Appendix C: Hydrology Report for Railway Spur

MMM Group Limited

Draft Design Brief

Railway Spur Line and Municipal Services
C.P. Rail to C.S. Wind Property

Prepared for
Corporation of the City of Windsor
32-11122-000-487

COMMUNITIES
TRANSPORTATION
BUILDINGS
INFRASTRUCTURE

MMM GROUP

March 2012

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF FIGURES

Following Pages

LIST OF TABLES

1.0 INTRODUCTION

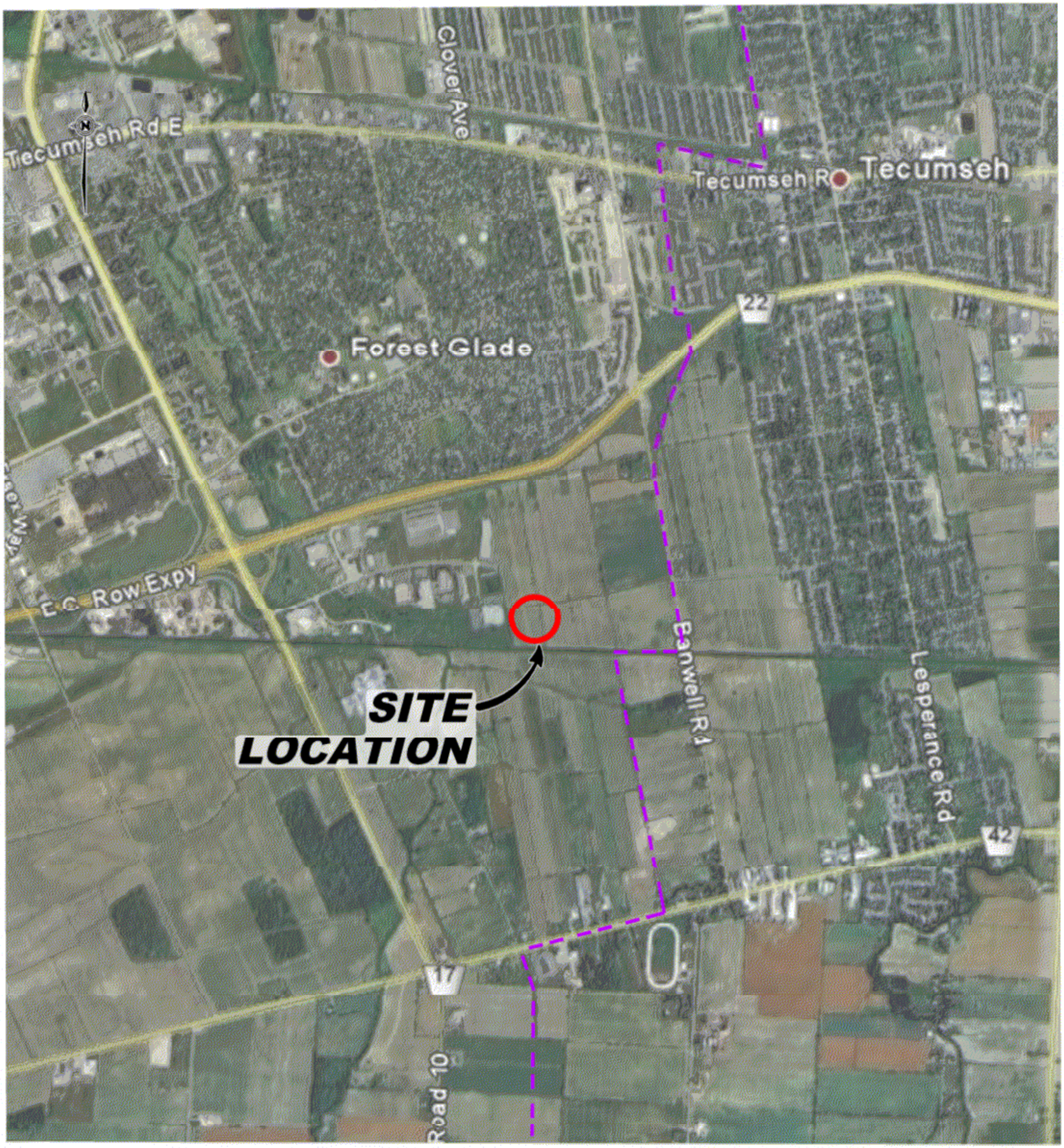
The Corporation of the City of Windsor has retained MMM Group Limited to provide consulting services for the proposed Railway Spur Line to be constructed northward from the Canadian Pacific (CP) Rail main track to the south side of the C.S. Wind property limits, located in the City of Windsor, Ontario (see Figure 1).

This design brief provides the considerations and rationale for the drainage and related environmental components of the proposed project, which includes the relocation of a 480 m long section of the Lachance Municipal Drain, which is located in the vicinity of the proposed track alignment.

The Lachance Drain is a regulated waterway that is under the jurisdiction of the Essex Region Conservation Authority (ERCA). A permit will be required (Section 28 of the *Conservation Authorities Act*) prior to undertaking works on the drain. For the new alignment, the proposed drain will be approximately 550 m long and will include the construction of two (2) new culvert crossings to carry the proposed spur line over the drain. In addition to these two main culverts, two drainage culverts are required below the spur tracks to maintain drainage within the CP Rail right-of-way (ROW).

The following are the main components covered by this design brief:

- The rationale and design basis for the proposed drainage design;
- Analysis of the level of service (LOS) provided by the existing drain and culverts;
- Drainage basin characteristics and flow analysis;
- Methodology and details of the proposed drain and culvert sizing;
- Environmental requirements, i.e., provision of terrestrial and fisheries habitat at the crossings; and
- Standard mitigation measures that are to be followed during construction.



@2011 Google Image@2011 First Base Solutions @2011 Tele Atlas

MUNICIPAL BOUNDARY

CLIENT CORPORATION OF THE CITY OF WINDSOR	MMM GROUP 100 Commerce Valley Dr. W. Thornhill, ON L3T 0A1 t. 905.882.1100 f. 905.882.1857 mmm@mmm.ca
TITLE LOCATION MAP	Checked: V.B; Drawn: AutoCAD/S.Y Date: MARCH 2012; Proj. No.: 32-11128-000-487 Scale: NTS; Figure No.: 1; Gr.No.: 010

FIGURE 1.dwg Site Loction S:\14-41\32\11128-000-487\ Mar 08, 2012 - 10:56am

2.0 DESIGN CRITERIA

In developing design criteria for the project, ERCA and the City of Windsor were consulted on hydraulic and environmental requirements. From the aforesaid consultations and a review of the AREMA[1] design manual, the following hydraulic design criteria were developed for the drain relocation and culvert crossings:

1. The level of service provided by the relocated Lachance Drain and proposed culverts should match or exceed that of the existing Lachance Drain and associated culverts;
2. Notwithstanding criterion (1), the AREMA (2008) Manual recommends that culverts be designed to discharge:
    a. a 25-year flood without static head at the entrance [i.e., a maximum headwater to culvert diameter/rise ratio (HW/D) of 1.0] ; and
    b. a 100-year flood using the available head at entrance – the head is to be 0.6 m below the base of rail (i.e., 0.6 m minimum freeboard), or results in a HW/D not exceeding 1.5, whichever is less.
3. Culverts requiring fish passage should be embedded a minimum of 10% of the culvert diameter/rise below the drain bottom.

[1] AREMA – American Railway Engineering and Maintenance of-Way Association

3.0 ECOLOGY

3.1 Aquatic Habitat

The aquatic habitat in the Lachance drain was divided into two reaches; a reach that flows east/west and a reach that flows north/south. The east/west reach flows between two fallow fields for approximately 275 m from its entrance onto undeveloped lands within the City of Windsor to where the drain changes flow direction and continues south. Within the proposed reach, the drain morphology is dominated by a uniform straight U shaped channel with all flat habitat (100%) over a clay, silt and sand substrate. Moderate in-water cover was present and was provided primarily by emergent vegetation along with woody debris. The banks appear to be stable and are well vegetated with small trees, shrubs and herbaceous species which provided moderate overhanging cover.

The north/south reach flows between the edge of an existing industrial park and a fallow field in the undeveloped lands for approximately 200 m. This reach has been previously altered and realigned in 2010 and is much larger than the channel in the east/west reach. Within the proposed reach to be realigned, the drain morphology is dominated by diffuse flow through dense in channel vegetation over a fine substrate consisting of clay, silt, sand and detritus. Dense in-water cover habitat was provided primarily by emergent vegetation. The banks along the drain were moderately to sparsely vegetated and provided minimal overhanging and overhead cover. Evidence of erosion along the west channel bank was observed.

3.2 Fish Community

The review of background fish community data combined with field sampling indicated three fish species present in the Lachance Drain (Table 1). No provincial or federal aquatic Species At Risk were identified within the Lachance Drain. The thermal classification of Lachance Drain within property limits of the City of Windsor and surrounding area has been classified as warmwater by the MNR. The fish community in Lachance Drain within the assessed area consists of warmwater baitfish and panfish species that are generalist feeders and have an intermediate tolerance to a range of environmental conditions (i.e. low oxygen levels).

Table 1: Lachance Drain Fish Community

Common Name	*Scientific Name*
Central Mudminnow	*Umbra limi*
Pumpkinseed	*Lepomis gibbosus*
Sunfish Species	*Centrarchidae sp.*

4.0 HYDROLOGY

4.1 Catchment Characteristics

The catchment area to the Lachance Drain at the proposed railway spur is approximately 151.2 ha, as shown on Figure 2. Note that the catchment delineation was based solely on the Ministry of Natural Resources (MNR) DEM data; therefore, it should not be used as the basis for any Drainage Report without verification. Generally, the catchment is relatively flat with the predominant drainage direction being westerly at an average slope of 0.1%. The eastern extent of the catchment consists of residential developments, which are drained by a system of storm sewers. Approximately 150 m west of Shawnee Road, the storm sewer system discharges to the Lachance drain, which conveys the flows westerly over a distance of 2.1 km through undeveloped lands (Zone BP) in the western portion of the catchment, and then outlets to the Little River west of the project site.

Surficial soils within the project limits are described in Report No. 11 of the Ontario Soil Survey (1949) for Essex County. According to that report, the main soil type is Brookston Clay, which is classified as Hydraulic Soil Group (HSG) “C.”

4.2 Design Flows

Design flows for the Lachance drain were estimated using the Rational Method under post-development conditions, i.e., with the proposed railway spur in place. The basic formula for the Rational Method is given by:

$$Q = 0.00278\ C\ I\ A$$

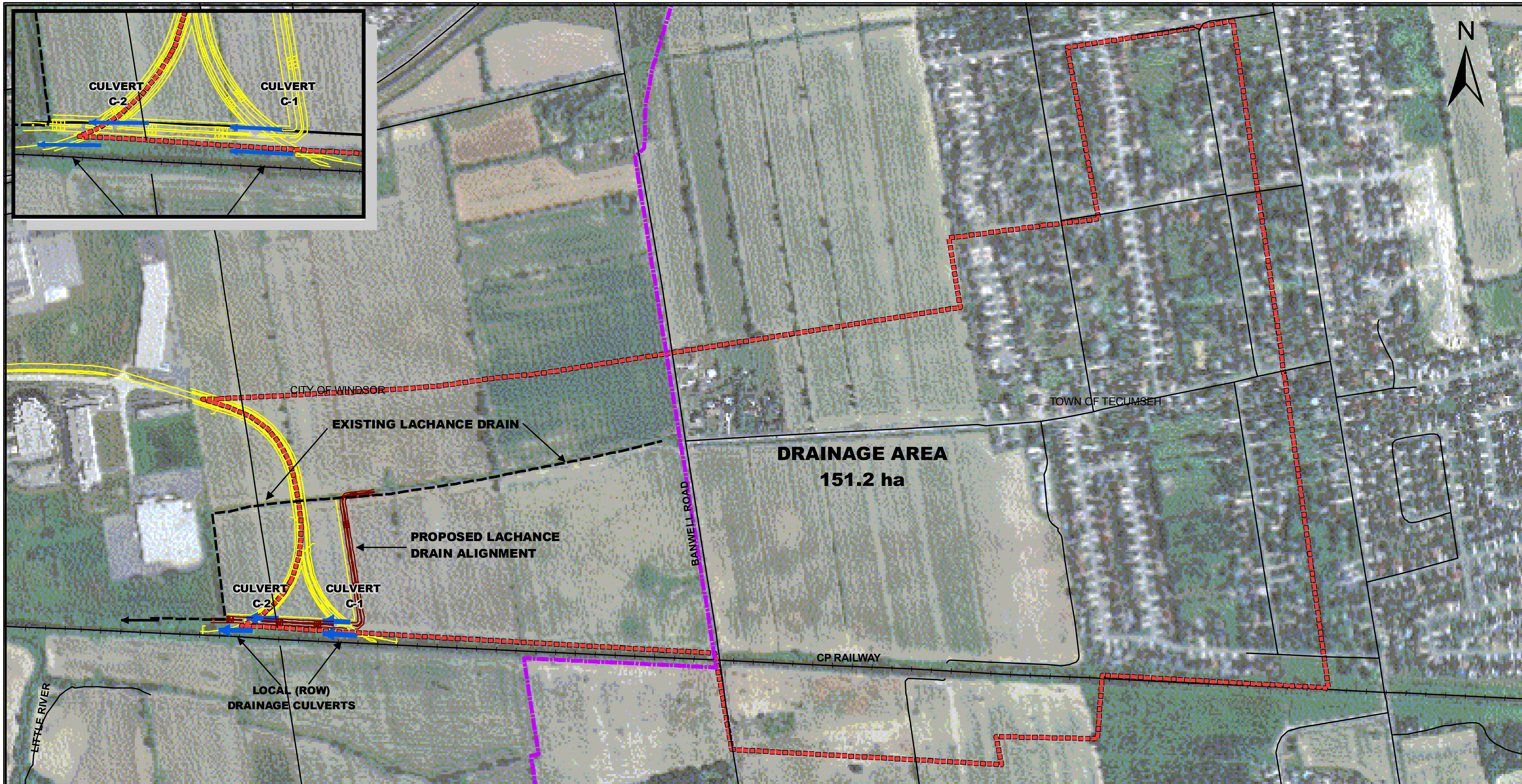
Where *C*, *I* and *A* are the runoff coefficient, rainfall intensity (mm/hr) and catchment area (ha), respectively.

Runoff coefficients were selected for the combination of land use and soil type from typical values used in drainage calculations, such as those from the MTO Drainage Management Manual (MTO, 1997). Accordingly, runoff coefficients of 0.34 and 0.35 were selected for undeveloped and low density residential lands, respectively.

The rainfall intensity *I* is a function of the storm duration, which is equated to the time of concentration for the catchment. The time of concentration was determined using the Bransby-Williams equation as follows:

$$t_c = 0.057\ L\ .\ A^{-0.2}.\ S^{-0.1}$$

Where *A*, *S* and *L* are the area (ha), slope (%) and length (m) of the catchment, respectively.



Legend

- PROPOSED CULVERTS
- MUNICIPAL BOUNDARY
- CATCHMENT BOUNDARY
- PROPOSED ALIGNMENT
- EXISTING DRAIN ALIGNMENT

Source: @2011 Google Image @ 2011 First Base Solutions @ 2011 Tele Atlas

CLIENT	CORPORATION OF THE CITY OF WINDSOR
TITLE	RAILWAY SPURLINE AND MUNICIPAL SERVICES CP RAIL TO C.S. WIND PROPERTY **DRAINAGE MOSAIC**

MMM GROUP

Checked: V.B	Drawn: S.Y
Date: MARCH 2012	Proj. No.: 32-11128-000-487
Scale: AS SHOWN	Figure No.: 2

Rainfall data were based on Environment Canada's Intensity-Duration-Frequency curves for the Windsor Airport (Station Windsor A).

Using the above data, flow rates associated with the 2- to 100-year storm events in the Lachance drain were calculated using the Rational Method. The results are shown in Table 2.

Table 2: **Flow Results**

Drainage Area (ha)	151.2					
Time of Concentration (mins)	142					
Return Period	**2-year**	**5-year**	**10-year**	**25-year**	**50-year**	**100-year**
Composite Runoff Coefficient (C)	0.35	0.35	0.35	0.39	0.42	0.44
Intensity Coefficient A	24.0	31.0	35.7	41.7	46.0	50.4
Intensity Coefficient B	-0.71	-0.71	-0.71	-0.71	-0.71	-0.71
Rainfall Intensity (mm/hr)	13.0	16.8	19.4	22.7	25.0	27.4
Peak Flow Rates (m^3/s)	**1.9**	**2.5**	**2.9**	**3.7**	**4.4**	**5.0**

Given the results in Table 2, the 50- and 100-year design flows are 4.4 and 5.0 m^3/s, respectively.

5.0 HYDRAULIC DESIGN

5.1 Existing Drain – Level of Service

The first analysis carried out for the drain relocation involved determining the level of service provided by the existing Lachance Drain. The level of service is here defined as the maximum flow rate that can be conveyed by the drain without spill— this is synonymous with drain capacity. The analysis for the level of service includes all hydraulic structures (e.g., culverts), that may impede flow conveyance and thereby reduce the free-flow capacity of the drain. In the case of Lachance Drain, there are two (2) existing 1200 mm diameter CSP culvert crossings on the drain, located approximately 450 m and 650 m west of Banwell Road, respectively. As noted in Section 3.0, the existing drain is heavily vegetated—photographs of the drain are included in Appendix A. ERCA stipulates that the cross-section used in the determination of the level of service should be the theoretical or nominal cross-section of the drain, i.e., the cross-section as stipulated in the Drainage Report prepared by Bruce D. Crozier Engineering (1988). The nominal cross-section is shown in Table 3. The drain depth of 2.1 m, as indicated in the table, represents the average depth of the channel for the existing reach from topographical survey data.

The level of service for the drain was determined as the lowest flow rate resulting from the following checks:

1. The free-flow capacity for the drain was computed, i.e., ignoring any backwater effects induced by the culverts;
2. The computed flow rate was used to analyze the existing culverts to determine headwater levels at their inlets; and
3. If spill occurred during (2), a new maximum flow rate was determined that could be applied to each culvert without the headwater level rising above the channel banks.

As shown in Table 3, the Lachance drain has a flow capacity of 9.0 m^3/s under free-flow conditions. However, backwater effects created at the culvert crossings results in its level of service being reduced to 3.0 m^3/s (this is the maximum flow rate that ensures the headwater remains within the channel). According to Table 2, a flow rate of 3.0 m^3/s corresponds roughly to a 1 in 10 year event. (Calculation details and results are provided in Appendix B.)

Table 3: **Existing Channel Characteristics**

Channel Shape	Bottom Width (m)	Side Slope	Average Depth (m)	Channel Slope (%)	Manning's Roughness *n*	Channel Velocity (m/s)	Free-Flow Capacity of Drain (m^3/s)	Flow Capacity of Drain with Existing Culverts (m^3/s)
Trapezoidal	0.9	1.5:1	2.1	0.10	0.03	1.1	9.0	3.0

5.2 Proposed Drain – Level of Service

The proposed plan alignment for the Lachance Drain relocation is shown on Figure 2. The proposed drain will have a trapezoidal cross-section: bottom width of 2 m and 1.5 to 1 side slopes. A shelf, 1.0 m wide and 0.25 m above the drain invert, will be created within the channel to provide snake habitat – see Figure 3. The free-flow capacity of the proposed drain was determined to be 14.2 m^3/s, which provides 60% more capacity than existing. The level of service for the proposed drain, however, will depend on the flow capacity of the spur line culvert crossings, which are discussed in the next section.

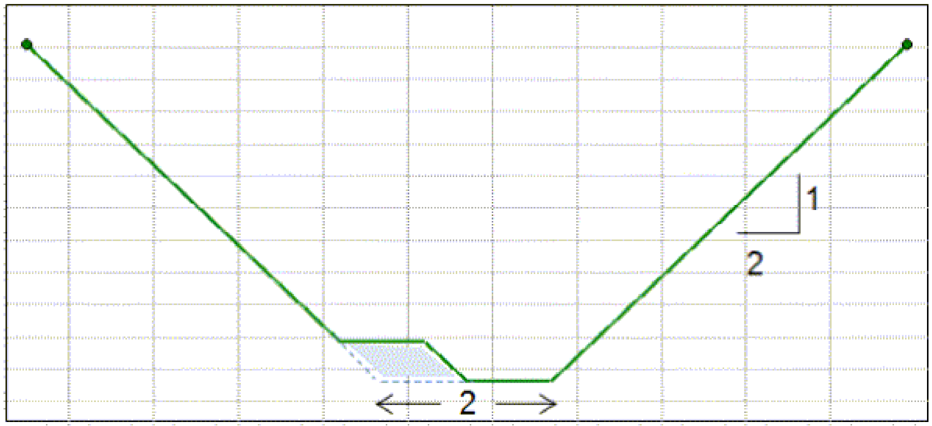


Figure 3: **Proposed Drain Cross-Section**

Table 4: Proposed Drain Characteristics

Channel Shape	Bottom Width (m)	Side Slope	Average Depth (m)	Channel Slope (%)	Manning's Roughness *n*	Channel Velocity (m/s)	Free-Flow Capacity of Drain (m^3/s)
Trapezoidal	2.0	2:1	2.1	0.1	0.03	1.1	14.2

The flow velocity in the proposed drain is 1.1 m/s, which is the same as existing conditions. This flow velocity does not exceed the maximum permissive velocity for clays, which would be used for the channel. Therefore, for the most part, the channel needs only be seeded and allowed sufficient time for vegetation to establish before being commissioned. However, there are two sharp bends in the channel alignment that will require slope protection due to higher flow velocities—resulting from the flow negotiating the bends. At such bends, a 300 mm thick layer of riverstone protection having a median size (D_{50}) of 150 mm should be placed along the entire outer bank and extend a distance of 3 m upstream and downstream of the bend. The riverstone slope protection should be "keyed in" a minimum depth of 450 mm below the channel bed – see Figure 4.

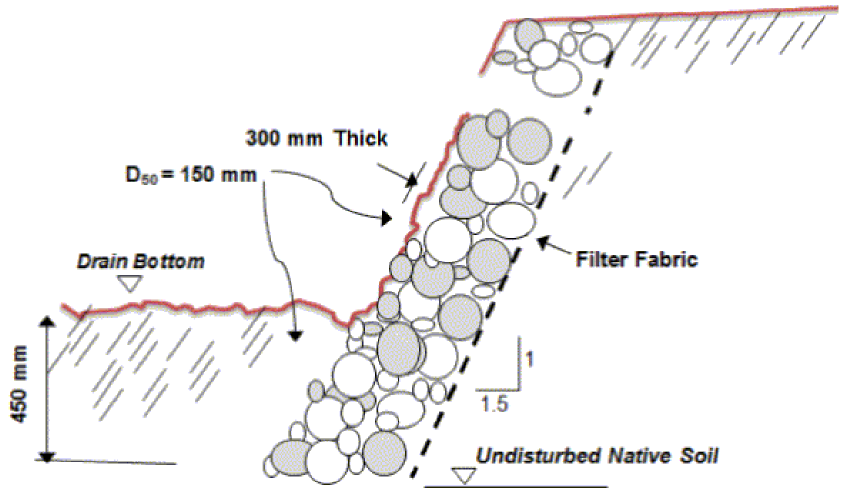


Figure 4: Outer Bend Slope Protection

5.3 Spur Line Culvert Crossings

Ultimately, the proposed spur line will have two crossings of the Lachance Municipal Drain. These two culvert crossings, designated as C-1 and C-2, occur just north of the CP Rail right-of-way at the east and west spurs. The east crossing C-1 is approximately 150 m upstream of the west crossing C-2. As noted in Section 2.0, the culverts will be sized to pass the 25-year design flow with a maximum headwater to diameter ratio (HW/D) of 1.0 or the 100-year flood with a maximum HW/D of 1.5. Note that this requirement would yield a much higher level of service for the proposed drain compared to existing. In addition, fish passage at the crossings will be enhanced by embedding the culverts a minimum of 10% of their diameters and lining the bottoms of the culvert with a graded riverstone substrate.

The proposed culverts were modeled using the Federal Highway Administration's (FHWA) HY-8 software program. Crossing information, i.e., culvert length, slope and invert elevations for the inlet and outlet of each culvert, is provided in Table 5. From Table 2, the 25-year and 100-year flows of 3.7 m^3/s and 5.0 m^3/s, respectively, were used to analyze both crossings.

Tailwater effects can be significant for culverts on relatively flat slopes, as is the case for the Lachance Drain. Culverts C-1 (east spur) and C-2 (west spur) are separated by only 150 m of channel at slope of 0.1%; therefore, backwater effects generated by the downstream culvert (C-2) would impact the flow capacity of the upstream crossing (C-1). For this reason, a rating curve was computed based on the headwater elevations at culvert C-2 and used as the tailwater for analyzing culvert C-1. Normal depth flows were assumed for tailwater conditions downstream of culvert C-2.

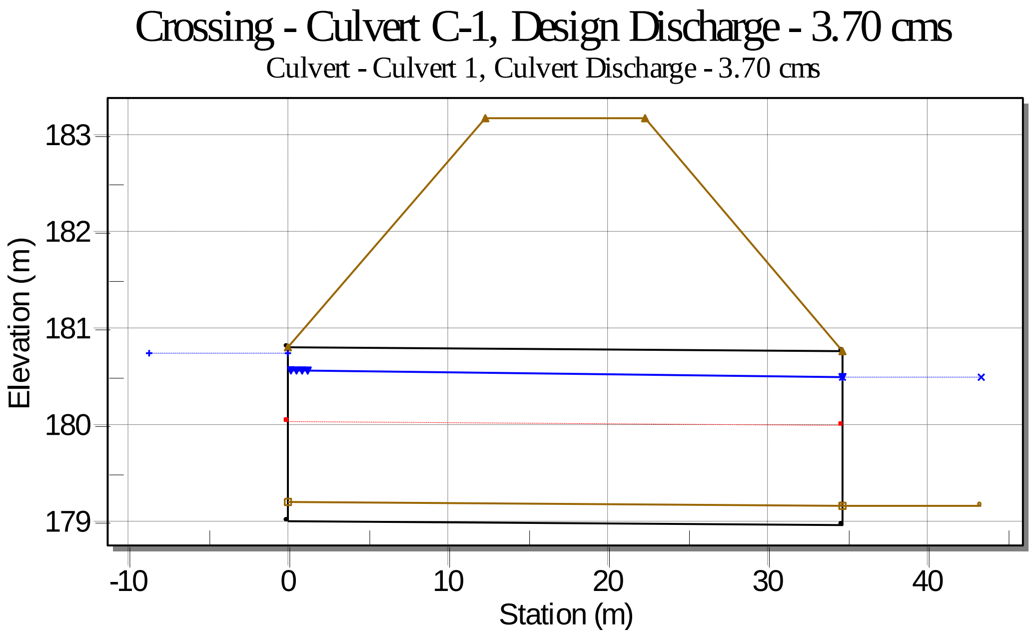
Hydraulic Results

The results of the hydraulic analyses for the culvert sizing are presented in Table 5. Plots of the water surface profiles for the two crossings are shown in Figure 5, and a plot of the Performance Rating Curve at culvert C-1 is shown in Figure 6.

As indicated in Table 4, an 1800 mm diameter concrete culvert will be required at each crossing. As expected, the headwater to diameter (HW/D) ratios for the 25- and 100-year events (HW/D of 1.0 and 1.2, respectively) were higher at culvert C-1 than at culvert C-2. In addition, freeboard to the base of rail is greater than 0.6 m for both crossings. Therefore, both culvert crossings satisfy the hydraulic design criteria established for the project in Section 2.0.

It should be note that given the increased capacity of the culvert crossings, the relocated drain will have a level of service exceeding the 1 in 100 year event, and will have a capacity 75 percent greater than existing.

For fish passage, the culverts are to be embedded to a depth of 200 mm below the drain bottom to accommodate riverstone substrate. Furthermore, both culverts should be lined with a 200 mm thick layer of riverstone having a median diameter (D_{50}) of 100 mm. This substrate material should be well-graded (ranging in stone sizes from 40 to 150 mm), with the voids filled with pit-run material or granular “B” – see Figure 7 for details.



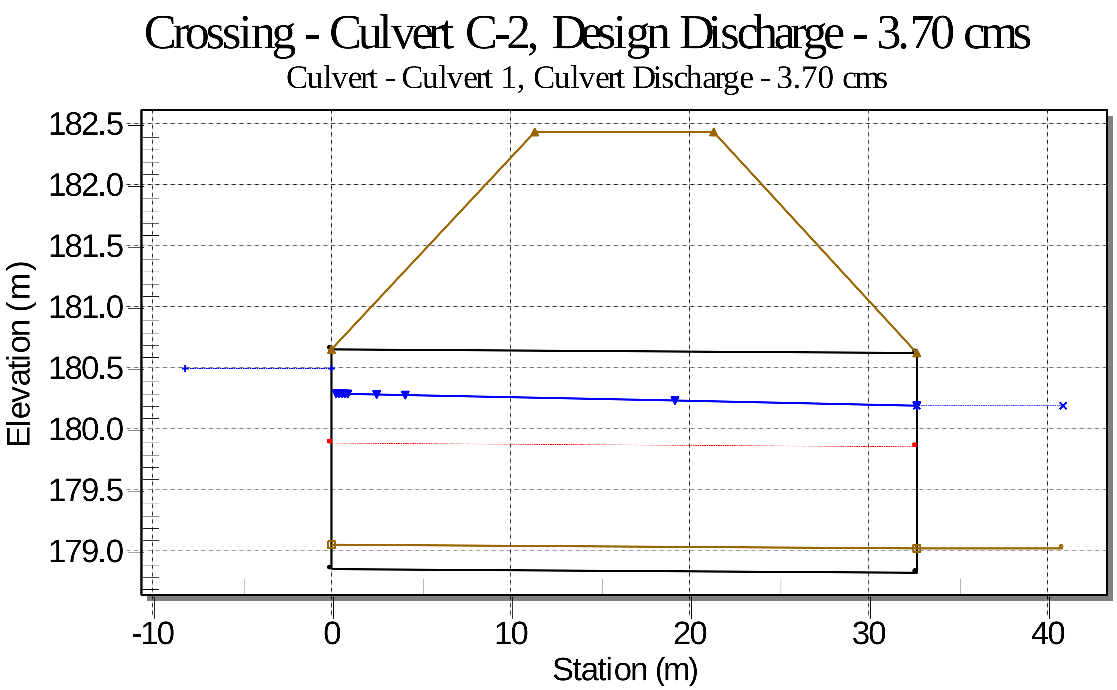


Figure 5: **25-Year Water Surface Profiles – Proposed Culverts**

Table 5: **Proposed Culvert Design**

Culvert ID	Culvert Parameters							Culvert Substrate		25-Year Design Event				100-Year Check Event		
	Culvert Type	Inlet Elevation* (m)	Outlet Elevation* (m)	Length (m)	Slope	Top of Bank Elevation (m)	Rise/ Diameter (mm)	Embedment (mm)	Substrate Size (D_{50}) (mm)	Flow Rate (m^3/s)	Maximum Velocity (m/s)	HW Elevation (m)	HW/D	Flow (m^3/s)	HW Elevation (m)	Freeboard to Top of Bank (m)
C-1 (East Spur)	RCP	179.00	178.96	34.7	0.10%	181.57	1800	200	100	3.7	1.7	180.74	1.0	5.0	181.17	0.40
C-2 (West Spur)	RCP	178.85	178.82	32.7	0.10%	181.36	1800	200	100	3.7	1.9	180.49	0.9	5.0	180.79	0.57

* Refers to actual pipe invert; to determine drain invert, add embedment to invert elevation.

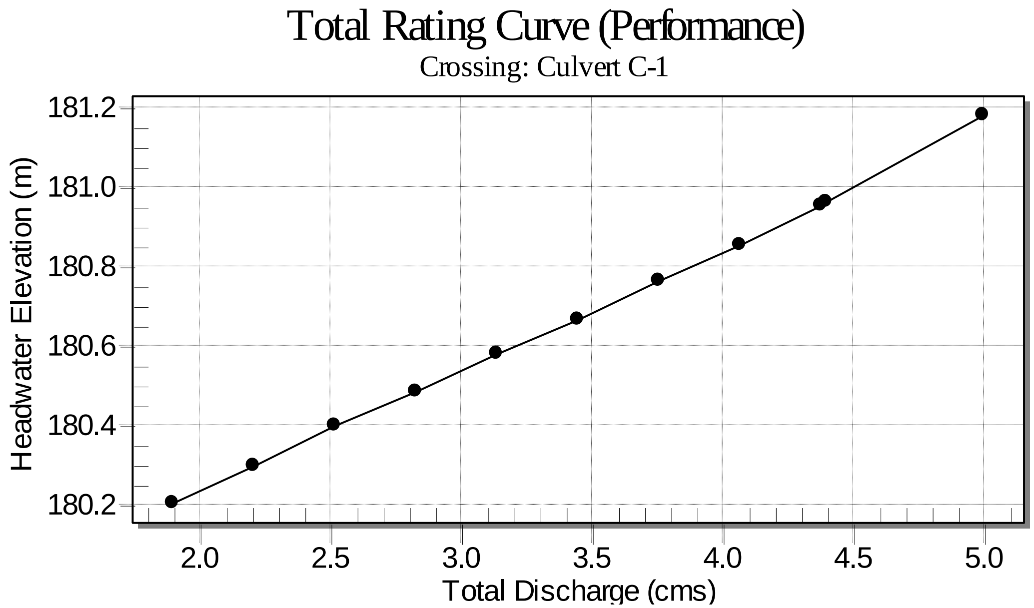


Figure 6: Culvert C-1 Performance Curve

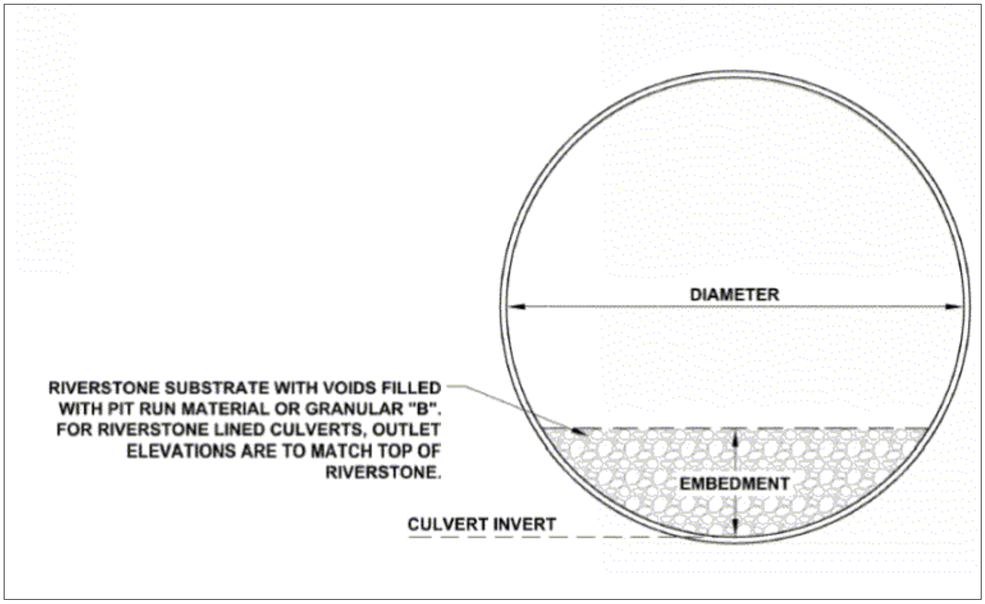


Figure 7*:* Substrate Arrangement for Culverts

5.4 Drainage Culverts – CP Rail ROW

Two culverts are proposed along the CP mainline ditch crossing at the proposed east and west spurs. Available topographic data confirms that where it is crossed by the proposed spur lines, the CP Mainline ditch conveys local drainage only. Therefore, the two proposed culverts within the CP Rail ROW will convey a limited amount of drainage. For these crossings, a concrete culvert with a minimum diameter of 600 mm is recommended. Given a minimum slope of 0.5% and HW/D of 1, each culvert can convey a maximum discharge rate of 0.4 m^3/s.

6.0 SEDIMENT AND EROSION CONTROL DURING CONSTRUCTION

During construction, when soils are exposed as a result of the removal of natural vegetative cover and roadway surface, there is a high potential to cause large magnitude, short-term sediment export from the site. To protect receiving waters and other natural features, on-site sediment controls during construction are necessary.

As part of a comprehensive project strategy focused on minimizing disruption and degradation of the environment, the sediment and erosion control plan will include the following measures:

- Sediment and erosion control works must be in place prior to the commencement of construction, and not removed until the end of the construction period, when the site has been stabilized.
- Construction phasing will be scheduled to minimize the extent and period to which disturbed soils are exposed to weathering. As such, all disturbed areas must be stabilized as quickly as possible. Stabilization of disturbed areas may be accomplished by sodding, seeding, mulching, hydroseeding and planting. Temporary measures may employ the use of biodegradable erosion control blankets.
- To minimize sediment wash off to the receiving watercourses, it is recommended that the bottom of ditch be lined immediately with an erosion resistant material such as sod or a bio-degradable blanket. The lining should be at least 3 m wide so that it extends entirely across the 2 m wide bottom of the drain and 0.5 m along the side slopes.
- All topsoil stock piles must be located away from natural features and drainage ways, where applicable.

To retain sediment on-site, continuous silt fencing will be installed downstream of all exposed areas. Temporary check dams will be placed as required during construction in sections where the slope is excessive.

The above noted sedimentation and erosion controls should be routinely inspected after each storm and cleaned out as required, to ensure that the controls remain effective.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The Corporation of the City of Windsor has retained MMM Group Limited to provide consulting services for the proposed Railway Spur Line to be constructed northward from the C. P. Rail main track to the south side of the C.S. Wind property limits, located in the City of Windsor, Ontario. This design brief provides the considerations and rationale for the drainage and related environmental components of the project, including the realignment of 480 m of the Lachance Municipal Drain, the installation of two (2) new culvert crossings under the east and west spur lines, the recommendations for drainage culverts located within the CP Rail right-of-way, and the strategy for sediment and erosion control during construction. The following are the main conclusions and recommendations from this report:

- Analysis showed that the level of service of the existing drain, considering the theoretical or nominal cross-section, was limited to 3.0 m^3/s—mainly due to high headwater levels at the existing culvert crossings. This flow rate corresponds roughly to 1 in 10 year event;

- Under free-flow conditions, i.e., ignoring culvert induced backwater effects, the existing Lachance drain would have a capacity of 9.0 m^3/s;

- The proposed realigned drain will be trapezoidal: bottom width of 2 m and 2 to 1 (H:V) side slopes. A shelf, 1.0 m wide and 0.25 m above the drain invert, will be created within the channel for snake habitat;

- Proposed culverts are designed to pass the 25-year design flow with a maximum headwater to diameter ratio (HW/D) of 1.0 or the 100-year flood with a maximum HW/D of 1.5.

- The 25-year and the 100-year flow rates were determined to be 3.7 m^3/s and 5.0 m^3/s, respectively, at the most downstream crossing—these flow rates were applied to both crossings;

- The proposed, realigned section of Lachance Drain will have sufficient capacity to pass the 1 in 100-year event and will provide a higher level of service than existing (using its nominal cross-section);

- The flow velocity in the proposed drain is relatively low (1.1 m/s); therefore, straight sections of the channel need only to be seeded and allowed sufficient time for vegetation to take root before commissioning;

- Channel bends will require slope protection in the form of a 300 mm thick layer of riverstone protection having a median size (D_{50}) of 150 mm to be placed along the entire outer bank and extended a distance of 3 m upstream and downstream of the bend. Riverstone protection should be “keyed in” a minimum of 450 mm below the channel bed;

- The two (2) proposed culverts under the east and west spur lines (culverts C-1 and C-2) are to be 1800 mm diameter concrete pipes embedded below the drain bottom by 200 mm;

- To enhance fish passage, the culverts should be lined with a 200 mm thick layer of riverstone having a median diameter (D_{50}) of 100 mm. The substrate material should be well-graded (ranging in stone sizes from 40 to 150 mm) and the voids filled with pit-run material or granular “B”; and

- The proposed drainage culverts within the C.P. Rail ROW convey local drainage only and are to be concrete pipes with a minimum diameter of 600 mm. There are no embedment requirements for these culverts.

Respectfully Submitted,

MMM GROUP LIMITED.

Vernon Brown, M.Sc., P.Eng.
Project Manager
Water Resources Department

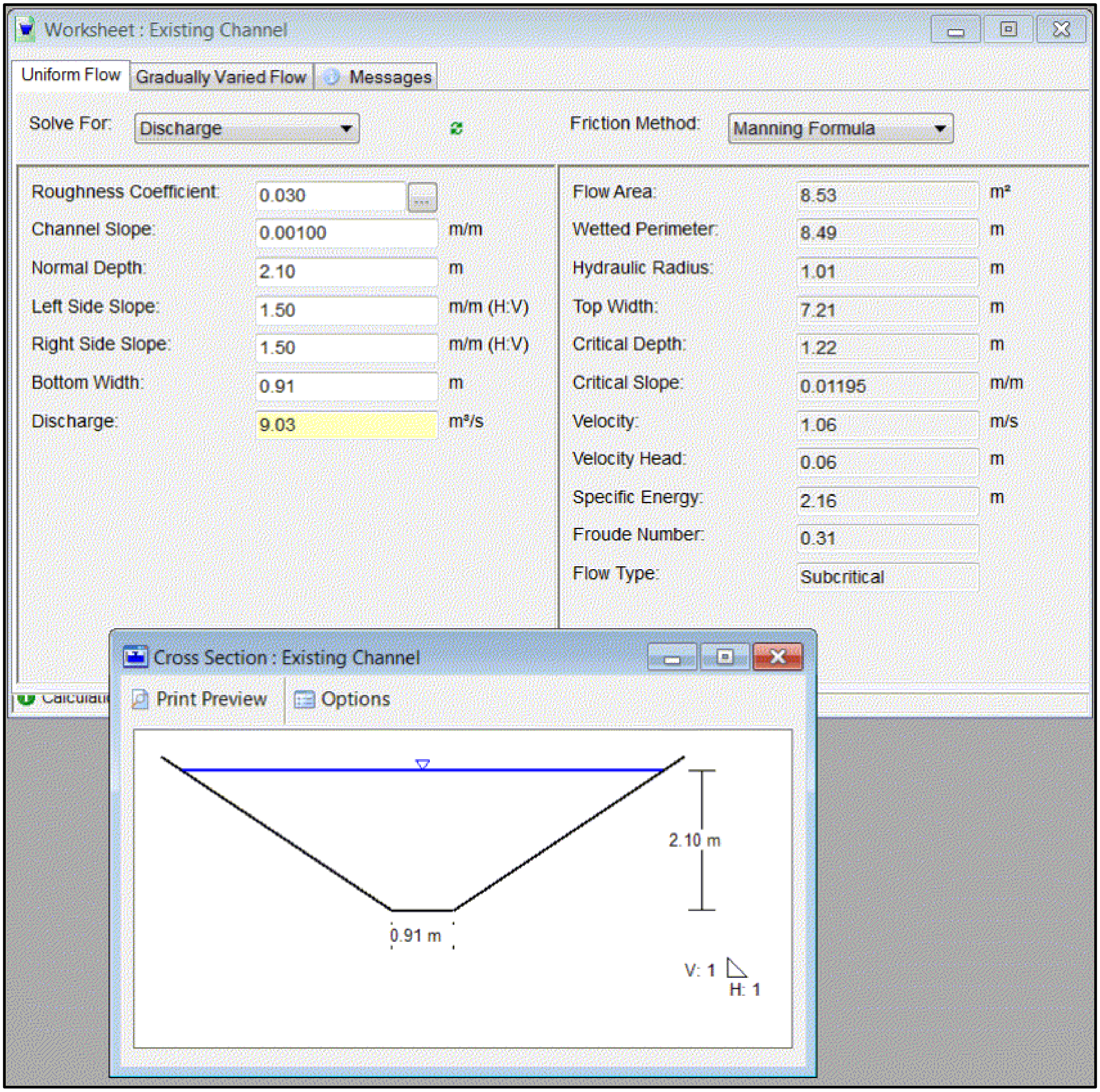
APPENDIX A – Photographs

Photograph 1 - Lachance Drain (Upstream of 1st Existing 1200 CSP Culvert)

Photograph 2 - Lachance Drain (Downstream of 1st Existing 1200 CSP Culvert)

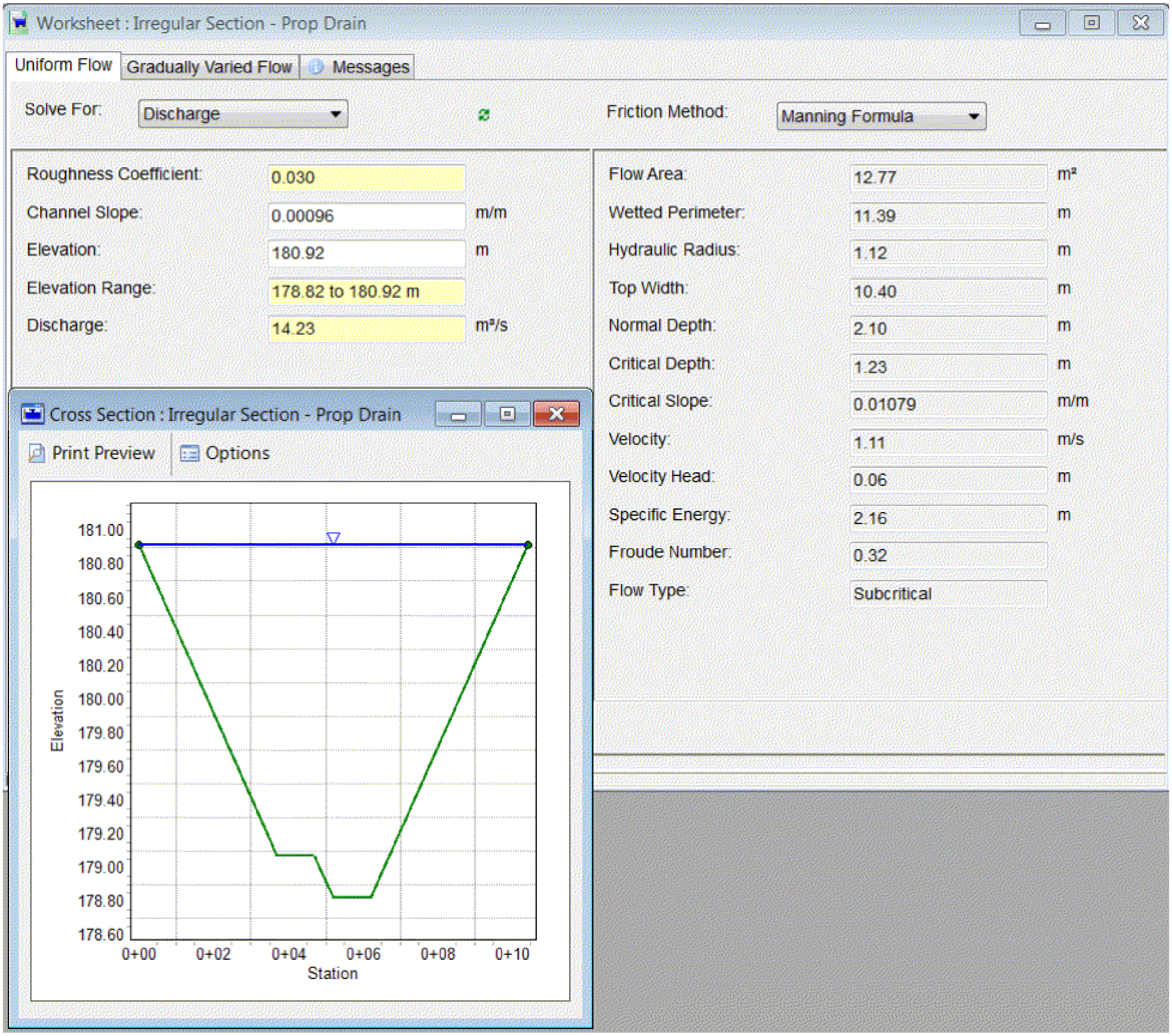
APPENDIX B – Analyses and Results

EXISTING LACHANCE DRAIN CROSS-SECTION

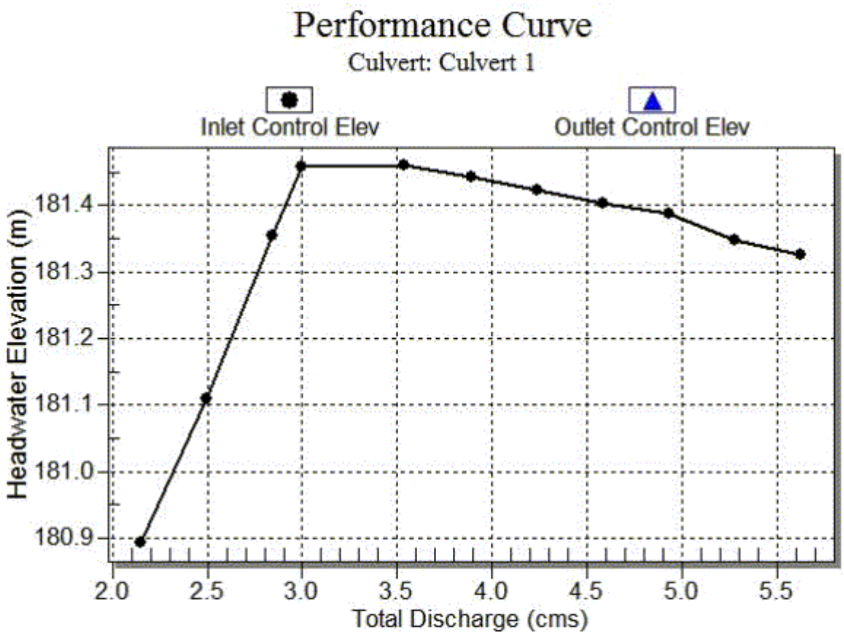


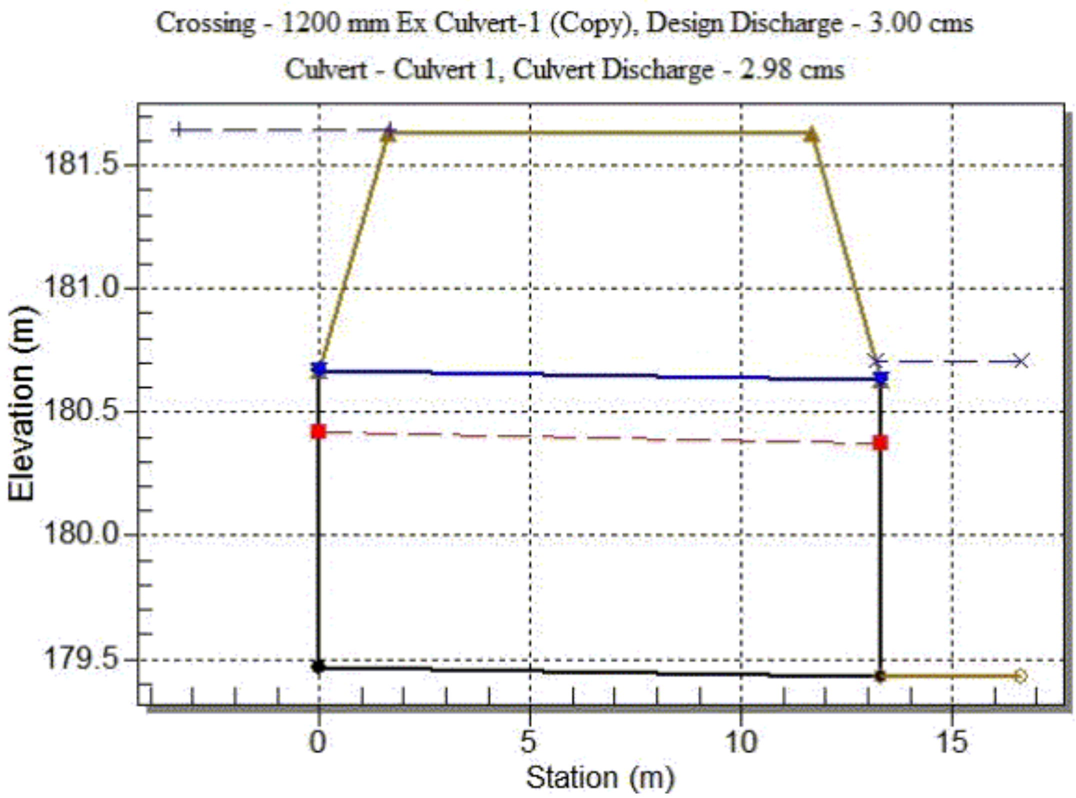
PROPOSED LACHANCE DRAIN CROSS-SECTION

UNIFORM FLOW ANALYSIS – BENTLEY FLOWMASTER WORKSHEET



Analysis – Existing Culverts on Lachance Drain





Culvert Data Summary - Culvert 1

Barrel Shape: Circular

Barrel Diameter: 1200.00 mm

Barrel Material: Corrugated Steel

Barrel Manning's n: 0.0240

Inlet Type: Conventional

Inlet Edge Condition: Thin Edge Projecting

HY-8 Culvert Analysis Report – Proposed Conditions

Table 1 - Summary of Culvert Flows at Crossing: Culvert C-1

Headwater Elevation (m)	Total Discharge (cms)	Culvert 1 Discharge (cms)	Roadway Discharge (cms)	Iterations
180.20	1.90	1.90	0.00	1
180.30	2.21	2.21	0.00	1
180.40	2.52	2.52	0.00	1
180.49	2.83	2.83	0.00	1
180.58	3.14	3.14	0.00	1
180.66	3.45	3.45	0.00	1
180.74	3.70	3.70	0.00	1
180.85	4.07	4.07	0.00	1
180.95	4.38	4.38	0.00	1
181.06	4.69	4.69	0.00	1
181.17	5.00	5.00	0.00	1
183.17	9.45	9.45	0.00	Overtopping

Rating Curve Plot for Crossing: Culvert C-1

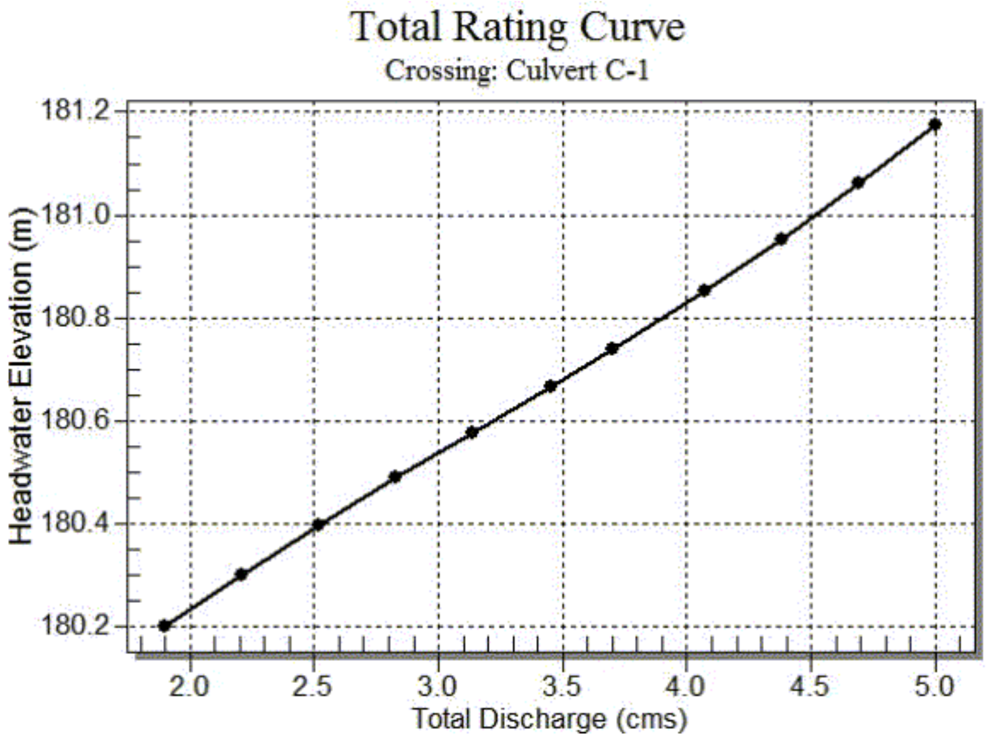


Table 2 - Culvert Summary Table: Culvert 1

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)
1.90	1.90	180.20	0.747	1.000	3-M2t	0.979	0.558	0.880	0.880	1.325	0.000
2.21	2.21	180.30	0.820	1.100	3-M2t	1.087	0.613	0.970	0.970	1.390	0.000
2.52	2.52	180.40	0.895	1.195	3-M2t	1.205	0.663	1.050	1.050	1.461	0.000
2.83	2.83	180.49	0.969	1.287	3-M2t	1.346	0.709	1.130	1.130	1.526	0.000
3.14	3.14	180.58	1.044	1.376	3-M2t	1.600	0.755	1.200	1.200	1.601	0.000
3.45	3.45	180.66	1.113	1.464	3-M2t	1.600	0.800	1.270	1.270	1.673	0.000
3.70	3.70	180.74	1.161	1.538	3-M2t	1.600	0.832	1.330	1.330	1.727	0.000
4.07	4.07	180.85	1.232	1.653	3-M2t	1.600	0.879	1.420	1.420	1.810	0.000
4.38	4.38	180.95	1.292	1.751	3-M2t	1.600	0.918	1.490	1.490	1.890	0.000
4.69	4.69	181.06	1.351	1.862	7-M2t	1.600	0.957	1.560	1.560	1.982	0.000
5.00	5.00	181.17	1.412	1.975	4-FFf	1.600	0.991	1.600	1.630	2.102	0.000

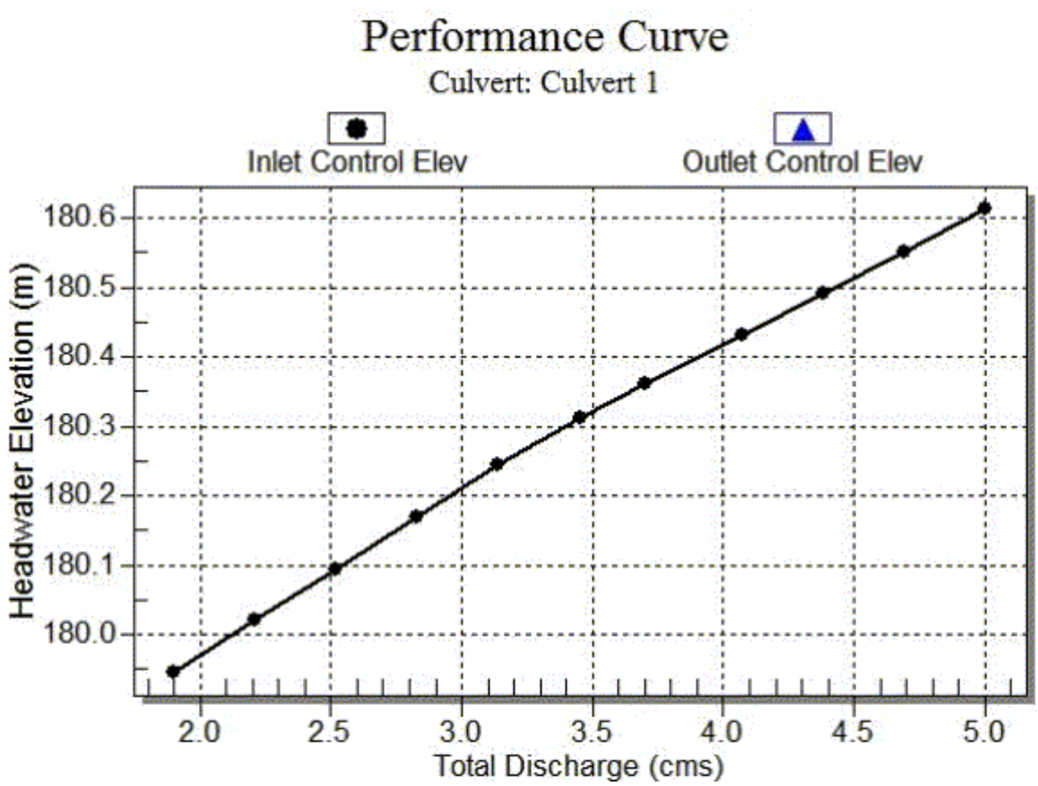
****

Inlet Elevation (invert): 179.20 m, Outlet Elevation (invert): 179.16 m

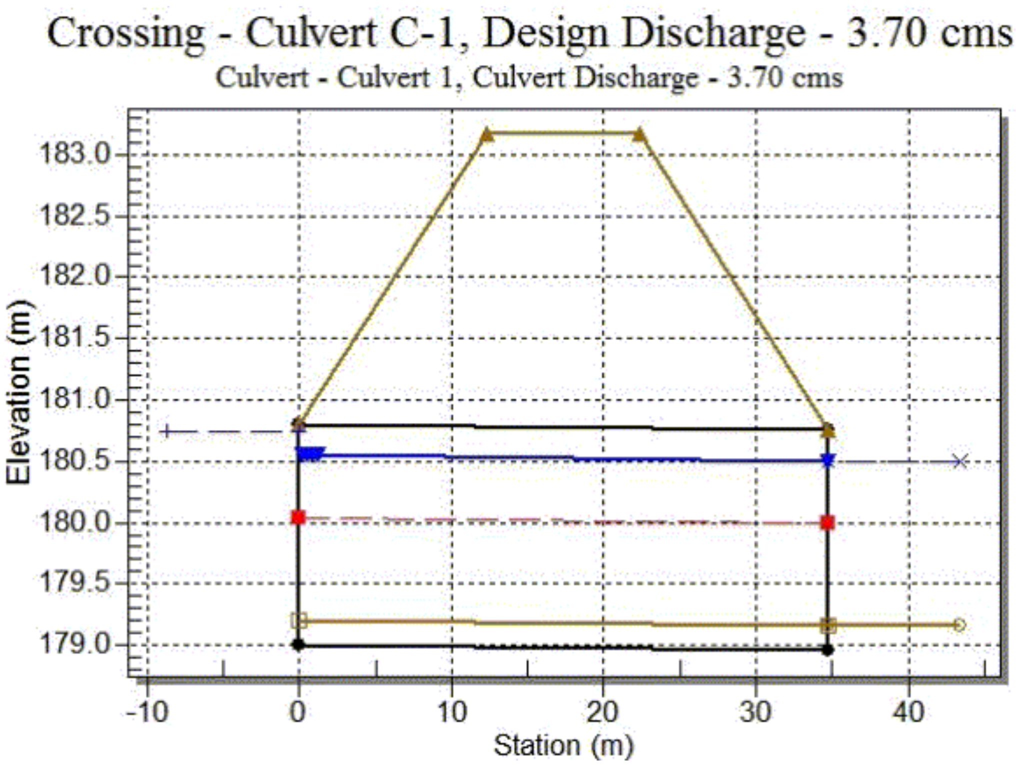
Culvert Length: 34.70 m, Culvert Slope: 0.0012

****

Culvert Performance Curve Plot: Culvert 1



Water Surface Profile Plot for Culvert: Culvert 1



Site Data - Culvert 1

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 m

Inlet Elevation: 179.00 m

Outlet Station: 34.70 m

Outlet Elevation: 178.96 m

Number of Barrels: 1

Culvert Data Summary - Culvert 1

Barrel Shape: Circular

Barrel Diameter: 1800.00 mm

Barrel Material: Concrete

Embedment: 200.00 mm

Barrel Manning's n: 0.0120 (top and sides)

Manning's n: 0.0300 (bottom)

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 3 - Downstream Channel Rating Curve (Crossing: Culvert C-1)

Headwater Elevation (m)	Total Discharge (cms)	Culvert 1 Discharge (cms)	Roadway Discharge (cms)	Iterations
180.04	1.90	1.90	0.00	1
180.13	2.21	2.21	0.00	1
180.21	2.52	2.52	0.00	1
180.29	2.83	2.83	0.00	1
180.36	3.14	3.14	0.00	1
180.43	3.45	3.45	0.00	1
180.49	3.70	3.70	0.00	1
180.58	4.07	4.07	0.00	1
180.65	4.38	4.38	0.00	1
180.72	4.69	4.69	0.00	1
180.79	5.00	5.00	0.00	1
182.43	9.79	9.79	0.00	Overtopping

Tailwater Channel Data - Culvert C-1

Tailwater Channel Option: Enter Rating Curve

Roadway Data for Crossing: Culvert C-1

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 10.00 m

Crest Elevation: 183.17 m

Roadway Surface: Paved

Roadway Top Width: 10.00 m

Table 4 - Summary of Culvert Flows at Crossing: Culvert C-2

Rating Curve Plot for Crossing: Culvert C-2

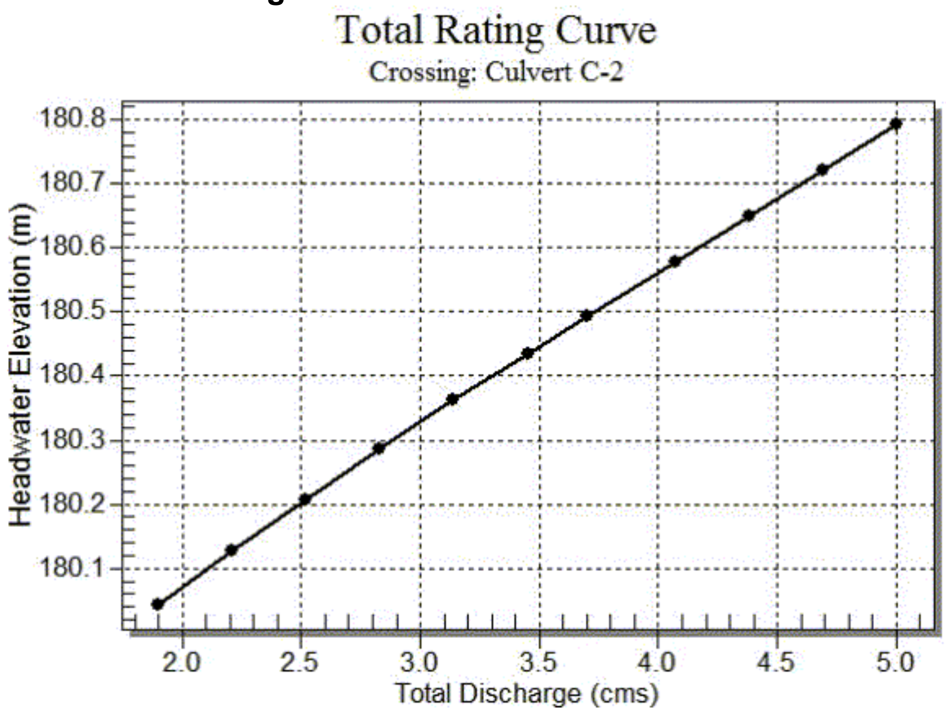


Table 5 - Culvert Summary Table: Culvert 1

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)
1.90	1.90	180.04	0.747	0.994	3-M2t	1.059	0.558	0.860	0.860	1.359	0.671
2.21	2.21	180.13	0.820	1.079	3-M2t	1.188	0.613	0.922	0.922	1.466	0.701
2.52	2.52	180.21	0.895	1.156	3-M2t	1.343	0.663	0.979	0.979	1.569	0.727
2.83	2.83	180.29	0.969	1.236	3-M2t	1.600	0.709	1.033	1.033	1.668	0.751
3.14	3.14	180.36	1.044	1.312	3-M2t	1.600	0.755	1.084	1.084	1.764	0.772
3.45	3.45	180.43	1.113	1.384	3-M2t	1.600	0.800	1.131	1.131	1.858	0.793
3.70	3.70	180.49	1.161	1.443	3-M2t	1.600	0.832	1.168	1.168	1.933	0.808
4.07	4.07	180.58	1.232	1.527	3-M2t	1.600	0.879	1.221	1.221	2.043	0.829
4.38	4.38	180.65	1.292	1.599	3-M2t	1.600	0.918	1.262	1.262	2.135	0.846
4.69	4.69	180.72	1.351	1.670	3-M2t	1.600	0.957	1.302	1.302	2.226	0.861
5.00	5.00	180.79	1.412	1.742	3-M2t	1.600	0.991	1.341	1.341	2.318	0.876

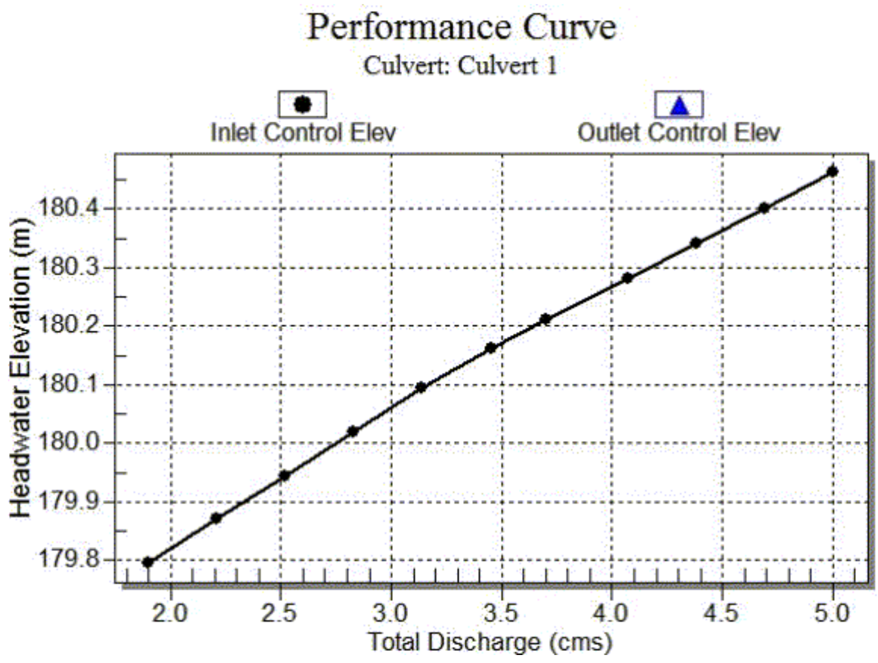
****

Inlet Elevation (invert): 179.05 m, Outlet Elevation (invert): 179.02 m

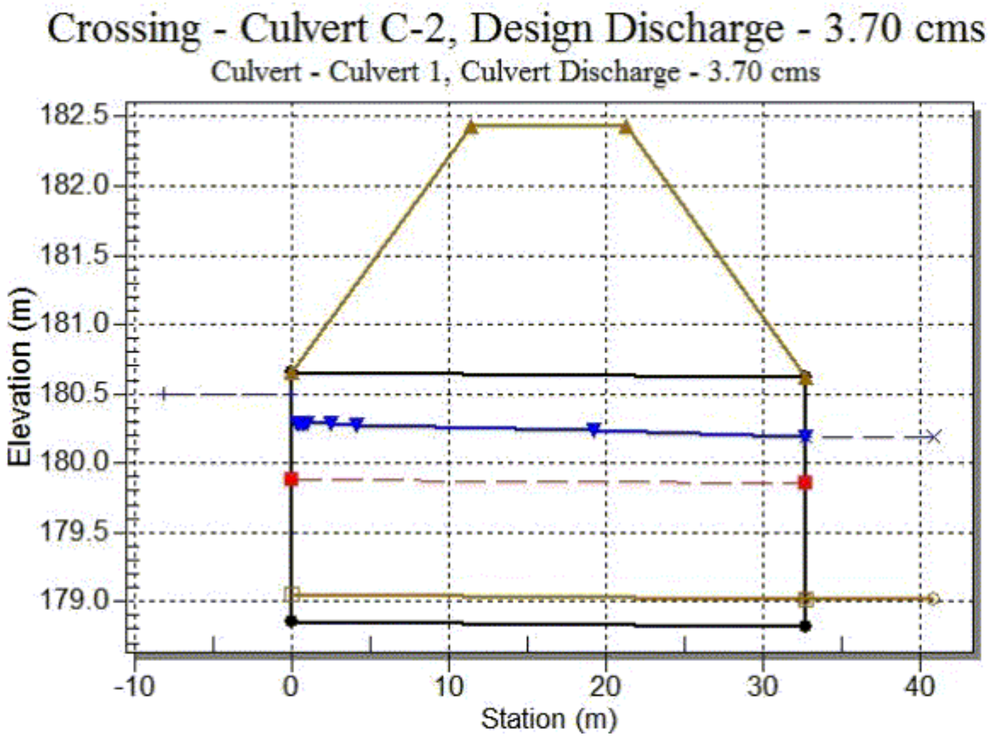
Culvert Length: 32.70 m, Culvert Slope: 0.0009

****

Culvert Performance Curve Plot: Culvert 1



Water Surface Profile Plot for Culvert: Culvert 1



Site Data - Culvert 1

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 m

Inlet Elevation: 178.85 m

Outlet Station: 32.70 m

Outlet Elevation: 178.82 m

Number of Barrels: 1

Culvert Data Summary - Culvert 1

Barrel Shape: Circular

Barrel Diameter: 1800.00 mm

Barrel Material: Concrete

Embedment: 200.00 mm

Barrel Manning's n: 0.0120 (top and sides)

Manning's n: 0.0300 (bottom)

Inlet Type: Conventional

Inlet Edge Condition: Beveled Edge (1:1)

Inlet Depression: NONE

Table 6 - Downstream Channel Rating Curve (Crossing: Culvert C-2)

Flow (cms)	Water Surface Elev (m)	Depth (m)	Velocity (m/s)	Shear (Pa)	Froude Number
1.90	179.88	0.86	0.67	8.43	0.29
2.21	179.94	0.92	0.70	9.04	0.29
2.52	180.00	0.98	0.73	9.60	0.29
2.83	180.05	1.03	0.75	10.12	0.30
3.14	180.10	1.08	0.77	10.62	0.30
3.45	180.15	1.13	0.79	11.09	0.30
3.70	180.19	1.17	0.81	11.45	0.30
4.07	180.24	1.22	0.83	11.96	0.30
4.38	180.28	1.26	0.85	12.37	0.30
4.69	180.32	1.30	0.86	12.77	0.30
5.00	180.36	1.34	0.88	13.14	0.31

Table 7 - Summary of Culvert Flows at Crossing: 600 mm Ex Culvert-3 North

Headwater Elevation (m)	Total Discharge (cms)	Culvert 1 Discharge (cms)	Roadway Discharge (cms)	Iterations
179.66	0.23	0.23	0.00	1
179.71	0.27	0.27	0.00	1
179.74	0.31	0.31	0.00	1
179.78	0.34	0.34	0.00	1
179.84	0.38	0.38	0.00	1
179.86	0.40	0.40	0.00	1
179.92	0.46	0.46	0.00	1
179.96	0.50	0.50	0.00	1
180.00	0.53	0.53	0.00	1
180.06	0.57	0.57	0.00	1
180.11	0.61	0.61	0.00	1
181.74	1.25	1.25	0.00	Overtopping

Rating Curve Plot for Crossing: 600 mm Ex Culvert-3 North

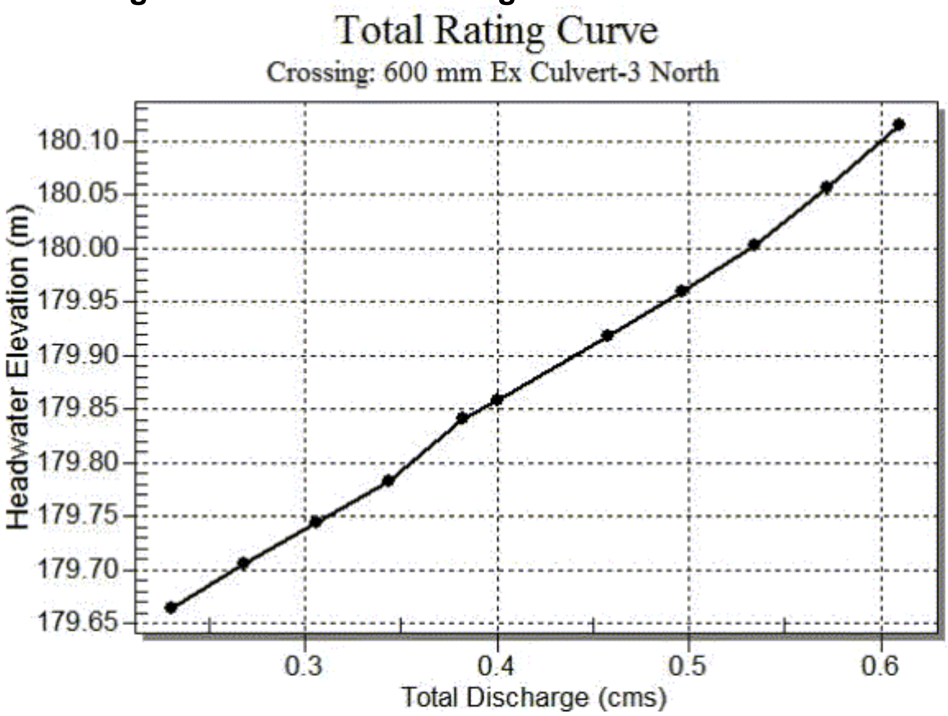


Table 8 - Culvert Summary Table: Culvert 1

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)
0.23	0.23	179.66	0.445	0.194	1-S2n	0.293	0.310	0.295	0.274	1.665	0.730
0.27	0.27	179.71	0.485	0.216	1-S2n	0.321	0.335	0.323	0.296	1.728	0.761
0.31	0.31	179.74	0.524	0.236	1-S2n	0.349	0.361	0.350	0.316	1.789	0.788
0.34	0.34	179.78	0.563	0.254	1-S2n	0.378	0.382	0.379	0.334	1.829	0.812
0.38	0.38	179.84	0.602	0.621	2-M2c	0.407	0.404	0.405	0.351	1.882	0.835
0.40	0.40	179.86	0.621	0.639	2-M2c	0.420	0.414	0.414	0.359	1.920	0.845
0.46	0.46	179.92	0.687	0.698	2-M2c	0.472	0.442	0.444	0.383	2.043	0.875
0.50	0.50	179.96	0.733	0.739	2-M2c	0.522	0.460	0.461	0.398	2.126	0.893
0.53	0.53	180.00	0.783	0.782	2-M2c	0.600	0.477	0.478	0.412	2.213	0.911
0.57	0.57	180.06	0.837	0.830	2-M2c	0.600	0.490	0.493	0.425	2.296	0.927
0.61	0.61	180.11	0.894	0.892	7-M2c	0.600	0.503	0.506	0.438	2.404	0.942

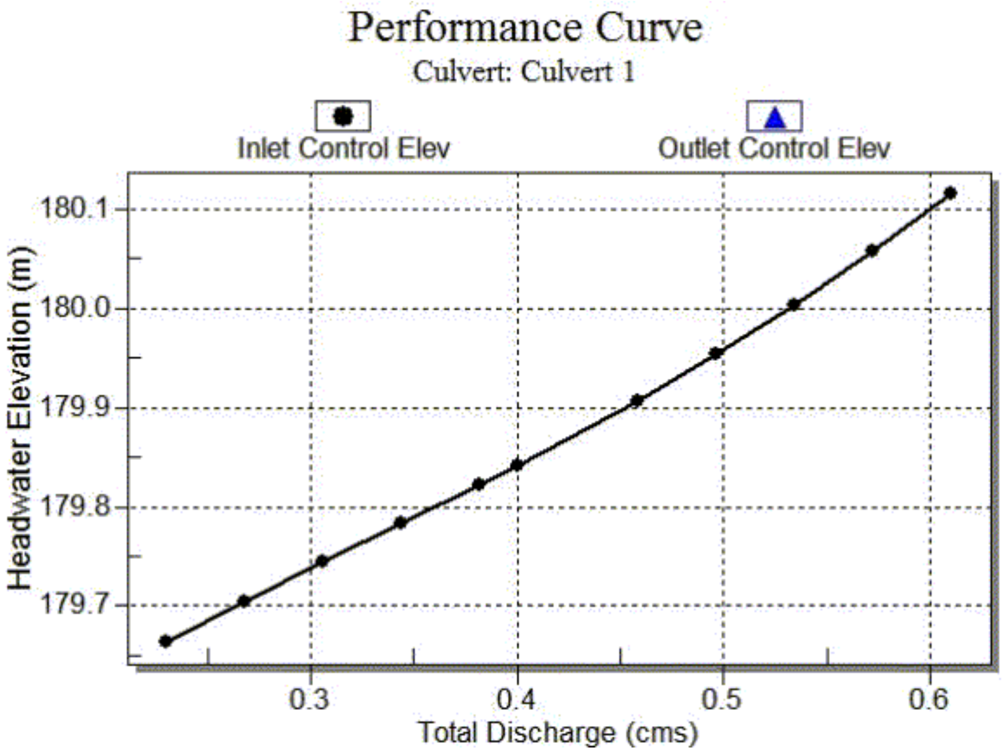
****

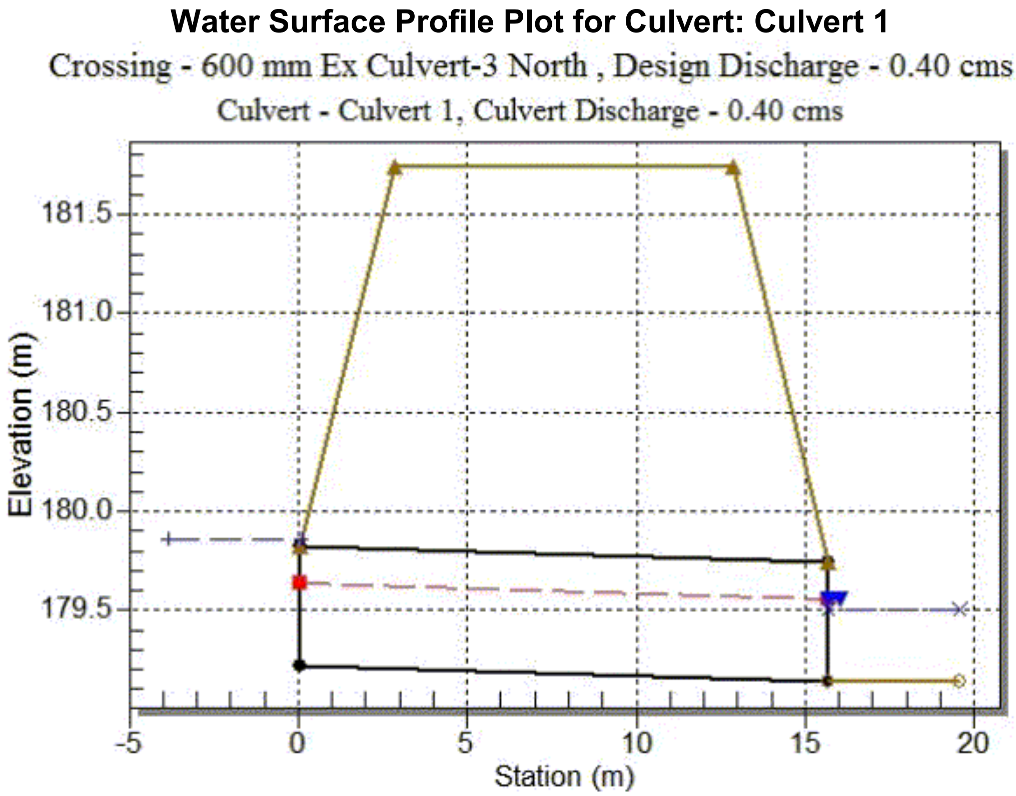
Inlet Elevation (invert): 179.22 m,   Outlet Elevation (invert): 179.14 m

Culvert Length: 15.60 m,   Culvert Slope: 0.005

****

Culvert Performance Curve Plot: Culvert 1





Site Data - Culvert 1

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 m

Inlet Elevation: 179.22 m

Outlet Station: 15.60 m

Outlet Elevation: 179.14 m

Number of Barrels: 1

Culvert Data Summary - Culvert 1

Barrel Shape: Circular

Barrel Diameter: 600.00 mm

Barrel Material: Concrete

Embedment: 0.00 mm

Barrel Manning's n: 0.0120

Inlet Type: Conventional

Inlet Edge Condition: Grooved End Projecting

Inlet Depression: NONE

Table 9 - Downstream Channel Rating Curve (Crossing: 600 mm Ex Culvert-3 North)

Flow (cms)	Water Surface Elev (m)	Depth (m)	Velocity (m/s)	Shear (Pa)	Froude Number
0.23	179.41	0.27	0.73	13.44	0.54
0.27	179.44	0.30	0.76	14.49	0.55
0.31	179.46	0.32	0.79	15.46	0.55
0.34	179.47	0.33	0.81	16.37	0.55
0.38	179.49	0.35	0.83	17.22	0.56
0.40	179.50	0.36	0.84	17.60	0.56
0.46	179.52	0.38	0.88	18.77	0.56
0.50	179.54	0.40	0.89	19.50	0.57
0.53	179.55	0.41	0.91	20.19	0.57
0.57	179.57	0.43	0.93	20.85	0.57
0.61	179.58	0.44	0.94	21.48	0.57