To	Basir Saleh, Siddhwartha Mandal	Page	1 of 54
CC	Fadi Shahin, Gordon Geoffrey		
Subject	Hydrologic and Hydraulics Analysis for Sinclair Culvert at Parks Gate, Kootenay National Park, BC		
From	Jagadish Kayastha		
Date	January 29, 2018	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.

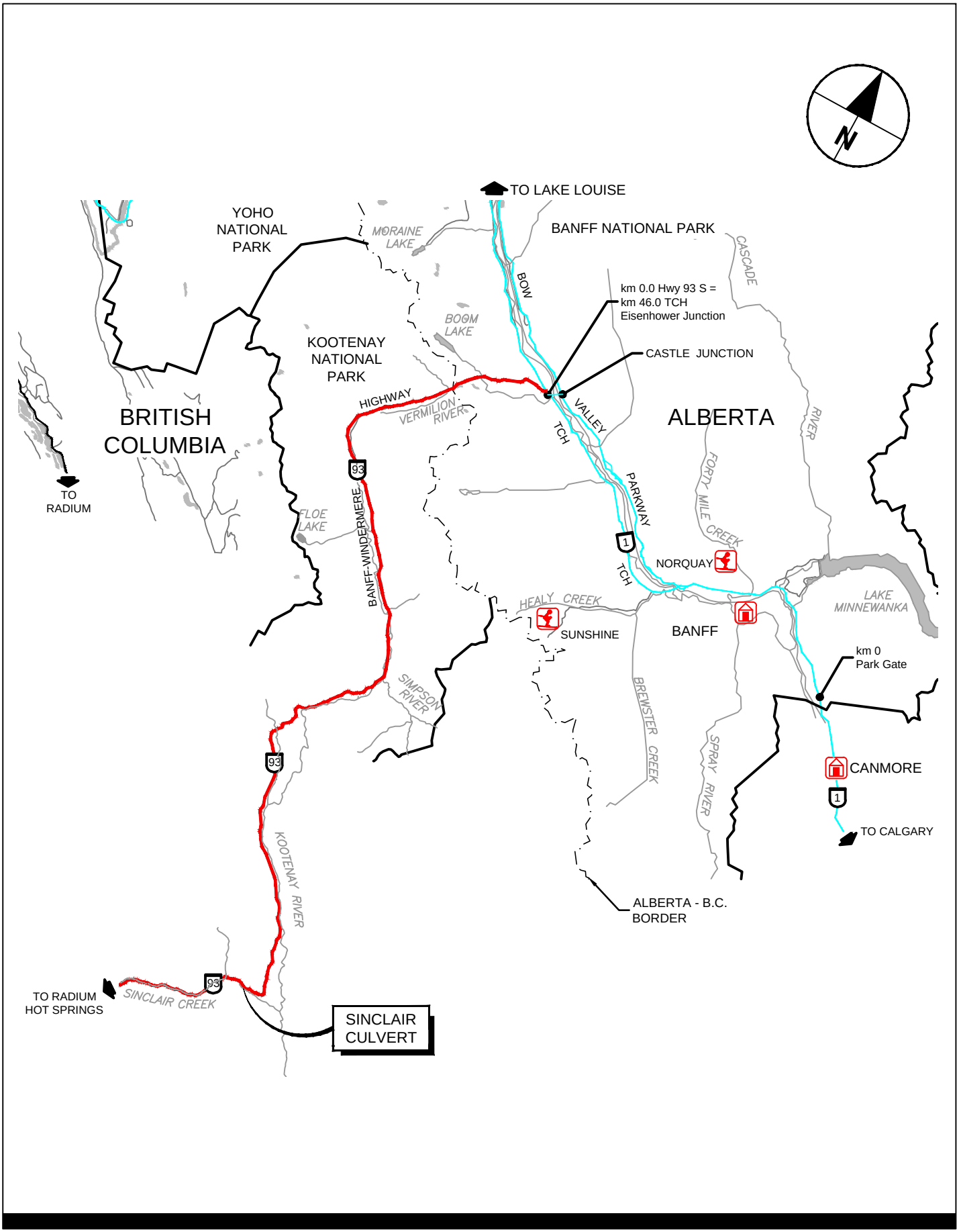
Sinclair Culvert is located at the Parks Gate (latitude 50^0 38' 07.16:N and longitude 116^0 01' 57.49"W) across Kootenay HWY 93S at the unnamed creek, is 102.03 km south of the Intersection of HWY 93S and the Trans-Canada Highway as shown in **Figure 1**.

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**.

Hydrologic and hydraulic analysis (H&H) is required for assessment of the existing culvert and designing new culvert crossing options. The H&H analysis and this technical memo 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.

The primary purpose of this memo is to estimate the hydrologic information and related hydraulics data for the existing and proposed culvert options. The 1:200 year return period flow was used to design structures to withstand appropriate levels of flooding during both construction and operations.

The hydrology study is specifically intended to support the assessment of the existing culvert and design of new culvert crossing options. The scope of this memo is consistent with the intended use of the results. The hydrology presented below is for the culvert inlet location.



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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

LOCATION PLAN

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PARKS - KOOTENAY NATIONAL PARK
Project No.: 60547362 Date: 2017-09-08

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Figure: 1

2. Hydrologic Analysis

2.1 Catchment

The watercourse in question is an unnamed creek which originates at a highpoint approximately 9.5 km northeast of the Sinclair culvert location. The watercourse flows southwest along the southeast side of Highway 93 and crosses to the parking lot area about 1.0 km east of the Radium Hot Springs.

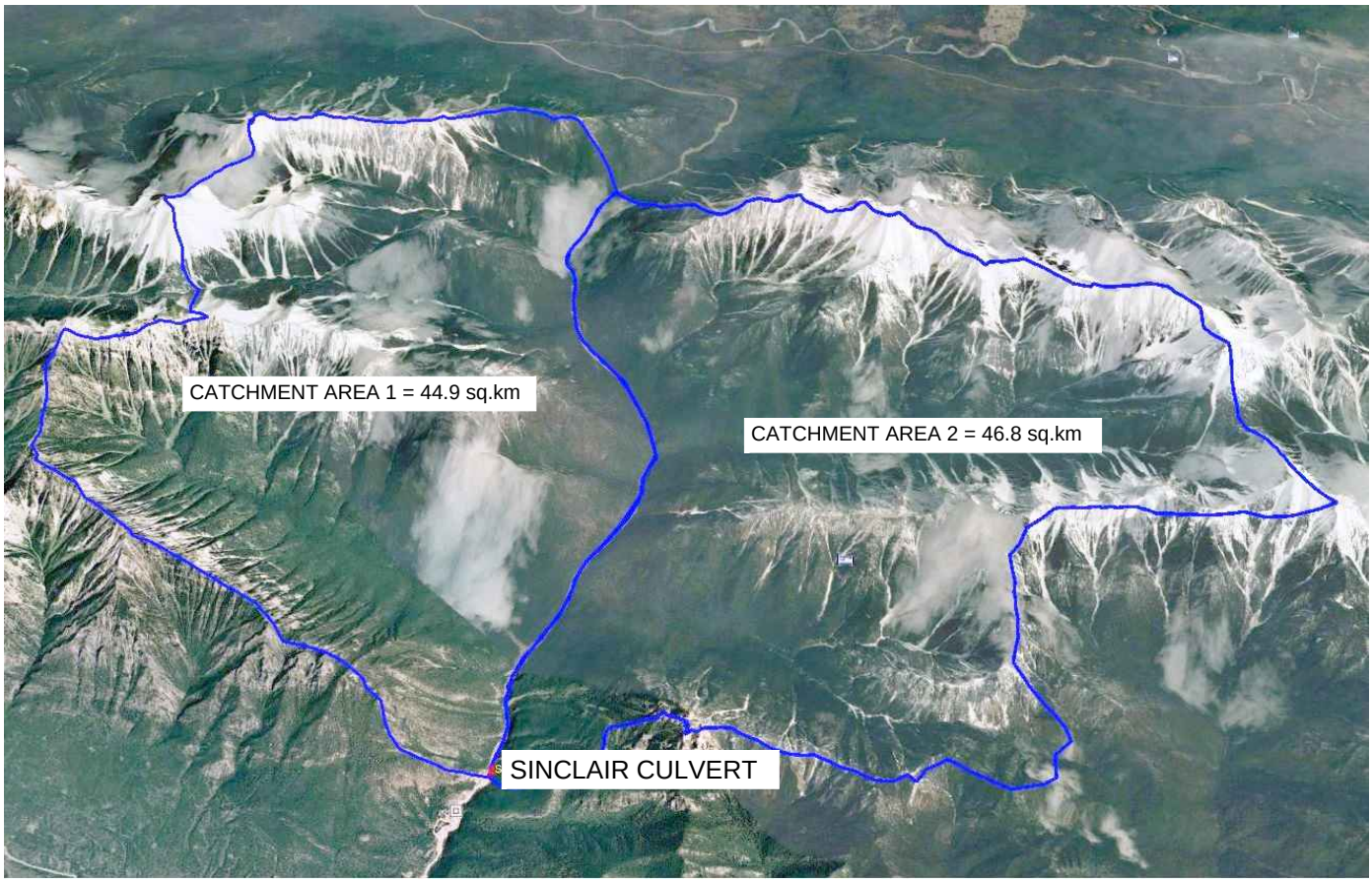
There is no flow record available for the unnamed creek at the culvert location. A regional reference gauging stations in the vicinity of the site with a longer period of record was selected for derivation of long-term discharge characteristics based on a regional analysis with the gauging stations data in the vicinity of the site.

Catchment delineation for the culvert inlet location was done using Google Earth as shown in **Figure 2**. This delineation was verified by a site visit conducted on July 14, 2017.

Catchment Area 1, located on the north side of HWY 93 has a drainage area of 44.9 km^2. Runoff from this catchment is captured by roadside ditches and then conveyed to the creek via the existing culverts crossing HWY 93.

Catchment Area 2, located on the south side of HWY 93 has a drainage area of 46.8 km^2. Runoff from this catchment drains directly to the unnamed creek.

The total drainage area contributing flow to the unnamed creek draining through the Sinclair culvert consists of Catchment Areas 1 and 2, totals 91.7 km^2.



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SINCLAIR CULVERT (REDWALL/PARKS GATE)
CATCHMENT AREAS

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Figure: 2

2.2 Regional Analysis

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 as shown in **Table 2.1**

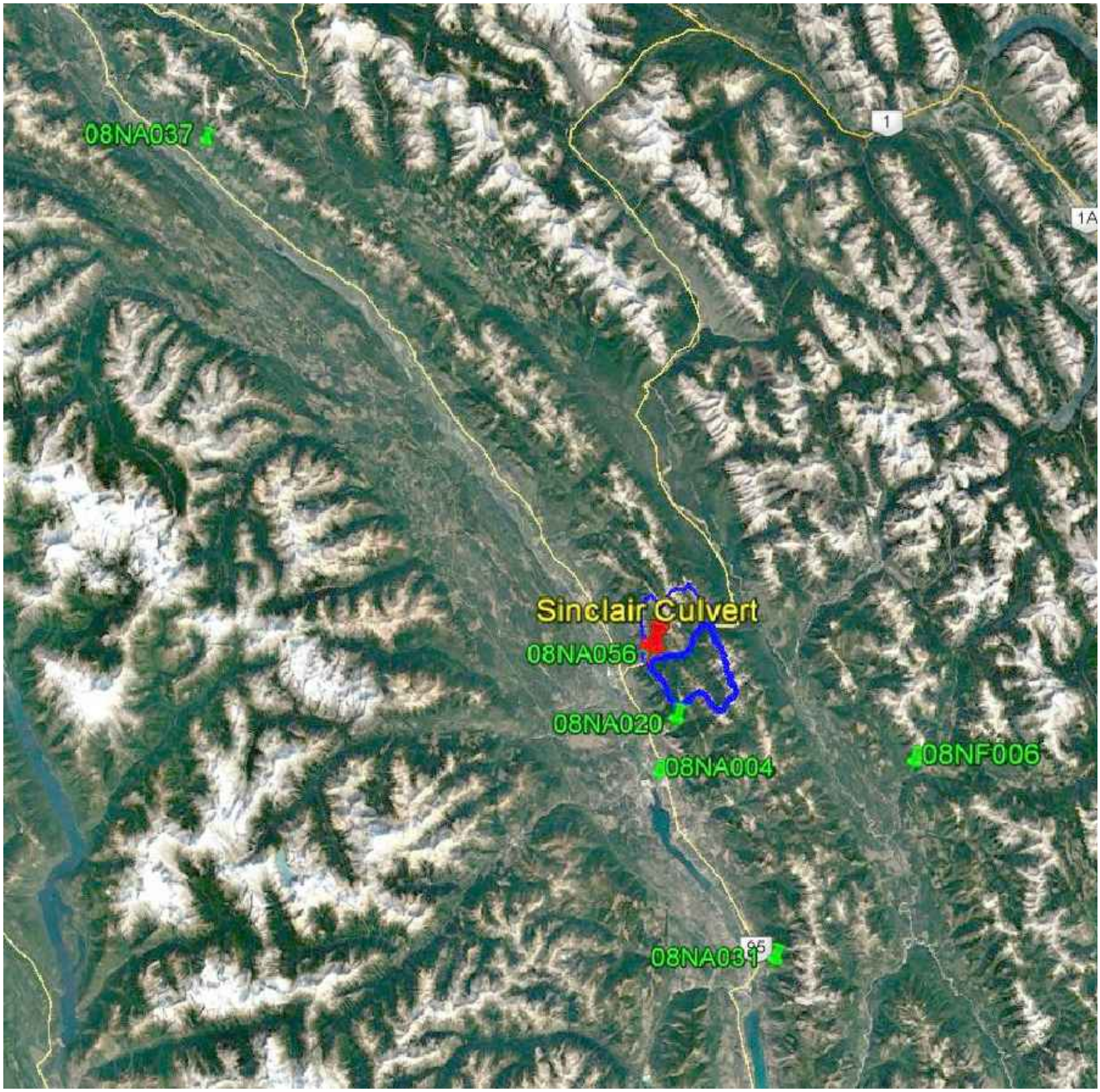
Therefore, a regional analysis was performed using flow data obtained from the regional WSC gauging stations. The 1:200 year flow data derived from the annual maximum flows for the gauging stations was used in the regional analysis.

Table 2.1
Regional Water Survey of Canada Referenced Hydrometric Stations

Station No.	Station Name	Area (km^2)	Period of Record	Years of Record	Locations
08NA004	Columbia River at Athalmer	1,340.0	1912 – 1984	73	50°30'56" N 116°01'08" W
08NA020	Stoddart Creek near Athalmer	21.2	19438 – 1982	45	50°34'06" N 115°59'29" W
08NA037	Carbonate Creek near McMurdo	8.03	1924 – 1998	74	51°08'35" N 116°44'23" W
08NA056	Gulch Creek near Radium Junction	4.4	1964 – 1974	11	50°35'13" N 116°02'00" W
08NF002	Kootenay River at Canal Flats	5,390.0	1939 - 1995	57	50°08'52" N 115°47'57" W
08NF006	Palliser River in Lot SL49	653.0	1973 – 1995	23	50°31'31" N 115°37'09" W

Figure 3 shows a Google image with nearby WSC gauging station locations in the vicinity of Sinclair culvert.

Annual maximum stream flows derived from the surrounding gauging stations were analyzed to obtain the 1:200 year flows using HYFRAN frequency analysis software. A regional analysis curves using the 1:200 year flows versus the catchment areas for the gauging stations is shown in **Figure 4**. The 1:200 year estimated flow for the culvert site corresponding to 91.7km^2 catchment areas is estimated at 13.5 m^3/s and 40.0 m^3/s from the regional analysis as illustrated in curves A and B, respectively. The spread in the 1:200 year flows varies a lot as shown in **Table 2-2**.



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SINCLAIR CULVERT (REDWALL/PARKS GATE)
WSC GAUGING STATIONS

PARKS - KOOTENAY NATIONAL PARK
Project No.: 60547362 Date: 2017-09-08

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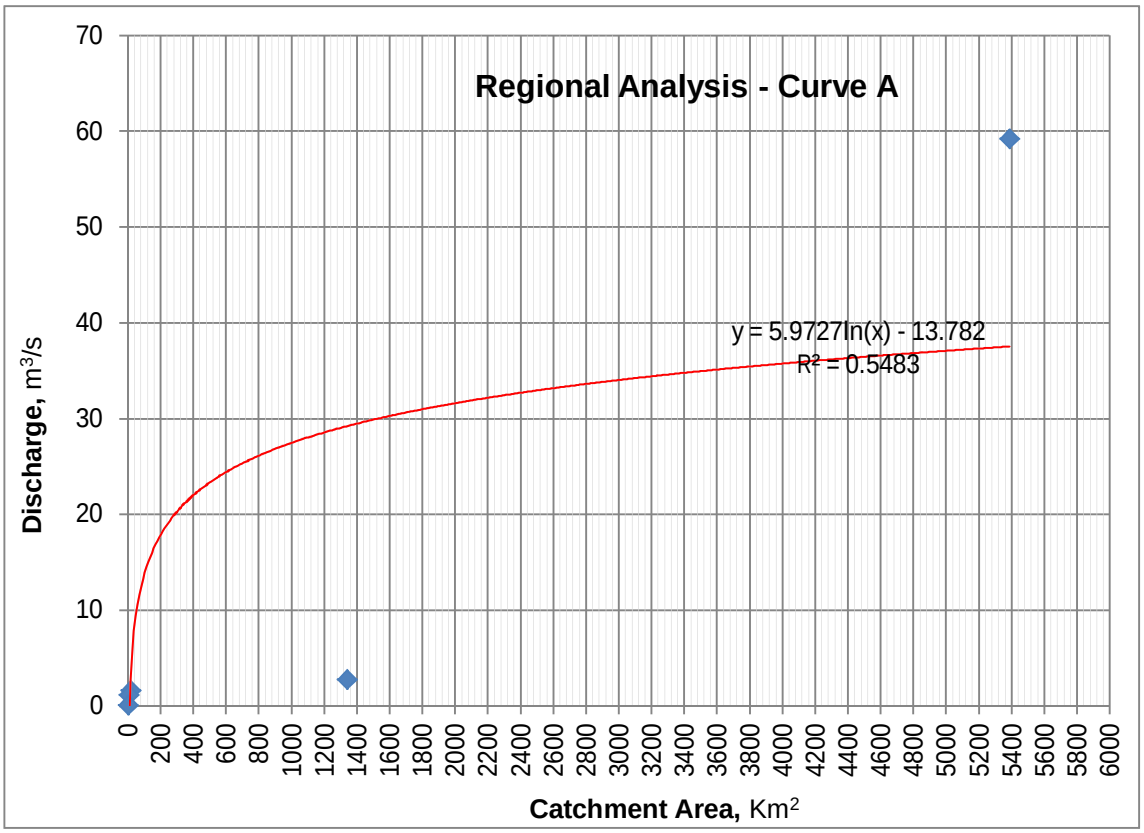
Figure: 3



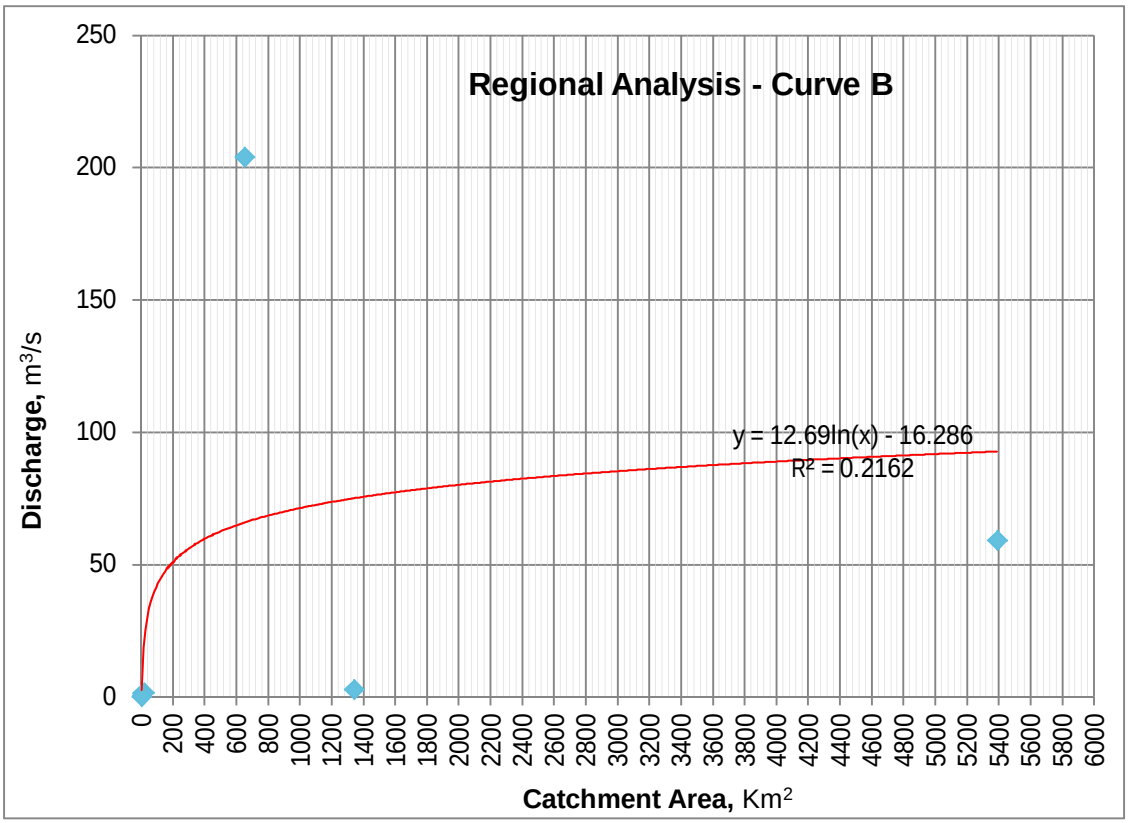


Figure 4: Regional Analysis Curves for the 1:200 Year Event

2.3 Extreme Flows

Peak flows are most likely to occur in response to snowmelt during the spring freshet. The magnitude of the peak flow depends on the extent of the snowpack and antecedent temperature conditions. For example, a cool spring could prolong the snowpack, which in turn could produce significant flooding if warming occurs quickly.

Peak flows for ungauged watersheds may be estimated using various methods depending on the size of the watershed and availability, quality, quantity, and proximity of hydrometric data. Available methods include the rational formula, unit hydrograph model, regional analysis, and transferred flood frequency analysis.

Regional hydrometric data are available in the vicinity of the site. However, these stations do not represent the project site hydrology in terms of catchment size and its characteristics. Thus a regional analysis was used for the current study. The 1:200 year flood frequencies were estimated for all the regional stations using the HYFRAN software (INRS, 2013).

Results of the flood frequency analysis for the referenced stations and the culvert inlet are summarized in **Table 2.2**. The 1:200 year return period flow at culvert location was estimated as 13.5 m^3/s by using the regional analysis curve corresponding to the culvert catchment area of 91.7 km^2. The curve A fit excludes gauging station 08NF006 which showed the 1:200 year discharge of 204 m^3/s for 653 km^2 drainage area. If this gauging station were included in the curve fit (Figure 4 Curve B), the 1:200 year design flow would have been approximately 40.0 m^3/s. Unit rate flow varies from 0.002 $m^3/s/Km^2$ to 0.317 $m^3/s/Km^2$. Therefore, the 1:200 year design discharge was chosen matching the existing culvert capacity of 14.0 m^3/s, which is slightly less than the estimated flow of 13.5 m^3/s.

Table 2.2 1:100 and 1:200 Year Flood Frequency Estimates

WSC Gauging Stations	1:100 Year Flow)	1:200 Year Flow)	Drainage Areas	1:200 year Unit Rate
	(m^3/s)	(m^3/s)	Km^2	($m^3/s/Km^2$)
08NA004	2.75	2.8	1340	0.002
08NA020	1.45	1.63	21.2	0.077
08NA037	1.09	1.2	8.03	0.149
08NA056	0.103	0.118	4.4	0.026
08NF002	54.7	59.2	5390	0.011
08NF006	184	204	653	0.312

2.4 Diversion Flows during Construction

In general, historical flooding in the Sinclair culvert location was observed during the months of May and June based on flooding records and the cause of the flooding was due to a combination of snow melt and rainfall. Therefore, construction period from July to October would be the most appropriate time for replacing the existing culvert to avoid potential flooding during construction season. Water Survey Canada gauging station 08NA020 was considered to check the recorded daily flows for July to October and there is 1815 number of daily flow records for 1938 to 1982. Figure 4-a shows recorded daily flow for the gauging station 08NA020 and equivalent synthetic flows at culvert inlet location. Daily equivalent flows at culvert inlet were obtained using multiplying factor of 4.325 to the

gauging station flows based on catchment pro-rate basis of the culvert location and the gauging station catchment areas and the maximum peak flow at culvert inlet location during July to October was estimated at 1.544 m^3/s based on recorded flows.

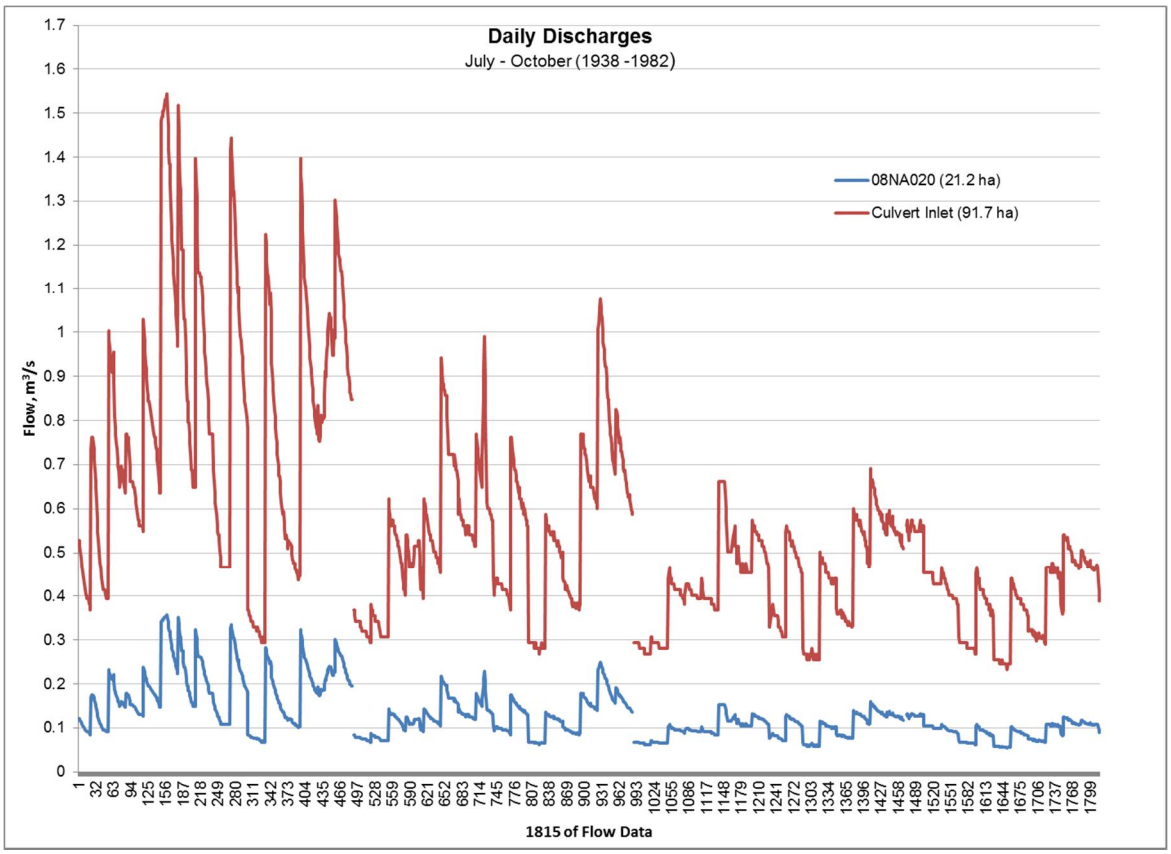


Figure 4-a: Daily Flows at Gauging Station 08NA020 and Culvert Inlet Location

Table 2-3 shows a different return period flows obtained from a frequency analysis for the chosen gauging station 08NA020 and pro-rated return period flows for the culvert location using a multiplier of 4.32 based on catchment area ratios.

Table 2.3: Return Period Flows for Construction Period

Return Period	Gauging Station #08NA020	Culvert Inlet Location
	(m^3/s)	(m^3/s)
1	0.010	0.043
2	0.453	1.957
5	0.720	3.11
10	0.893	3.858
20	1.050	4.536

It is recommended to use a double barrel of 750 mm HDPE pipes or three number of 600 HDPE pipes with a longitudinal slope of 4.13%, which provides total hydraulic capacity of 5.344 m^3/s and 4.8 m^3/s respectively at free flow condition for the 1:20 year peak flow. Thus, it is recommended to use either a double barrel 750 mm or three (3) 600 mm diameter HDPE pipes for flow diversion during construction season.

3. Hydraulic Analysis

3.1 Culvert Alignments

A 165.29 m long existing pipe arch culvert made of steel structural plate of 3480 mm span and 2210 mm rise is sloped at 4.13%. The existing culvert pipe bends at two locations at 137.178 m distance from the culvert inlet, the second is at additional 12.628 m distance further on as shown in **Figure 5**. The existing layout plan is named as Alignment 1.

Figure 6 shows a new Alignment 2 which is similar to alignment 1. This option was proposed with two HDPE diversion pipes meant to be used during construction. There is only one bend proposed for alignment 2 at 143.184 m distance from the inlet. The following structural options were proposed for alignments 1 and 2.

Hydraulic capacity of the culvert was assessed using HY-8 culvert analysis software (version 7.5). This software was prepared by the USA Department of Transportation, Federal Highway Administration (FHA). The culvert does not include any fish passage provision and there is 1.0 m vertical drop at the downstream outlet. The 1:200 year design flow of 14.0 m^3/s was used to predict an upstream headwater elevation and other hydraulics characteristics. **Figure 7** shows the existing culvert section with a slip liner plate section.

Hydraulic capacity of the existing corrugated structural pipe arch culvert was checked for the design flow using HY-8 analysis. Based on culvert analysis results from HY-8, the existing culvert can handle the 1:200 year maximum flow of 14.0 m^3/s without overtopping the road surface. Head water elevation was estimated at 1029.78 m. **Figure 8** shows the rating curve for the existing condition. **Figure 9** illustrates the HGL profile obtained from HY-8 analysis. The existing HY-8 culvert report is attached in Appendix A.

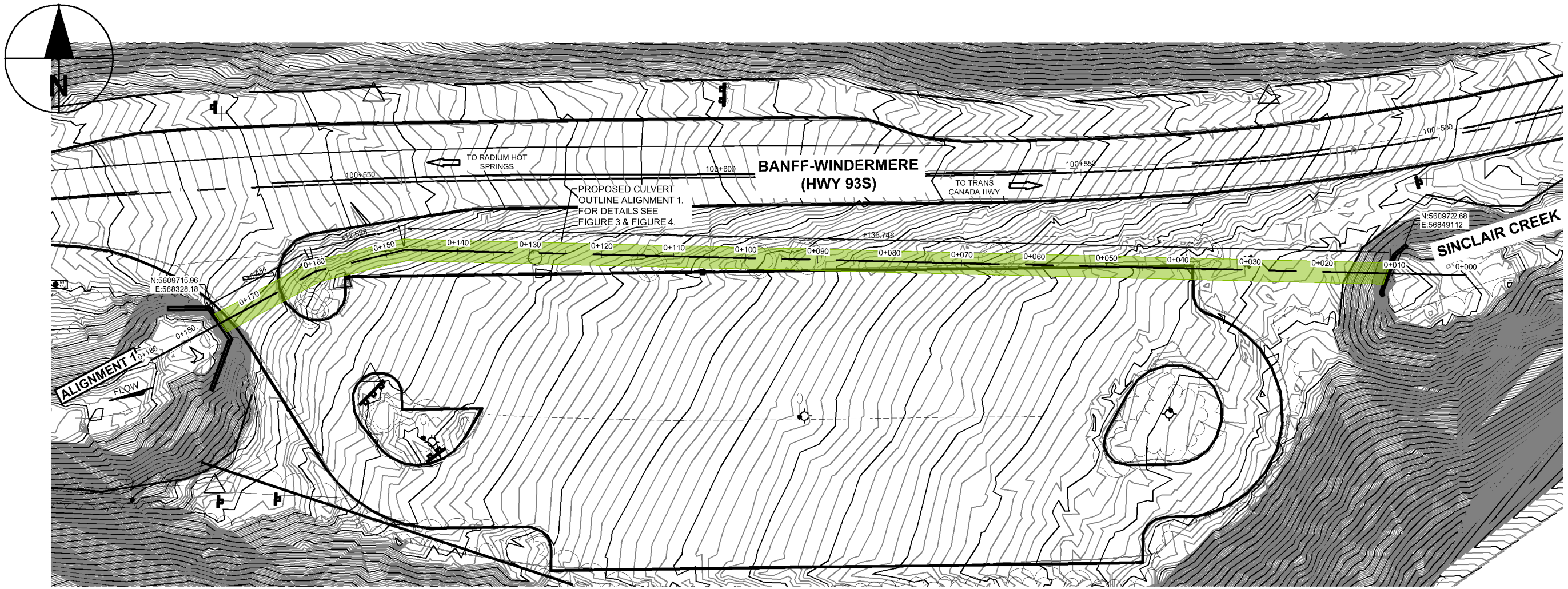
3.2 Culvert Option Considerations

The existing culvert is large enough to handle the estimated 1:200 year design flow of 14.0 m^3/s. However, the culvert inspection report reveals that the culvert needs to be replaced in the near future because of its deformed bolts and corrosion of steel plates at many locations. Therefore, three different structural section options have been analysed to check the hydraulic capacity in reference to the 1:200 year design discharge.

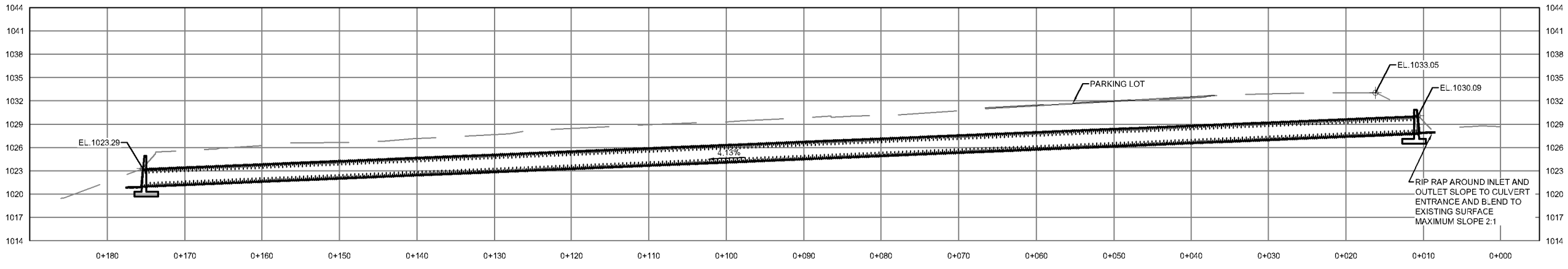
3.2.1 Structural Options

No change in the existing culvert alignment was proposed for a structural option 1 rehabilitation task. The following list three options that have been reviewed in this report:

- Structural Option 1: slip line the existing culver with a 3097 mm span by 1990 mm rise slip liner steel plate section in conjunction along Alignment 1. Refer to **Figure 7** for the structural section;
- Structural Option 2: replace the existing culver with a 3000 mm span by 2400 mm rise concrete box section as shown in **Figure 10**; and
- Structural Option 3: replace the existing culvert with a 3960 mm span by 2060 mm rise corrugated structural plate steel arch section as shown in **Figure 11**.



PLAN
Scale 1:300



LONGITUDINAL SECTION - ALIGNMENT 1
Scale 1:300

Issue Status: DRAFT

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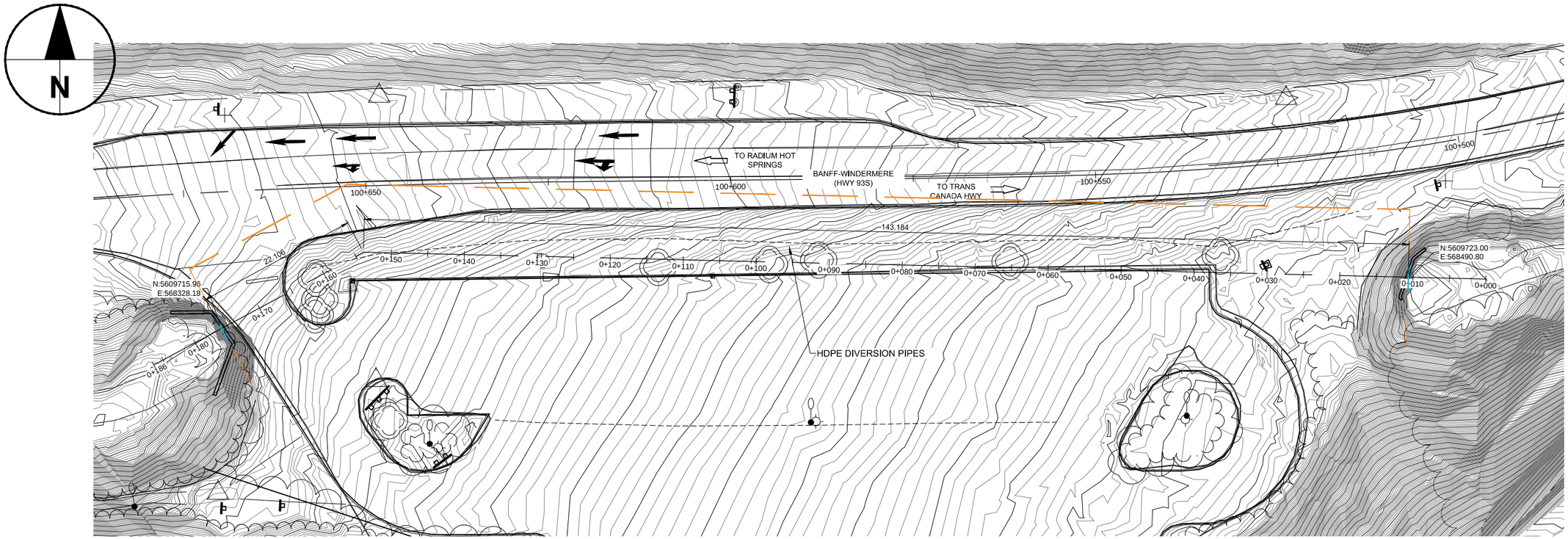
FIGURE 5

PLAN & ELEVATION - ALIGNMENT 1

PARKS CANADA - KOOTENAY NATIONAL PARK
Project No.: 60547362 Date: 2017-9-13



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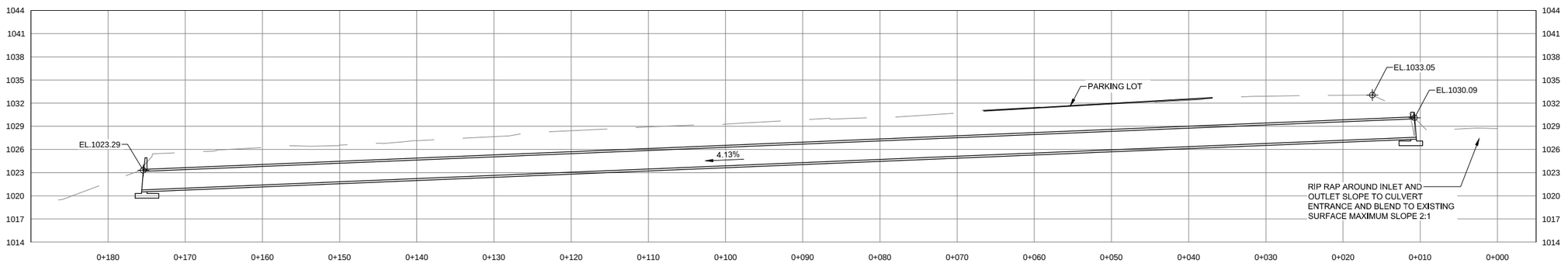

ELEVATION
Scale 1:300

Issue Status: DRAFT

AECOM
FIGURE 6

PLAN & ELEVATION - ALIGNMENT 2

PARKS CANADA - KOOTENAY NATIONAL PARK
Project No.: 60547362 Date: 2017-9-13

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

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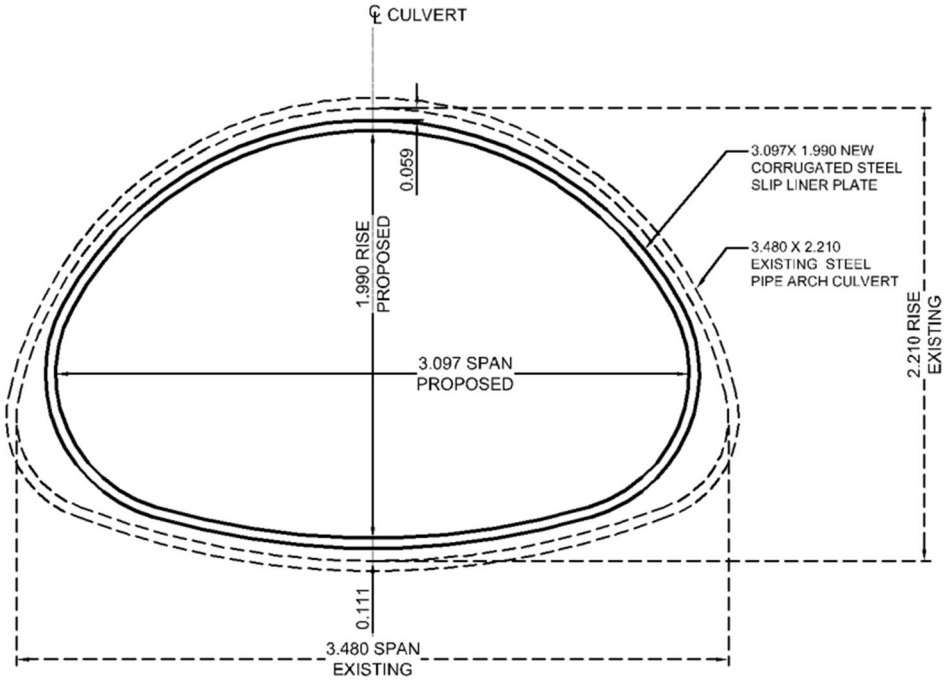

Figure 7: Existing and Option 1 Culvert Section

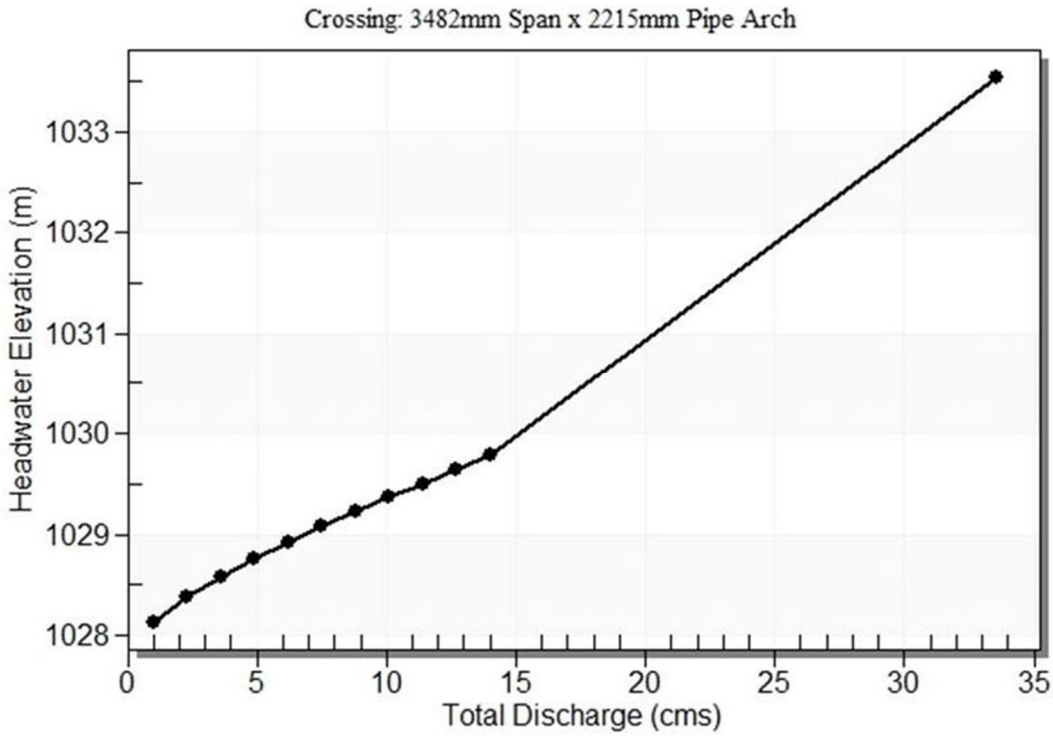

Figure 8: Existing Culvert Rating Curve

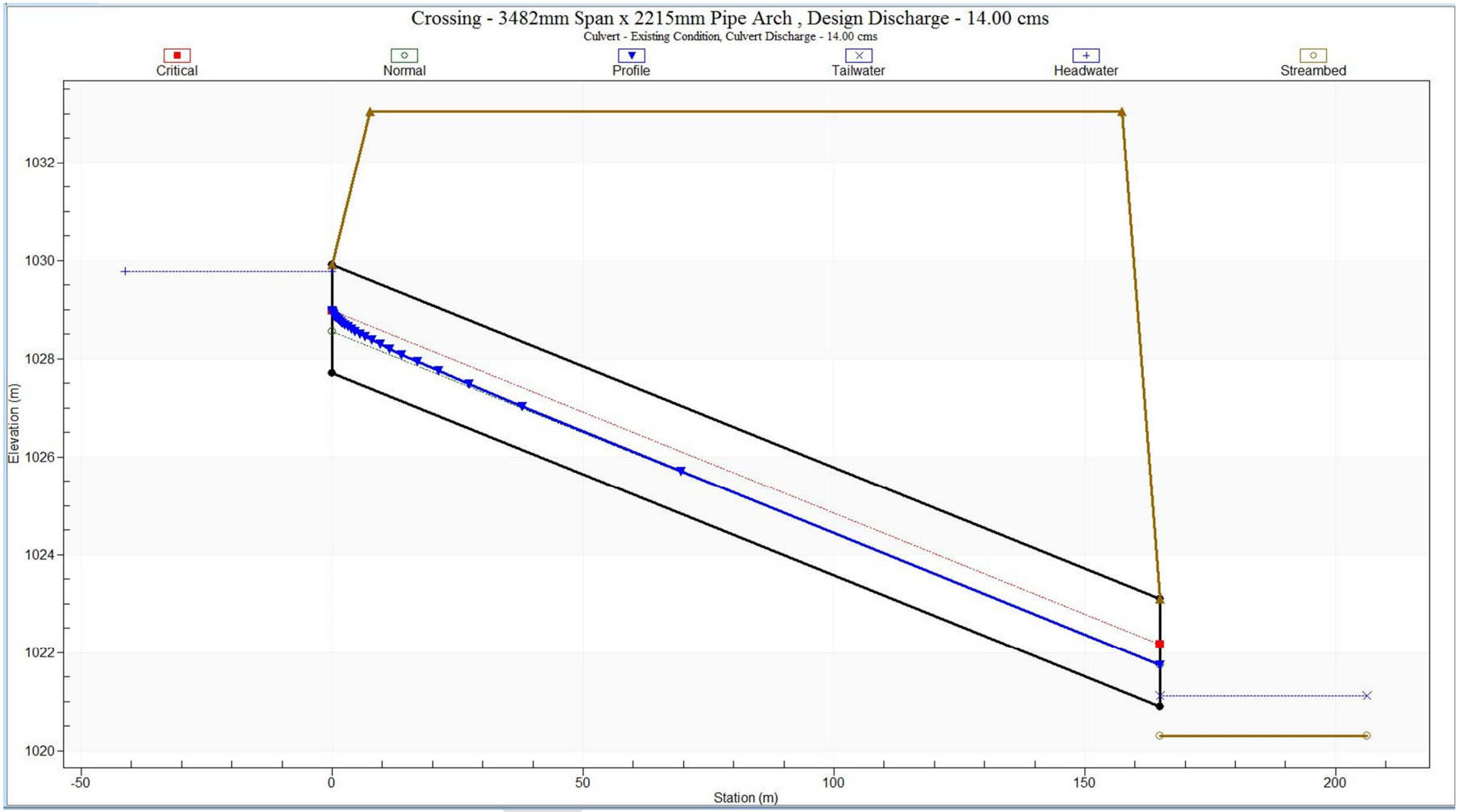

Figure 9: HGL Profile for the Existing Culvert

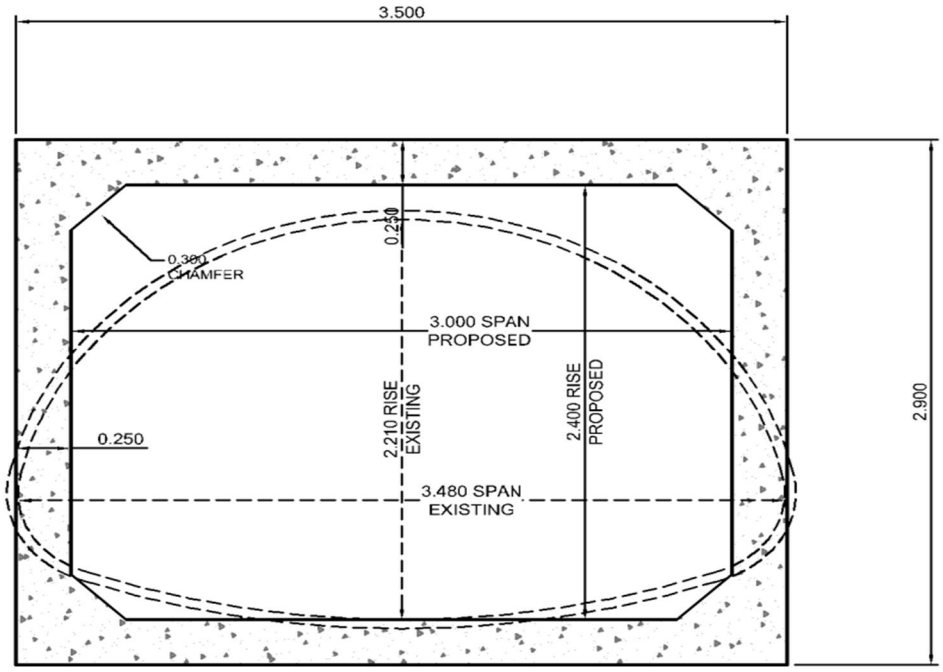

Figure 10: Option 2 Culvert Section

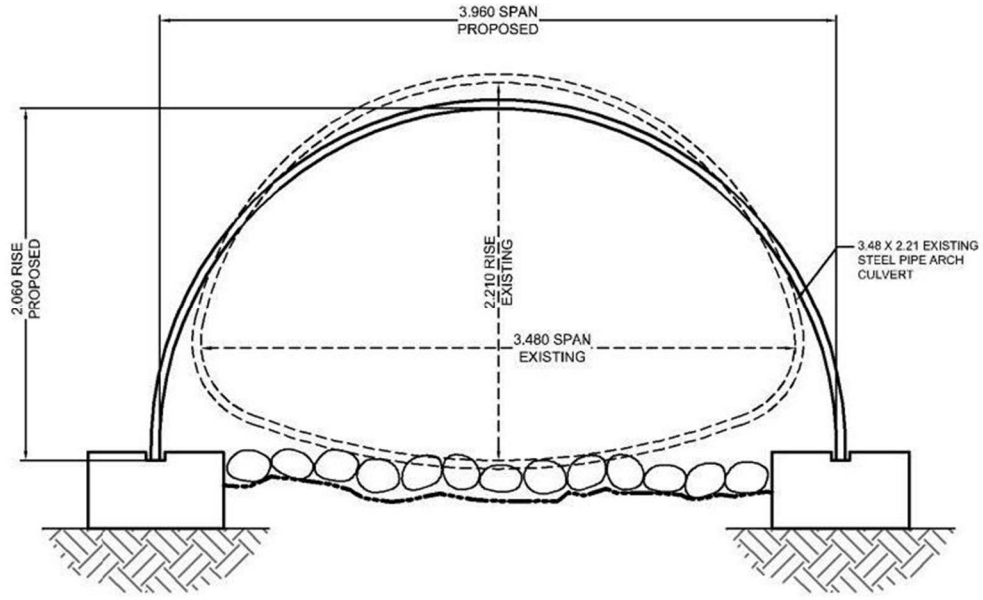

Figure 11: Option 3 Culvert Section of Steel Arch

Figures 12 through 14 illustrate HGL profiles for options 1 to 3, respectively. Results are based on the 1:200 year design flow of 14.0 m^3/s obtained from HY-8 culvert analysis as presented in Appendix B. **Figures 15 through 17** illustrate rating curves for options 1 to 3, respectively.

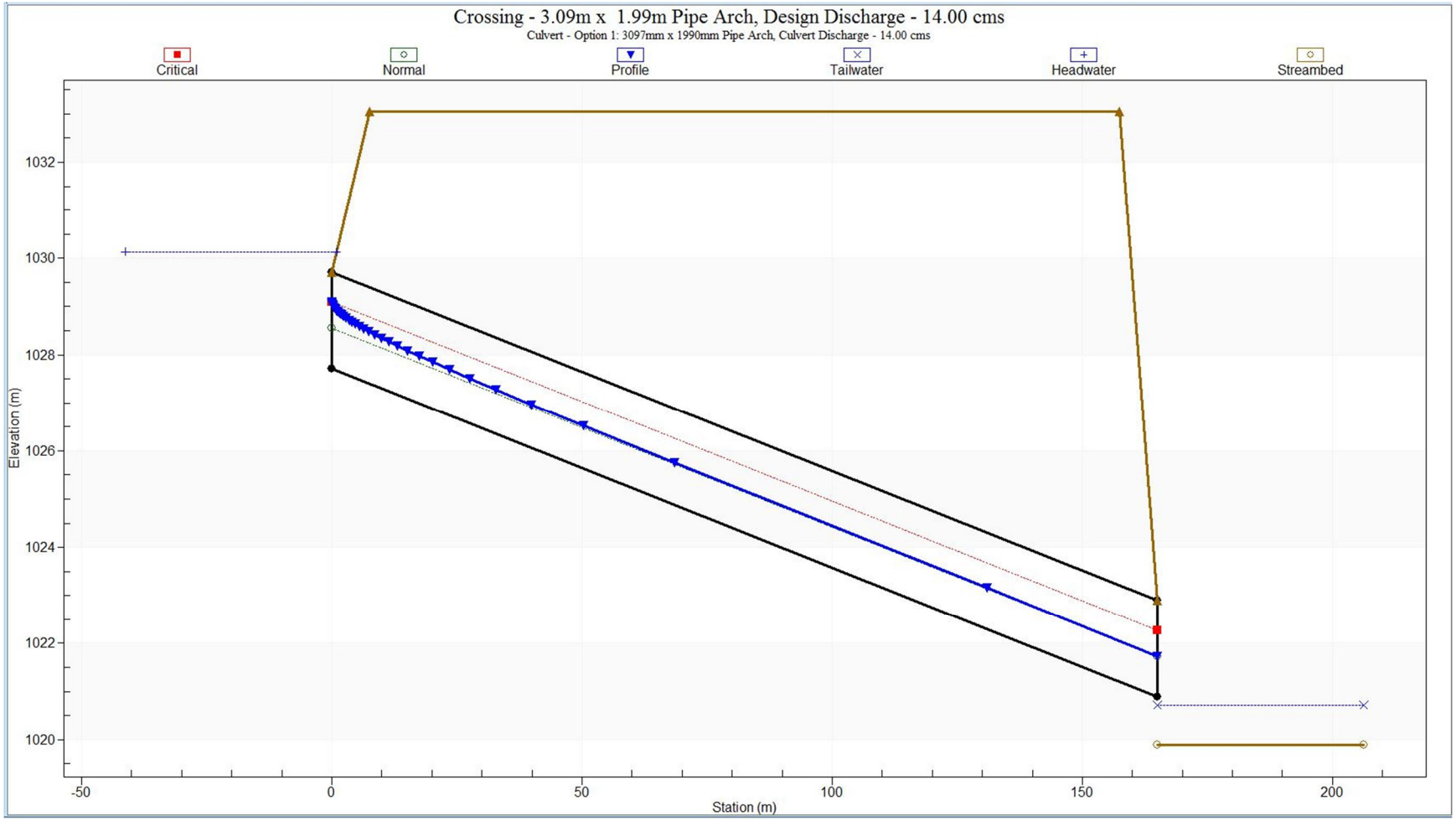

Figure 12: HGL Profile for Option 1 Culvert Section

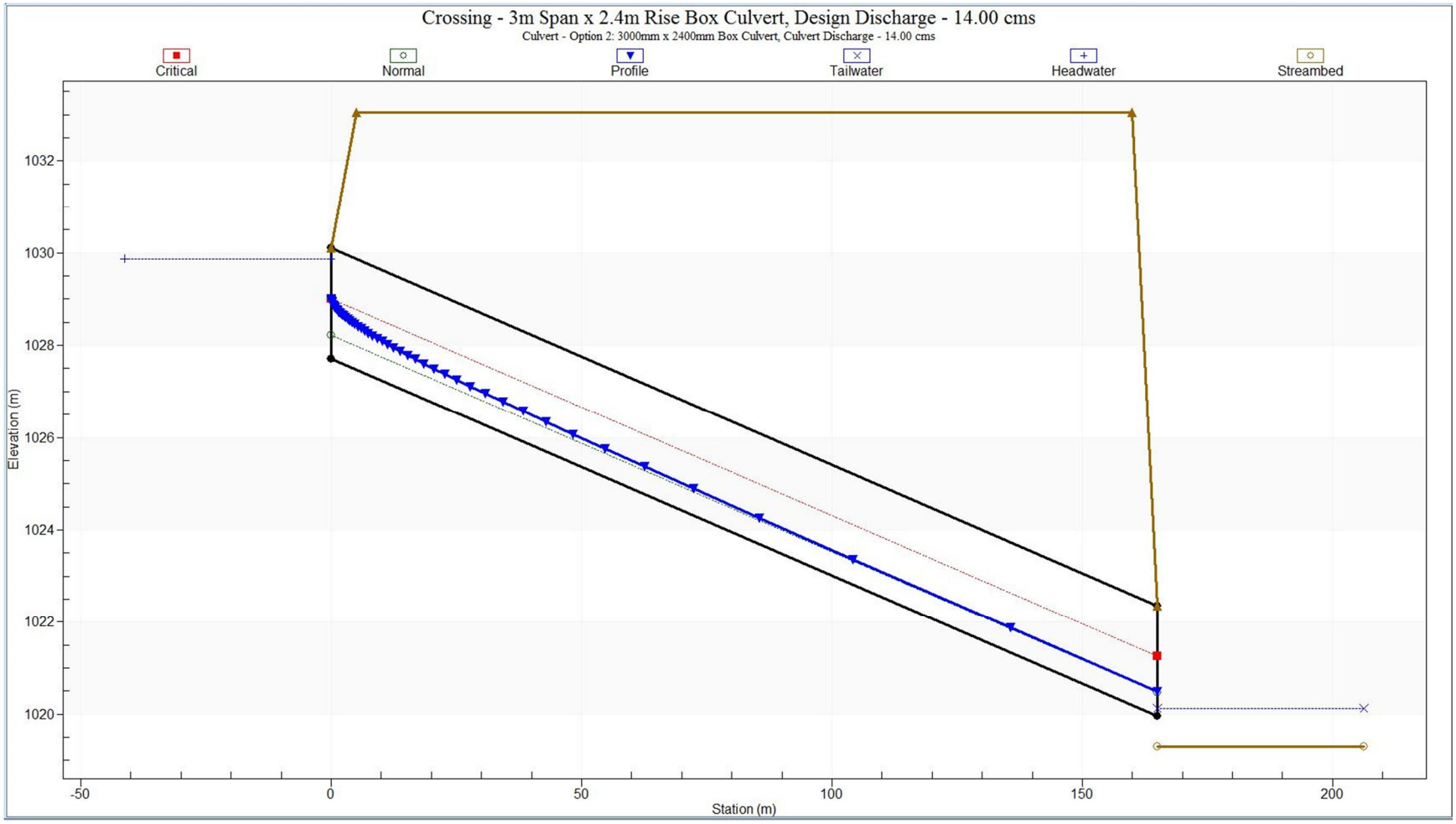

Figure 13: HGL Profile for Option 2 Culvert Section

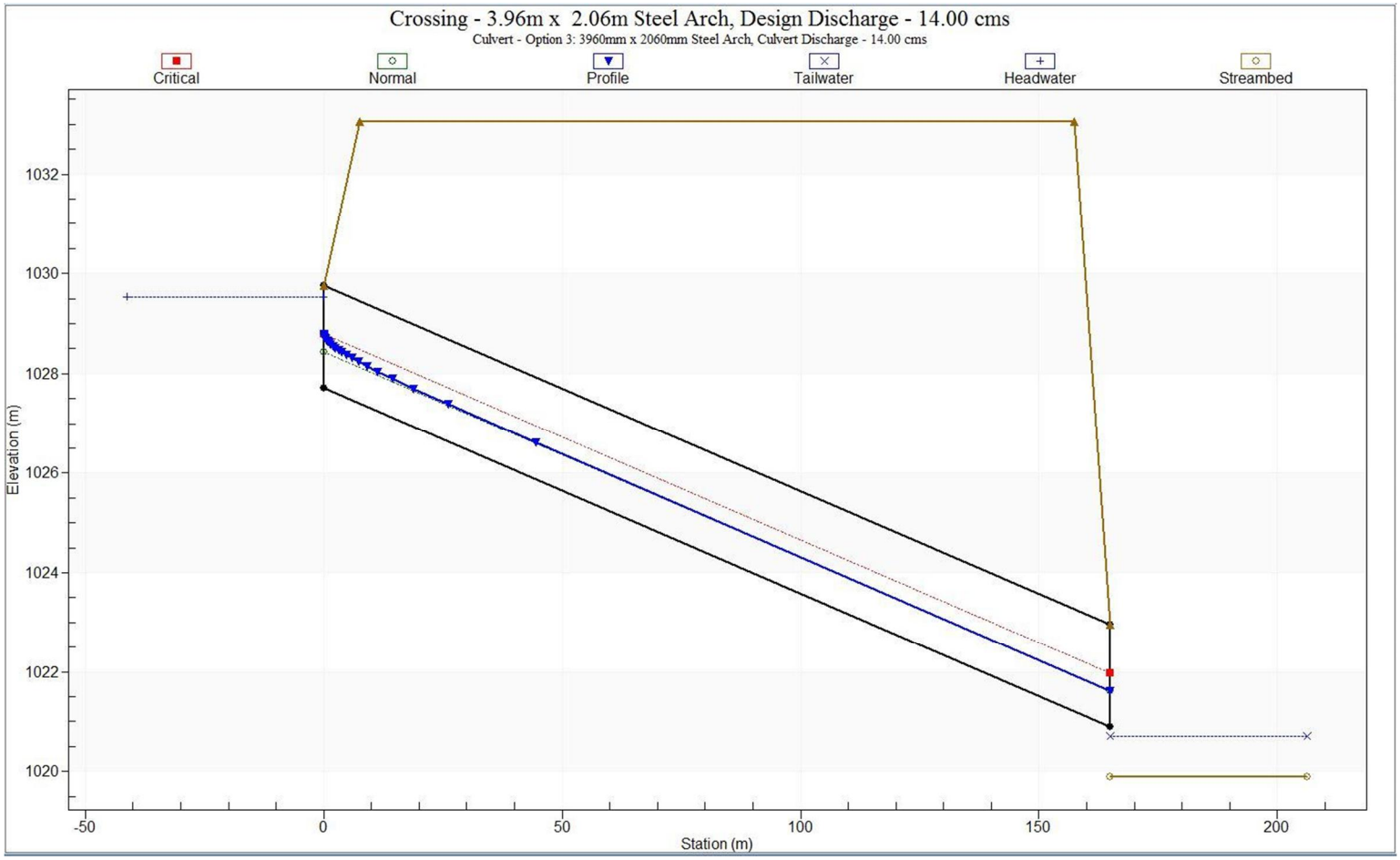

Figure 14: HGL Profile for Option 3 Culvert Section

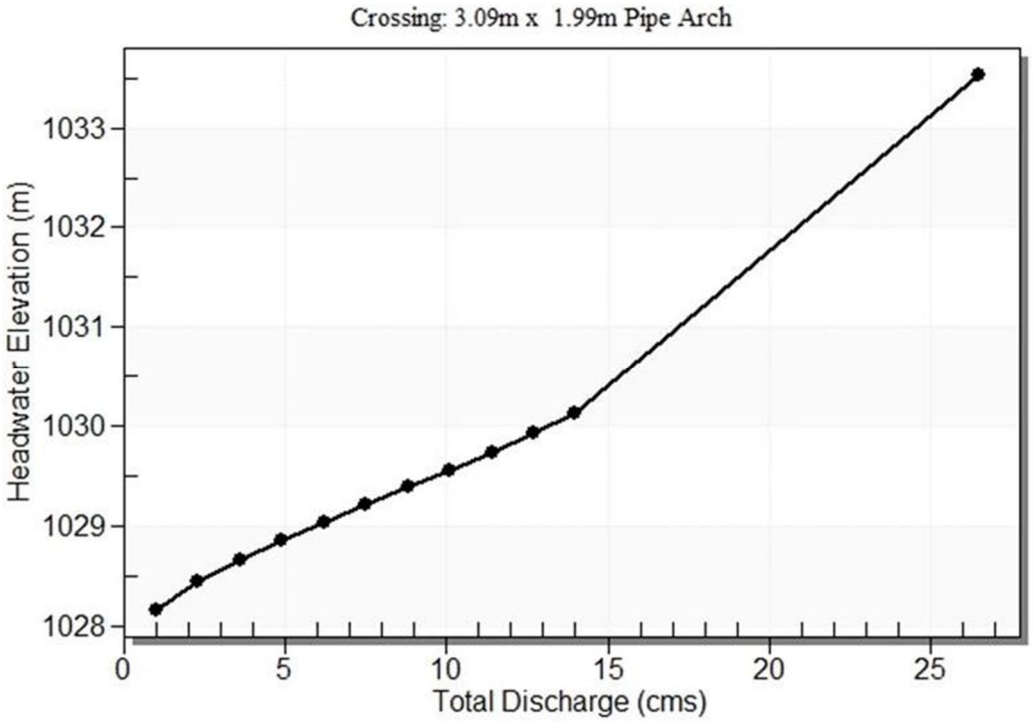

Figure 15: Option 1 Culvert Rating Curve

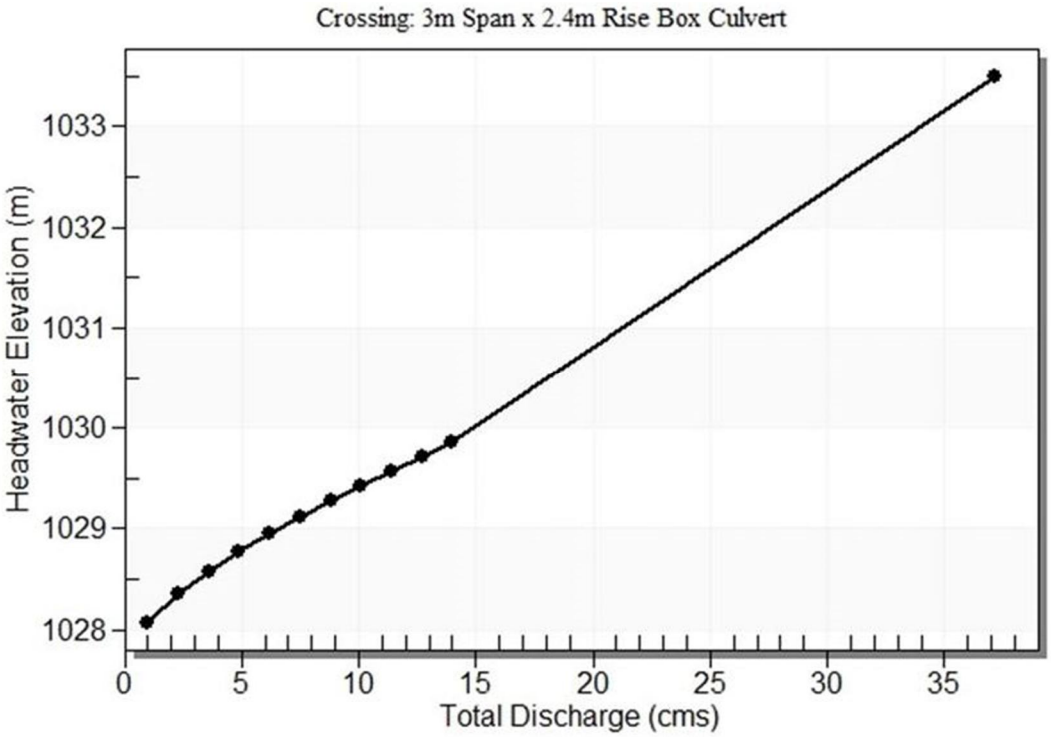

Figure 16: Option 2 Culvert Rating Curve

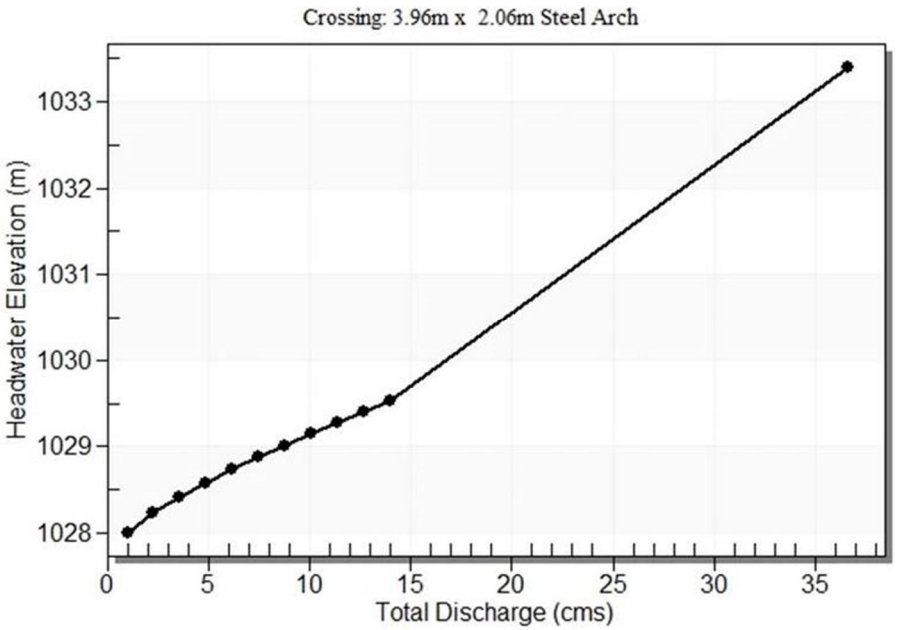

Figure 17: Option 3 Culvert Rating Curve

4. Recommendations for Detailed Design

All above mentioned options are able to convey the 1:200 year design flow of 14.0 m^3/s without having any road overtopping elevation at the spill elevation of 1033.048 m. Headwater elevations are within the pipe overt except option 1 where a minimum freeboard of 2.918 m was maintained. Option 1 headwater elevation was estimated at 1030.13 m at design flow of 14 m^3/s, which is 0.432 m above the culvert obvert elevation. Option 2 of concrete box section of 3.48 m spam and 2.21 m rise among the three (3) options was considered for detail design per Parks Canada's reviews and its construction cost, maintenance and projected life span. A separate technical memo dated December 18, 2017 was prepared by AECOM for the design of fish passage for the new culvert.

5. 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.

Prepared by:

PROFESSIONAL ENGINEER ALBERTA
JAGADISH KAYASTHA

Jan 29, 2018

Jagadish Kayastha, P. Eng., PMP
Senior Water Resources Engineer
Jagadish.kayastha@aecom.com

Reviewed by:

Gordon Geoffrey, P.Eng.
Senior Manager – Engineering, Water
gordon.geoffrey@aecom.com

PERMIT TO PRACTICE
AECOM CANADA LTD.
Signature
Date 29 Jan 2018
PERMIT NUMBER: P10450
The Association of Professional Engineers and Geoscientists of Alberta

Encl: Appendix A – Existing Culvert HY-8 Culvert Analysis Results
Appendix B – Proposed Culverts HY-8 Culvert Analysis Results

Appendix A

Existing Culvert

HY-8 Culvert Analysis Results

Crossing Discharge Data

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

Minimum Flow: 1.0 m^3/s

Design Flow: 14.0 m^3/s

Maximum Flow: 33.58 m^3/s

Table 1 - Summary of Culvert Flows at Crossing: 3482mm Span x 2215mm Pipe Arch

Headwater Elevation (m)	Total Discharge (cms)	Existing Condition Discharge (cms)	Roadway Discharge (cms)	Iterations
1028.13	1.00	1.00	0.00	1
1028.38	2.30	2.30	0.00	1
1028.58	3.60	3.60	0.00	1
1028.75	4.90	4.90	0.00	1
1028.92	6.20	6.20	0.00	1
1029.07	7.50	7.50	0.00	1
1029.22	8.80	8.80	0.00	1
1029.36	10.10	10.10	0.00	1
1029.50	11.40	11.40	0.00	1
1029.64	12.70	12.70	0.00	1
1029.78	14.00	14.00	0.00	1
1033.05	33.58	33.58	0.00	Overtopping

Rating Curve Plot for Crossing: 3482mm Span x 2215mm Pipe Arch

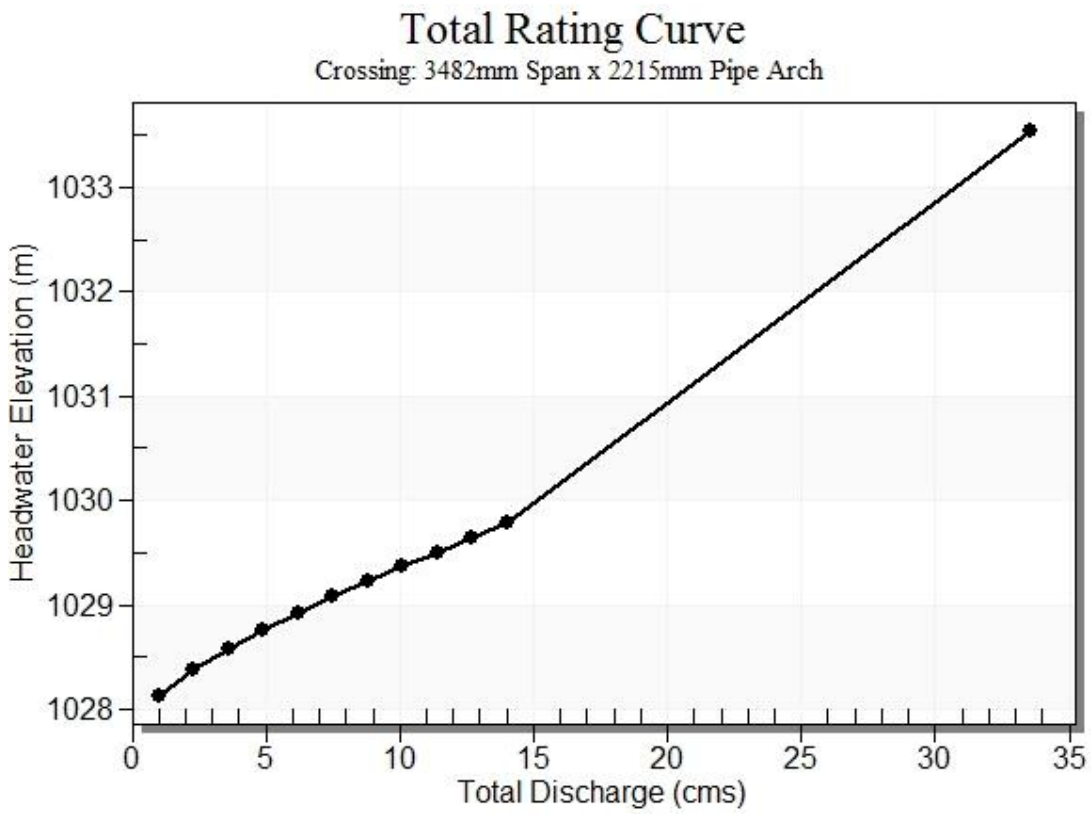

Table 2 - Culvert Summary Table: Existing Condition

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)
1.00	1.00	1028.13	0.426	0.0*	1-S2n	0.223	0.300	0.223	0.192	2.162	1.279
2.30	2.30	1028.38	0.672	0.0*	1-S2n	0.326	0.462	0.326	0.309	2.889	1.684
3.60	3.60	1028.58	0.868	0.0*	1-S2n	0.406	0.589	0.406	0.396	3.374	1.938
4.90	4.90	1028.75	1.041	0.0*	1-S2n	0.474	0.696	0.474	0.469	3.752	2.129
6.20	6.20	1028.92	1.208	0.0*	1-S2n	0.536	0.796	0.536	0.533	4.064	2.283
7.50	7.50	1029.07	1.365	0.0*	1-S2n	0.593	0.888	0.593	0.590	4.332	2.414
8.80	8.80	1029.22	1.513	0.0*	1-S2n	0.648	0.974	0.648	0.642	4.567	2.528
10.10	10.10	1029.36	1.655	0.0*	1-S2n	0.701	1.054	0.701	0.690	4.774	2.629
11.40	11.40	1029.50	1.794	0.0*	1-S2n	0.752	1.128	0.752	0.735	4.960	2.721
12.70	12.70	1029.64	1.933	0.0*	1-S2n	0.803	1.202	0.803	0.777	5.129	2.804
14.00	14.00	1029.78	2.074	0.0*	1-S2n	0.852	1.273	0.852	0.817	5.283	2.882

* Full Flow Headwater elevation is below inlet invert.

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Straight Culvert

Inlet Elevation (invert): 1027.71 m, Outlet Elevation (invert): 1020.89 m

Culvert Length: 165.14 m, Culvert Slope: 0.0413

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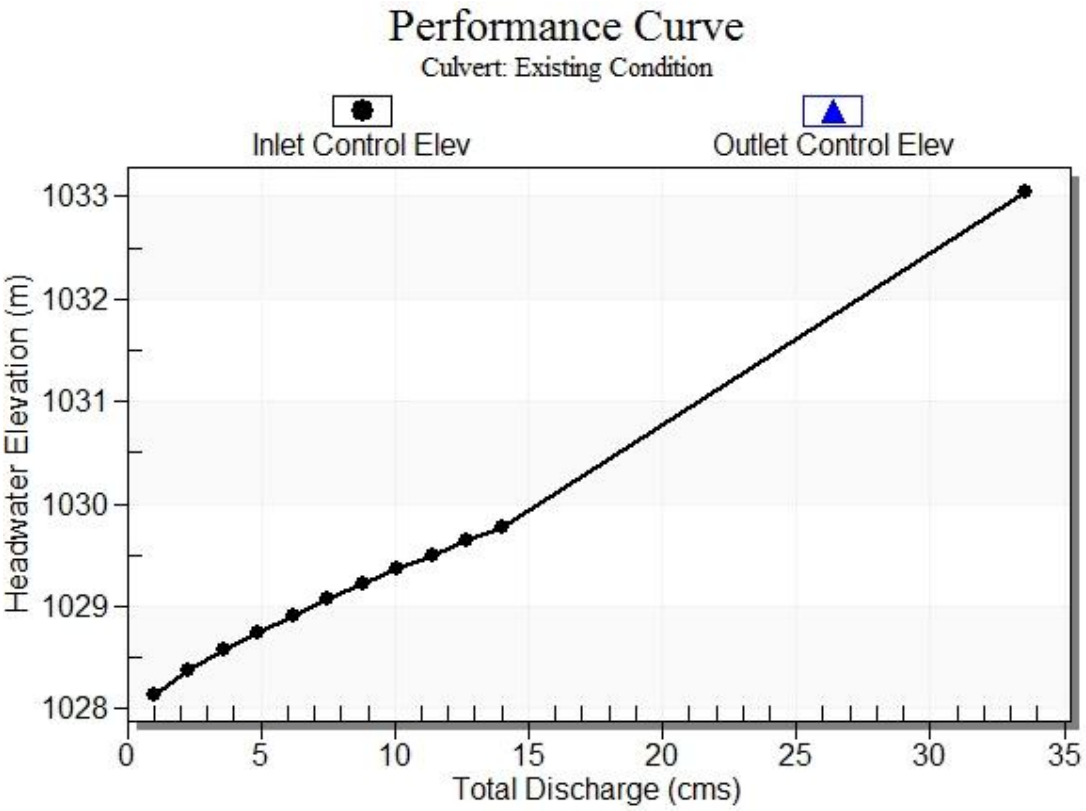
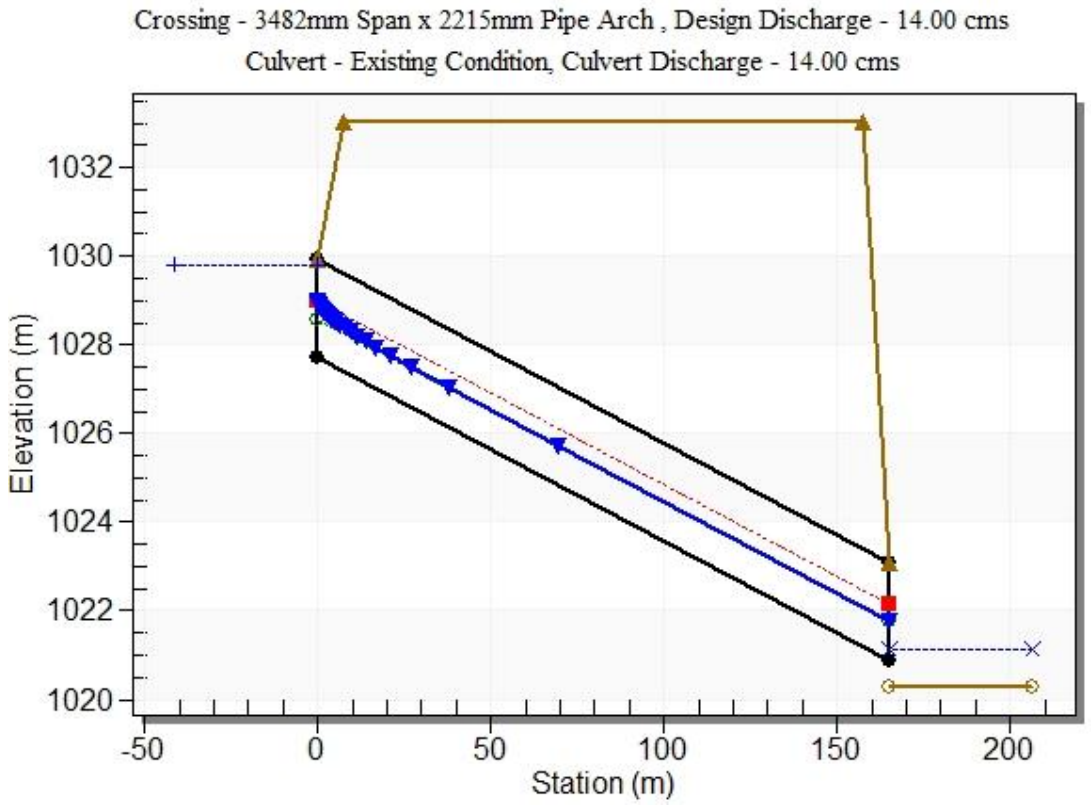
Culvert Performance Curve Plot: Existing Condition



Water Surface Profile Plot for Culvert: Existing Condition



Site Data - Existing Condition

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 m

Inlet Elevation: 1027.71 m

Outlet Station: 165.00 m

Outlet Elevation: 1020.89 m

Number of Barrels: 1

Culvert Data Summary - Existing Condition

Barrel Shape: Pipe Arch

Barrel Span: 3479.80 mm

Barrel Rise: 2209.80 mm

Barrel Material: Steel or Aluminum

Embedment: 0.00 mm

Barrel Manning's n: 0.0270

Culvert Type: Straight

Inlet Configuration: Headwall

Inlet Depression: None

Table 3 - Downstream Channel Rating Curve (Crossing: 3482mm Span x 2215mm

Flow (cms)	Water Surface Elev (m)	Depth (m)	Velocity (m/s)	Shear (Pa)	Froude Number
1.00	1020.49	0.19	1.28	41.36	1.00
2.30	1020.61	0.31	1.68	66.54	1.06
3.60	1020.70	0.40	1.94	85.43	1.10
4.90	1020.77	0.47	2.13	101.16	1.13
6.20	1020.83	0.53	2.28	114.88	1.14
7.50	1020.89	0.59	2.41	127.17	1.16
8.80	1020.94	0.64	2.53	138.39	1.17
10.10	1020.99	0.69	2.63	148.75	1.18
11.40	1021.03	0.73	2.72	158.42	1.19
12.70	1021.08	0.78	2.80	167.50	1.20
14.00	1021.12	0.82	2.88	176.08	1.21

Pipe Arch)

Tailwater Channel Data - 3482mm Span x 2215mm Pipe Arch

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: 1020.30 m

Roadway Data for Crossing: 3482mm Span x 2215mm Pipe Arch

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 m

Crest Elevation: 1033.05 m

Roadway Surface: Paved

Roadway Top Width: 150.00 m

Appendix B

Proposed Culverts

HY-8 Culvert Analysis Results

Appendix B

Option 1

HY-8 Culvert Analysis Results

Crossing Discharge Data

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

Minimum Flow: 1.0 m^3/s

Design Flow: 14.0 m^3/s

Maximum Flow: 26.45 m^3/s

Table 1 - Summary of Culvert Flows at Crossing: 3.09m x 1.99m Pipe Arch

Headwater Elevation (m)	Total Discharge (cms)	Option 1: 3097mm x 1990mm Pipe Arch Discharge (cms)	Roadway Discharge (cms)	Iterations
1028.16	1.00	1.00	0.00	1
1028.43	2.30	2.30	0.00	1
1028.65	3.60	3.60	0.00	1
1028.85	4.90	4.90	0.00	1
1029.04	6.20	6.20	0.00	1
1029.22	7.50	7.50	0.00	1
1029.39	8.80	8.80	0.00	1
1029.56	10.10	10.10	0.00	1
1029.74	11.40	11.40	0.00	1
1029.92	12.70	12.70	0.00	1
1030.13	14.00	14.00	0.00	1
1033.05	26.45	26.45	0.00	Overtopping

Rating Curve Plot for Crossing: 3.09m x 1.99m Pipe Arch

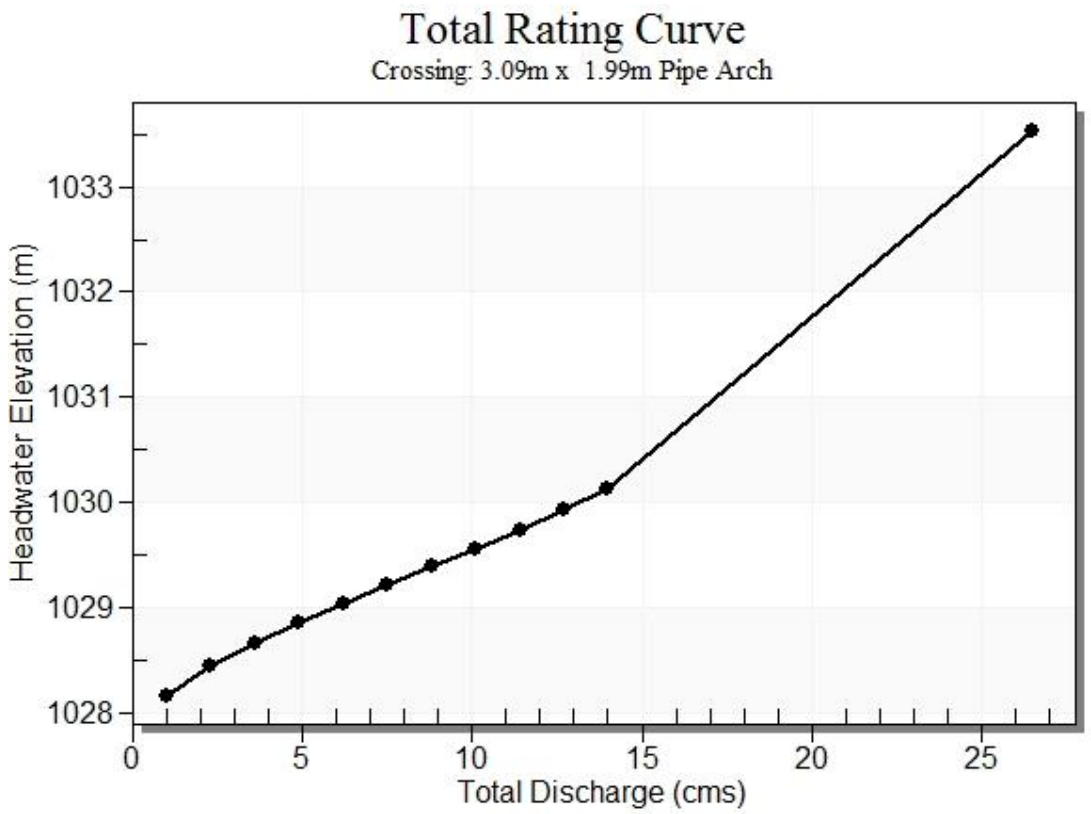


Table 2 - Culvert Summary Table: Option 1: 3097mm x 1990mm Pipe Arch

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)
1.00	1.00	1028.16	0.456	0.0*	1-S2n	0.213	0.320	0.213	0.192	2.619	1.279
2.30	2.30	1028.43	0.725	0.0*	1-S2n	0.315	0.497	0.315	0.309	3.470	1.684
3.60	3.60	1028.65	0.943	0.0*	1-S2n	0.394	0.638	0.394	0.396	4.043	1.938
4.90	4.90	1028.85	1.145	0.0*	1-S2n	0.462	0.760	0.462	0.469	4.481	2.129
6.20	6.20	1029.04	1.332	0.0*	1-S2n	0.523	0.868	0.523	0.533	4.849	2.283
7.50	7.50	1029.22	1.508	0.0*	1-S2n	0.581	0.968	0.581	0.590	5.157	2.414
8.80	8.80	1029.39	1.678	0.0*	1-S2n	0.636	1.058	0.661	0.642	5.192	2.528
10.10	10.10	1029.56	1.850	0.0*	1-S2n	0.689	1.146	0.705	0.690	5.520	2.629
11.40	11.40	1029.74	2.028	0.0*	5-S2n	0.741	1.229	0.760	0.735	5.715	2.721
12.70	12.70	1029.92	2.216	0.0*	5-S2n	0.791	1.308	0.791	0.777	6.076	2.804
14.00	14.00	1030.13	2.418	0.0*	5-S2n	0.841	1.382	0.841	0.817	6.251	2.882

* Full Flow Headwater elevation is below inlet invert.

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Straight Culvert

Inlet Elevation (invert): 1027.71 m, Outlet Elevation (invert): 1020.89 m

Culvert Length: 165.14 m, Culvert Slope: 0.0413

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Appendix B

Option 2

HY-8 Culvert Analysis Results

Crossing Discharge Data

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

Minimum Flow: 1.0 m^3/s

Design Flow: 14.0 m^3/s

Maximum Flow: 37.16 m^3/s

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

Headwater Elevation (m)	Total Discharge (cms)	Option 2: 3000mm x 2400mm Box Culvert Discharge (cms)	Roadway Discharge (cms)	Iterations
1028.08	1.00	1.00	0.00	1
1028.35	2.30	2.30	0.00	1
1028.57	3.60	3.60	0.00	1
1028.77	4.90	4.90	0.00	1
1028.95	6.20	6.20	0.00	1
1029.12	7.50	7.50	0.00	1
1029.28	8.80	8.80	0.00	1
1029.43	10.10	10.10	0.00	1
1029.58	11.40	11.40	0.00	1
1029.72	12.70	12.70	0.00	1
1029.86	14.00	14.00	0.00	1
1033.05	37.16	37.16	0.00	Overtopping

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

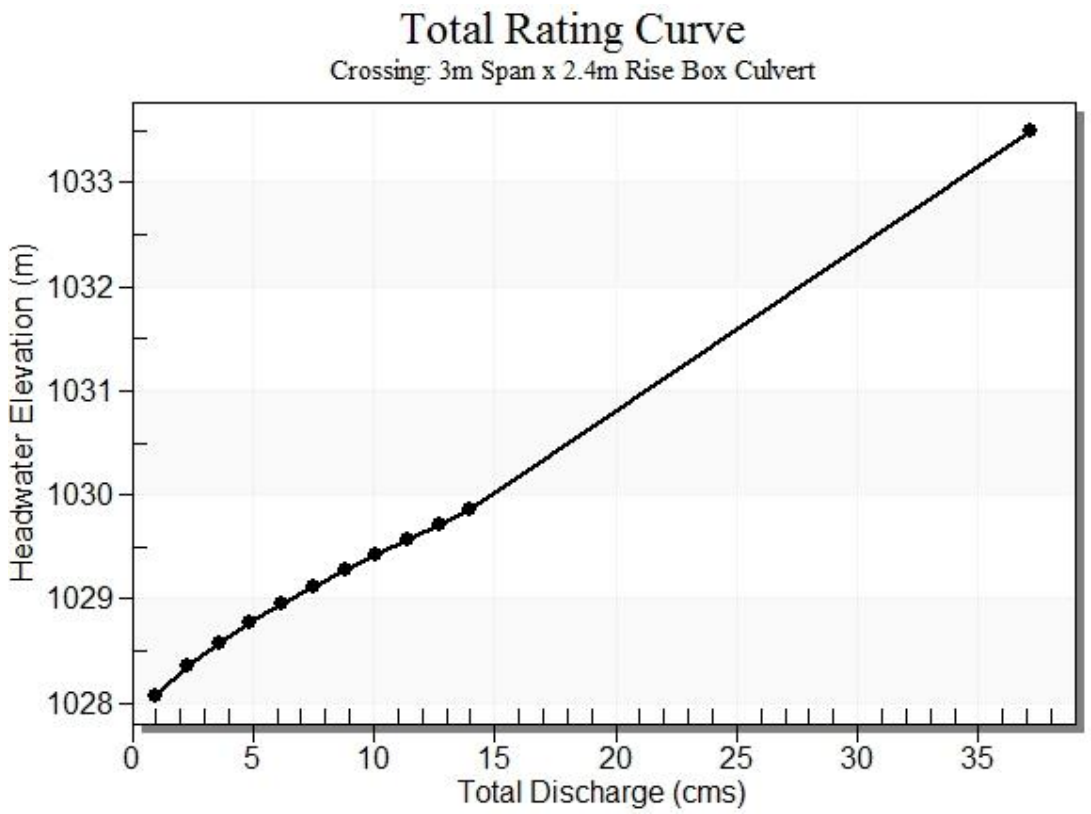

Table 2 - Culvert Summary Table: Option 2: 3000mm x 2400mm Box Culvert

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)
1.00	1.00	1028.08	0.368	0.0*	1-S2n	0.092	0.225	0.092	0.192	3.610	1.279
2.30	2.30	1028.35	0.641	0.0*	1-S2n	0.158	0.391	0.158	0.309	4.847	1.684
3.60	3.60	1028.57	0.864	0.0*	1-S2n	0.211	0.527	0.211	0.396	5.697	1.938
4.90	4.90	1028.77	1.061	0.0*	1-S2n	0.257	0.648	0.257	0.469	6.353	2.129
6.20	6.20	1028.95	1.241	0.0*	1-S2n	0.299	0.758	0.316	0.533	6.543	2.283
7.50	7.50	1029.12	1.411	0.0*	1-S2n	0.338	0.860	0.355	0.590	7.052	2.414
8.80	8.80	1029.28	1.570	0.0*	1-S2n	0.376	0.957	0.376	0.642	7.807	2.528
10.10	10.10	1029.43	1.723	0.0*	1-S2n	0.411	1.049	0.426	0.690	7.911	2.629
11.40	11.40	1029.58	1.869	0.0*	1-S2n	0.445	1.137	0.466	0.735	8.149	2.721
12.70	12.70	1029.72	2.011	0.0*	1-S2n	0.479	1.222	0.502	0.777	8.432	2.804
14.00	14.00	1029.86	2.151	0.0*	1-S2n	0.511	1.304	0.537	0.817	8.689	2.882

* Full Flow Headwater elevation is below inlet invert.

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Straight Culvert

Inlet Elevation (invert): 1027.71 m, Outlet Elevation (invert): 1019.95 m

Culvert Length: 165.18 m, Culvert Slope: 0.0470

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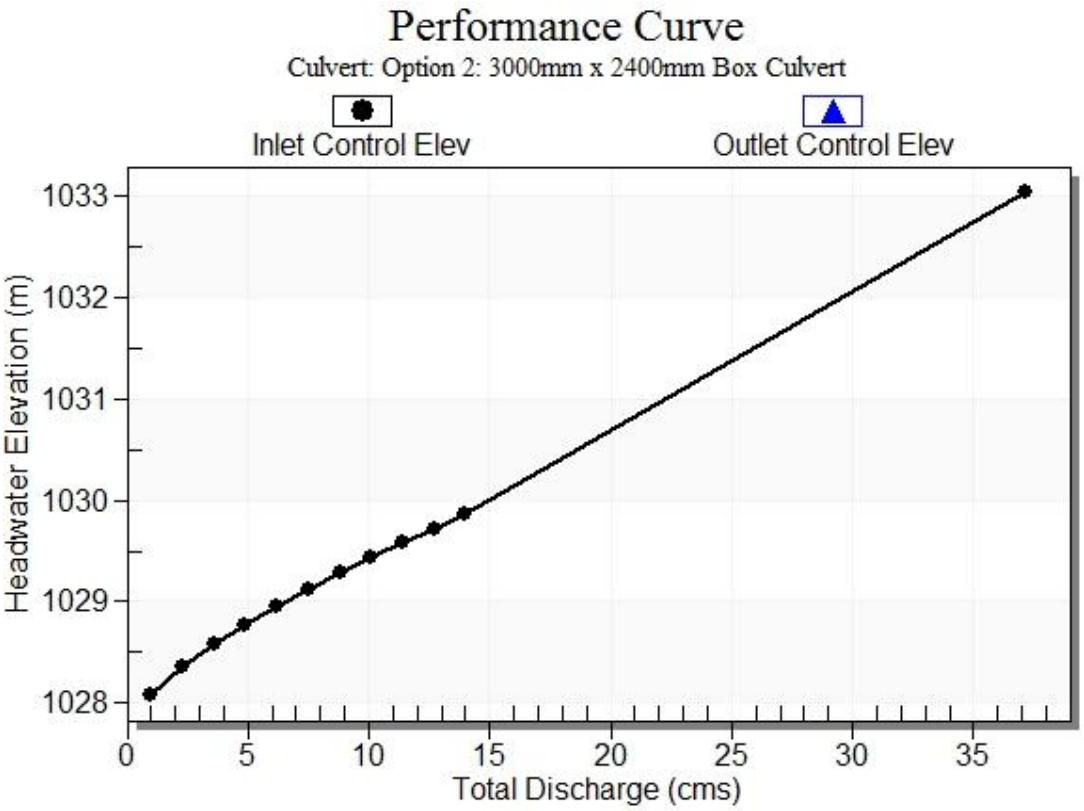
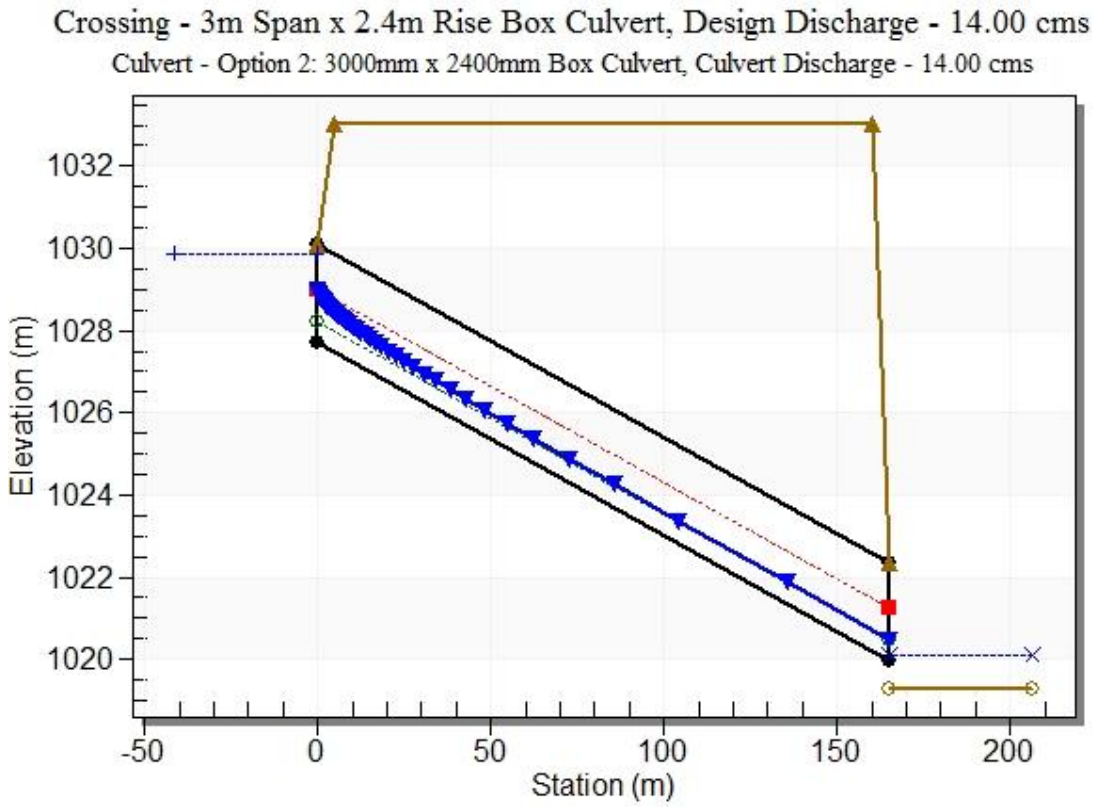
Culvert Performance Curve Plot: Option 2: 3000mm x 2400mm Box Culvert



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: 165.00 m

Outlet Elevation: 1019.95 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: 0.00 mm

Barrel Manning's n: 0.0130

Culvert Type: Straight

Inlet Configuration: Square Edge (90º) Headwall

Inlet Depression: None

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

Flow (cms)	Water Surface Elev (m)	Depth (m)	Velocity (m/s)	Shear (Pa)	Froude Number
1.00	1019.49	0.19	1.28	41.36	1.00
2.30	1019.61	0.31	1.68	66.54	1.06
3.60	1019.70	0.40	1.94	85.43	1.10
4.90	1019.77	0.47	2.13	101.16	1.13
6.20	1019.83	0.53	2.28	114.88	1.14
7.50	1019.89	0.59	2.41	127.17	1.16
8.80	1019.94	0.64	2.53	138.39	1.17
10.10	1019.99	0.69	2.63	148.75	1.18
11.40	1020.03	0.73	2.72	158.42	1.19
12.70	1020.08	0.78	2.80	167.50	1.20
14.00	1020.12	0.82	2.88	176.08	1.21

Tailwater Channel Data - 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: 1019.30 m

Roadway Data for Crossing: 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

Appendix B

Option 3

HY-8 Culvert Analysis Results

Crossing Discharge Data

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

Minimum Flow: 1.0 m^3/s

Design Flow: 14.0 m^3/s

Maximum Flow: 33.13 m^3/s

Table 1 - Summary of Culvert Flows at Crossing: 3.48m x 2.06m Pipe Arch

Headwater Elevation (m)	Total Discharge (cms)	Option 3: 3480mm x 2060mm Pipe Arch Discharge (cms)	Roadway Discharge (cms)	Iterations
1028.20	1.00	1.00	0.00	1
1028.44	2.30	2.30	0.00	1
1028.63	3.60	3.60	0.00	1
1028.80	4.90	4.90	0.00	1
1028.96	6.20	6.20	0.00	1
1029.12	7.50	7.50	0.00	1
1029.28	8.80	8.80	0.00	1
1029.42	10.10	10.10	0.00	1
1029.56	11.40	11.40	0.00	1
1029.69	12.70	12.70	0.00	1
1029.84	14.00	14.00	0.00	1
1033.05	32.13	32.13	0.00	Overtopping

Rating Curve Plot for Crossing: 3.48m x 2.06m Pipe Arch

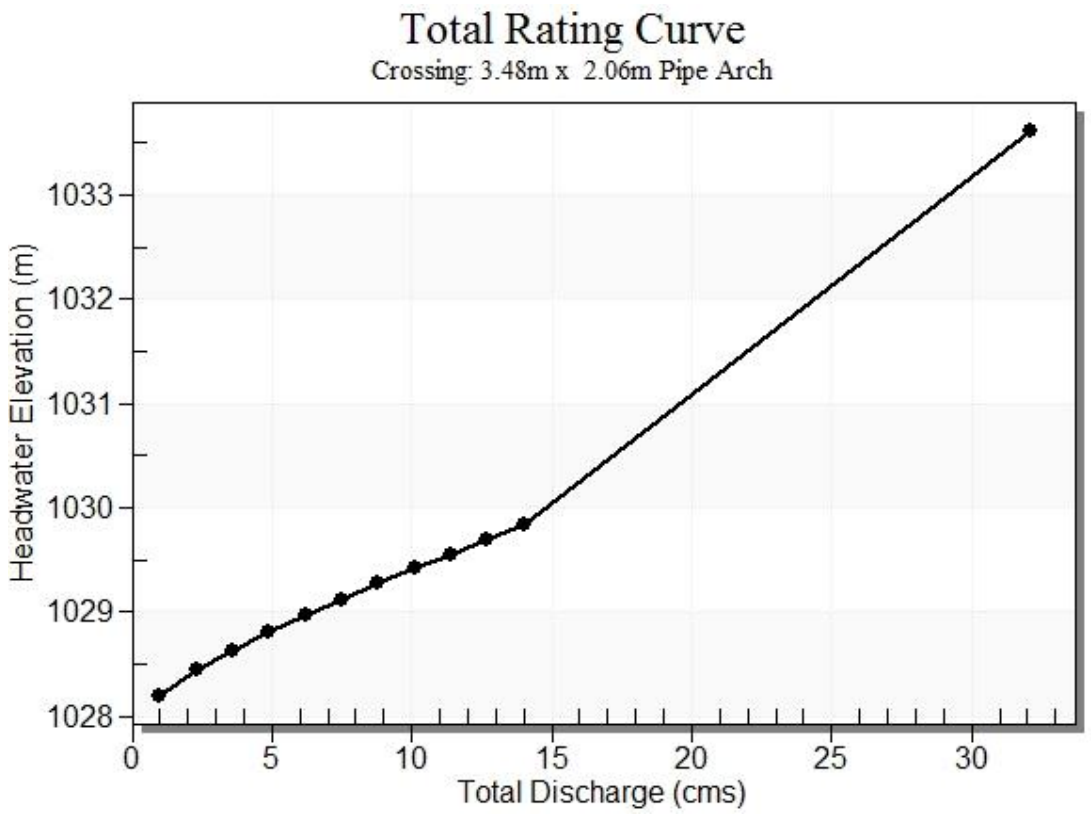


Table 2 - Culvert Summary Table: Option 3: 3480mm x 2060mm Pipe Arch

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)
1.00	1.00	1028.20	0.347	0.0*	1-S2n	0.148	0.229	0.148	0.192	2.264	1.279
2.30	2.30	1028.44	0.585	0.0*	1-S2n	0.241	0.387	0.241	0.309	3.060	1.684
3.60	3.60	1028.63	0.777	0.0*	1-S2n	0.314	0.510	0.314	0.396	3.582	1.938
4.90	4.90	1028.80	0.947	0.0*	1-S2n	0.378	0.622	0.378	0.469	3.993	2.129
6.20	6.20	1028.96	1.106	0.0*	1-S2n	0.435	0.720	0.435	0.533	4.333	2.283
7.50	7.50	1029.12	1.265	0.0*	1-S2n	0.488	0.812	0.488	0.590	4.623	2.414
8.80	8.80	1029.28	1.424	0.0*	1-S2n	0.540	0.898	0.562	0.642	4.668	2.528
10.10	10.10	1029.42	1.564	0.0*	1-S2n	0.589	0.978	0.589	0.690	5.102	2.629
11.40	11.40	1029.56	1.700	0.0*	1-S2n	0.637	1.051	0.637	0.735	5.305	2.721
12.70	12.70	1029.69	1.835	0.0*	1-S2n	0.684	1.124	0.700	0.777	5.360	2.804
14.00	14.00	1029.84	1.981	0.0*	1-S2n	0.730	1.196	0.730	0.817	5.658	2.882

* Full Flow Headwater elevation is below inlet invert.

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Straight Culvert

Inlet Elevation (invert): 1027.86 m, Outlet Elevation (invert): 1021.04 m

Culvert Length: 165.14 m, Culvert Slope: 0.0413

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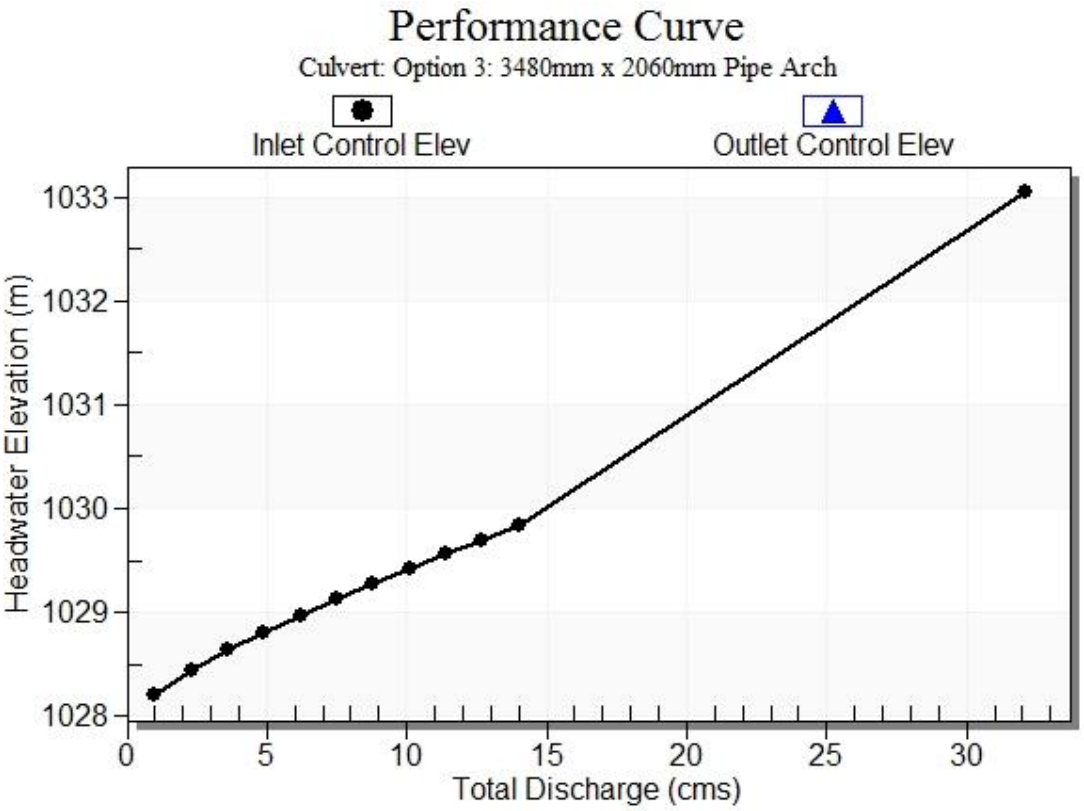
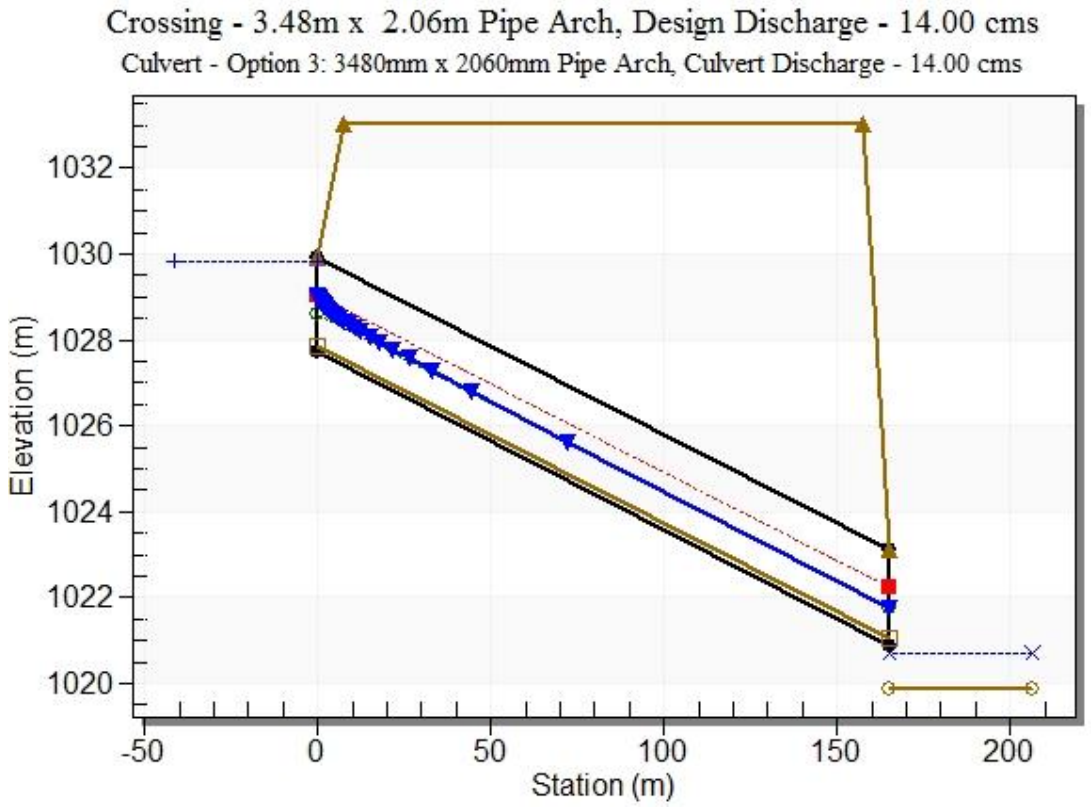
Culvert Performance Curve Plot: Option 3: 3480mm x 2060mm Pipe Arch



Water Surface Profile Plot for Culvert: Option 3: 3480mm x 2060mm Pipe Arch



Site Data - Option 3: 3480mm x 2060mm Pipe Arch

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 m

Inlet Elevation: 1027.71 m

Outlet Station: 165.00 m

Outlet Elevation: 1020.89 m

Number of Barrels: 1

Culvert Data Summary - Option 3: 3480mm x 2060mm Pipe Arch

Barrel Shape: Pipe Arch

Barrel Span: 3479.80 mm

Barrel Rise: 2209.80 mm

Barrel Material: Steel or Aluminum

Embedment: 149.00 mm

Barrel Manning's n: 0.0240 (top and sides)

Manning's n: 0.0240 (bottom)

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: None

Table 3 - Downstream Channel Rating Curve (Crossing: 3.48m x 2.06m Pipe Arch)

Flow (cms)	Water Surface Elev (m)	Depth (m)	Velocity (m/s)	Shear (Pa)	Froude Number
1.00	1020.08	0.19	1.28	41.36	1.00
2.30	1020.20	0.31	1.68	66.54	1.06
3.60	1020.29	0.40	1.94	85.43	1.10
4.90	1020.36	0.47	2.13	101.16	1.13
6.20	1020.43	0.53	2.28	114.88	1.14
7.50	1020.48	0.59	2.41	127.17	1.16
8.80	1020.53	0.64	2.53	138.39	1.17
10.10	1020.58	0.69	2.63	148.75	1.18
11.40	1020.63	0.73	2.72	158.42	1.19
12.70	1020.67	0.78	2.80	167.50	1.20
14.00	1020.71	0.82	2.88	176.08	1.21

Tailwater Channel Data - 3.48m x 2.06m Pipe Arch

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: 1019.89 m

Roadway Data for Crossing: 3.48m x 2.06m Pipe Arch

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 50.00 m

Crest Elevation: 1033.05 m

Roadway Surface: Paved

Roadway Top Width: 150.00 m