APPENDIX E

DRAFT HYDROLOGY REPORT

COUNTY OF BRUCE

HYDRAULIC REPORT

TEESWATER RIVER BRIDGE AND TEMPORARY DETOUR BRIDGE

BMROSS
engineering better communities

COUNTY OF BRUCE

HYDRAULIC REPORT

TEESWATER RIVER BRIDGE AND TEMPORARY DETOUR BRIDGE

July 8, 2021

B. M. ROSS AND ASSOCIATES LIMITED
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File No. BR1400

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- Cumming Cockburn Limited (October 1990). Saugeen Valley Conservation Authority Village of Paisley Flood Control Study – Part II
- Cumming Cockburn Limited (November 1989). Saugeen Valley Conservation Authority Village of Paisley Flood Control Study Hydraulic Analysis.
- Kilborn Limited (November 1982). Flood Protection Works Village of Paisley Stage IIA - As constructed Drawings
- Kilborn Limited (December 1981). Flood Protection Works Village of Paisley Stage I - as constructed Drawings
- Kilborn Limited (January 1979). Saugeen Valley Conservation Authority – Flood Control Study for the Village of Paisley

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COUNTY OF BRUCE
HYDRAULIC REPORT
TEESWATER RIVER BRIDGE AND TEMPORARY DETOUR BRIDGE
VILLAGE OF PAISLEY

1.0 INTRODUCTION

The County of Bruce retained B. M. Ross and Associates (BMROSS) to complete a Schedule C Environmental Assessment (EA) and engineering design for the replacement of the Teeswater River Bridge located on County Road 3 (Queen Street) in the Village of Paisley. The existing bridge spans the Teeswater River immediately upstream of the confluence with the Saugeen River (See Figure 2.1).

The EA has identified the replacement of the existing bridge in its current location and will require a detour during the projected year long construction period. The preferred detour option involves the construction of a temporary bridge across the Saugeen River, to connect Goldie Street with Church Street, immediately downstream of the confluence of the Saugeen and Teeswater River.

Hydraulic conditions in the study area are complex. The design of the replacement structure must account for high water levels due to the confluence of the Saugeen and Teeswater River, existing dyke flood protection levels, potential ice jam conditions, and preserve the historical mill race flows along the south span. The design of the proposed temporary detour structure, spanning the Saugeen River, requires careful consideration of any temporary impacts to flood water levels, floodplain fill, ice conveyance, and impacts to the existing flood protection dyke system.

2.0 OBJECTIVES

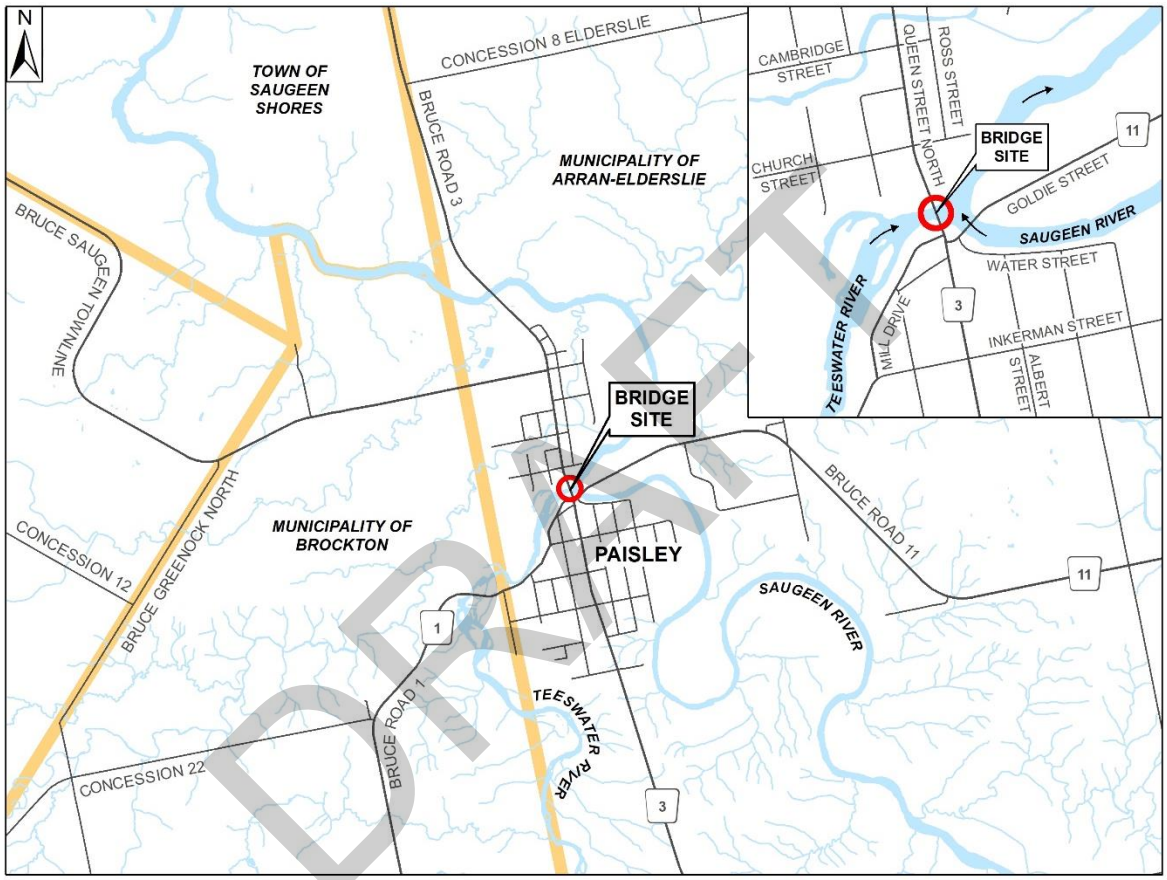
The purpose of this report is to outline the relevant background information and hydrotechnical design criteria for the preliminary design of the proposed Teeswater River Bridge replacement structure and temporary detour bridge.

The preliminary design assesses the hydraulic adequacy of the existing crossing, and identifies constraints and sizing for the design proposed structures. This is achieved by completing:

- a desktop review to collect information on the crossing and upstream watershed, including previous flood studies;
- a hydrologic analysis on streamflow gauges on the Teeswater and Saugeen River to confirm design flows at the replacement and temporary bridge locations;

- a hydraulic analysis to evaluate conditions at the existing bridge;
- a hydraulic analysis to evaluate proposed alternatives for the replacement bridge;
- a hydraulic analysis to evaluate proposed alternatives for the temporary detour bridge;
- a scour assessment to determine appropriate rock protection;
- an assessment of potential ice jam conditions at the crossings; and
- an assessment on floodplain fill impacts.

Figure 2.1 Teeswater River Bridge Location Map



3.0 BACKGROUND INFORMATION

As part of the EA process, SVCA provided the following relevant flood studies and information for the Village of Paisley.

- Historical photos of several flood and ice events from 2019, 2018, 2014, 2008, 2007, and 2004. It is noted that the soffit of the existing Teeswater River Bridge structure has been submerged during many of these recent events.
- Stream gauge data for the Saugeen River at the MacBeath Gauge and the Teeswater River at the Ellengowan Gauge and Greenock Gauge.
- Cumming Cockburn Limited (October 1990). Saugeen Valley Conservation Authority Village of Paisley Flood Control Study – Part II
- Cumming Cockburn Limited (November 1989). Saugeen Valley Conservation Authority Village of Paisley Flood Control Study Hydraulic Analysis.

- Kilborn Limited (November 1982). Flood Protection Works Village of Paisley Stage IIA - As constructed Drawings
- Kilborn Limited (December 1981). Flood Protection Works Village of Paisley Stage I - as constructed Drawings
- Kilborn Limited (January 1979). Saugeen Valley Conservation Authority – Flood Control Study for the Village of Paisley

Previous flood studies were completed in 1979 and 1989/1990. The 1979 Kilborn Limited Flood Control Study was initiated following severe flooding in 1977. The study recommended the construction of the existing flood protection dyke system along the north bank of the Teeswater and Saugeen River, as well as Willow Creek. These works were designed and constructed in 1981 and 1982 to protect to the regional event with no freeboard. The dyke system is currently owned and maintained by the SVCA.

The purpose of the 1990 Flood Control Study by Cumming Cockburn Limited was to assess flooding problems for areas not included in the original 1979 study. The study included updated hydrologic and hydraulic analysis, and floodplain mapping for the Village of Paisley. No additional flood control measures were constructed following the 1990 study. The 1990 study identified that the flood protection dyke had reduce protection level to the 100 year event.

It is well established based on historical studies and local knowledge that the flooding of the Saugeen and Teeswater River in the Village of Paisley is primarily due to the larger Saugeen River. Flood events typically occur during spring months as a result of rapid snowmelt and severe rainfall events. Where possible historical information, including photographs of ice flows and high water events, will be used to aid in the design of the replacement and temporary structure.

4.0 EXISTING STRUCTURE AND PROPOSED WORKS

4.1 Existing Teeswater River Bridge

The Teeswater River Bridge is located at the confluence of the Teeswater River and the Saugeen River. The existing Teeswater River Bridge is a cast-in-place concrete structure spanning the Teeswater River along County Road No. 3, just north of County Road. No. 1. The bridge was constructed in 1937 as a three-span bridge with clear span lengths of 11.8 m, 31.6 m, and 11.8 m. The low concrete elevation is at 217.04 m along the north pier. The bridge has several structural deficiencies warranting its replacement. Figure 4.1 below illustrates the existing structure.

Figure 4.1. Teeswater River Bridge West Elevation

The Teeswater River Bridge soffit is known to become partially submerged for during high water events. Figure 4.2 shows recent flooding and ice conditions in 2014 and 2018 provided by SVCA at Teeswater River Bridge with limited to no clearance provided.

Figure 4.2 Teeswater River Bridge Flooding and Ice Jams

Note: Teeswater River Bridge flooding in 2014 looking east (left); Teeswater River Bridge and Goldie Street Bridge with ice jam conditions in 2018, looking south at confluence. Photos provided by SVCA.

4.2 Existing Flood Protection System

The existing bridge incorporates cement panel flood barriers along the north approach that tie into the flood protection dyke upstream and downstream of the structure at an elevation of 219.03 m, as per Kilborn Limited 1981 as-constructed drawings. Stormwater outfalls also exist upstream and downstream of the bridge, which include backflow gates to protect urban areas from flooding. The existing dyke is visible on the bottom left of Figure 4.1.

Based on the BMROSS geodetic survey conducted as part of this study, it was identified that the top of dyke elevations immediately upstream of the Teeswater River Bridge ranges from 218.59 m – 218.87 m, indicating reduce flood protection of up to 0.44 m from the intended design elevation of 219.03 m. Downstream of the Teeswater River Bridge the dyke ranges from 219.12 m – 219.20 m, consistent and above the minimum intended designed elevations. Further discussions with SVCA were held to discuss the discrepancy in elevations. Additional survey confirmed that the BMROSS geodetic survey was 122 mm lower than SVCA benchmark elevations. For the purpose of the bridge evaluations and basis of comparison design, the BMROSS geodetic elevations are applied in the modeling and analysis.

4.3 Old Mill Dam and Historical Mill Race

The old mill dam, located approximately 80 m upstream of the Teeswater River Bridge, provides the head for the mill race to power historical mill sites. The downstream end of a mill race runs beneath the south span of the existing bridge. Figure 4.3 illustrates the existing mill race and the old mill dam looking upstream from Teeswater River Bridge.

Figure 4.3 Existing Mill Race and Old Mill Dam

Note: Existing mill race beneath south span (left), and the old mill dam looking upstream from Teeswater River Bridge (right).

4.4 Proposed Teeswater Replacement Bridge

The replacement of the Teeswater River Bridge is being recommended within the existing road allowance. Based on existing features, the bridge is likely to carry two lanes of traffic and sidewalks on both sides. The vertical alignment of Queen Street is such that it is not practical to raise the road grade on the bridge and still provide practical entrances to the businesses north of the bridge. Any potential to raise the bridge soffit above the existing elevations is only possible by reducing the thickness of the new bridge superstructure. A thinner bridge section is made possible by shorter spans or multiple spans.

The Class EA has identified preferred design configuration for the new bridge as a twin span structure, with equal span lengths of 22.75 m. The new bridge includes the replacement of two existing piers with one new pier and raising the low soffit elevation.

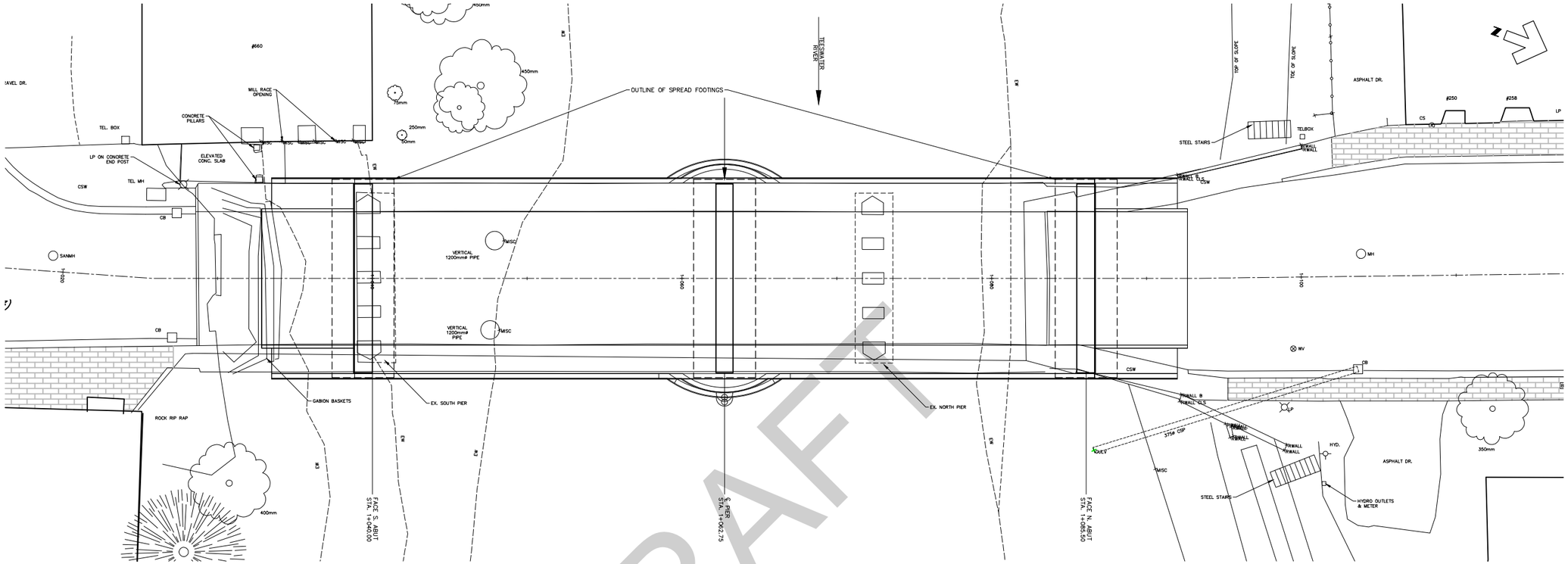
The low concrete elevation is proposed at 217.51 m at the proposed north abutment. The mill race on the south span will be preserved. A 4.0 m by 2.4 m culvert embedded behind new south abutment is proposed to maintain mill race flows. The location of existing storm outlets will be considered and integrated into proposed grading and erosion protection measures. Flood protection measures will be integrated into the bridge railing to ensure no change in the level of service. Opportunities to increase flood protection will be assessed in railing options at the detailed design stage.

Elevation details of the proposed structure are presented in Figure 4.4.

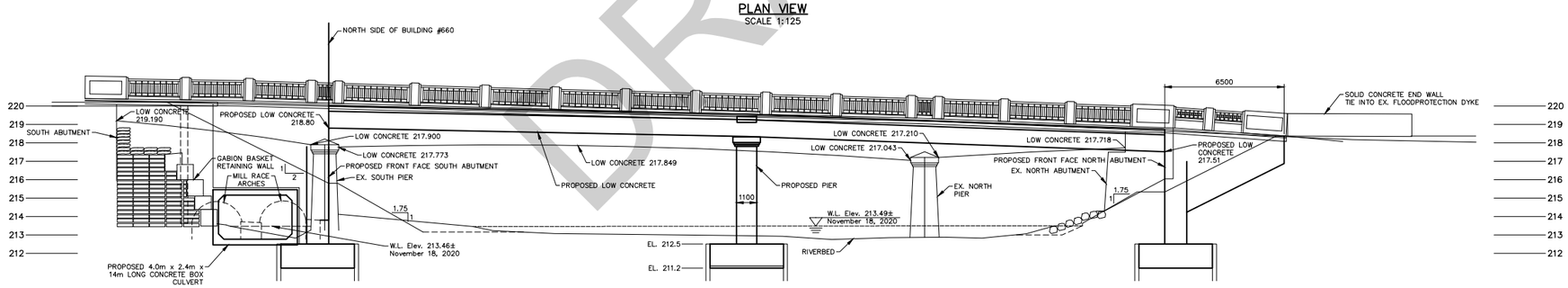
4.5 Proposed Temporary Detour Bridge

A temporary detour bridge is being proposed connecting Goldie Street to Church Street, immediately downstream of the confluence of the Teeswater and Saugeen River. A concept of the temporary bridge is provided in Figure 4.5.

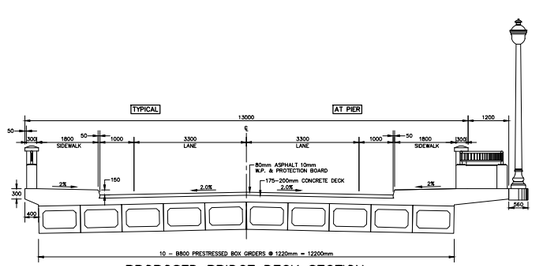
The temporary bridge is being proposed as modular steel panel bailey bridge with a single span of 65.5 m and low steel elevation of 218.57 m. The structure will require a temporary roadway to be built along municipal lands, behind the arena and beside the firehall. The design of the low steel has been iterated to minimize impacts to upstream water levels.



PLAN VIEW
SCALE 1:125



TEESWATER RIVER BRIDGE TWO SPAN – EAST ELEVATION
SCALE 1:125



PROPOSED BRIDGE DECK SECTION
SCALE 1:75

NOTES:
1. Hurricane Hazel Regional Event for Teeswater River as per BMROSS Irwin Bridge Modelling (2014)
2. Historical Hurricane Hazel Regional Event as per Conservation Authorities Branch (1974)

KEY MODEL RESULTS AND REVIEW OF WATER SURFACE ELEVATIONS AT BRIDGE SITE

Storm Event	Saugeen River Tailwater Conditions			Normal Depth Conditions		
	Existing Condition	Proposed Bridge	Difference (mm)	Existing Condition	Proposed Bridge	Difference (mm)
5yr	217.50 m	217.49 m	−1	215.09 m	214.95 m	−14
25yr	218.43 m	218.40 m	−3	215.34 m	215.18 m	−16
50yr	219.03 m	219.00 m	−2	215.47 m	215.29 m	−18
100yr	219.37 m	219.33 m	−4	215.56 m	215.37 m	−19
HAZEL[1]	219.74 m	219.66 m	−8	216.38 m	216.11 m	−27
HAZEL[2]	220.52 m	220.18 m	−34	220.40 m	219.60 m	−80

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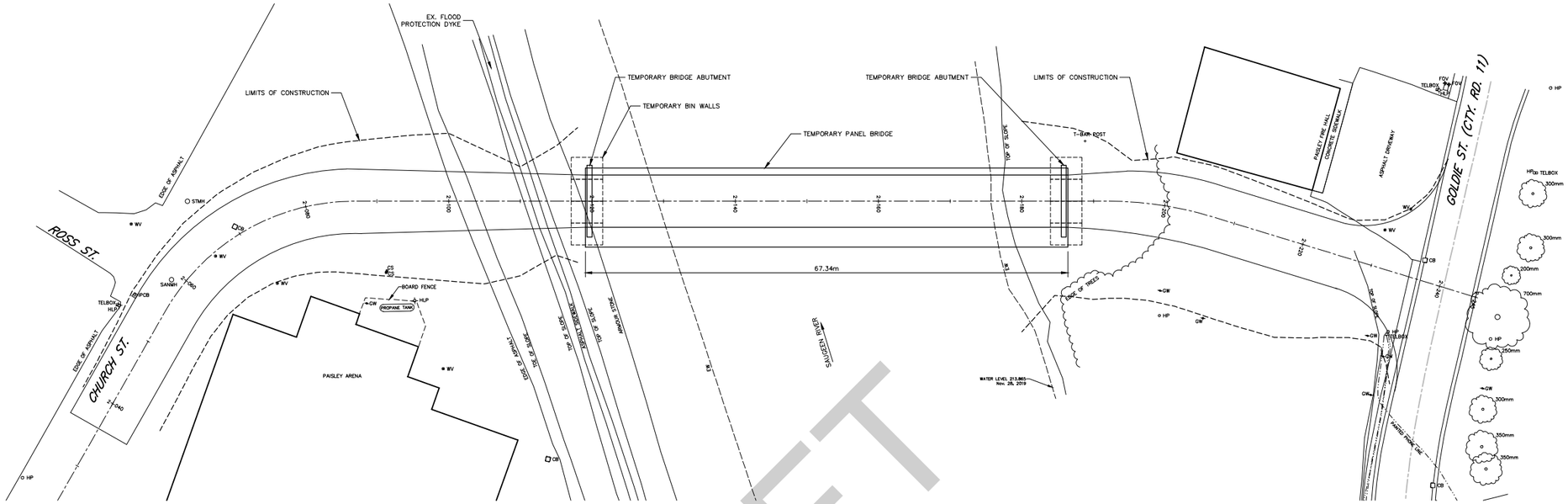
County of Bruce
Teeswater River Bridge

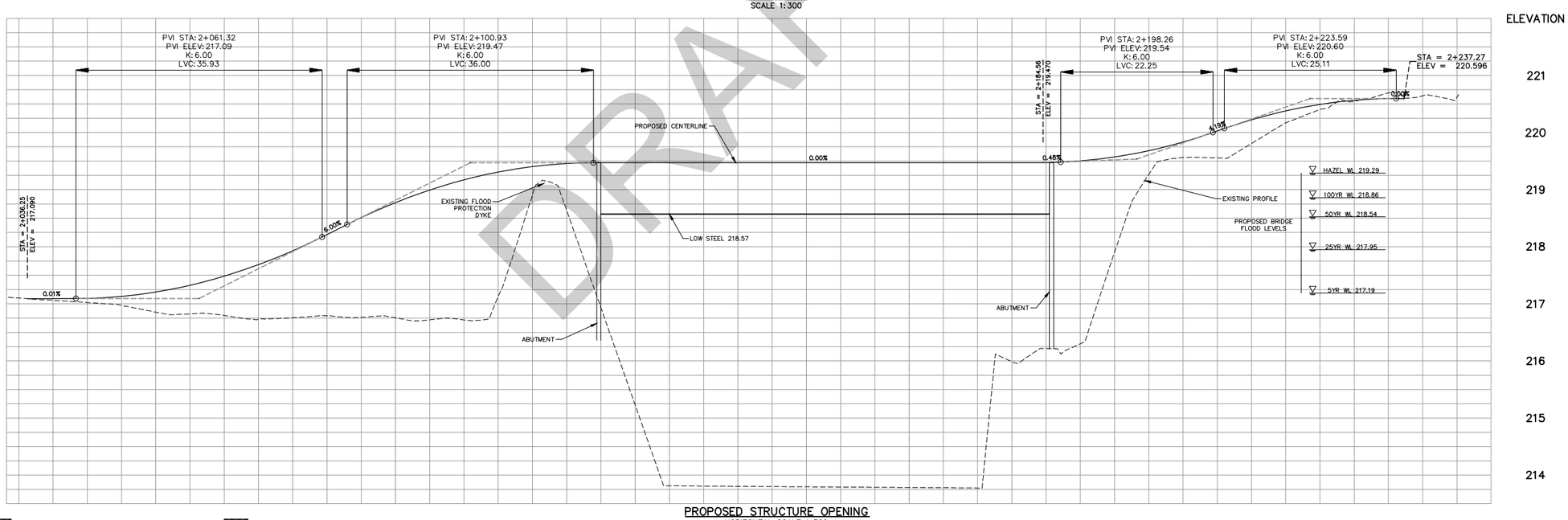
Proposed Bridge Arrangement and Opening

Hydraulic Water Surface Comparison at the Proposed Bridge Crossing

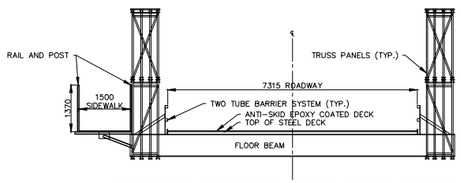
DATE	PROJECT No.
June 2020	BR1400
SCALE	FIGURE No.
AS SHOWN	4.4



PLAN VIEW
SCALE 1:300



PROPOSED STRUCTURE OPENING
HORIZONTAL SCALE 1:300
VERTICAL SCALE 1:30



PROPOSED TEMPORARY BRIDGE CROSS SECTION
SCALE 1:75

Storm Event	SUMMARY OF KEY MODEL RESULTS AT BRIDGE SITE		
	Existing Condition	Proposed Bridge	Difference (mm)
5yr	217.16 m	217.19 m	3
25yr	217.90 m	217.95 m	5
50yr	218.47 m	218.54 m	7
100yr	218.68 m	218.86 m	18
HAZEL	218.90 m	219.29 m	39

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County of Bruce
Teeswater River Detour Bridge

Proposed Bridge Arrangement and Opening

Hydraulic Water Surface Comparison at the Proposed Temporary Bridge Crossing

DATE	PROJECT No.
June 2020	BR1400
SCALE	FIGURE No.
AS SHOWN	4.5

5.0 DESIGN CRITERIA

The design criteria for the proposed replacement and temporary structures includes the following:

- Bridge Design Code requirements for design flood flows, allowable vertical clearance, and freeboard;
- Integration with existing flood protection measures;
- Allowable increase in the flood elevation upstream of the structure;
- Ice jam assessment;
- Scour and rock protection design;
- Floodplain fill and storage analysis.

5.1 Bridge Design Code: Design Flow, Vertical Clearance, and Freeboard

County Road No. 3 through the Village of Paisley is considered an urban arterial road. Table 5.1 below summarizes the relevant MTO and Canadian Highway Bridge Design Code (CHBDC) requirements for design flow, vertical clearance, and freeboard requirements for this classification of roadway.

Table 5.1 Bridge Design Code Requirements – Urban Arterial Road (>6m span)

Parameter	Unit	Highway Drainage Design Standard
Return Period of Design Flow	100 year	MTO directive B-100/ Section 1.1.1
Minimum Vertical Clearance[1]	1.0 m	CHBDC Section 1.9.7.1
Minimum Freeboard to Road[2]	1.0 m	CHBDC Section 1.9.8.2

Notes:
1. Clearance between the soffit of the structure and the design flow high water level, shall be sufficient to prevent damage to the structure by the action of flowing water, ice flows, or debris, and unless otherwise approved.
2. Freeboard from the edge of through traffic lanes to the design flow high water level.

The design of the proposed Teeswater River Bridge will aim to enhance the overall hydraulic performance as feasible. At a minimum, vertical clearance and freeboard must be provided at the site similar to what currently is available with the existing opening.

It is acknowledged that the code requirement of 1.0 m vertical clearance cannot be achieved at this site while maintaining practical road approaches in the urban setting. The proposed bridge profile is considered to be to a tolerable standard and the bridge soffit is raised to reduce the frequency of submergence.

It is proposed that the temporary detour bridge be designed with a reduced 50 year design flow. This is consistent with the MTO directive if a road classification for a new bridge is to be degraded within 5 years of construction. It is assumed that this criterion

is acceptable for a short-term condition of about one year from start of construction of the temporary bridge to final demobilization.

5.2 Integration with Existing Flood Control Dykes

The north end of the existing Teeswater River Bridge structure includes a concrete retaining wall, which is part of the existing dyke protection system. The proposed replacement structure will include an equivalent or greater flood protection barrier tied into the existing dyke system.

For the temporary bridge, it is proposed that any dyke breach and flood impacts of the proposed structure be limited to the 50 year flood level.

In case there is a forecast high-water event, construction contingency plans will include the stockpiling of sandbags or steel sheet piling to fill any breach in the dyke at Queen Street generated as part of replacement bridge construction or the temporary detour bridge breach. Full restoration of all affected dyke segments will be included in the contract.

5.3 Backwater Elevation

In accordance with good design practice there shall be minimal (if any) increase in the flood elevations for the full range of design storms for the proposed Teeswater River Bridge replacement structure.

It is requested that small increases in flood levels may be accepted for the temporary detour structure, such that floods are contained within the channel and no significant increase in flood hazard (flood depth or velocity) is predicted upstream.

5.4 Ice Jams

The Saugeen and Teeswater River are susceptible to ice jams and ice flows. Ice jams typically occur at locations with sudden changes in flow velocity, direction, or constrictions in the river channel or at bridges and their approaches. Ice jams and flows are known to influence channel and bridge capacity.

Jamming of ice at the confluence of the Saugeen and Teeswater River has historically not a been problem. Upstream of Goldie Street Bridge, the Saugeen River floodplain widens to approximately 500 m. This area has been known to provide significant storage for ice flows.

Ice jamming is a concern for the mouth of the Teeswater River, upstream of the Teeswater River Bridge. The Starks Dam, located approximately 2 km upstream of the old mill dam, prevents large sheets of ice from passing downstream. The dam effectively controls and breaks up ice as it passes over the dam (Kilborn 1979). Ice sheets that form immediately upstream of the old mill dam can be lifted by runoff from the Teeswater River and backwater from the Saugeen River and move downstream to the Teeswater River Bridge. The old mill dam has a low sill elevation and insufficient drop to effectively break large sheets of ice. Under severe conditions, ice tends to accumulate at the soffit of the Teeswater River Bridge.

The design of the proposed replacement structure aims to reduce the opportunities for ice jams to occur at the crossing location by improving hydraulic efficiency (potentially removing a pier, raising design soffit, and increasing span). The potential formation and/or aggravation of ice jams as a result of the replacement and temporary structures is to be reviewed.

5.5 Scour and Rock protection

The CHBDC guidelines require the prediction and/or prevention of scour for bridge design purposes. Erosion protection at the bridge site should be provided to protect the stream banks at the abutments and to slow the rate of scour in the watercourse. It is recommended that erosion protection be provided to 100 year flood level to increase the resiliency of the proposed replacement structure. Erosion protection to the 50 year event flow is proposed for the temporary bridge structure.

5.6 Floodplain Fill

An assessment of cut/fill will be conducted for the proposed replacement bridge. The temporary bridge will require fill within the floodway and flood fringe. A cut/fill analysis will be conducted and any impact to flood storage will be evaluated using reach storage analysis for the 100 year and regional flood levels.

6.0 HYDROLOGY

6.1 Drainage Overview

The Village of Paisley sits at the confluence of the Saugeen and Teeswater Rivers. The Saugeen River also receives flows from Willow Creek and the North Saugeen River approximately 0.2 km and 1.3 km downstream of the Teeswater River mouth. Immediately upstream of their confluence, the Saugeen and Teeswater River have a drainage areas of approximately 2,552 km^2 and 689 km^2 respectively. The total drainage area for the Saugeen River downstream of the North Saugeen River is 3,569 km^2. The village is impacted by multiple drainage confluences and complex hydrologic and hydraulic conditions.

The Teeswater River watershed also includes the Greenock Swamp, which covers approximately 81 km^2 (12%) of the total drainage basin. Previous studies have shown that the storage in swamp and wide flat floodplain downstream significantly reduce and delay the flood peaks along the Teeswater River through Paisley (Kilborn 1977).

6.2 Flood Frequency Analysis

Previous hydrologic analyses conducted as part of historical flood studies from 1979 and 1989/1990 were reviewed. Based on updated stream flow records, a flood frequency analysis was conducted as part of the current study to confirm flood flows through the Village of Paisley.

Flow gauge data has been assessed to confirm the 2, 5, 10, 25, 50 and 100 year design of flows for the Saugeen River. SVCA's gauge station at MacBeath located 7 km upstream of Paisley has been used to confirm Saugeen River flows. This gauge has a period of record from 1985-2020, and was not available in the previous 1979 or 1990 studies. The Water Survey of Canada (WSC) Ellengowan station (02FC015) immediately upstream of Paisley on the Teeswater River has been recently evaluated by BMROSS in 2014 for the replacement of the Big Irwin Bridge. This gauge was also used to establish Teeswater Flows in 1990, however the period of record was limited to 16 years of data (1972-1988) at the time of the previous analysis.

A flood frequency analysis was carried out for the MacBeath gauge using maximum annual instantaneous stream flow data. The Log Pearson distribution was determined to be the most conservative. Table 6.1 below presents the frequency flows for both the gauge site locations. Teeswater River flows at the Ellengowan Gauge were obtained from the Big Irwin Bridge Hydrology report (BMROSS, 2014). Flow estimates at each flow change location through Paisley were estimated based on the Modified Index Method based on calculated drainage areas.

Table 6.1 Proposed Design Flood Flows for the Saugeen and Teeswater River (m^3/s)

		Event Frequency (yr.)					
River Name & Gauge Location	**Drainage Area (km^2)**	**2**	**5**	**10**	**25**	**50**	**100**
Teeswater River at Ellengowan Gauge	663	92	116	130	142	156	166
Saugeen River at MacBeath Gauge	2516	349	480	577	710	819	935
Teeswater River at Paisley[1]	689	95	119	134	146	161	171
Saugeen River Upstream of Teeswater River[2]	2552	353	485	583	718	828	945
Saugeen River Downstream of Teeswater River[2]	3241	422	580	697	859	990	1131
Saugeen River Downstream of Willow Creek[2]	3304	428	589	707	871	1004	1147
Saugeen River Downstream of N. Saugeen River[2]	3569	454	624	749	923	1064	1216

Notes:
1. Teeswater River Flows based on transposition from WSC Ellengowan Gauge (02FC0015), located 6 km upstream of Paisley, based on the Modified Index Flood method. Flood frequency analysis for Ellengowan gauge as per the Big Irwin Bridge Replacement, Teeswater River – Hydrology Report. 2014 BMROSS. BR1097
2. Saugeen River Flows based on transposition from SVCA MacBeath Gauge, located 7 km upstream of Paisley, based on Modified Index Flood method.

3. Modified Index Method:

Where,

Q1 = Known discharge

Q2 = Unknown discharge

A1 = Known basin drainage area

A2 = Unknown basin drainage area

$$Q_2 = Q_1 * \left(\frac{A_2}{A_1}\right)^{.75}$$

Table A1 in Appendix A provides a comparison of the proposed design flows to historical flood flows from the 1990 and 1979 studies. The proposed flows for the Saugeen River established by the MacBeath gauge are consistent with the 1979 flood flows, and higher than the previous 1990 flows. It is noted that the 1979 flood flows used both the WSC Port Elgin gauge (02FC001) and the WSC Walkerton gauge (02FC002) datasets to estimate flows through Paisley, where the 1990 study used only the Walkerton gauge data. The data from the McBeath Gauge has provided more information than was available during pervious studies, and more reliability in estimation of design flows for the Saugeen River through the Village of Paisley.

The proposed Teeswater River flood flows closely resemble previous 1990 flows. As noted previously the Ellengowan gauge was used for both analyses. The 1979 Teeswater River flows are significantly lower and were estimated based on hymo hydrology model, originally developed for the SVCA Greenock Swamp study in 1977. Limited stream gauge records were available at that time.

It is noted that the peak annual instantaneous flows used in the frequency analysis for both the Saugeen River (MacBeath Gauge) and Teeswater River (Ellengowan Gauge), occur almost entirely in the late winter/spring. It is assumed some of the maximum flood records occurred with open water and/or ice conditions. Future detailed flood studies and analysis may further assess potential ice influence on gauge records and calibrate flows to known highwater levels if available.

6.3 Regional Storm

The Hurricane Hazel regional storm values for the Saugeen and Teeswater River were previously established by the Conservation Authorities Branch in 1974 and are summarized in Table 6.2 below. The 1974 values were carried in the 1979 and 1990 hydraulic studies without modification.

Table 6.2 Hurricane Hazel Regional Storm Flood Flows for Saugeen and Teeswater River at the Village of Paisley (m^3/s)

Location	1974 Conservation Authorities Branch[1]	1979 Kilborn[2]	2014 BMROSS[3]
Saugeen River	1376	-	-
Teeswater River	793	170	280

Notes:

1. *Regional storm event flows for Hurricane Hazel based on historical studies completed by the Conservation Authorities Branch in 1974. (obtained from Kilborn 1979)*
2. *Regional storm flow from 1979 Kilborn study, obtained from Greenock Swamp calibrated hydrology model.*
3. *Hurricane Hazel flood flow based on a lump watershed using Hydro-Pak software,* as per *the Big Irwin Bridge Replacement, Teeswater River – Hydrology Report. 2014 BMROSS. BR1097*

As a check on the 1974 flow values for the Teeswater River, the 1979 study by Kilborn used the SVCA's Greenock Swamp hydrology model and estimated the regional event at 170 m^3/s. BMROSS previously estimated the Teeswater River Hurricane Hazel flood flow for the Big Irwin Bridge assessment at 280 m^3/s using a bulk watershed assessment. These flow estimates are significantly lower than the 1974 regional flow estimate of 793 m^3/s, as summarized in Table 6.1Table 6.2. The discrepancy in the Teeswater River regional storm flow appears to be related to attenuation effects of the

Greenock Swamp. No details were provided in previous reports how the 1974 regional flows were developed. It is also noted that the regional flow for the Teeswater River is estimated at 57% of the total Saugeen River regional flow, while the Teeswater River watershed only accounts for approximately 21% of the Saugeen River watershed at the confluence of the rivers. It is further acknowledged at a single flood flow of 1,376 m^3/s is provided for the for the entire Saugeen River through the Village of Paisley. No flow changes are noted at Saugeen River confluence points at the Teeswater River, Willow Creek or the North Saugeen River.

To maintain consistency with previous studies, the 1974 Conservation Authorities Branch regional flows are be applied in the current study for both the Saugeen and Teeswater River. As a comparison, the lower 2014 Teeswater River BMROSS estimate is also provided in model results. It is acknowledged SVCA may want to reassess flows used for the regional flood plain mapping specifically for the Teeswater River. A detailed review and hydrology assessment of the regional storm flood flow is beyond the scope of this study.

7.0 HYDRAULIC ANALYSIS

7.1 Previous Hydraulic Models and Floodplain Mapping

The most recent hydraulic study for the Village of Paisley was completed as part of the 1990 Flood Control Study by Cumming Cockburn Limited. The Saugeen and Teeswater River were modelled with separate HEC2 files. The 1990 floodplain mapping and hydraulic modelling took into account the flood protection works designed and constructed in the early 1980s. It is noted that the 1990 report identified higher flood levels along the Saugeen River than previously indicated with the 1979 Kilborn Limited study, indicating spills for the Hurricane Hazel regional event. The 100 year flows were contained along both the Teeswater and Saugeen River flood protection works.

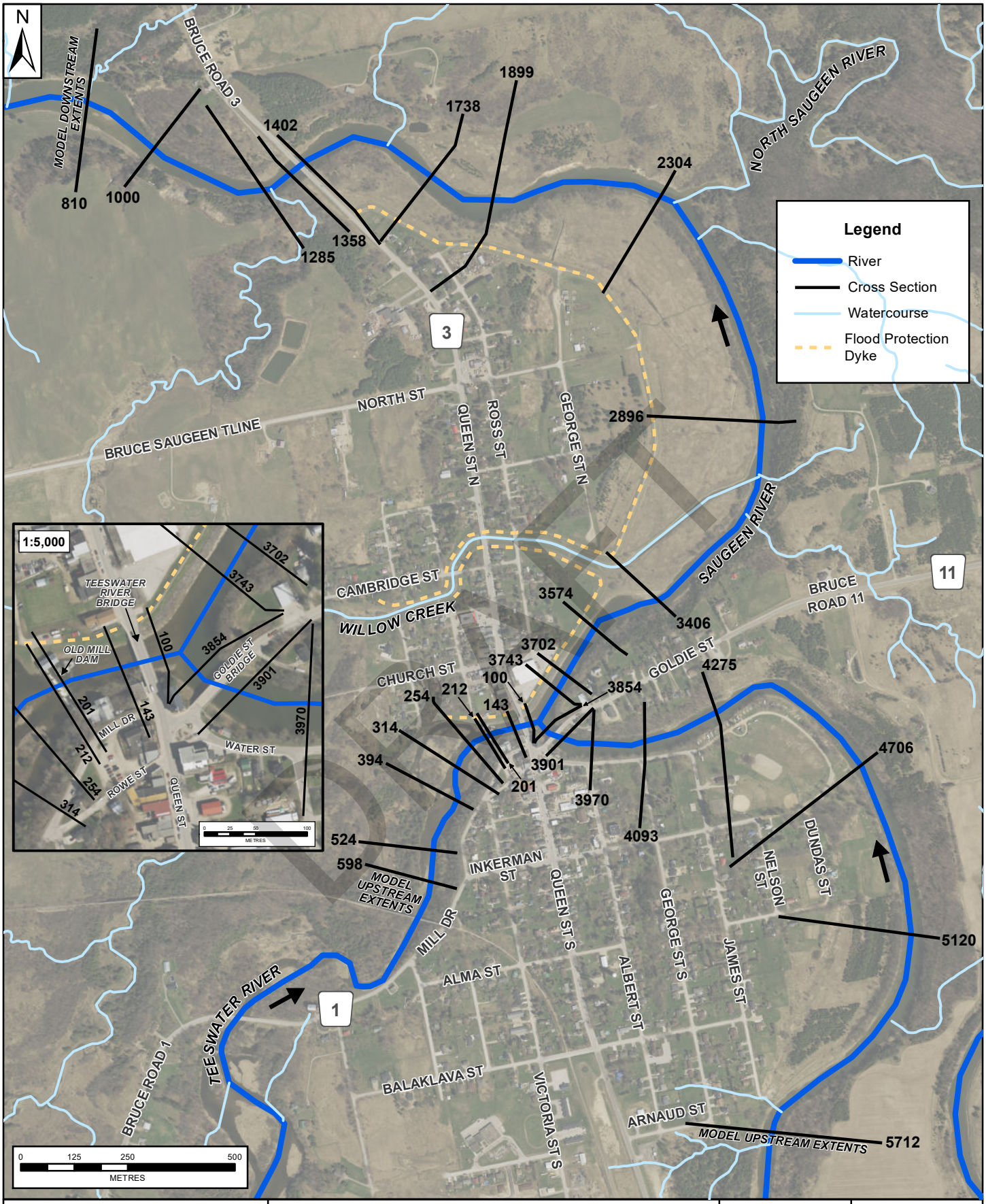
SVCA have previously indicated that existing HEC2 floodplain modelling is out-of-date and erroneous for the Teeswater River upstream of Teeswater River Bridge. The 1990 HEC2 floodplain modelling for the Teeswater River was previously reviewed by BMROSS as part of a development proposal in 1999. Errors were identified in the Teeswater River model upstream of the Teeswater River Bridge. In a note to file, SVCA agreed that earlier floodplain calculations, specifically the 1988 Fletcher and Associates calculations, produced for the Stark's Mill development should be applied for the Teeswater River. The 1988 Fletcher model was reviewed apart of this study. It was noted that critical depth was assumed as the boundary condition at the confluence of Saugeen River. Therefore the flood levels at the Teeswater River Bridge do not account for the significant backwater associated with the confluence of the Saugeen River. The flood values provided in the 1988 Fletcher model were deemed not applicable to the current bridge assessment.

7.2 Updated Hydraulic Model Development

To facilitate the hydraulic analysis of the existing bridge, proposed bridge replacement and temporary detour bridge structure, a new HEC-RAS model was created for the Teeswater and Saugeen Rivers compiling information from previous studies, new topographic and bathymetric survey, and flow data. Figure 7.1 illustrates the model extents and cross-section locations of the Saugeen and Teeswater River HEC-RAS models.

As part of the model development, the 1990 HEC2 model inputs were reviewed. Cross-section locations from the previous modelling were incorporated along with additional sections as required for the current analysis. Cross-section points were extracted from the provincial 2015 SWOOP DTM information and supplemented with BMROSS 2020 ground and bathymetry survey in the vicinity of the proposed works. Channel survey bathymetry points from the 1990 HEC2 model were incorporated as appropriate for the remaining cross-sections as available. The existing flood protection elevations were extracted from survey data where available, and supplemented with the provincial DTM. An ineffective area was modelled for the protected area behind the top of dyke level. Therefore, the model does not account for the flow or volume of a potential dyke spill and flows are assumed to be contained within the model cross-sections.

Flow values for the updated Teeswater and Saugeen River models were applied for all flow events, as summarized in Table 6.1 and Table 6.2. To maintain consistency with



BMROSS engineering better communities	**COUNTY OF BRUCE** REPLACEMENT OF TEESWATER RIVER BRIDGE - PAISLEY **HYDRAULIC FIGURE**	DATE JUNE 17, 2021	PROJECT No. BR1400
		SCALE 1 : 12,000	FIGURE No. 7.1

previous studies, the regional flow values established by the 1974 Conservation Authorities Branch are be applied to both the Saugeen and Teeswater River. As a comparison, the lower BMROSS regional flow estimate for the Teeswater River is also provided in model results.

To maintain conservative flood elevations and consistency with previous studies, flood levels along the Teeswater River should account for backwater levels in the Saugeen River at peak values. Downstream boundary conditions for the Teeswater River were therefore established based on model results from the new Saugeen River Model for each return event. For comparison purposes, the Teeswater River model was also evaluated assuming normal depth at the confluence with a slope of 0.4%, to represent a lower flood level if flood events did not coincide.

As part of the current model development, a sensitivity test on the downstream boundary condition for the Saugeen River has been conducted. A normal depth boundary condition was assumed with a slope of 0.1%. A sensitivity analysis confirmed that this boundary condition is appropriate and no change in the water surface elevations were noted along the study area reach through Paisley with changes to the assumed level downstream.

The new BMROSS models of the Teeswater and Saugeen River allow for a basis of comparison to existing conditions for all flood events, 2, 10, 25, 50, 100 and Hurricane Hazel regional event. It is not the intention of the current hydraulic modelling to formally calibrate or update the floodplain mapping of the Village of Paisley. A formal update to the floodplain mapping is considered outside the current project scope.

7.3 Existing Condition Model

Existing condition water surface elevations at all the modelled cross-section locations are summarized in Appendix A, Table A.3 for the Saugeen River and Table A.4 and A.5 for the Teeswater River. Appendix Table A.4 summarizes results when the Teeswater and Saugeen River flows peaks coincide. Table A.5 provides water surface elevations when normal depth is assumed at the Teeswater and Saugeen River confluence. Figure 7.1 provides model cross section locations. The existing hydraulic performance of the existing Teeswater River Bridge is discussed in further in Section 7.4.

7.3.1 Comparison to Historical Models

The BMROSS HEC-RAS model results were checked for consistency against previous HEC2 modelling efforts completed by 1990 Cumming Cockburn. A summary of modelled water surface elevations and differences for the 50, 100 and regional event are provided in Table 7.1. Cross-sections locations are limited to those corresponding with previous 1990 modeling. The updated BMROSS model was also run with the previous 1990 flow values to compare differences in model setup. It is acknowledged that flood elevations between the previous 1990 model and updated BMROSS model may differ due to updated cross-sectional data from the provincial DTM data and survey, revised boundary conditions, manning’s n values, and computational differences between HEC2 and HEC-RAS software.

Table 7.1 Comparison of Model Results - Existing Conditions
Water Surface Elev. (m)

Cross-section Station		Cumming Cockburn 1990 Model			BMRoss 2020 Model - 1990 Flows			BMRoss 2020 Model - 2020 Flows		
2020 Station	1990 Station	50	100	Hazel	50	100	Hazel	50	100	Hazel
1000	300	215.74	215.9	216.93	215.57	215.7	216.6	216	216.3	216.6
1285	590	216.32	216.48	217.53	216.02	216.16	217.11	216.47	216.79	217.11
1358	660	216.51	216.67	217.71	216.21	216.33	217.13	216.57	216.85	217.13
Bruce Road 3										
1402	700	216.74	216.92	218.34	216.66	216.78	217.87	217.68	217.76	217.87
1738	1040	217.06	217.22	218.51	217.01	217.16	218.37	218	218.17	218.37
1899	1475	217.41	217.56	218.75	217.17	217.31	218.46	218.08	218.26	218.46
2304	1875	217.65	217.81	218.95	217.32	217.47	218.63	218.2	218.4	218.63
2896	2405	217.83	217.98	219.12	217.55	217.71	218.83	218.37	218.59	218.83
3406	2930	217.98	218.13	219.27	217.76	217.91	219.02	218.51	218.75	219.02
3574	2990	217.97	218.12	219.24	217.73	217.86	218.87	218.44	218.65	218.87
3854	3310	218.09	218.24	219.53	218.23	218.41	219.6	218.99	219.31	219.6
Goldie Street Bridge										
3901	3351	218.27	218.43	220.5	218.23	218.4	219.91	219.02	219.39	219.91
3970	3420	218.28	218.45	220.55	218.26	218.44	220.05	219.07	219.46	220.05
4706	5660	218.5	218.68	221.03	218.61	218.8	220.73	219.46	219.88	220.73
5120	6070	218.66	218.85	221.16	218.79	218.97	220.89	219.62	220.02	220.89

Water Surface Elevation Difference – Comparison to 1990 Cumming Cockburn Model (m)

Cross-section Station		Cumming Cockburn 1990 Model			BMRoss 2020 Model - 1990 Flows			BMRoss 2020 Model - 2020 Flows		
2020 Station	1990 Station	50	100	Hazel	50	100	Hazel	50	100	Hazel
1000	300				-0.17	-0.20	-0.33	0.26	0.40	-0.33
1285	590				-0.30	-0.32	-0.42	0.15	0.31	-0.42
1358	660				-0.30	-0.34	-0.58	0.06	0.18	-0.58
Bruce Road 3										
1402	700				-0.08	-0.14	-0.47	0.94	0.84	-0.47
1738	1040				-0.05	-0.06	-0.14	0.94	0.95	-0.14
1899	1475				-0.24	-0.25	-0.29	0.67	0.70	-0.29
2304	1875				-0.33	-0.34	-0.32	0.55	0.59	-0.32
2896	2405				-0.28	-0.27	-0.29	0.54	0.61	-0.29
3406	2930				-0.22	-0.22	-0.25	0.53	0.62	-0.25
3574	2990				-0.24	-0.26	-0.37	0.47	0.53	-0.37
3854	3310				0.14	0.17	0.07	0.90	1.07	0.07
Goldie Street Bridge										
3901	3351				-0.04	-0.03	-0.59	0.75	0.96	-0.59
3970	3420				-0.02	-0.01	-0.50	0.79	1.01	-0.50
4706	5660				0.11	0.12	-0.30	0.96	1.20	-0.30
5120	6070				0.13	0.12	-0.27	0.96	1.17	-0.27

The updated BMROSS 2020 HEC-RAS model produces slightly lower water surface elevations than the 1990 Cumming Cockburn HEC 2 model for the same flow values. This is illustrated by the model scenario, in which the updated BMROSS model was run with the lower 1990 flows for the 50 and 100 year event, with an average difference in calculated water surface elevations of 0.18 m and 0.19 m respectively. Higher water surface elevations provided in the 2020 BMROSS model with 2020 flows can be mostly attributed to the higher flow values from the updated flood frequency analysis, as noted previously in Section 6.2. All models use the same 1974 Conservation Branch flows for the Hurricane Hazel regional event for the Saugeen River. The BMROSS 2020 HEC-RAS model estimates lower regional event flood levels than the 1990 model, with the exception of immediately downstream of Goldie Street Bridge. The average differences in the regional event water surface is approximately 0.34 m.

Since there is a difference in water levels between the 1990 model and the updated BMROSS model, the more conservative values from the BMROSS modelling will be use in the design criteria and analysis of the proposed replacement and temporary structures for the 100 and 50 year design events.

7.3.2 Existing Flood Dyke Performance

The hydraulic performance of the existing flood dyke was accessed as part of the review of existing conditions. Along the Saugeen River, updated modeling indicates the 100 year and regional storm overtopping the existing dyke at the confluence of the Saugeen and Teeswater River, as well upstream of the Teeswater River Bridge. Further downstream the dyke appears to contain up to the Hurricane Hazel regional event. Detailed assessment of the downstream dyke was not completed.

Water surface elevations and freeboard to BMROSS surveyed dyke elevations are summarized in At the confluence of the Saugeen and Teeswater Rivers, the dyke provides protection up to the 50 year event with 0.13 m freeboard. Upstream of the Teeswater River Bridge (Queen Street), the dyke has reduced protection based on survey elevations to the 25 year event. If the dyke is reinstated to the design elevation of 219.03 m, the dyke would provide protection to the 50 year event upstream with no freeboard.

It is recommended that the proposed bridge replacement design implement a heightened flood protection barrier tied into the existing dyke system, as feasible. Future flood studies should confirm the performance of the dyke and potential upgrades.

Table 7.2 at the confluence of the Teeswater and Saugeen Rivers and upstream of the proposed replacement bridge and detour bridge structures. HEC-RAS model cross-sections are noted. Dyke performance for all model cross-sections is summarized in Appendix A, Table A.6 for the Saugeen River and Table A.7 and A.8 for the Teeswater River. Appendix Table A.7 summarizes results when the Teeswater and Saugeen River flows peaks coincide. Table A.8 provides dyke freeboard elevations when normal depth is assumed at the Teeswater and Saugeen River confluence.

At the confluence of the Saugeen and Teeswater Rivers, the dyke provides protection up to the 50 year event with 0.13 m freeboard. Upstream of the Teeswater River Bridge (Queen Street), the dyke has reduced protection based on survey elevations to the 25

year event. If the dyke is reinstated to the design elevation of 219.03 m, the dyke would provide protection to the 50 year event upstream with no freeboard.

It is recommended that the proposed bridge replacement design implement a heightened flood protection barrier tied into the existing dyke system, as feasible. Future flood studies should confirm the performance of the dyke and potential upgrades.

Table 7.2 Existing Condition Dyke Performance

Location	**Upstream of the Teeswater River Bridge**		**Confluence of the Saugeen and Teeswater Rivers**		**Temporary Structure Location**	
Cross-section ID	*XS -143*		*XS - 3854*		*XS - 3743*	
Top of Dyke Elevation (BMROSS Survey)	*(218.59 -218.87)*		*(219.12-219.20)*		*219.18*	
Return Event	Water Surface (m)[3]	Dyke Freeboard (m)	Water Surface (m)	Dyke Freeboard (m)	Water Surface (m)	Dyke Freeboard (m)
2 Year	216.83	1.76	216.83	2.29	216.59	2.59
5 Year	217.50	1.09	217.49	1.63	217.16	2.02
10 Year	217.92	0.67	217.90	1.22	217.50	1.68
25 Year	218.42	0.17	218.40	0.72	217.90	1.28
50 Year	219.02	-0.43	218.99	0.13	218.47	0.71
100 Year	219.36	-0.77	219.31	-0.19	218.68	0.50
Hazel – BMROSS[1]	219.72	-1.13	-	-	-	-
Hazel - Historical [2]	220.48	-1.89	219.6	-0.48	218.90	0.28

Notes:
1. Hurricane Hazel Regional Event - Teeswater River flow as per BMROSS Irwin Bridge Modeling (2014)
2. Hurricane Hazel Regional Event - Historical Flow applied for Saugeen and Teeswater River as per historical Conservation Authorities Branch (1974)
3. Teeswater River results for Saugeen River Tailwater conditions.

At the temporary structure location the dyke is shown to contain the 100 year and regional Hurricane Hazel event. However, as noted, the dyke has a reduced protection to the 50 year event at the confluence immediately upstream. Therefore the design of the proposed temporary bridge should not impact flood levels or reduce existing protection levels upstream for the 50 year event.

7.4 Proposed Teeswater Conditions

Table 7.3 and 7.4 summarize the model results at the Teeswater River Bridge site for existing and proposed conditions, and includes details related to anticipated clearances and water surface levels for the various flow events. The values generated at cross section 143, immediately upstream of the structure, are used for comparison purposes. Table 7.3 results are presented with Saugeen River Tailwater Conditions, in which backwater conditions of the Saugeen River influence flooding along the lower Teeswater River. Table 7.4 provides results assuming normal depth at the confluence with a slope of 0.4%, to represent a lower flood level if flood events did not coincide.

Table 7.3 Hydraulic Comparison of Existing and Proposed Teeswater River Bridge Structures – Saugeen River Tailwater

Description	Teeswater River Bridge (Queen Street Bridge)		
	Existing	Proposed	Diff.
Dyke Elev./Low top of Road Elevation[1]	218.59	219.03	
Flow Event at which road floods/ Dyke overtopped	>25 year	>50 year	
Low Concrete/Soffit	217.04	217.51	
Modeled Headwater Elevation (m)[2]			
2 Year	216.83	216.83	0.00
5 Year	217.50	217.49	-0.01
10 Year	217.92	217.90	-0.02
25 Year	218.43	218.40	-0.03
50 Year	219.03	219.00	-0.03
100 Year	219.37	219.33	-0.04
Hazel – BMROSS[3]	219.74	219.66	-0.08
Hazel - Historical [4]	220.52	220.18	-0.34
Freeboard to Top of Dyke (m)			
2 Year	1.76	2.17	--
5 Year	1.09	1.51	--
10 Year	0.67	1.10	--
25 Year	0.16	0.60	--
50 Year	-0.44	0.00	--
100 Year	-0.78	-0.33	--
Hazel – BMROSS[3]	-1.15	-0.66	--
Hazel - Historical [4]	-1.93	-1.18	--
Clearance to Low Concrete/Steel (m)			
2 Year	0.21	0.68	--
5 Year	-0.46	0.02	--
10 Year	-0.88	-0.39	--
25 Year	-1.39	-0.89	--
50 Year	-1.99	-1.49	--
100 Year	-2.33	-1.82	--
Hazel – BMROSS[3]	-2.70	-2.15	--
Hazel - Historical [4]	-3.48	-2.67	--
Velocity at Structure (m/s)			
2 Year	0.74	0.69	-0.05
5 Year	0.79	0.72	-0.07
10 Year	0.86	0.73	-0.13
25 Year	0.94	0.74	-0.20
50 Year	1.03	0.80	-0.23
100 Year	1.06	0.85	-0.21
Hazel - BMROSS[3]	1.62	1.40	-0.22
Hazel - Historical [4]	4.12	3.96	-0.16

Notes:
1. Dyke elevation upstream of Queen Street Bridge, based on BMROSS survey 218.59 m. Design Elev from 1979 Kilborn is 219.03 m. Design elevation assumed for proposed conditions.
2. Modelled flood levels include backwater effect from Saugeen River.
3. Hurricane Hazel Flow for Teeswater River as per BMROSS Irwin Bridge Modeling.
4. Historical Hurricane Hazel Flow applied for Teeswater River as per historical Conservation Branch Studies

Table 7.4 Hydraulic Comparison of Existing and Proposed Teeswater River Bridge Structures – Normal Depth Tailwater

Description	Teeswater River Bridge (Queen Street Bridge)		
	Existing	Proposed	Diff.
Dyke Elv/Low top of Road Elevation[1]	218.59	219.03	
Flow Event at which road floods/ Dyke overtopped	Regional	Regional	
Low Concrete/Soffit	217.04	217.51	
Modeled Headwater Elevation (m)[2]			
2 Year	214.84	214.72	-0.12
5 Year	215.09	214.95	-0.14
10 Year	215.23	215.08	-0.15
25 Year	215.34	215.18	-0.16
50 Year	215.47	215.29	-0.18
100 Year	215.56	215.37	-0.19
Hazel – BMROSS[3]	216.38	216.12	-0.26
Hazel - Historical [4]	220.40	218.69	-1.71
Freeboard to Top of Dyke (m)			
2 Year	3.75	4.28	--
5 Year	3.50	4.05	--
10 Year	3.36	3.92	--
25 Year	3.25	3.82	--
50 Year	3.12	3.71	--
100 Year	3.03	3.63	--
Hazel – BMROSS[3]	2.21	2.88	--
Hazel - Historical [4]	-1.81	0.31	--
Clearance to Low Concrete/Steel (m)			
2 Year	2.2	2.79	--
5 Year	1.95	2.56	--
10 Year	1.81	2.43	--
25 Year	1.7	2.33	--
50 Year	1.57	2.22	--
100 Year	1.48	2.14	--
Hazel – BMROSS[3]	0.66	1.39	--
Hazel - Historical [4]	-3.36	-1.18	
Velocity at Structure (m/s)			
2 Year	1.93	2.10	0.17
5 Year	2.07	2.28	0.21
10 Year	2.14	2.37	0.23
25 Year	2.2	2.44	0.24
50 Year	2.26	2.51	0.25
100 Year	2.29	2.56	0.27
Hazel – BMROSS[3]	2.64	2.89	0.25
Hazel - Historical [4]	4.20	4.07	-0.13

Notes:
1. Dyke elevation upstream of Queen Street Bridge, based on BMROSS survey 218.59 m. Design Elev from 1979 Kilborn is 219.03 m. Design elevation assumed for proposed conditions.
2. Modelled flood levels with Normal Depth Boundary Condition at Confluence.
3. Hurricane Hazel Flow for Teeswater River as per BMROSS Irwin Bridge Modeling.
4. Historical Hurricane Hazel Flow applied for Teeswater River as per historical Conservation Branch Studies

Under Saugeen River tailwater conditions (Table 7.3), the existing bridge soffit is submerged for the 5 year event and above. This is consistent with SVCA's photos of repeat submergence of the bridge soffit during semi-infrequent events. Due to the existing low point on the dyke, freeboard to the existing dyke is only provided to the 25 year event. As mentioned in Section 7.3.2., if the dyke is reinstated to the designelevation of 219.03, flood protection is provided to the 50 year event upstream of the Teeswater River Bridge.

The proposed bridge will improve hydraulic performance by raising the low soffit elevation by 0.47 m. Clearance is improved (Table 7.3) such that the bridge will convey the 5 year event. Water surface elevations for the 100 year design event are reduced by approximately 0.04 m. It is noted that the 100 year flood level at the confluence downstream of the bridge is estimated at 219.31 m. It is recommended to increase the flood protection provided at the bridge to the upstream 100 year flood level of 219.33 m. Future dyke improvements may include heightening the top of dyke elevation in this area. Flood protection recommendations is further discussed in Section 7.6.1. Due to the Saugeen River tailwater conditions, there are limited opportunities to improve the hydraulic performance of the proposed Teeswater River Bridge replacement structure.

If the Teeswater and Saugeen River flood events do not coincide, water surface elevations are drastically lower at the Teeswater River Bridge, as summarized in Table 7.4. The existing bridge conveys the 100 year design event with 1.48 m of clearance. Ample freeboard to the dyke is provided. Under proposed bridge conditions, water surface elevations are further reduced, with slight increases in velocity at the structure. The high velocities under this scenario are conservatively applied in rock protection sizing, further discussed in Section 7.6.4.

Results are provided for the historically applied Hurricane Hazel flow and the BMROSS Hazel flow, as summarized in Section 6.3. As noted previously, the historical flow value for the Teeswater River appears to be overestimated, resulting high flood elevations upstream of the Teeswater River Bridge and indicating significant spills along the existing flood protection system. The lower BMROSS flow values are provided for comparison purposes only, and result in significantly lower flood elevations. Detailed evaluation of the dyke system under the regional event was outside the project scope.

A water surface comparison between existing and proposed replacement bridge conditions for all cross-sections and design events is provided in Appendix A, Table A.10 to A.13, for Saugeen River and Normal depth tailwater conditions respectively.

7.5 Proposed Temporary Bridge Condition

The Saugeen River existing condition model included two additional cross-sections (Section 3743 and 3702) to evaluate the proposed detour structure. Model results for the proposed Temporary Detour bridge structure are summarized in Table 7.5. The values generated at cross section 3743, immediately upstream of the structure, are used for comparison purposes.

The proposed temporary structure has been designed for the 50 year event. The design of the low steel elevation has been optimized to reduce flood impacts of the structure. Clearance is provided to the 50 year. Freeboard to the dyke is maintained for the 50

Table 7.5 Hydraulic Comparison of Existing Conditions and Proposed Detour Structures

Description	Detour Bridge		
	Existing	Proposed	Diff.
Dyke Elv/Low top of Road Elevation[1]	219.12	219.12	
Flow Event at which road floods/ Dyke overtopped[2]	100 year	100 year	
Low Concrete/Soffit	-	218.57	
Modeled Headwater Elevation (m)[3]			
2 Year	216.59	216.61	0.02
5 Year	217.16	217.19	0.03
10 Year	217.50	217.53	0.03
25 Year	217.90	217.95	0.05
50 Year	218.47	218.54	0.07
100 Year	218.68	218.86	0.18
Hazel - Historical [5]	218.90	219.29	0.39
Freeboard to Top of Dyke (m)[4]			
2 Year	2.53	2.51	-0.02
5 Year	1.96	1.93	-0.03
10 Year	1.62	1.59	-0.03
25 Year	1.22	1.17	-0.05
50 Year	0.65	0.58	-0.07
100 Year	0.44	0.26	-0.18
Hazel - Historical [5]	0.22	-0.17	-0.39
Clearance to Low Concrete/Steel (m)			
2 Year	--	1.96	--
5 Year	--	1.38	--
10 Year	--	1.04	--
25 Year	--	0.62	--
50 Year	--	0.03	--
100 Year	--	-0.29	--
Hazel - Historical [5]	--	-0.72	--
Velocity at Structure (m/s)			
2 Year	2.13	1.95	-0.18
5 Year	2.56	2.29	-0.27
10 Year	2.86	2.53	-0.33
25 Year	3.25	2.85	-0.40
50 Year	3.35	2.92	-0.43
100 Year	3.69	3.38	-0.31
Hazel - Historical [5]	4.32	3.99	-0.33

Notes:
1. Elevation of Flood protection dyke downstream of at Queen Street Bridge, based on BMROSS survey 219.12 to 219.20 m. Design Elev from 1979 Kilborn is 219.03 m.
2. Dyke overtops for 100 year at confluence as per cross-section 3854.
3. Water surface elevations obtained from cross-section 3743, immediately upstream of proposed detour bridge
4. Dyke freeboard calculated from cross-section 3743, immediately upstream of proposed detour bridge.
5. Historical Hurricane Hazel Flow applied for Teeswater River as per historical Conservation Branch Studies

year event at the cross-section immediately upstream (XS-3743) as well as at the confluence of the Saugeen and Teeswater River. The proposed structure will not worsen any existing flood conditions and limits upstream water surface impacts to 0.05 m for the 50 year event. Due to the temporary condition of the structure, this impact is considered acceptable. A water surface comparison between existing and proposed temporary bridge conditions for all cross-sections and design events is provided in Appendix A, Table A.14 and A.15.

7.6 Discussion

7.6.1 Flood Protection

The railing of the existing bridge includes solid concrete panels that tie into the 219.03 m flood protection elevation of the existing dyke. To increase the provided flood protection, it is recommended at a minimum that the parapet railing and solid concrete panels of the proposed bridge be increased to flood protection height 219.33 m, which is the 100 year elevation upstream of the bridge (219.31 m at the confluence with the Saugeen River). The proposed higher elevation will allow the bridge to be more easily incorporated into any future dyke protection works. It is noted that flood protection opportunities are limited based on maintaining existing road grades and feasible height of the parapet railing system.

As part of the construction of the proposed replacement bridge, the flood protection top of dyke elevation upstream may be reinstated to the 1980 design elevation of 219.03 m.

7.6.2 Floodplain Fill

Negligible impacts to floodplain storage are anticipated between the existing and proposed Teeswater River Bridge replacement and proposed detour bridge structures.

The proposed replacement bridge design includes extending the south abutment to approximately the midline location of the existing south pier. Floodplain fill for the proposed south abutment is compensated in the bridge design by the raised soffit, culvert within the south abutment, and adjustment of the north abutment 3 m north. Based on the design of the proposed bridge, a cut and fill volumes are estimated at 374 and 479 m^3 for the 100 year and Hurricane Hazel regional flood respectively, resulting in a cut/fill balance of -105 m^3 below the bridge soffit. Table 7.6 provides an assessment of cut/fill against floodplain storage for the Teeswater River Reach between the Old Mill Dam the Confluence with the Saugeen River. As shown, the percent of floodplain storage loss is considered negligible at 0.30% and 0.24% for the existing 100 year and Hurricane Hazel regional event floods levels respectively.

Table 7.6 Proposed Replacement Bridge Floodplain Fill Analysis

Return Event	Total Reach Storage (m^3)[1]	Proposed Floodplain Fill (m^3)	Percentage of Floodplain Storage (Reach Basis)
100 year	34,540	105	0.30%
Hazel	44,600	105	0.24%

Note:

1. *Total Reach Storage Volumes calculated in HEC-RAS from downstream of Goldie Street Bridge to upstream of Whirl Creek confluence with the Saugeen River. Floodplain volume between cross-section 3854 to 3406 for the Saugeen River existing condition model.*

The temporary bridge will require fill within the floodway and flood fringe. Table 7.7 summarizes the proposed fill volumes estimated below the 100 year and regional Hurricane Hazel event levels. Volumes include fill at the south and north approaches as well as the proposed temporary bridge deck. Total reach storage amounts are calculated for the Saugeen River reach from downstream of Goldie Street Bridge to Upstream of Willow Creek (Cross-section 3854 to 3406). Negligible impacts on a reach basis are anticipated for the proposed floodplain fill, at 0.45% and 0.54% for the existing 100 year and regional Hurricane Hazel event floods respectively. The fill associated with the temporary structure will be removed post decommissioning.

Table 7.7 Proposed Temporary Bridge Floodplain Fill Analysis

Return Event	Total Reach Storage (m3)	Proposed Floodplain Fill (m3)	Percentage of Floodplain Storage (Reach Basis)
100 year	228,490	1,020	0.45%
Hazel	240,050	1,298	0.54%

Note:

1. *Total Reach Storage Volumes calculated in HEC-RAS from the Old Mil Dam to the confluence with the Saugeen River. Floodplain volume between cross-section 201 to 100 for the Teeswater River existing condition model.*

Based on the floodplain fill assessment, both the proposed replacement and detour structure will not cause significant impacts to floodplain storage.

7.6.3 Mill Race

The existing mill race operates at normal flow conditions. Head is provided by the historical Old Mill Dam 80 m upstream. Under flood conditions, the historical mill buildings and arches immediately upstream constrict the flows to the existing middle and north span of the Teeswater River Bridge. Refer to Figure 7.2. For the purpose of floodplain modeling, the south span has been conservatively been assumed as an ineffective flow area, and does not contribute to the conveyance of flood flows.

Figure 7.2 Existing Mill Race

Under proposed conditions, flows from the mill race will be preserved by a 4.0 m by 2.4 m culvert embedded behind new south abutment as shown in Figure 4.4. The total flow area of the proposed culvert is estimated at 7.9 m^2, including a 0.4 m counter sink allowance. The proposed culvert flow area is larger than the flow area provided by existing upstream mill races twin arches, as summarized in Table 7.8 below. Flow areas of upstream twin arches were determined based on BMROSS field survey information. The 2nd building upstream, significantly constricts flow to 1 m^2. Therefore the proposed culvert will maintain the required operating flows for the existing mill race.

Table 7.8 Mill Race Flow Area

Location	Description	Total Flow Area (m^2)
1st Building upstream, North Opening	Arc 1	4.0
1st Building upstream, South Opening	Arc 2	2.8
Total Area 1st Building		**6.7**
2nd Building upstream, North Opening	Arc 3	1.0
2nd Building upstream, South Opening	Arc 4	- [1]
Total Area 2nd Building		**1.0**
Proposed Culvert	**4x 2.4 (0.4 m counter sink)**	**7.9**

Note:
1. Arc 4 – 2nd Building upstream, South Opening was completed filled with sediment upon survey.

7.6.4 Rock Protection

Erosion protection at the replacement and detour bridge sites is to be provided to protect the stream banks at the abutments and to slow the rate of scour in the watercourse.

At the proposed bridge site, the highest velocities for a given return event will occur if the Saugeen and Teeswater River peak flows do not coincide. The higher potential velocity is conservatively applied for rock sizing. As per Table 7.4, the velocity for the 100 year event is in the range of 2.56 m/s, it is recommended that a nominal 250 mm

stone rip rap be applied. In addition to the rock protection at the bridge site, additional rock protection is proposed at the toe of the dyke immediately upstream, including some canoe access points to the river with armour stone.

At the temporary detour bridge site, it is recommended to size rock for the 50 year event. As per Table 7.5 the 50 year event is in the range of 2.92 m/s. It is therefore recommended that a nominal 300 mm stone rip rap be applied. Table 7.4

Refer to Appendix D for rip rap sizing calculations. The rip rap should be placed on the channel slopes at each end of the structure and under the deck over the abutment fill. It is recommended that erosion protection be provided to 100 year flood level to increase the resiliency of the proposed replacement bridge structure. It is recommended that the detour structure include erosion protection to the 50 year flood level. Erosion protection on the bed of the stream should be maintained by replacing existing cobbles and boulders where they may exist.

7.6.5 Ice Jams and Ice Flows

Ice jamming is a concern for the mouth of the Teeswater River, upstream of the Teeswater River Bridge. The existing structure is known to accumulate ice at the existing soffit. The design of the Teeswater River replacement bridge will improve the conveyance of ice due to a raised soffit and increased span lengths. The proposed deck also includes a smooth soffit and will reduce potential for ice accumulation. The north abutment is proposed 3 m further north from the existing abutment limit, increasing the flow area for ice along the river.

As previously noted, ice jams at the confluence of the Saugeen and Teeswater River has historically not been an issue. The proposed temporary detour bridge is proposed to span the Saugeen River and not reduce the river width available for moving ice. The proposed detour structure is not expected to initiate ice jam formation during spring ice breakup events for its anticipated 1 year of service.

8.0 CONCLUSIONS AND RECOMMENDATIONS

The County of Bruce has initiated a Class EA to address the replacement of the Teeswater River Bridge located on County Road 3 (Queen Street) in the Village of Paisley. The EA has identified the replacement of the existing bridge in its current location. The preferred detour option includes the construction a temporary bridge across the Saugeen River, immediately downstream of the confluence of the Saugeen and Teeswater River.

Hydraulic conditions at the replacement and temporary bridge sites are complex due to existing flood protection works, Saugeen tailwater conditions, ice jams and ice flows, the Old Mill dam and historical mill race. A review of background information and relevant flood studies was completed. As part of the current study, a flood frequency analysis was conducted to confirm flood flows through the Village of Paisley based on updated stream gauge records for the 2 to 100 year design events. Historical Hurricane Hazel flows have been maintained for consistency with previous studies and regulatory floodplain mapping. The hydraulic adequacy of the existing crossing and proposed structures were evaluated using a new HEC-RAS model, generated based on information from previous studies, new survey information and flow data.

The proposed replacement bridge is recommended as a twin span structure, with equal lengths of 22.75 m. The design of the replacement bridge included an assessment of upstream water levels, existing flood dyke protection level, ice jam conditions, mill race flows, and floodplain fill. The potential to raise the bridge was limited due to providing practical entrances to business north of the bridge. There are also limited opportunities to improve the hydraulic performance of the proposed structure due to the Saugeen River tailwater conditions. The proposed replacement bridge design increases the hydraulic performance of the crossing by raising the soffit as feasible and increasing span lengths. The proposed structure also includes a smooth soffit to reduce the potential accumulation of ice. Reductions in flood elevations are observed for the 2 to 100 year design events. Flows from the historical mill race are proposed to be maintained by a new 4.0 m x 2.4 m box culvert embedded behind the new south abutment. Negligible impacts on floodplain storage are predicted with the proposed works. Although the proposed structure does not meet the required clearance and freeboard in accordance with CHBDC requirements, the structure does provide additional clearance, in comparison with existing structure and reduces upstream flooding conditions.

For the replacement of the Teeswater River Bridge, it is therefore recommended that:

- The proposed 22.75 m twin span bridge to be used for final design on the Teeswater River, located along County Road 3 (Queen Street) in the Village of Paisley.

- Flood protection provided in the proposed replacement bridge railing/parapet be increased from 219.03 m to 219.33 m, corresponding to modelled 100 year elevations. Flood protection works shall be provided such that they can be integrated into any future dyke upgrades. The level of flood protection with

proposed railing/parapet will be confirmed with SVCA at the detailed design stage.

- Rip rap protection, nominal 250 mm stone, should be placed at the bridge site. Additional rock protection is proposed at the toe of the dyke immediately upstream, including some canoe access points to the river with armour stone.

- In case there is a forecast high-water event, construction contingency plans should include the stockpiling of sandbags or steel sheet piling to fill any breach in the dyke at Queen Street generated as part of replacement bridge construction. Full restoration of all affected dyke segments will be included in the contract.

The temporary detour bridge is proposed as a single 65.5 m span connecting Goldie Street to Church Street immediately downstream of the confluence of the Saugeen and Teeswater River. The design of the proposed temporary structure required design iteration and careful consideration of any temporary impacts to flood water levels, floodplain fill, ice conveyance, and impacts to the existing flood protection dyke system. The proposed temporary bridge has been designed to the 50 year event, and will pass the design event with minimal clearance. The design of the structure and low steel elevation has been optimized to reduce flood impacts of the structure. For the 50 year design event, flood impacts of the proposed structure are estimated at 0.05 m at the upstream river confluence. Existing dyke performance is maintained to the 50 year event. Due to the temporary condition of the structure, this impact is considered acceptable. It is therefore recommended that:

- The proposed 65.5 m single span temporary detour bridge be used for final design on the Saugeen River, connecting Goldie Street to Church Street in the Village of Paisley.

- Rip rap protection, nominal 300 mm stone, should be placed on the stream banks for erosion protection at the temporary bridge site.

- In case there is a forecast high-water event, construction contingency plans should include the stockpiling of sandbags or steel sheet piling to fill any breach in the dyke at the temporary detour bridge location. Full restoration of all affected dyke segments will be included in the contract.

It is requested that the Saugeen Valley Conservation Authority (SVCA) review and approve of the proposed structures under their “Development Interference with Wetlands and Alterations to Shorelines and Watercourses Regulation.” In addition, the following has been identified for consideration by SVCA:

- It is acknowledged SVCA may choose to reassess flows used floodplain mapping.

    - For the Teeswater River, it was identified that the historically applied Hurricane Hazel regional flood flow used in floodplain mapping may be

significantly over estimated. A detailed review of the regional storm flood flow was beyond the scope of this study.

- For the Saugeen River, the updated flood frequency analysis for the MacBeath Gauge showed an increase in flood flows the 50 and 100 year event, resulting in higher flood levels than previous 1990 floodplain studies.
- Future detailed flood studies and analysis may further assess potential ice influence on gauge records (ice causing gauge station records to be inaccurate) and calibrate flows to known highwater levels if available.

- Upon further analysis, the SVCA may wish to further evaluate and confirm the protection level provided by the flood protection system for the Village of Paisley.

  It is noted that the results of the updated modeling indicated reduced dyke performance at the confluence of the Saugeen and Teeswater River to the 50 year event. Previous 1990 modeling indicated the dyke protecting to the 100 year event. Upstream of the existing Teeswater River Bridge, survey information has indicated lower top of dyke elevation ranging from 218.59 to 218.87, indicating reduce flood protection of up to 0.44 m from the intended design elevation of 219.03. The performance of the existing dyke upstream is therefore limited to the 25 year event.

- As part of the construction of the proposed replacement bridge, the flood protection top of dyke elevation immediately upstream may be reinstated to the 1980 design elevation of 219.03 m.

Yours very truly

B. M. ROSS AND ASSOCIATES LIMITED

Per _____

B. L. Verhoeven, P. Eng.

Per _____

A. I. Ross, P. Eng.

AIR:es

c.c. Jim Donohoe, County of Bruce

Appendix A

Tables

Table A.1
Comparison of Proposed to Historical Design Flood Flows (m^3/s)

River Name & Gauge Location	Drainage Area (km^2)	Return Event (yr.) 2	5	10	20	25	50	100
Proposed Flows								
Teeswater River at Ellengown Gauge	663	92	116	130	-	142	156	166
Saugeen River at MacBeath Gauge	2516	349	480	577	-	710	819	935
Teeswater River at Paisley	689	95	119	134	-	146	161	171
Saugeen River Upstream of Teeswater River	2552	353	485	583	-	718	828	945
Saugeen River Downstream of Teeswater River	3241	422	580	697	-	859	990	1131
Saugeen River Downstream of Willow Creek	3304	428	589	707	-	871	1004	1147
Saugeen River Downstream of N. Saugeen River	3569	454	624	749	-	923	1064	1216
Notes: *1. Teeswater River Flows based on transposition from the Ellengowan Gauge (02FC015), located 6 km upstream of Paisley.* *2. Saugeen River Flows based on transposition from SVCA MacBeath Gauge, located 7 km upstream of Paisley.*								
1990 Flow by Cumming Cockburn								
Teeswater River at Paisley	689	98	122	134	143	-	152	159
Saugeen River Upstream of Teeswater River	2513	358	455	513	565	-	629	675
Saugeen River Downstream of Teeswater River	3176	447	569	642	708	-	787	844
Saugeen River Downstream of Willow Creek	3241	456	581	655	721	-	803	861
Saugeen River Downstream of N. Saugeen River	3570	491	625	705	777	-	865	927
Notes: *1. Teeswater River Flows based on transposition from the Ellengowan Gauge (02FC015), located 6 km upstream of Paisley.* *2. Saugeen River Flows based on transposition from the Walkerton Gauge (02FC002) located 37 km upstream of Paisley.*								
1979 Flows by Kilborn								
Teeswater River at Paisley	-	-	-	-	-	27.2	30.6	37.7
Saugeen River Upstream of Teeswater River	2618	351	496	589	-	714	804	892
Saugeen River Downstream of Teeswater River	3284	442	614	731	-	878	991	1085
Saugeen River Downstream of Willow Creek	3556	479	665	787	-	943	1062	1161
Saugeen River Downstream of N. Saugeen River	3862	487	677	804	-	963	1082	1181
Notes: *1. Teeswater River Flows based on hydrology model for the Teeswater River, originally developed by on the SVCA Greenock Swamp study in 1977.* *2. Saugeen River Flows based on transposition from both the Port Elgin (02FC001) and the Walkerton Gauge (02FC002).*								

Table A.2
HEC-RAS Steady Flow Data (m^3/s)

			Return Even (yr.)								
River Name & Gauge Location	**XS Location**	**Drainage Area (km^2)**	**2**	**5**	**10**	**20**	**25**	**50**	**100**	**Hazel[4]**	**Hazel[3] BMROSS**
Teeswater River at Paisley	598	689	95	119	134	-	146	161	171	793	280
Saugeen River Upstream of Teeswater River	5712	2552	353	485	583	-	718	828	945	1376	--
Saugeen River Downstream of Teeswater River	3743	3241	422	580	697	-	859	990	1131	1376	---
Saugeen River Downstream of Willow Creek	3702	3304	428	589	707	-	871	1004	1147	1376	--
Saugeen River Downstream of N. Saugeen River	2304	3569	454	624	749	-	923	1064	1216	1376	--

Notes:
1. Teeswater River Flows based on transposition from the Ellengowan Gauge (02FC015), located 6 km upstream of Paisley.
2. Saugeen River Flows based on transposition from SVCA MacBeath Gauge, located 7 km upstream of Paisley.
3. Regional storm event flows for Hurricane Hazel based on historical studies completed by the Conservation Authorities Branch in 1974. (obtained from Kilborn 1979)
4. Hurricane Hazel flood flow based on a lump watershed using Hydro-Pak software, as per the Big Irwin Bridge Replacement, Teeswater River – Hydrology Report. 2014 BMROSS. BR1097

Table A.3
Saugeen River
Existing Condition - Water Surface Elevation (m)

Station	Dyke Elev. (m)	Return Event (yr.)						
		2	5	10	25	50	100	Hazel
810	--	214.32	214.85	215.19	215.61	215.92	216.23	216.54
1000	--	214.47	214.97	215.29	215.69	216.00	216.30	216.60
1285	--	214.85	215.39	215.73	216.15	216.47	216.79	217.11
1358	--	215.05	215.64	215.96	216.32	216.57	216.85	217.13
1387 Queen Street N								
1402	**218.58**	215.53	216.09	216.41	216.78	217.68	217.76	217.87
1738	**218.80**	215.72	216.33	216.70	217.15	218.00	218.17	218.37
1899	**218.75**	215.93	216.52	216.88	217.30	218.08	218.26	218.46
2304	**218.97**	216.06	216.66	217.02	217.46	218.20	218.40	218.63
2896	**219.02**	216.28	216.89	217.25	217.69	218.37	218.59	218.83
3406	**219.13**	216.53	217.12	217.47	217.90	218.51	218.75	219.02
3574	**219.18**	216.55	217.12	217.46	217.86	218.44	218.65	218.87
3702	**219.13**	216.57	217.13	217.46	217.86	218.43	218.64	218.85
3743	**219.16**	216.59	217.16	217.50	217.90	218.47	218.68	218.90
3854	**219.12**	216.83	217.49	217.90	218.40	218.99	219.31	219.60
3878.85 Goldie Street Bridge								
3901	--	216.82	217.48	217.89	218.40	219.02	219.39	219.91
3970	--	216.84	217.51	217.92	218.45	219.07	219.46	220.05
4093	--	216.89	217.58	218.03	218.60	219.24	219.65	220.39
4275	--	216.97	217.68	218.13	218.71	219.34	219.76	220.56
4706	--	217.10	217.82	218.28	218.85	219.46	219.88	220.73
5120	--	217.30	218.03	218.48	219.04	219.62	220.02	220.89
5712	--	217.61	218.27	218.69	219.23	219.76	220.15	221.00

Table A.4

Teeswater River
(Saugeen River Tailwater Boundary Condition)
Existing Condition - Water Surface Elevation (m)

Station	Dyke Elev. (m)	Return Event (yr.)							
		2	5	10	25	50	100	BMROSS Hazel	Hazel
100.00	219.12	216.83	217.49	217.90	218.40	218.99	219.31	219.60	219.60
118.89 - Teeswater River Bridge									
143.00	218.75	216.83	217.50	217.92	218.43	219.03	219.37	219.74	220.52
201.00	219.18	216.86	217.53	217.95	218.45	219.05	219.39	219.80	220.86
206 - Old Mill Dam									
212.00	219.01	216.87	217.52	217.95	218.46	219.06	219.40	219.80	220.90
254.00	--	216.89	217.54	217.96	218.47	219.07	219.41	219.83	221.02
314.00	--	216.89	217.54	217.96	218.47	219.07	219.41	219.83	221.03
394.00	--	216.93	217.56	217.97	218.48	219.07	219.41	219.83	221.04
524.00	--	216.98	217.57	217.98	218.48	219.08	219.42	219.84	221.06
598.00	--	217.07	217.61	218.00	218.49	219.08	219.42	219.85	221.09

Table A.5

Teeswater River
(Normal Depth Tailwater Boundary Condition)
Existing Condition - Water Surface Elevation (m)

Station	Dyke Elev. (m)	Return Event (yr.)							
		2	5	10	25	50	100	BMROSS Hazel	Hazel
100.00	219.12	214.75	215.00	215.14	215.25	215.38	215.47	216.30	219.02
118.89 - Teeswater River Bridge									
143.00	218.75	214.84	215.09	215.23	215.34	215.47	215.56	216.38	220.40
201.00	219.18	215.03	215.30	215.46	215.58	215.73	215.82	216.72	220.76
206 - Old Mill Dam									
212.00	219.01	216.23	216.38	216.46	216.53	216.61	216.66	217.15	220.80
254.00	--	216.27	216.43	216.53	216.60	216.69	216.75	217.29	220.92
314.00	--	216.20	216.40	216.51	216.59	216.68	216.74	217.31	220.93
394.00	--	216.56	216.68	216.76	216.82	216.90	216.95	217.44	220.94
524.00	--	216.72	216.84	216.91	216.97	217.04	217.09	217.56	220.96
598.00	--	216.90	217.05	217.13	217.20	217.28	217.33	217.81	220.99

Table A.6

Saugeen River
Existing Condition – Flood Protection Dyke Freeboard (m)

Station	Dyke Elev. (m)	Return Event (yr.)						
		2	5	10	25	50	100	Hazel
810	--							
1000	--							
1285	--							
1358	--							
1387 Queen Street N								
1402	218.58	3.05	2.49	2.17	1.80	0.90	0.82	0.71
1738	218.80	3.08	2.47	2.10	1.65	0.80	0.63	0.43
1899	218.75	2.82	2.23	1.87	1.45	0.67	0.49	0.29
2304	218.97	2.91	2.31	1.95	1.51	0.77	0.57	0.34
2896	219.02	2.74	2.13	1.77	1.33	0.65	0.43	0.19
3406	219.13	2.60	2.01	1.66	1.23	0.62	0.38	0.11
3574	219.18	2.63	2.06	1.72	1.32	0.74	0.53	0.31
3702	219.13	2.56	2.00	1.67	1.27	0.70	0.49	0.28
3743	**219.16***	2.57	2.00	1.66	1.26	0.69	0.48	0.26
3854	**219.12***	2.29	1.63	1.22	0.72	0.13	-0.19	-0.48
3878.85 Goldie Street Bridge								
3901	--							
3970	--							
4093	--							
4275	--							
4706	--							
5120	--							
5712	--							

Note:

1. *BMROSS survey top of dyke elevation indicated with (*). Remaining top of dyke extracted from provincial DTM.*

Table A.7

Teeswater River
(Saugeen River Tailwater Boundary Condition)
Existing Condition – Flood Protection Dyke Freeboard (m)

Station	Dyke Elev. (m)	Return Event (yr.)							
		2	5	10	25	50	100	BMROSS Hazel	Hazel
100.00	219.12	2.29	1.63	1.22	0.72	0.13	-0.19	-0.48	-0.48
118.89 - Teeswater River Bridge									
143.00	218.75	1.92	1.25	0.83	0.32	-0.28	-0.62	-0.99	-1.77
201.00	219.18	2.32	1.65	1.23	0.73	0.13	-0.21	-0.62	-1.68
206 - Old Mill Dam									
212.00	219.01	2.14	1.49	1.06	0.55	-0.05	-0.39	-0.79	-1.89
254.00	--								
314.00	--								
394.00	--								
524.00	--								
598.00	--								

Table A.8

Teeswater River
(Normal Depth Tailwater Boundary Condition)
Existing Condition – Flood Protection Dyke Freeboard (m)

Station	Dyke Elev. (m)	Return Event (yr.)							
		2	5	10	25	50	100	BMROSS Hazel	Hazel
100.00	219.12	4.37	4.12	3.98	3.87	3.74	3.65	2.82	0.10
118.89 - Teeswater River Bridge									
143.00	218.75	3.91	3.66	3.52	3.41	3.28	3.19	2.37	-1.65
201.00	219.18	4.15	3.88	3.72	3.60	3.45	3.36	2.46	-1.58
206 - Old Mill Dam									
212.00	219.01	2.78	2.63	2.55	2.48	2.40	2.35	1.86	-1.79
254.00	--								
314.00	--								
394.00	--								
524.00	--								
598.00	--								

Table A.9 Comparison of Model Results -Existing Conditions

Water Surface Elev. (m)

Cross-section Station		Cumming Cockburn 1990 Model			BMRoss 2020 Model - 1990 Flows			BMRoss 2020 Model - 2020 Flows		
2020 Station	1990 Station	50	100	Hazel	50	100	Hazel	50	100	Hazel
1000	300	215.74	215.9	216.93	215.57	215.7	216.6	216	216.3	216.6
1285	590	216.32	216.48	217.53	216.02	216.16	217.11	216.47	216.79	217.11
1358	660	216.51	216.67	217.71	216.21	216.33	217.13	216.57	216.85	217.13
Bruce Road 3										
1402	700	216.74	216.92	218.34	216.66	216.78	217.87	217.68	217.76	217.87
1738	1040	217.06	217.22	218.51	217.01	217.16	218.37	218	218.17	218.37
1899	1475	217.41	217.56	218.75	217.17	217.31	218.46	218.08	218.26	218.46
2304	1875	217.65	217.81	218.95	217.32	217.47	218.63	218.2	218.4	218.63
2896	2405	217.83	217.98	219.12	217.55	217.71	218.83	218.37	218.59	218.83
3406	2930	217.98	218.13	219.27	217.76	217.91	219.02	218.51	218.75	219.02
3574	2990	217.97	218.12	219.24	217.73	217.86	218.87	218.44	218.65	218.87
3854	3310	218.09	218.24	219.53	218.23	218.41	219.6	218.99	219.31	219.6
Goldie Street Bridge										
3901	3351	218.27	218.43	220.5	218.23	218.4	219.91	219.02	219.39	219.91
3970	3420	218.28	218.45	220.55	218.26	218.44	220.05	219.07	219.46	220.05
4706	5660	218.5	218.68	221.03	218.61	218.8	220.73	219.46	219.88	220.73
5120	6070	218.66	218.85	221.16	218.79	218.97	220.89	219.62	220.02	220.89

Water Surface Elevation Difference – Comparison to 1990 Cumming Cockburn Model (m)

Cross-section Station		Cumming Cockburn 1990 Model			BMRoss 2020 Model - 1990 Flows			BMRoss 2020 Model - 2020 Flows		
2020 Station	1990 Station	50	100	Hazel	50	100	Hazel	50	100	Hazel
1000	300				-0.17	-0.20	-0.33	0.26	0.40	-0.33
1285	590				-0.30	-0.32	-0.42	0.15	0.31	-0.42
1358	660				-0.30	-0.34	-0.58	0.06	0.18	-0.58
Bruce Road 3										
1402	700				-0.08	-0.14	-0.47	0.94	0.84	-0.47
1738	1040				-0.05	-0.06	-0.14	0.94	0.95	-0.14
1899	1475				-0.24	-0.25	-0.29	0.67	0.70	-0.29
2304	1875				-0.33	-0.34	-0.32	0.55	0.59	-0.32
2896	2405				-0.28	-0.27	-0.29	0.54	0.61	-0.29
3406	2930				-0.22	-0.22	-0.25	0.53	0.62	-0.25
3574	2990				-0.24	-0.26	-0.37	0.47	0.53	-0.37
3854	3310				0.14	0.17	0.07	0.90	1.07	0.07
Goldie Street Bridge										
3901	3351				-0.04	-0.03	-0.59	0.75	0.96	-0.59
3970	3420				-0.02	-0.01	-0.50	0.79	1.01	-0.50
4706	5660				0.11	0.12	-0.30	0.96	1.20	-0.30
5120	6070				0.13	0.12	-0.27	0.96	1.17	-0.27

Table A10.

Proposed Teeswater River Bridge Replacement: Comparison Water Surface Elevation (m)
Saugeen River Tailwater Conditions

Cross-section Station	Existing Conditions Teeswater River								Proposed Conditions Teeswater River							
Return Event	**2**	**5**	**10**	**25**	**50**	**100**	**BMROSS Hazel[1]**	**Hazel[2]**	**2**	**5**	**10**	**25**	**50**	**100**	**BMROSS Hazel[1]**	**Hazel[2]**
100	216.83	217.49	217.9	218.4	218.99	219.31	219.6	219.6	216.83	217.49	217.9	218.4	218.99	219.31	219.6	219.6
118.89 - Teeswater River Bridge (Queen Street)																
143	216.83	217.5	217.92	218.43	219.03	219.37	219.74	220.52	216.83	217.49	217.9	218.4	219	219.33	219.66	220.18
201	216.86	217.53	217.95	218.45	219.05	219.39	219.8	220.86	216.86	217.52	217.93	218.43	219.03	219.35	219.71	220.55
206 - Old Mill Dam																
212	216.87	217.52	217.95	218.46	219.06	219.4	219.8	220.9	216.86	217.52	217.93	218.43	219.03	219.36	219.72	220.59
254	216.89	217.54	217.96	218.47	219.07	219.41	219.83	221.02	216.89	217.53	217.94	218.44	219.04	219.37	219.74	220.72
314	216.89	217.54	217.96	218.47	219.07	219.41	219.83	221.03	216.89	217.54	217.95	218.45	219.04	219.37	219.75	220.74
394	216.93	217.56	217.97	218.48	219.07	219.41	219.83	221.04	216.93	217.55	217.96	218.45	219.05	219.37	219.75	220.75
524	216.98	217.57	217.98	218.48	219.08	219.42	219.84	221.06	216.98	217.57	217.97	218.46	219.05	219.37	219.76	220.78
598	217.07	217.61	218	218.49	219.08	219.42	219.85	221.09	217.07	217.6	217.99	218.47	219.06	219.38	219.77	220.81

Table A11.
Proposed Teeswater River Bridge Replacement: Comparison Water Surface Elevation Difference (m)
Saugeen River Tailwater Conditions

Cross-section Station	Return Event							
	2	**5**	**10**	**25**	**50**	**100**	**BMROSS Hazel[1]**	**Hazel[2]**
100	0	0	0	0	0	0	0	0
118.89 - Teeswater River Bridge (Queen Street)								
143	0	-0.01	-0.02	-0.03	-0.03	-0.04	-0.08	-0.34
201	0	-0.01	-0.02	-0.02	-0.02	-0.04	-0.09	-0.31
206 - Old Mill Dam								
212	-0.01	0	-0.02	-0.03	-0.03	-0.04	-0.08	-0.31
254	0	-0.01	-0.02	-0.03	-0.03	-0.04	-0.09	-0.3
314	0	0	-0.01	-0.02	-0.03	-0.04	-0.08	-0.29
394	0	-0.01	-0.01	-0.03	-0.02	-0.04	-0.08	-0.29
524	0	0	-0.01	-0.02	-0.03	-0.05	-0.08	-0.28
598	0	-0.01	-0.01	-0.02	-0.02	-0.04	-0.08	-0.28

Note:

1. *BMROSS Hazel – Hurricane Hazel flood flow based on a lump watershed using Hydro-Pak software,* as per *the Big Irwin Bridge Replacement, Teeswater River – Hydrology Report. 2014 BMROSS. BR1097*
2. *Regional storm event flows for Hurricane Hazel based on historical studies completed by the Conservation Authorities Branch in 1974.*

Table A12.
Proposed Teeswater River Bridge Replacement: Comparison Water Surface Elevation (m)
Normal Depth Tailwater Conditions

Cross-section Station	Existing Conditions Teeswater River								Proposed Conditions Teeswater River							
Return Event	**2**	**5**	**10**	**25**	**50**	**100**	**BMROSS Hazel[1]**	**Hazel[2]**	**2**	**5**	**10**	**25**	**50**	**100**	**BMROSS Hazel[1]**	**Hazel[2]**
100	214.75	215	215.14	215.25	215.38	215.47	216.3	219.02	214.63	214.85	214.98	215.08	215.2	215.28	216.03	218.52
118.89 - Teeswater River Bridge (Queen Street)																
143	214.84	215.09	215.23	215.34	215.47	215.56	216.38	220.40	214.72	214.95	215.08	215.18	215.29	215.37	216.12	218.69
201	215.03	215.3	215.46	215.58	215.73	215.82	216.72	220.76	214.94	215.20	215.35	215.47	215.60	215.69	216.54	219.42
206 - Old Mill Dam																
212	216.23	216.38	216.46	216.53	216.61	216.66	217.15	220.8	216.23	216.38	216.46	216.53	216.61	216.66	217.15	219.45
254	216.27	216.43	216.53	216.6	216.69	216.75	217.29	220.92	216.27	216.43	216.53	216.60	216.69	216.75	217.29	219.69
314	216.2	216.4	216.51	216.59	216.68	216.74	217.31	220.93	216.20	216.40	216.51	216.59	216.68	216.74	217.31	219.71
394	216.56	216.68	216.76	216.82	216.9	216.95	217.44	220.94	216.56	216.68	216.76	216.82	216.90	216.95	217.44	219.74
524	216.72	216.84	216.91	216.97	217.04	217.09	217.56	220.96	216.72	216.84	216.91	216.97	217.04	217.09	217.56	219.80
598	216.9	217.05	217.13	217.2	217.28	217.33	217.81	220.99	216.90	217.05	217.13	217.20	217.28	217.33	217.81	219.88

Table A13.
Proposed Teeswater River Bridge Replacement: Comparison Water Surface Elevation Difference (m)
Normal Depth Tailwater Conditions

Cross-section Station	Return Event							
	2	**5**	**10**	**25**	**50**	**100**	**BMROSS Hazel[1]**	**Hazel[2]**
100	-0.12	-0.15	-0.16	-0.17	-0.18	-0.19	-0.27	-0.50
118.89 - Teeswater River Bridge (Queen Street)								
143	-0.12	-0.14	-0.15	-0.16	-0.18	-0.19	-0.26	-1.71
201	-0.09	-0.10	-0.11	-0.11	-0.13	-0.13	-0.18	-1.34
206 - Old Mill Dam								
212	0	0	0	0	0	0	0	-1.35
254	0	0	0	0	0	0	0	-1.23
314	0	0	0	0	0	0	0	-1.22
394	0	0	0	0	0	0	0	-1.20
524	0	0	0	0	0	0	0	-1.16
598	0	0	0	0	0	0	0	-1.11

Note:

1. *BMROSS Hazel – Hurricane Hazel flood flow based on a lump watershed using Hydro-Pak software,* as per *the Big Irwin Bridge Replacement, Teeswater River – Hydrology Report. 2014 BMROSS. BR1097*
2. *Regional storm event flows for Hurricane Hazel based on historical studies completed by the Conservation Authorities Branch in 1974.*

Table A14.
Comparison Water Surface Elevation Difference (m)
Proposed Temporary Bridge

Cross-section Station	Existing Condition Saugeen River							Proposed Temporary Bridge Saugeen River						
	Return Event							Return Event						
	2	5	10	25	50	100	Hazel	2	5	10	25	50	100	Hazel
810	214.32	214.85	215.19	215.61	215.92	216.23	216.54	214.32	214.85	215.19	215.61	215.92	216.23	216.54
1000	214.47	214.97	215.29	215.69	216.00	216.30	216.60	214.47	214.97	215.29	215.69	216.00	216.30	216.60
1285	214.85	215.39	215.73	216.15	216.47	216.79	217.11	214.85	215.39	215.73	216.15	216.47	216.79	217.11
Bruce Road 3														
1358	215.05	215.64	215.96	216.32	216.57	216.85	217.13	215.05	215.64	215.96	216.32	216.57	216.85	217.13
1402	215.53	216.09	216.41	216.78	217.68	217.76	217.87	215.53	216.09	216.41	216.78	217.68	217.76	217.87
1738	215.72	216.33	216.70	217.15	218.00	218.17	218.37	215.72	216.33	216.70	217.15	218.00	218.17	218.37
1899	215.93	216.52	216.88	217.30	218.08	218.26	218.46	215.93	216.52	216.88	217.30	218.08	218.26	218.46
2304	216.06	216.66	217.02	217.46	218.20	218.40	218.63	216.06	216.66	217.02	217.46	218.20	218.40	218.63
2896	216.28	216.89	217.25	217.69	218.37	218.59	218.83	216.28	216.89	217.25	217.69	218.37	218.59	218.83
3406	216.53	217.12	217.47	217.90	218.51	218.75	219.02	216.53	217.12	217.47	217.90	218.51	218.75	219.02
3574	216.55	217.12	217.46	217.86	218.44	218.65	218.87	216.55	217.12	217.46	217.86	218.44	218.65	218.87
3702	216.57	217.13	217.46	217.86	218.43	218.64	218.85	216.59	217.16	217.49	217.90	218.47	218.68	218.91
Temporary Bridge Location														
3743	216.59	217.16	217.50	217.90	218.47	218.68	218.90	216.61	217.19	217.53	217.95	218.54	218.86	219.29
3854	216.83	217.49	217.90	218.40	218.99	219.31	219.60	216.85	217.51	217.93	218.44	219.04	219.44	219.88
Goldie Street Bridge														
3901	216.82	217.48	217.89	218.40	219.02	219.39	219.91	216.84	217.50	217.92	218.43	219.07	219.54	220.24
3970	216.84	217.51	217.92	218.45	219.07	219.46	220.05	216.86	217.53	217.95	218.48	219.13	219.60	220.39
4093	216.89	217.58	218.03	218.60	219.24	219.65	220.39	216.90	217.60	218.05	218.62	219.29	219.78	220.68
4275	216.97	217.68	218.13	218.71	219.34	219.76	220.56	216.98	217.70	218.15	218.73	219.39	219.88	220.83
4706	217.10	217.82	218.28	218.85	219.46	219.88	220.73	217.11	217.84	218.30	218.87	219.51	220.00	220.96
5120	217.30	218.03	218.48	219.04	219.62	220.02	220.89	217.31	218.04	218.50	219.06	219.66	220.13	221.10
5712	217.61	218.27	218.69	219.23	219.76	220.15	221.00	217.62	218.28	218.70	219.24	219.80	220.24	221.18

Table A15.

Water Surface Elevation Difference (m)
Proposed Temporary Bridge – Existing Conditions

Saugeen River

Cross-section Station	Return Event						
	2	5	10	25	50	100	Hazel
810	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1285	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bruce Road 3							
1358	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1402	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1738	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1899	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2304	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2896	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3406	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3574	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3702	0.02	0.03	0.03	0.04	0.04	0.04	0.06
Temporary Bridge location							
3743	0.02	0.03	0.03	0.05	0.07	0.18	0.39
3854	0.02	0.02	0.03	0.04	0.05	0.13	0.28
Goldie Street Bridge							
3901	0.02	0.02	0.03	0.03	0.05	0.15	0.33
3970	0.02	0.02	0.03	0.03	0.06	0.14	0.34
4093	0.01	0.02	0.02	0.02	0.05	0.13	0.29
4275	0.01	0.02	0.02	0.02	0.05	0.12	0.27
4706	0.01	0.02	0.02	0.02	0.05	0.12	0.23
5120	0.01	0.01	0.02	0.02	0.04	0.11	0.21
5712	0.01	0.01	0.01	0.01	0.04	0.09	0.18

Appendix B

Rock Sizing Calculations

Rock Protection sizing - Proposed Teeswater River Bridge

Design Flow

100 Yr Event: 171 m^3/s

Structure Exit Velocity: 2.56 m/s

(To be provided by other calculations)

Method No. 1 : Based on USEPA Tables:

Formula: $y=ax^b$ Where: a = 50.8719

b = 1.79527

Calculated Rock Size (USEPA): 275 mm

Method No. 2 : Based on MTO Chart I4-6

Formula: y=a+bx+cx^2+dx^3... Where: a = 2.0786

b = -20.2571

c = 33.3073

d = 1.51143

Calculated Rock Size (MTO): 194 mm

Method No. 3: Ontario Ministry of Transportation (MTO) Highway Drainage Design Manual

Required Rock Size, D_{50} 200 mm

Stone Sizes For Scour And Erosion Protection – Low Volume Roads							
Velocity (m/s)	< 2.0	< 2.6	< 3.0	< 3.5	< 4.0	< 4.7	< 5.2
Nominal Stone Size(1) (mm)	100	200	300	400	500	800	1000
Notes 1) Maximum stone size to be 1.5 times the nominal stone size. 80% of stones (by mass) must have a diameter of at least 60% of nominal stone size.							

Selected Rock Size (Average USEPA / MTO charts) **220** mm

Use **250** mm

Maximum Stone Size 1.5 times D_{50} **375** mm

Thickness of Rip-Rap Layer 2.25 times D_{50} **560** mm

Rock Protection sizing - Temporary Detour Bridge

Design Flow

50 Yr Event: 828 m^3/s
Structure Exit Velocity: 2.92 m/s
(To be provided by other calculations)

Method No. 1 : Based on USEPA Tables:

Formula: $y=ax^b$ Where: a = 50.8719
b = 1.79527

Calculated Rock Size (USEPA): 348 mm

Method No. 2 : Based on MTO Chart I4-6

Formula: y=a+bx+cx^2+dx^3... Where: a = 2.0786
b = -20.2571
c = 33.3073
d = 1.51143

Calculated Rock Size (MTO): 265 mm

Method No. 3: Ontario Ministry of Transportation (MTO) Highway Drainage Design Manual

Required Rock Size, D_{50} 300 mm

Stone Sizes For Scour And Erosion Protection – Low Volume Roads							
Velocity (m/s)	< 2.0	< 2.6	< 3.0	< 3.5	< 4.0	< 4.7	< 5.2
Nominal Stone Size(1) (mm)	100	200	300	400	500	800	1000
Notes 1) Maximum stone size to be 1.5 times the nominal stone size. 80% of stones (by mass) must have a diameter of at least 60% of nominal stone size.							

Selected Rock Size (Average USEPA / MTO charts) **300** mm

Use **300** mm

Maximum Stone Size 1.5 times D_{50} **450** mm

Thickness of Rip-Rap Layer 2.25 times D_{50} **680** mm

Appendix C

HEC-RAS Model Files

(Model files to be provided electronically)