most appropriate for determining the relevant FPDD in the vicinity of the proposed culvert location and the basin transfer method was used to estimate the fish passage design flows. Low and high fish passage design flows were estimated for the gauging station 08NA020 as follows:

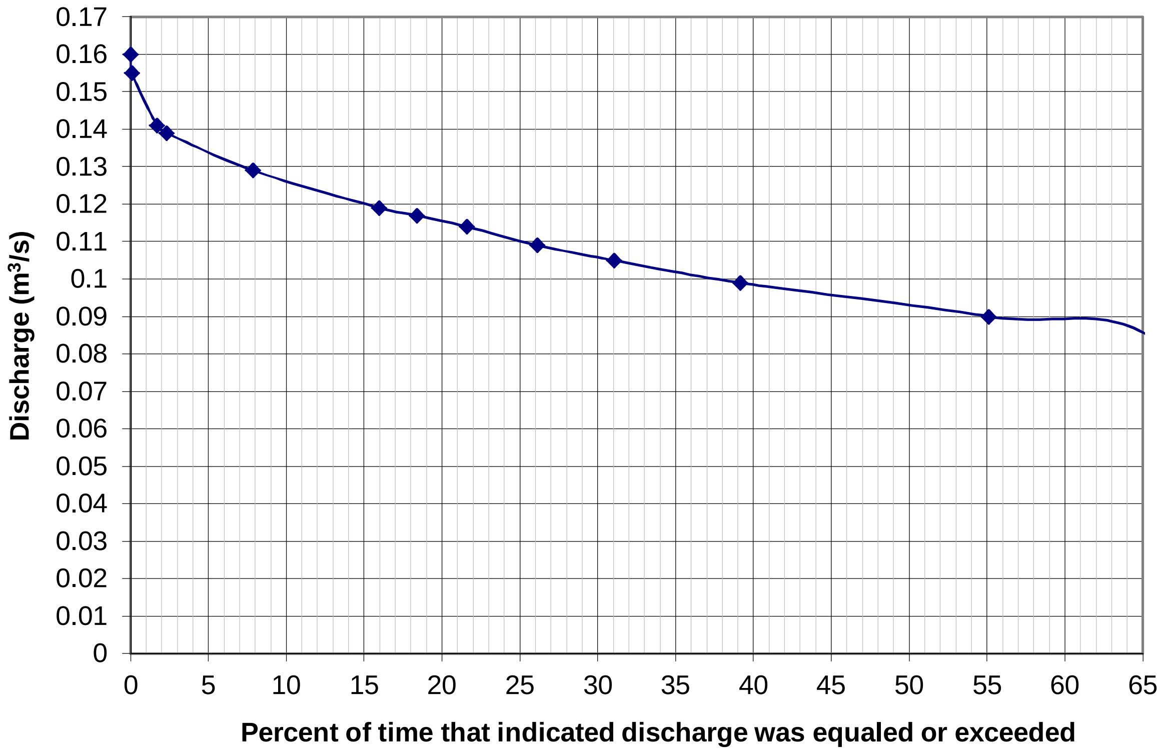
- Upper fish passage flow limit for adult Brook Trout equals the 1% exceedance flow; and
- Lower fish passage flow equals the 50% exceedance flow

Basin Parameters:

- Sinclair Clair culvert drainage area = 91.7 Km^2
- No Gage data available on the proposed culvert location
- Gage data available on nearby creek is gauging station 08NA020 with daily average flows
- Gauging station drainage area = 21.2 Km^2
- Period of Record: 1972 to 1986 (migration time considered as September to November)
- 1121 data points during fish migration time

Brook Trout fish was considered as main fish available in the creek per information available from Parks Canada. A young Brook Trout can tackle a maximum flow velocity of 0.6 m/s, while an adult fish is able to sustain even a higher flow velocity. Similarly, minimum water depth requirements vary with fish life stage. Brook Trout requires the minimum water depth as 0.24 m during migration time. Fish tackle flow velocity and the minimum water depth for Brook Trout was referenced from "Hydraulic Engineering Circular No. 26, First Edition" US Department of Transportation Federal Highway Administration. Spawning migration time for this type of fish is usually in the fall when water temperatures reach around 9^0C to 11^0C. Based on culvert location thus the fish migration period of September to November (91 days) was recommended by the fish biologist. Thus, mean daily discharges occurring during the fall spawning migration (91 days) were considered from the selected gauging station as mentioned above for determining FPDD. **Figure 3** shows a flow duration curve illustrating a percent of time flow exceeded for the referenced Water Survey Canada (WSC) gauging station 08NA020.

Figure 3: Flow Duration Curve for Gauging Station 08NA020)



Flows were ranked from highest to lowest (a rank of i=1 given to the highest flow). The lowest flow will have a rank of n, which equals the total number of flows recorded (1121 data points). The 50-percent and 1-percent exceedance flows were linked to a particular rank using the following formulas:

$i_{50\%} = 0.5\ (n+1)$ $\qquad$ $i_{1\%} = 0.01\ (n+1)$

The corresponding flow rates at these rankings are:

$Q_{50\%} = 0.093\ m^3/s$ (Low Fish Passage Flow)
$Q_{1\%} = 0.148\ m^3/s$ (High Fish Passage Flow)

These design flows were applied to the proposed culvert location by multiplying the flows obtained in the above $Q_{50\%}$ and $Q_{1\%}$ by the ratio of the culvert drainage area to the drainage area of the gauged creek at the creek crossing. Multiplying by this ratio of 4.32 adjusts for differences in drainage area between watersheds. Thus, fish passage design discharges are given in the following Table 2.1 below.

Table 2.1: Fish Passage Design Discharges	
Low Fish Passage Flow	High Fish Passage Flow
(91.7\21.2) x 0.093 = 0.402 m^3/s	(91.7\21.2) x 0.148 = 0.61 m^3/s

High fish passage flow was related to fish swimming performance against the flow velocity (fish exhausted at burst speed) and low fish passage flow was related to a minimum flow depth requirement for fish migration time. As fish require adequate depth of flow for migration, the minimum depth of flow applied for determining the FPDD was 0.24 m.

2.3 Hydraulics Analysis

A 165.29 m long existing pipe arch culvert made of steel concrete box of 3000 mm span and 2210 mm rise is sloped at 4.13%. The existing culvert is recommended to be replaced by 3000 mm span by 2400 mm rise concrete box section as shown in **Figure 4,** which is large enough to handle the estimated 1:200 year design flow of 14.0 m^3/s with 250 mm high baffles. This culvert section was analysed for the FPDD of 0.402 m^3/s and 0.640 m^3/s with the baffles using HY-8 culvert analysis software.

<u>Proposed Culvert Characteristics:</u>
Construction: Box Concrete 3000 mm span and 2400 mm rise as shown in **Figure 4**
Installation: At Grade of 4.13% longitudinal slope
Inlet bottom elevation: 1027.708
Outlet bottom elevation: 1020.893
Culvert length: 164.342 m
Inlet condition: Wing Wall
Inlet head loss coefficient: 0.2
Manning's roughness at bottom: 0.08

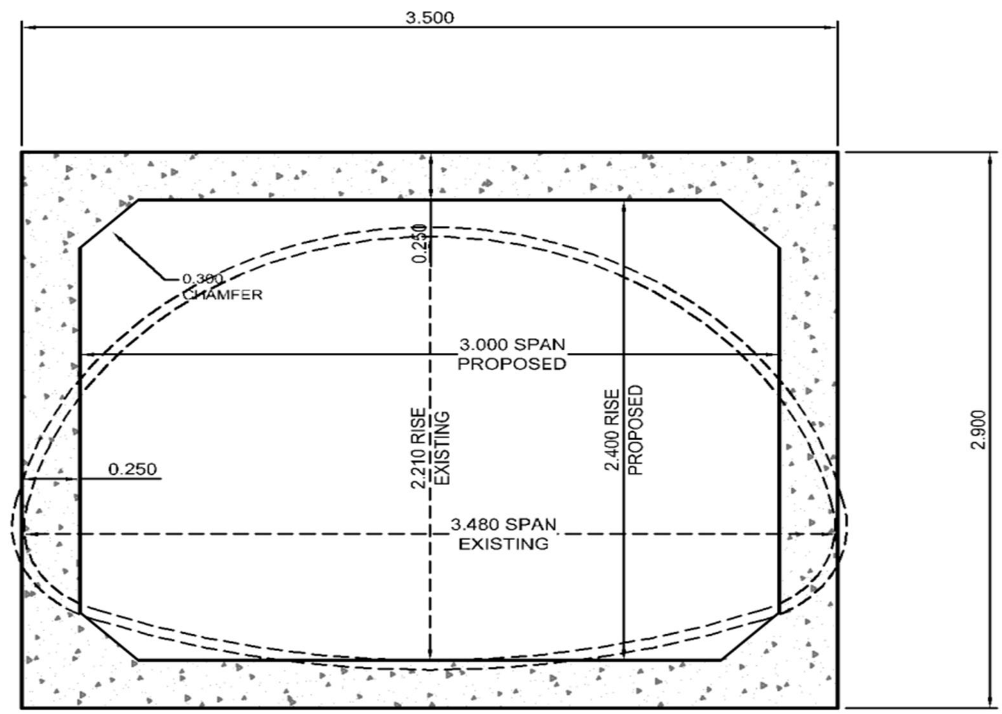


Figure 4: Concrete Box Culvert Section

Baffle design criteria for adult Brook Trout that must be met for the proposed concrete box culvert as follows:

- Maximum average velocity is 0.6 m/s during high passage flows;
- Minimum water depth 0.24m within step pools during low fish passage flows; and
- Energy dissipation pool at the culvert outlet with a minimum 0.61 m drop as shown in **Figure 8**.

HY-8 culvert analysis software was used to check the outlet flow velocities and normal flow depths at 0.640 m^3/s and 0.402 m^3/s respectively without using the baffles. Table 2.2 shows culvert summary results for 0.402 m^3/s low fish passage design flows. Maximum flow depth during low fish passage flows was estimated at 0.174m which is less than required 0.24 m flow depth. Similarly, Table 2.3 shows culvert summary report for 0.640 m^3/s high fish passage design flow.

Table 2.2
Culvert Summary for Low Fish Passage Design Discharge without Fish Baffles

Culvert Discharge (m^3/s)	Headwater Elevation (m)	Inlet Control Depth (m)	Outlet Control Depth (m)	Normal Depth (m)	Critical Depth (m)	Outlet Depth (m)	Tailwater Depth (m)	Outlet Velocity (m/s)	Velocity between baffles (m/s)	Tailwater Velocity (m/s)
0.00	1027.96	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.000
0.04	1028.01	0.032	0.049	0.036	0.021	0.021	0.029	0.626	0.19	0.390
0.08	1028.04	0.058	0.080	0.063	0.039	0.039	0.043	0.690	0.21	0.510
0.12	1028.06	0.077	0.104	0.080	0.052	0.052	0.055	0.776	0.23	0.595
0.16	1028.08	0.097	0.127	0.097	0.063	0.063	0.066	0.845	0.25	0.664
0.20	1028.11	0.111	0.147	0.113	0.074	0.074	0.075	0.903	0.27	0.721
0.24	1028.12	0.126	0.165	0.125	0.084	0.084	0.083	0.955	0.29	0.771
0.28	1028.14	0.139	0.183	0.138	0.094	0.094	0.091	1.001	0.30	0.816
0.32	1028.16	0.153	0.200	0.150	0.103	0.103	0.099	1.043	0.31	0.857
0.36	1028.17	0.165	0.216	0.163	0.111	0.111	0.106	1.082	0.32	0.895
0.40	1028.19	0.177	0.231	**0.174**	0.120	0.120	0.113	1.118	0.34	0.929

Baffle Spacing

Baffle spacing was calculated for proposed low flow design flows with 250 mm baffle height for culvert sloped at 4.13% as follows.

Baffle height, h1 = 0.25 m (refer to **Figure 5**)
Baffle spacing = 2.0 m
Flow depth just downstream of baffle, h3 = h1 – 2.0 x 0.0413 = 0.167m, which is less than 0.25 m. Thus, the baffle with slot dimension of 0.1 m depth and 0.5 m width is recommended to achieve flow depth more than 0.24 m.

<u>Flow depth on Baffle Top</u>

Flow depth over the baffle crest was estimated at 0.135 m using a weir flow formula as a broad-crested weir with coefficient as 2.7. Thus, the baffle with a small notch or depression of 0.10 m within the baffle is required to ensure that a passage way of sufficient depth for fish migration is available at the facility with a minimum flow levels. Baffle notch opening would be designed as 0.10 m depth by 0.5 m long and positioned as shown in **Figure 6**.

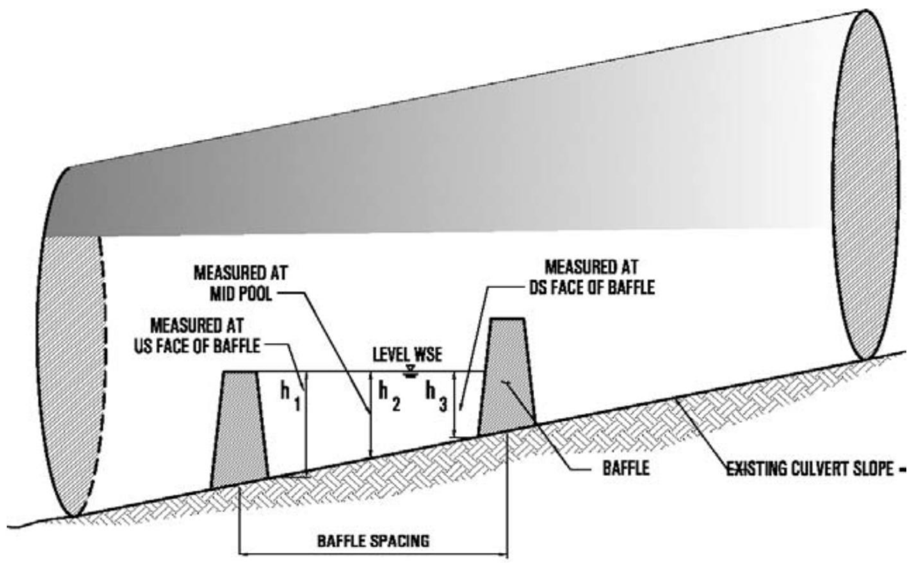


Figure 5: Baffle height and water depth illustration downstream face of the baffle

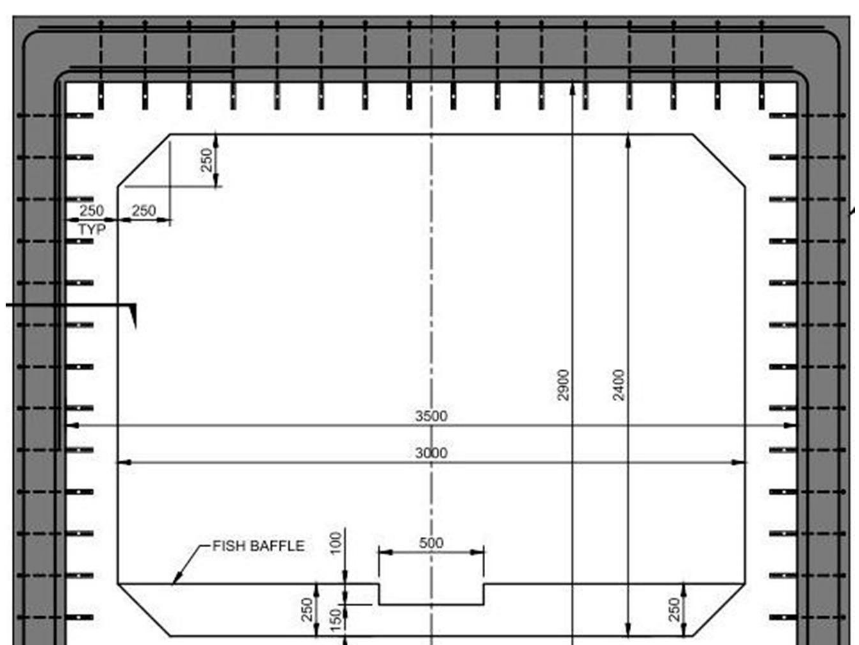


Figure 6: Concrete box culvert section with baffles and notch

Table 2.3
Culvert Summary for High Fish Passage Design Discharge without Fish Baffles

Culvert Discharge (m^3/s)	Headwater Elevation (m)	Inlet Control Depth (m)	Outlet Control Depth (m)	Critical Depth (m)	Outlet Depth (m)	Tailwater Depth (m)	Outlet Velocity (m/s)	Velocity between baffles (m/s)	Tailwater Velocity (m/s)
0.00	1027.96	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.000
0.06	1028.03	0.049	0.070	0.033	0.033	0.038	0.647	0.19	0.467
0.13	1028.07	0.081	0.109	0.054	0.054	0.057	0.789	0.24	0.609
0.19	1028.10	0.108	0.143	0.072	0.072	0.073	0.891	0.27	0.709
0.26	1028.13	0.131	0.172	0.088	0.088	0.086	0.972	0.29	0.789
0.32	1028.16	0.152	0.199	0.102	0.102	0.099	1.042	0.31	0.855
0.38	1028.18	0.172	0.225	0.116	0.116	0.110	1.102	0.33	0.914
0.45	1028.21	0.190	0.248	0.129	0.129	0.120	1.157	0.35	0.966
0.51	1028.23	0.208	0.271	0.141	0.141	0.130	1.207	0.36	1.013
0.58	1028.25	0.225	0.293	0.153	0.153	0.139	1.253	0.38	1.056
0.61	1028.27	0.242	0.314	0.165	0.165	0.148	1.295	**0.39**	1.097

Average culvert outlet flow velocity was estimated at 1.295 m/s as shown in Table 2.3 for high fish passage design flows excluding fish baffles. Flow velocity in the pool between the baffles will be reduced at least 70% as shown in **Figure 7**, experimentally obtained typical velocity profile for open channel flow.

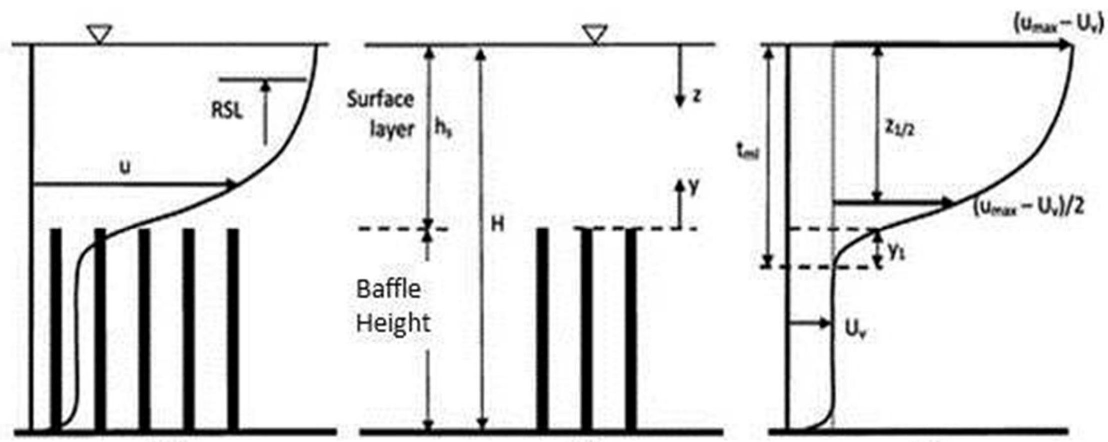


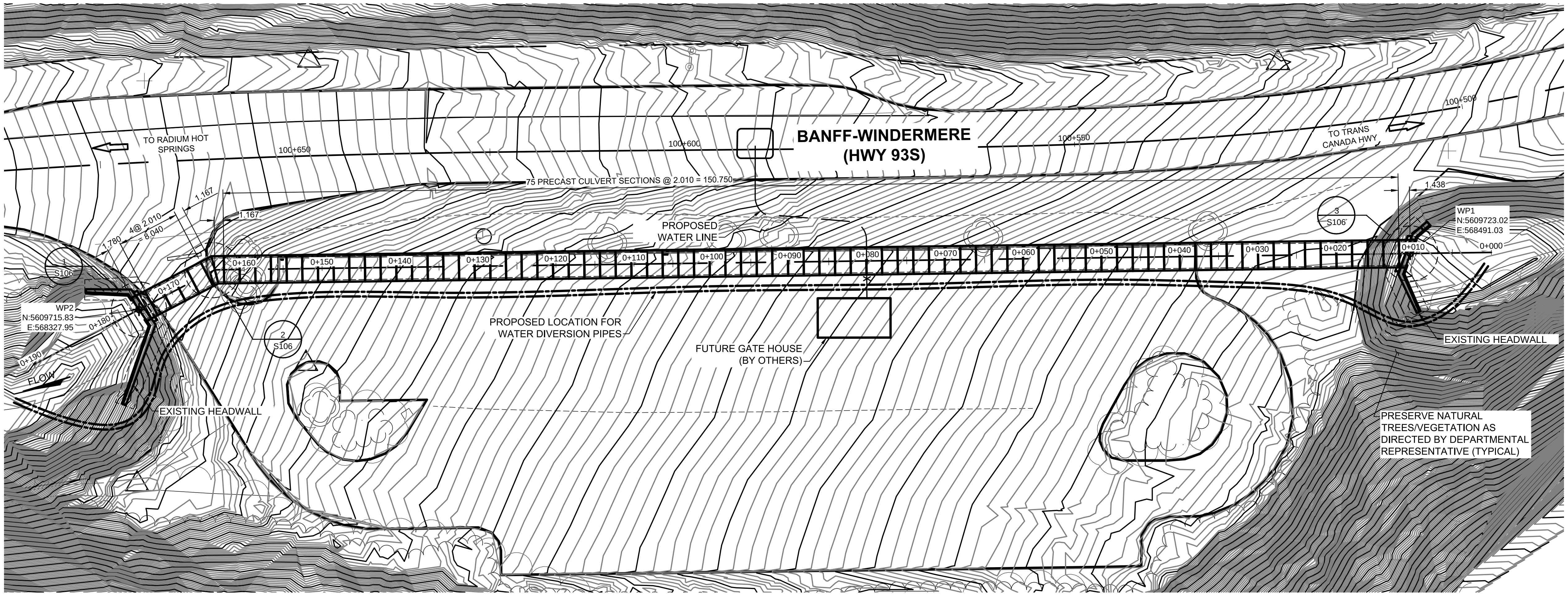
Figure 7: Typical Velocity Profile for Open Channel Surface Flow

Thus, the flow velocity in the pool between the baffles during high fish passage flow was estimated at approximately 0.4 m/s, which is less than design criteria flow velocity of 0.6 m/s. Table 2.4 shows summary of fish passage hydraulic baffle design.

Table 2.4: Baffle Design Summary		
	Designed	Criteria
Flow velocity for High Fish Passage Flows	0.4 m/s	0.6 m/s
Flow Depth at downstream face of baffle slot for Low Fish Passage Flows	0.267 m	0.24 m
Baffle Spacing	2.0m	
Baffle Height	0.25 m	
Baffle Thickness	0.25m	
Baffle Notch	100 mm x 500 mm	

3.0 Energy Dissipation Pool Design

Figure 7 shows the proposed culvert plan and a longitudinal section. Energy dissipation pools are required at the culvert outlet for the proposed closed-bottom concrete box culvert. The outlet energy dissipation pool with tailwater control capabilities should be constructed at the downstream end of the culvert facility. The pool was sized to ensure stability of the pool during the 1:200 year event peak flows. The length and width of the outlet pool should be twice the rise of the culvert and the bottom elevation of the pool should be at least 0.61 m below the invert elevation of the culvert, at the outlet. The crest elevation of the tailwater control device should be sufficient to provide a minimum depth of 0.24 m throughout the culvert during the low fish passage design flows. Riprap should be used to armour the natural streambed for an appropriate distance below the tailwater control structure to ensure the smooth transition to the natural streambed. **Figure 8** shows the energy dissipation pool plan, section and details.



PLAN

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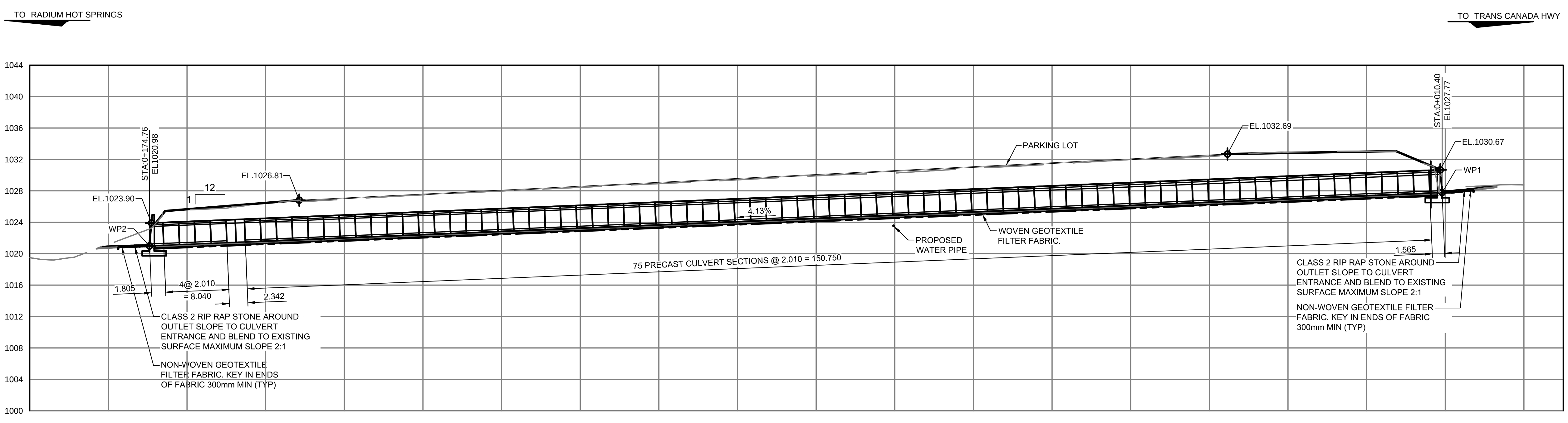

ELEVATION

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AECOM

Figure 7

Issue Status: DRAFT

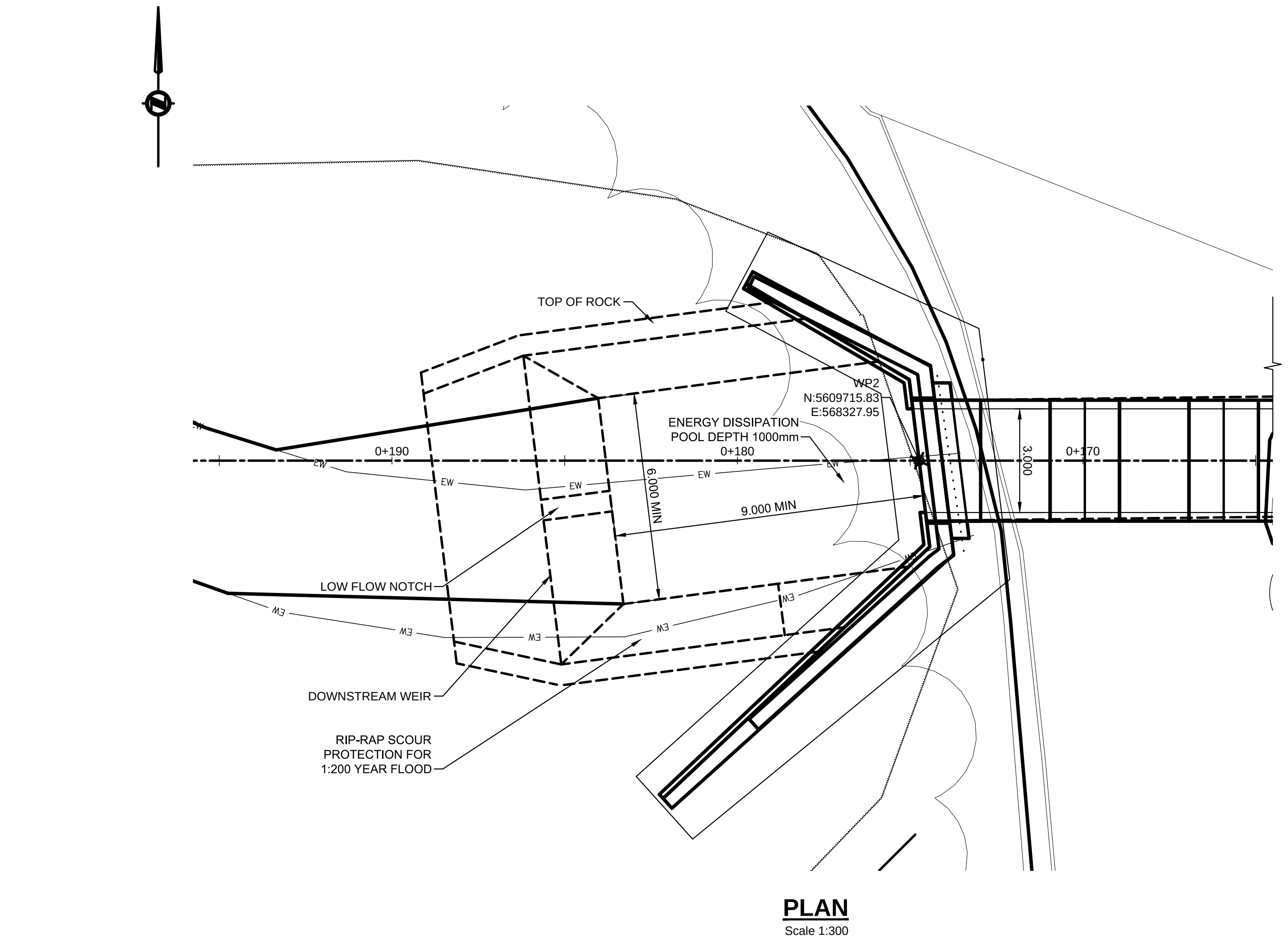
NEW CULVERT LAYOUT

PARKS CANADA - KOOTENAY NATIONAL PARK

Project No.: 60547362 Date: 2017-11-30

Project Management Initials: ____ Designer: ____ Checked: ____ Approved: ____ ANSI D 558.8mm x 863.6mm

Last saved by: ZHANGD1(2017-12-05) Last Plotted: 2017-12-05
Filename: P:\60547362\900-CAD_GIS\910-CAD\25-SKETCHES\CW01 SINCLAIR CREEK CULVERT KM102.03 HWT 93S\60547362-FIG-01-CWF07.DWG



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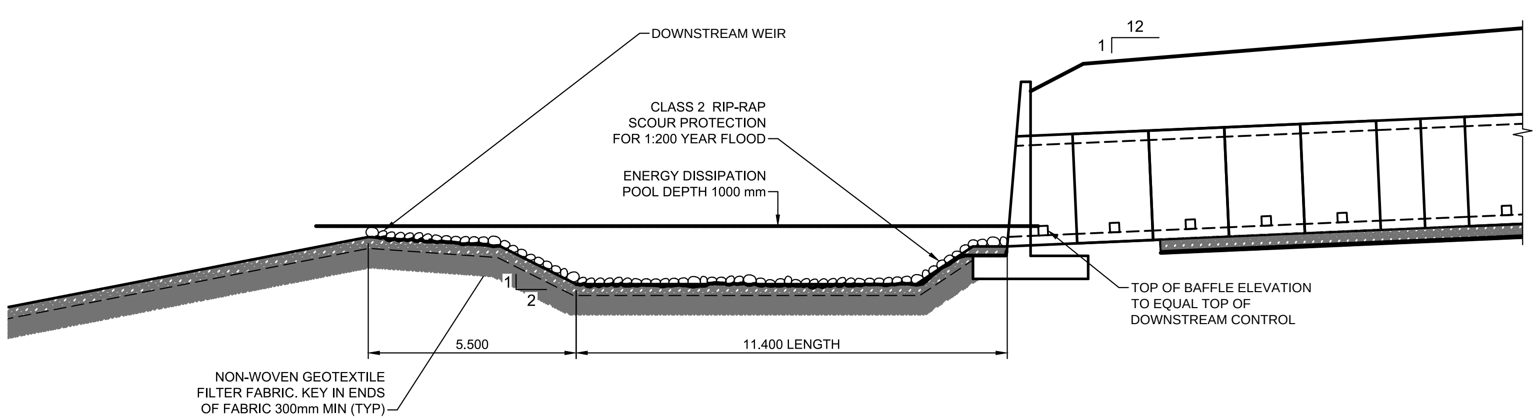

ELEVATION
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GENERAL NOTES

1. ALL DIMENSIONS SHOWN ON THIS DRAWING ARE METRIC UNLESS NOTED OTHERWISE.
2. FOR THE ENERGY DISSIPATION POOL HEAVY ROCK RIPRAP SHALL COVER THE AREA SHOWN ON THIS DRAWING.
3. HEAVY ROCK RIPRAP TO BE PLACED TO THE ELEVATIONS SHOWN ON THIS DRAWINGS AND SHALL BE PLACED TO A MINIMUM THICKNESS OF 800 mm. HEAVY ROCK RIPRAP SHALL MEET THE FOLLOWING GRADAION REQUIREMENTS:

HEAVY ROCK RIPRAP CLASS 2		
REQUIRED PROPERTIES	UNITS	
NOMINAL MASS	kg	200
NOMINAL DIAMETER	mm	500
NONE GREATER THAN	kg	700
	mm	800
20% TO 50%	kg	300
	mm	600
50% TO 80%	kg	200
	mm	500
100% GREATER THAN	kg	40
	mm	300

3. PLACE NON-WOVEN GEOTEXTILE FILTER FABRIC UNDER ALL HEAVY ROCK RIPRAP.
4. GEOTEXTILE FILTER FABRIC SHOWN SHALL MEET THE FOLLOWING REQUIREMENTS:

NON-WOVEN GEOTEXTILE FILTER FABRIC	
SPECIFICATIONS AND PHYSICAL PROPERTIES	
	CLASS 1M,1,2,3
GRAB STRENGTH	900 N
ELONGATION (FAILURE)	50%
PUNCTURE STRENGTH	550 N
TRAPEZOIDAL TEAR	350 N
MINIMUM FABRIC LAP TO BE 1000mm	

Issue Status: DRAFT

AECOM

Figure 8

ENERGY DISSIPATION POOL DETAILS

PARKS CANADA - KOOTENAY NATIONAL PARK
Project No.: 60547362 Date: 2017-11-30

3. Conclusion and Recommendations

The proposed box culvert with 250 mm baffle is able to convey the 1:200 year design flow of 14.0 m^3/s with a free surface flow with the box section. The road top elevation is 1033.048 m. The fish passage was designed with a 250 mm high baffle, spaced at 2.0 m within culvert length. The designed flow depth and velocity satisfy the fish passage design criteria for low FPDD.

Removal of the existing culvert and maintenance should adhere to general fish window timing (June to August) in which changes in stream bed would cause the least risk of impact to fish habitat. An appropriate fish salvage, rescue and release program should be in place for works outside the periods of least risk for instream works for relevant fish species.

Baffles installed within the culvert length will be in general a good location for sediment and debris catchers and thus a regular maintenance is required for effective fish migration.

4. Closure

We trust this memorandum satisfies your present requirements. We would be pleased to provide any further information required during the course of this project. Feel free to contact the undersigned should you have any questions.

Respectfully Submitted,
AECOM Canada Ltd.

PROFESSIONAL ENGINEER ALBERTA
JAGADISH KAYASTHA

Prepared by:

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Dec. 18, 2017

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Encl:

Appendix A – Proposed Culverts HY-8 Culvert Analysis Results

Appendix A

Proposed Culvert

HY-8 Culvert Analysis Results

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0 cms

Design Flow: 0.402 cms

Maximum Flow: 0.402 cms

Table 1 - Summary of Culvert Flows at Crossing: Flow Depth: 3m Span x 2.4m Rise

Headwater Elevation (m)	Total Discharge (cms)	Option 2: 3000mm x 2400mm Box Culvert Discharge (cms)	Roadway Discharge (cms)	Iterations
1027.96	0.00	0.00	0.00	1
1028.01	0.04	0.04	0.00	1
1028.04	0.08	0.08	0.00	1
1028.06	0.12	0.12	0.00	1
1028.08	0.16	0.16	0.00	1
1028.11	0.20	0.20	0.00	1
1028.12	0.24	0.24	0.00	1
1028.14	0.28	0.28	0.00	1
1028.16	0.32	0.32	0.00	1
1028.17	0.36	0.36	0.00	1
1028.19	0.40	0.40	0.00	1
1033.05	31.32	31.32	0.00	Overtopping

Box Culvert (Copy)

Rating Curve Plot for Crossing: Flow Depth: 3m Span x 2.4m Rise Box Culvert (Copy)

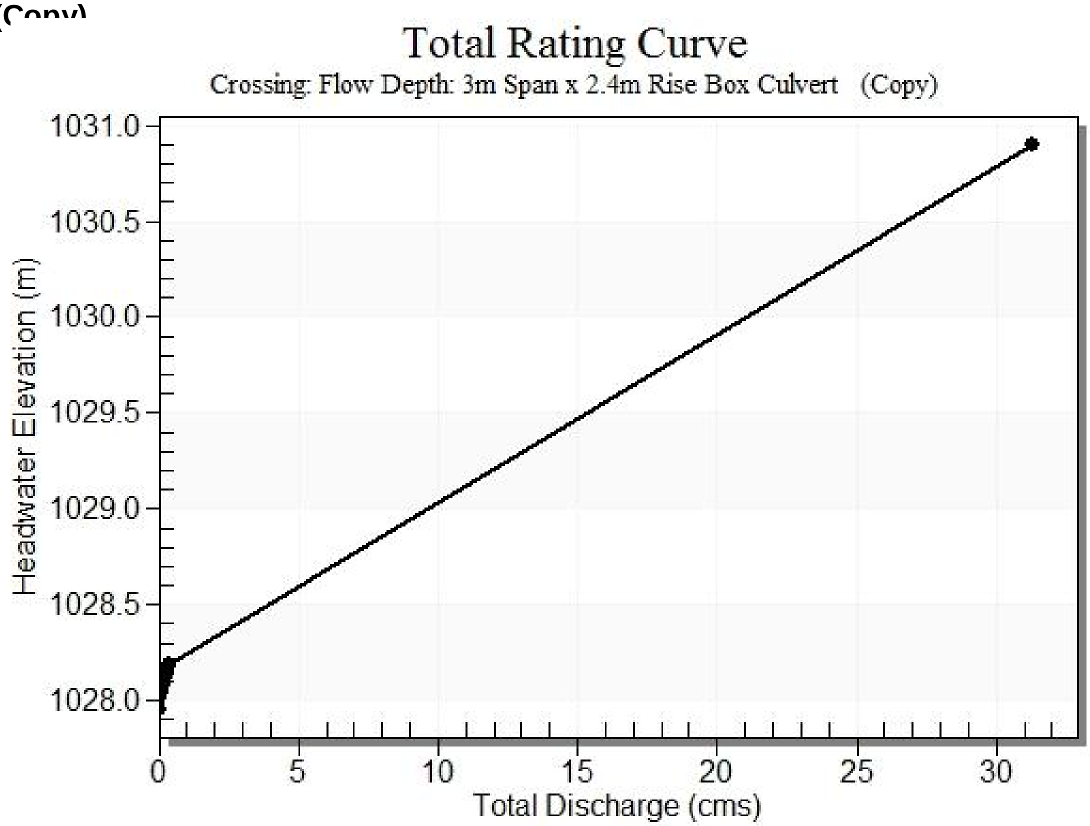


Table 2 - Culvert Summary Table: Option 2: 3000mm x 2400mm Box Culvert

Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control Depth (m)	Outlet Control Depth (m)	Flow Type	Normal Depth (m)	Critical Depth (m)	Outlet Depth (m)	Tailwater Depth (m)	Outlet Velocity (m/s)	Tailwater Velocity (m/s)
0.00	0.00	1027.96	0.000	0.000	0-NF	0.000	0.000	0.000	0.000	0.000	0.000
0.04	0.04	1028.01	0.032	0.049	2-M2c	0.036	0.021	0.021	0.029	0.626	0.390
0.08	0.08	1028.04	0.058	0.080	2-M2c	0.063	0.039	0.039	0.043	0.690	0.510
0.12	0.12	1028.06	0.077	0.104	2-M2c	0.080	0.052	0.052	0.055	0.776	0.595
0.16	0.16	1028.08	0.097	0.127	2-M2c	0.097	0.063	0.063	0.066	0.845	0.664
0.20	0.20	1028.11	0.111	0.147	2-M2c	0.113	0.074	0.074	0.075	0.903	0.721
0.24	0.24	1028.12	0.126	0.165	2-M2c	0.125	0.084	0.084	0.083	0.955	0.771
0.28	0.28	1028.14	0.139	0.183	2-M2c	0.138	0.094	0.094	0.091	1.001	0.816
0.32	0.32	1028.16	0.153	0.200	2-M2c	0.150	0.103	0.103	0.099	1.043	0.857
0.36	0.36	1028.17	0.165	0.216	2-M2c	0.163	0.111	0.111	0.106	1.082	0.895
0.40	0.40	1028.19	0.177	0.231	2-M2c	0.174	0.120	0.120	0.113	1.118	0.929

****

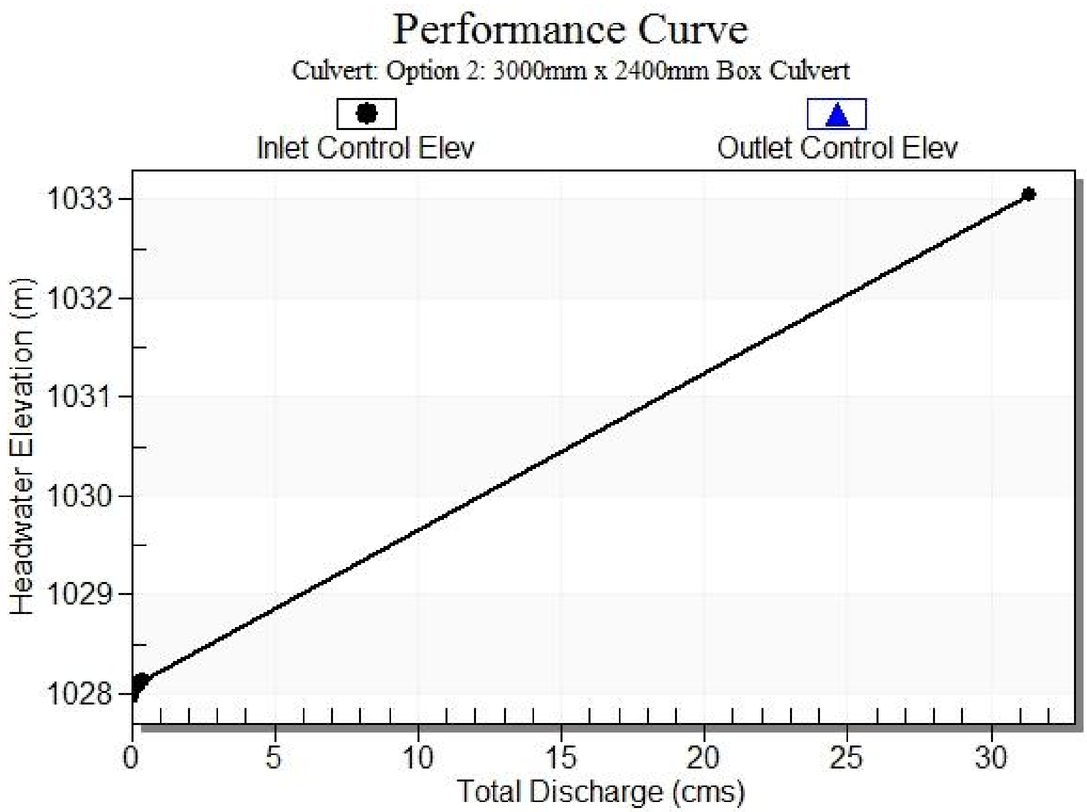
Straight Culvert

Inlet Elevation (invert): 1027.96 m,   Outlet Elevation (invert): 1021.14 m

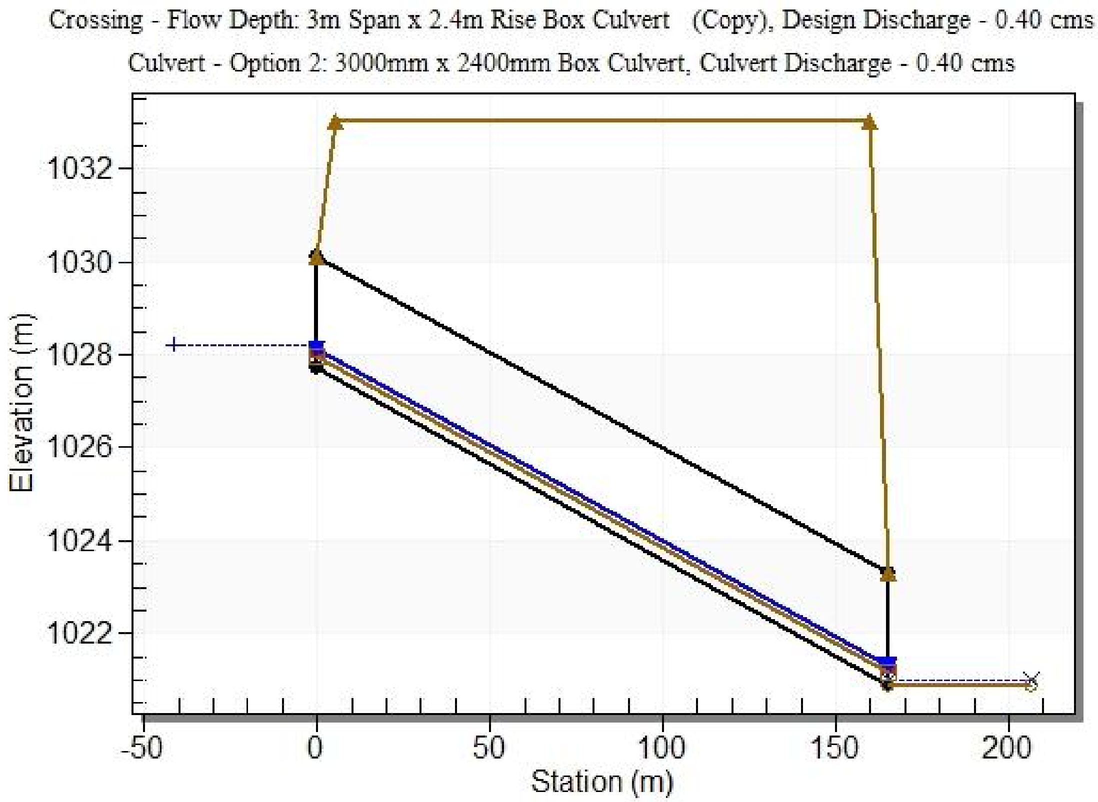
Culvert Length: 165.28 m,   Culvert Slope: 0.0413

****

Culvert Performance Curve Plot: Option 2: 3000mm x 2400mm Box Culvert



Water Surface Profile Plot for Culvert: Option 2: 3000mm x 2400mm Box Culvert



Site Data - Option 2: 3000mm x 2400mm Box Culvert

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 m

Inlet Elevation: 1027.71 m

Outlet Station: 165.14 m

Outlet Elevation: 1020.89 m

Number of Barrels: 1

Culvert Data Summary - Option 2: 3000mm x 2400mm Box Culvert

Barrel Shape: Concrete Box

Barrel Span: 3000.00 mm

Barrel Rise: 2400.00 mm

Barrel Material: Concrete

Embedment: 250.00 mm

Barrel Manning's n: 0.0130 (top and sides)

Manning's n: 0.0800 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

Table 3 - Downstream Channel Rating Curve (Crossing: Flow Depth: 3m Span x 2.4m Rise Box Culvert (Copy))

Flow (cms)	Water Surface Elev (m)	Depth (m)	Velocity (m/s)	Shear (Pa)	Froude Number
0.00	1020.89	0.00	0.00	0.00	0.00
0.04	1020.92	0.03	0.39	6.19	0.74
0.08	1020.94	0.04	0.51	9.36	0.80
0.12	1020.95	0.06	0.59	11.93	0.83
0.16	1020.96	0.07	0.66	14.14	0.85
0.20	1020.97	0.07	0.72	16.14	0.87
0.24	1020.98	0.08	0.77	17.98	0.88
0.28	1020.98	0.09	0.82	19.70	0.89
0.32	1020.99	0.10	0.86	21.31	0.90
0.36	1021.00	0.11	0.89	22.85	0.91
0.40	1021.01	0.11	0.93	24.30	0.92

Tailwater Channel Data - Flow Depth: 3m Span x 2.4m Rise Box Culvert (Copy)

Tailwater Channel Option: Trapezoidal Channel

Bottom Width: 3.50 m

Side Slope (H:V): 3.00 (_:1)

Channel Slope: 0.0220

Channel Manning's n: 0.0350

Channel Invert Elevation: 1020.89 m

Roadway Data for Crossing: Flow Depth: 3m Span x 2.4m Rise Box Culvert (Copy)

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 m

Crest Elevation: 1033.05 m

Roadway Surface: Paved

Roadway Top Width: 155.00 m

HY-8 Culvert Analysis Report

Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 0 cms

Design Flow: 0.61 cms

Maximum Flow: 0.61 cms

Table 1 - Summary of Culvert Flows at Crossing: Flow Velocity: 3m Span x 2.4m Rise

Headwater Elevation (m)	Total Discharge (cms)	Option 2: 3000mm x 2400mm Box Culvert Discharge (cms)	Roadway Discharge (cms)	Iterations
1027.96	0.00	0.00	0.00	1
1028.03	0.06	0.06	0.00	1
1028.07	0.13	0.13	0.00	1
1028.10	0.19	0.19	0.00	1
1028.13	0.26	0.26	0.00	1
1028.16	0.32	0.32	0.00	1
1028.18	0.38	0.38	0.00	1
1028.21	0.45	0.45	0.00	1
1028.23	0.51	0.51	0.00	1
1028.25	0.58	0.58	0.00	1
1028.27	0.64	0.64	0.00	1
1033.05	31.31	31.31	0.00	Overtopping

Box Culvert

Rating Curve Plot for Crossing: Flow Velocity: 3m Span x 2.4m Rise Box Culvert

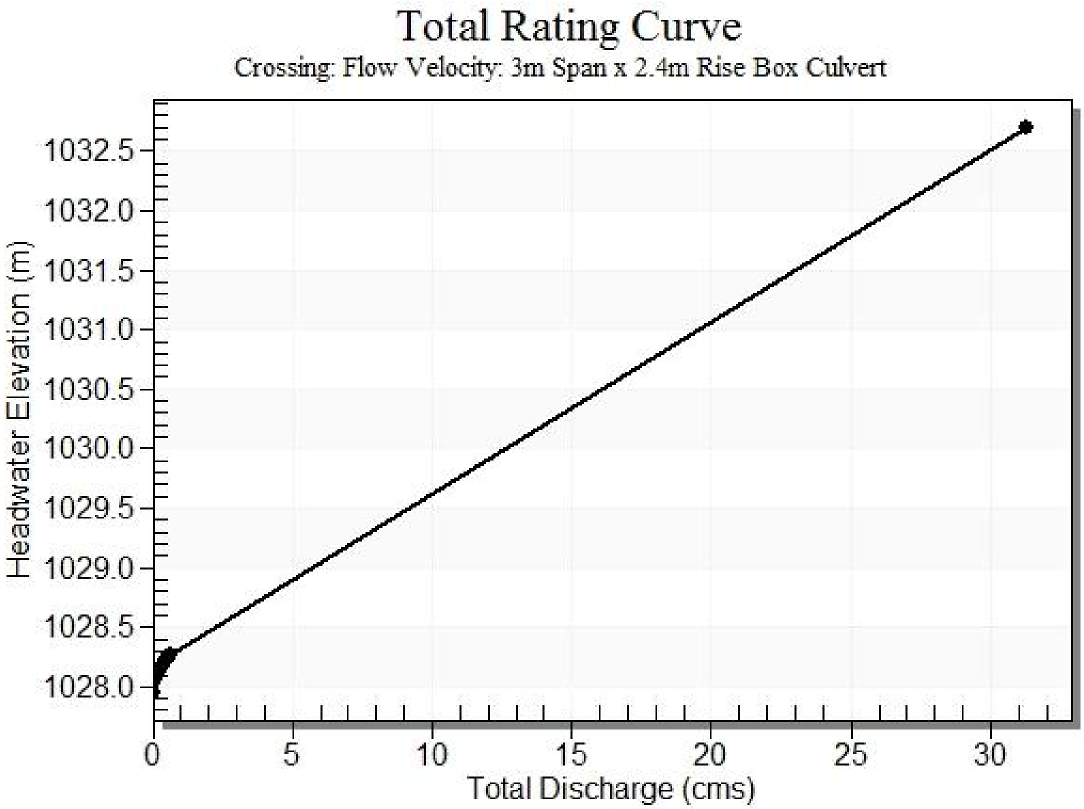


Table 2 - Culvert Summary Table: Option 2: 3000mm x 2400mm Box Culvert

Total Discharge (cms)	Culvert Discharge (cms)	Headwater Elevation (m)	Inlet Control Depth (m)	Outlet Control Depth (m)	Flow Type	Normal Depth (m)	Critical Depth (m)	Outlet Depth (m)	Tailwater Depth (m)	Outlet Velocity (m/s)	Tailwater Velocity (m/s)
0.00	0.00	1027.96	0.000	0.000	0-NF	0.000	0.000	0.000	0.000	0.000	0.000
0.06	0.06	1028.03	0.049	0.070	2-M2c	0.056	0.033	0.033	0.038	0.647	0.467
0.13	0.13	1028.07	0.081	0.109	2-M2c	0.083	0.054	0.054	0.057	0.789	0.609
0.19	0.19	1028.10	0.108	0.143	2-M2c	0.110	0.072	0.072	0.073	0.891	0.709
0.26	0.26	1028.13	0.131	0.172	2-M2c	0.130	0.088	0.088	0.086	0.972	0.789
0.32	0.32	1028.16	0.152	0.199	2-M2c	0.150	0.102	0.102	0.099	1.042	0.855
0.38	0.38	1028.18	0.172	0.225	2-M2c	0.169	0.116	0.116	0.110	1.102	0.914
0.45	0.45	1028.21	0.190	0.248	2-M2c	0.185	0.129	0.129	0.120	1.157	0.966
0.51	0.51	1028.23	0.208	0.271	2-M2c	0.202	0.141	0.141	0.130	1.207	1.013
0.58	0.58	1028.25	0.225	0.293	2-M2c	0.218	0.153	0.153	0.139	1.253	1.056
0.64	0.64	1028.27	0.242	0.314	2-M2c	0.233	0.165	0.165	0.148	1.295	1.097

****

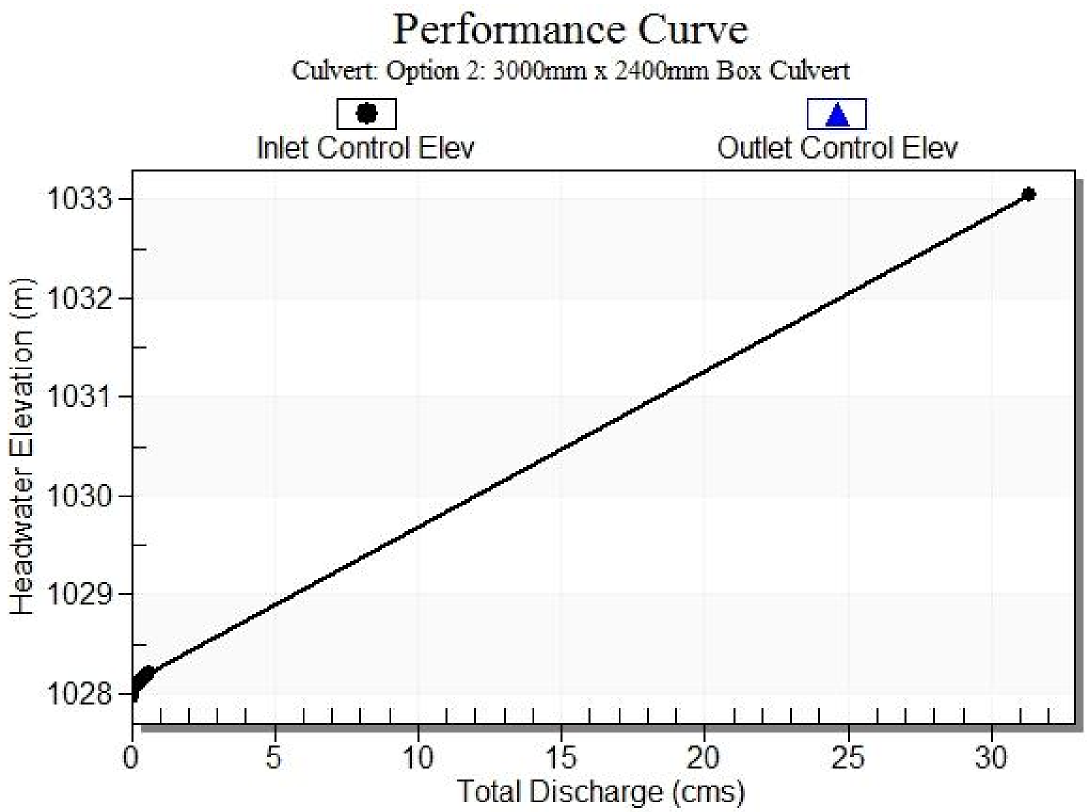
Straight Culvert

Inlet Elevation (invert): 1027.96 m, Outlet Elevation (invert): 1021.14 m

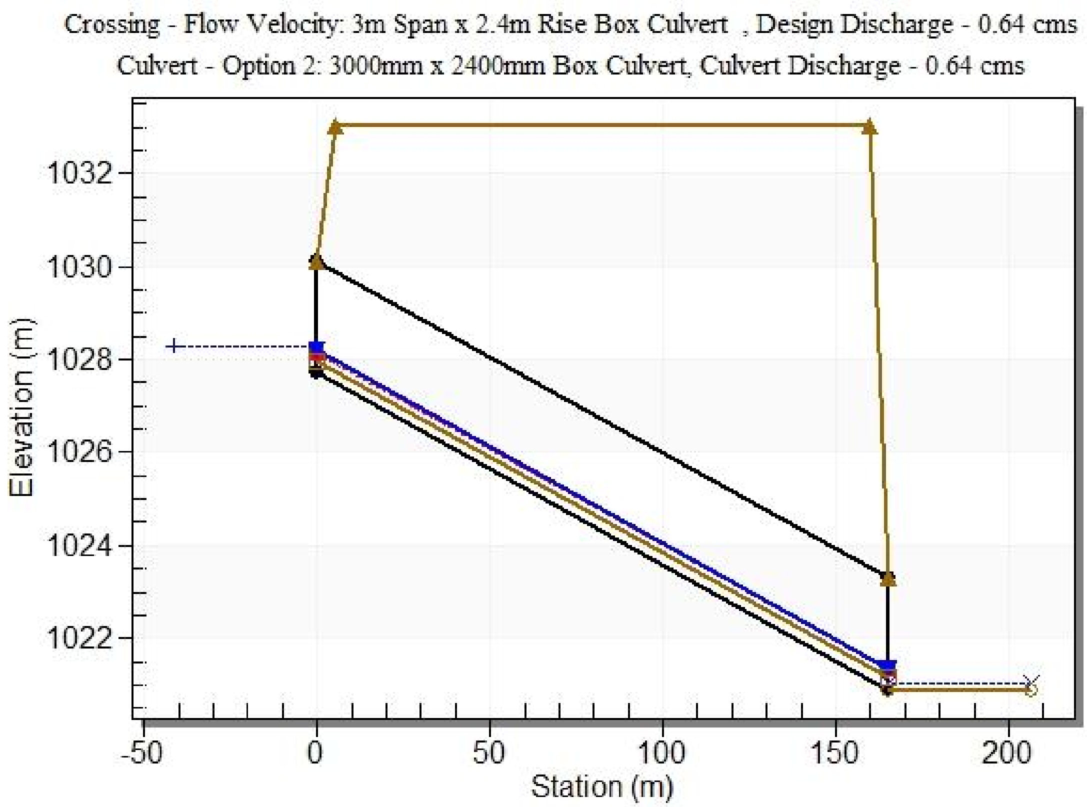
Culvert Length: 165.28 m, Culvert Slope: 0.0413

****

Culvert Performance Curve Plot: Option 2: 3000mm x 2400mm Box Culvert



Water Surface Profile Plot for Culvert: Option 2: 3000mm x 2400mm Box Culvert



Site Data - Option 2: 3000mm x 2400mm Box Culvert

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 m

Inlet Elevation: 1027.71 m

Outlet Station: 165.14 m

Outlet Elevation: 1020.89 m

Number of Barrels: 1

Culvert Data Summary - Option 2: 3000mm x 2400mm Box Culvert

Barrel Shape: Concrete Box

Barrel Span: 3000.00 mm

Barrel Rise: 2400.00 mm

Barrel Material: Concrete

Embedment: 250.00 mm

Barrel Manning's n: 0.0130 (top and sides)

Manning's n: 0.0800 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

Table 3 - Downstream Channel Rating Curve (Crossing: Flow Velocity: 3m Span x 2.4m Rise Box Culvert)

Flow (cms)	Water Surface Elev (m)	Depth (m)	Velocity (m/s)	Shear (Pa)	Froude Number
0.00	1020.89	0.00	0.00	0.00	0.00
0.06	1020.93	0.04	0.47	8.17	0.78
0.13	1020.95	0.06	0.61	12.34	0.83
0.19	1020.97	0.07	0.71	15.71	0.86
0.26	1020.98	0.09	0.79	18.62	0.89
0.32	1020.99	0.10	0.86	21.25	0.90
0.38	1021.00	0.11	0.91	23.66	0.92
0.45	1021.01	0.12	0.97	25.90	0.93
0.51	1021.02	0.13	1.01	28.01	0.94
0.58	1021.03	0.14	1.06	30.01	0.95
0.64	1021.04	0.15	1.10	31.91	0.96

Tailwater Channel Data - Flow Velocity: 3m Span x 2.4m Rise Box Culvert

Tailwater Channel Option: Trapezoidal Channel

Bottom Width: 3.50 m

Side Slope (H:V): 3.00 (_:1)

Channel Slope: 0.0220

Channel Manning's n: 0.0350

Channel Invert Elevation: 1020.89 m

Roadway Data for Crossing: Flow Velocity: 3m Span x 2.4m Rise Box Culvert

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 m

Crest Elevation: 1033.05 m

Roadway Surface: Paved

Roadway Top Width: 155.00 m