APPENDIX

I

HYDROLOGICAL STUDY

NS DEPARTMENT OF PUBLIC WORKS

CAMBRIDGE INTERCHANGE ENVIRONMENTAL IMPACT ASSESSMENT

HYDROLOGICAL STUDY

DECEMBER 10, 2021

FINAL REPORT

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HYDROLOGICAL STUDY

NS DEPARTMENT OF PUBLIC WORKS

FINAL REPORT

PROJECT NO.: 211-04152-00
CLIENT REF:RTP-01
DATE: DECEMBER 10, 2021

WSP
1 SPECTACLE LAKE DRIVE
DARTMOUTH, NS
CANADA B3B 1X7

T: +1 902-835-9955
F: +1 902-835-1645
WSP.COM

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SIGNATURES

PREPARED BY

Matt MacEachern, MScE., EIT
Design Engineer in Training

December 10, 2021
Date

APPROVED BY

Devin Bell

Devin Bell, P.Eng.
Water Resources Engineer, Infrastructure

December 10, 2021
Date

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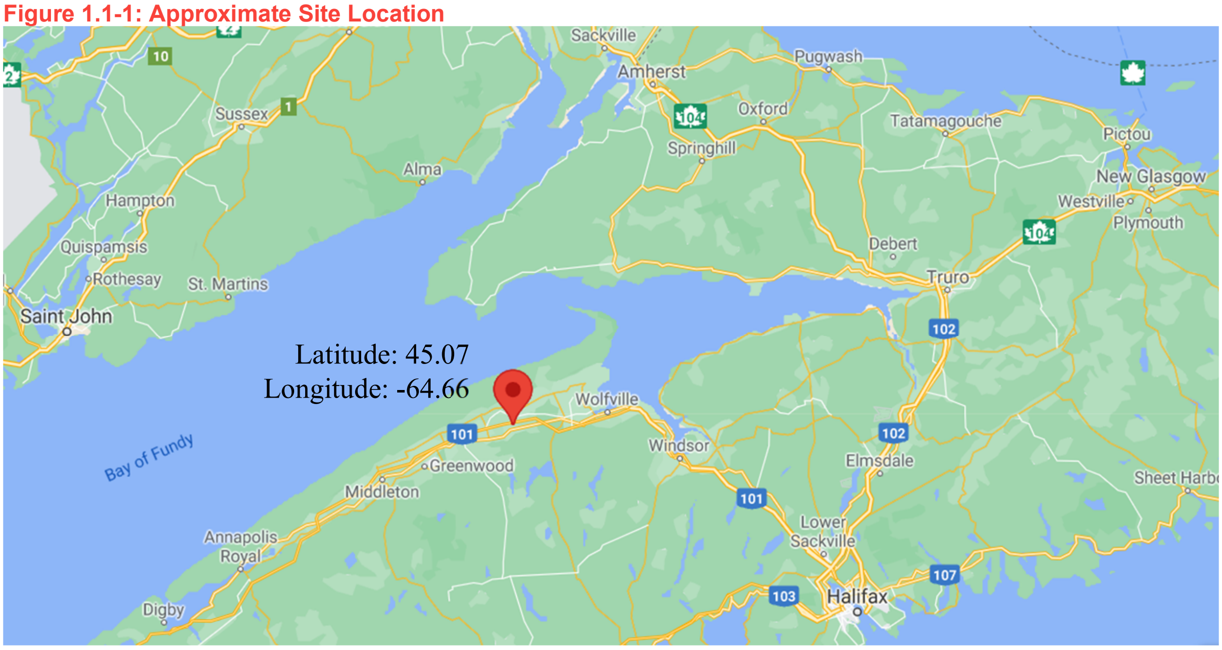
1 INTRODUCTION

1.1 PROJECT OVERVIEW

WSP has been retained by Nova Scotia Department of Public Works (NSDPW) to conduct the Hydrological investigation of the proposed Cambridge Interchange, Cambridge, Nova Scotia, in support of the Cambridge Interchange Environmental Impact Assessment. The Cambridge Interchange site is located adjacent to Coleman Brook, where the brook crosses Highway 101 within the Cornwallis River Valley of Nova Scotia, approximately 96 km northwest of Halifax. The southern portions of the site are accessed via municipally owned and Annapolis Valley First Nation's roads. The northern portion of the site is not serviced by any roads, primarily consisting of farmland with vegetated tree bands along Coleman Brook. **Figure 1.1-1** shows the approximate location of the Interchange site within Nova Scotia.

Figure 1.1-1: Approximate Site Location

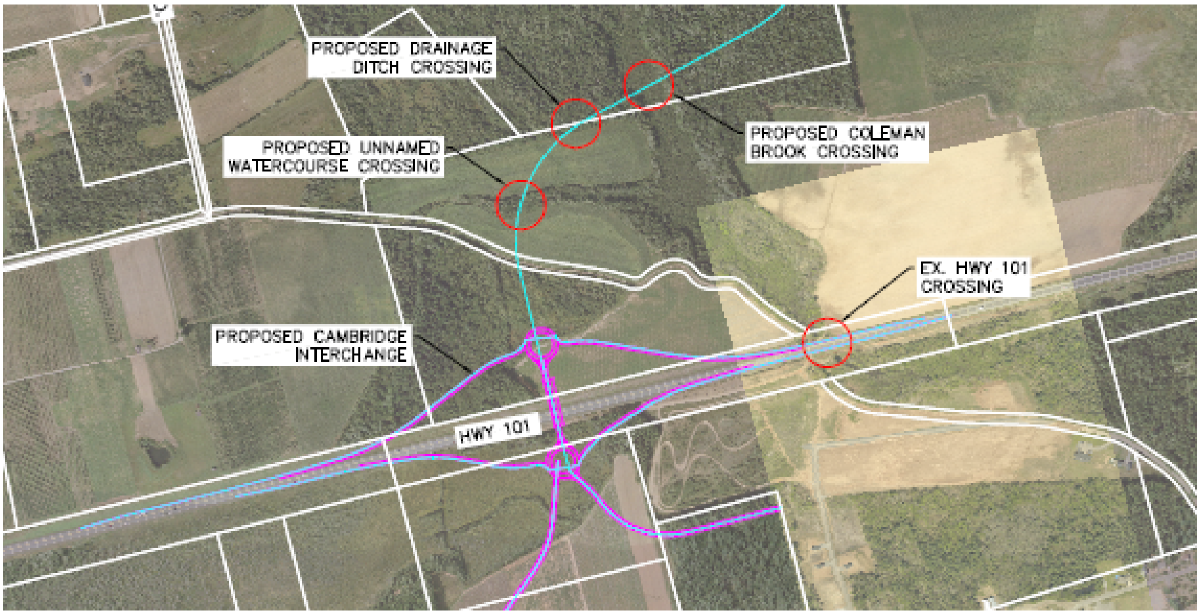


The Interchange site boundary is located within two watersheds, with the first being the Coleman Brook watershed, and the second being the Cornwallis River watershed. These two watersheds are approximately 948 ha and 8,170 ha respectively. However, the Cornwallis River watershed is outside the scope of this report and was assessed separately. For that assessment please refer to the Cornwallis River Bridge Hydrological Assessment, SMH Canada Consulting Inc., 2020.

The purpose of this report is to perform a hydrological study to review the four watercourse crossings which either are or will be impacted by the Interchange and its access roads, within the northern half of the site, in order to assess the peak flows reaching these locations and to recommend crossing structure options as well as options to accommodate fish passage.

There are four water crossings, as seen in **Figure 1.1-2**, that are currently impacted by the proposed Cambridge Interchange alignment. A full sized figure can be found in Appendix B. The first is an existing crossing of Coleman Brook at HWY101 were there is currently a double culvert arrangement. The alignment crosses Coleman Brook for a second time north of the current crossing and there are two smaller water crossings North-East of the existing HWY101 crossing where the alignment crosses a small unnamed watercourse as well as what is believed to be a drainage ditch adjacent to farmland. Flows are significantly lower in the two tributary water/drainage courses in comparison to the main Coleman Brook.

Figure 1.1-2: Proposed Crossing Locations



The report is outlined as follows:

- **Section 2** outlines the regulatory bodies, both provincial and federal, and their respective requirements for crossing structures in Nova Scotia.
- **Section 3** outlines the available climatological data including temperature, precipitations, evapotranspiration, snowfall, and information on rain gauge locations within close proximity of the proposed Interchange site.
- **Section 4** presents the Hydrological model development using the HEC-HMS software and the methods employed and the modeling results highlighting peak runoff rates determined for each approximate crossing location.
- **Section 5** presents a summary of the study and preliminary conclusions.

2 DESIGN REQUIREMENTS

The proposed Cambridge Interchange crossing structures must be sized to accommodate the following applicable design requirements depending on the crossing width and type of structure, clear span or closed bottom:

CANADIAN HIGHWAY BRIDGE CODE (CHBDC)

The Canadian Highway Bridge Design Code (CHBDC) applies to all public bridge structures and defines a bridge as a structure which has a span that exceeds 3.0m across a watercourse. The CHBDC requires that a bridge be designed to accommodate the normal design flood flow with a 50-year return period, without resulting in any damage to the bridge approaches and bridge structure. The bridge must also be designed to withstand a check flood flow with at least twice the normal design flood flow return period (i.e. a 100-year event), without endangering the structure and without incurring failure of the approach embankments. Therefore, at a minimum, the lowest part of the new bridge (soffit) must be located at an elevation that is sufficiently high that the 100-year check flood flow will pass below it without any damage to the structure or embankments.

The CHBDC also states that the clear opening must have sufficient freeboard clearance between the soffit and the normal high water level (50-year event) to prevent damage by the action of flowing water, ice floes, or floating debris. For freeways, arterial roads and collector roads, this clearance must be at least 1.0m and for local roads the clearance must be at least 0.3m. The proposed road running north, connecting the proposed Interchange to Brooklyn Street, is considered by NSDPW to be a collector road, therefore recommended clearances of 1.0m from the 50-year flood level have been presented in this report for spans greater than 3.0m wide.

REGULATORY PERMITTING

Nova Scotia Environment (NSE) requires that all watercourse crossing structures, clear span or closed bottom, must have a hydraulic capacity large enough to pass the 100-year peak flow with a maximum velocity of 1.8 m/s, unless otherwise approved by the Minister of Environment. In addition, NSE requires all closed bottom crossing structures to have a dissipation pool installed at the downstream outlet of the structure, with a very strong preference for single barrel structures over multi barre structures.

NSE stipulates that a Watercourse Alteration Permit must be obtained for construction work within the banks of a watercourse and work involving diversion of an existing watercourse to a new location. A Wetland Alteration Permit would also be required by NSE for any work within an existing wetland area.

Department of Fisheries and Oceans Canada (DFO) requirements apply when fish are present in a watercourse. If this is the case, the 2015 Guidelines for the Design of Fish Passage for Culverts in Nova Scotia should be followed.

CLIMATE CHANGE

NSDPW requires that the effects of future climate change be considered as part of the hydrological analysis. It is noted that climate science in Canada has been evolving in recent years, and currently no formal standard exists for computation of future climate analyses. One possible analysis uses predictions of the impact of future climate change derived from the International Panel on Climate Change's Fifth Assessment Report (IPCC-AR5). The IPCC-AR5 has described four possible scenarios (RCP 2.6, 4.5, 6.0 and 8.5) for climate projections through to the year 2100. In the lead up to the IPCC Assessment Report 6, the energy modelling community has developed a new set of emissions scenarios driven by different socioeconomic assumptions. These are the named Shared Socioeconomic Pathways (SSPs). The most common SSPs selected by climate modeling centers and for which outputs are produced are SSP2-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5. SSP2-4.5 is considered a moderate climate scenario, where some mitigating measures are put in place to combat increasing global temperatures. In many cases, this equates to an approximate 20% increase in peak rainfall. However, such analyses are continuously evolving, and have been identified in recent work as highly sensitive to data ranges and outliers within current IDF curves.

Based on our previous work, review of analyses throughout Nova Scotia, and literature surrounding the use of these climate scenarios, the SSP2-4.5 future climate scenario is a current industry best-practice and therefore been considered for the current project.

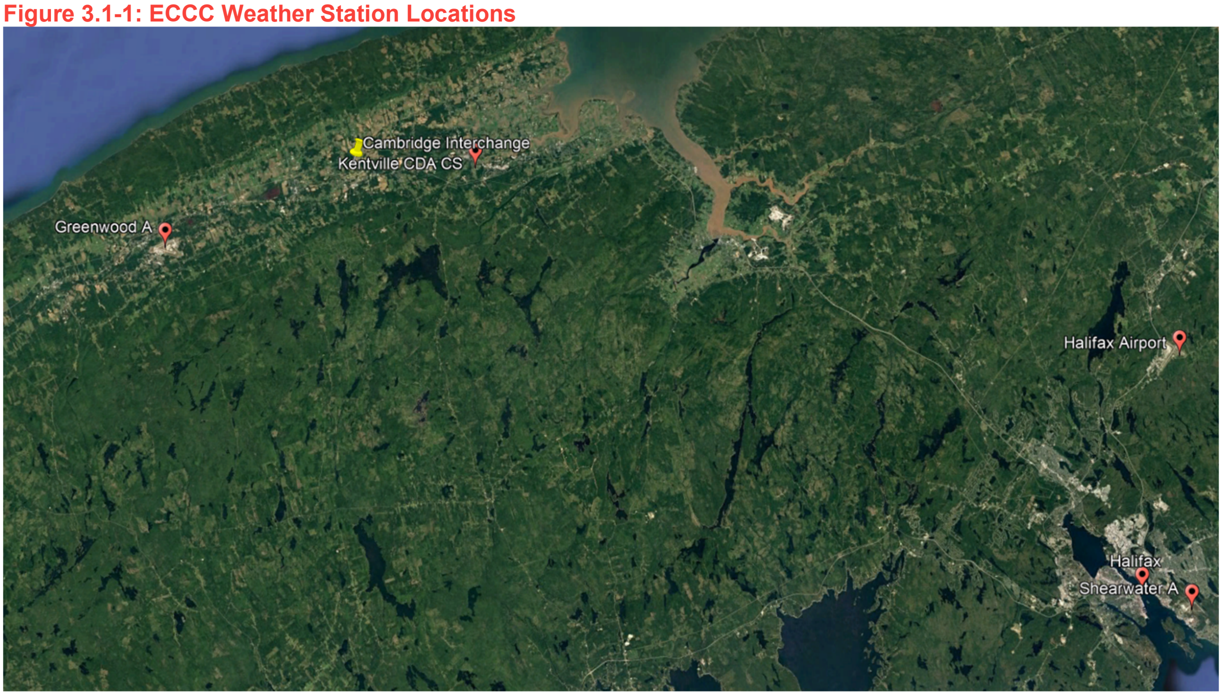
3 CLIMATOLOGICAL ANALYSIS

The Cambridge Interchange site lies in a mid-temperature zone where the climate is classified as continental rather than maritime. The temperature extremes of the continental climate are moderated by the Bay of Fundy (Atlantic Ocean) which is situated approximately 15 km north and 24.5km east of the site. The seasonal distribution of precipitation based on the continental classification indicates higher precipitation volumes in the summer season compared to the winter. This section discusses the main parameters describing the climatology of the study area, i.e. temperature, precipitation.

3.1 REVIEW OF AVAILABLE CLIMATE DATA

Environment and Climate Change Canada (ECCC) operates many weather stations across the province and for those stations with a minimum of 15 years of data, also compiles Climate Normals. Climate Normals, both averages and extremes, are calculated or interpolated for a period of 30 years for as many of a particular station's measured parameters as possible. The last edition of Climate Normals covers 1981 to 2010 and provides a lot of statistical data for these specific stations. Figure 3.1-1 shows the position of the weather stations near the study area, and **Table 3.1-1** describes their main characteristics.

Figure 3.1-1: ECCC Weather Station Locations



Regionally, data is being actively collected by ECCC at the airports of Halifax and Canadian Forces Base Shearwater and Greenwood, as well as in the community of Kentville. However, ECCC has replaced the gauge at Halifax Airport as of their respective end of record year, and as such reset those stations' period of record moving forward. This means that current data is available but will not have been included in any Climate Normal or Intensity-Duration-Frequency (IDF) curve calculations. The City of Halifax is a station which is no longer active, but ECCC has produced IDF curves for these locations.

Table 3.1-1: ECCC Weather Station Characteristics

Station	Latitude/Longitude	Elevation (m)	Distance (km)	Period of Record	Climate Normals	IDF Curves
Kentville CDA CS	45°04'00.0" N 64°29'00.0" W	48	20	1964 - 2016	Yes[1]	Yes
Greenwood A	44°59'00.0" N 64°55'00.0" W	28	30	1960 - 2013	Yes	Yes
Halifax Airport[1]	44°52'48.0" N 63°30'00.0" W	145.4	120	1977 – 2013	Yes	Yes
Shearwater A	44°38'00.0" N 63°30'00.0" W	44.0	155	1953 – Present	Yes	Yes
Halifax	44°39'00.0" N 63°34'00.0" W	31.7	140	1941 – 1973	No	Yes

Note: [1] Station is active to date however ECCC has replaced this gauge and reset the period of record. Therefore, the Climate Normals are taken from the previous station at this location.

The most complete weather station nearest the study area is located in Kentville, Kentville CDA CS, approximately 20 km away, and given the proximity of this station it is considered representative of the conditions of the study area. This is an actively reporting climate station.

3.2 RESULTS AND DISCUSSION

Greenwood A also has a similar period of record and proximity to the study area, however, after reviewing the data, this station produces return periods storms which are slightly smaller than those obtained from Kentville. In an effort to produce a conservative analysis, the Kentville CDA CS station was preferred.

3.2.1 TEMPERATURE

Table 3.2-1 presents the Temperature Normals reported by the ECCC Kentville for the years between 1981-2010. The average annual temperature is 7.1 ºC, while the minimum and maximum of the data set are -9.8 ºC and 24.9ºC, respectively. The extreme minimum and maximum values are -31.1 and 37.8 respectively. The extreme maximum and minimum were recorded on February 1, 1920 and August 12, 1944 respectively.

From the temperature ranges, it appears that the ideal period to look for a 1:100 year winter storm is between the months of December through to the end of February, where all three Temperature Normals are either very near or below 0ºC. This suggests rainfall during this period is very likely to fall on frozen ground.

Table 3.2-1: ECCC Kentville Temperature Normals

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Normals$_{avg}$	-5.6	-4.9	-1.0	5.3	11.0	16.0	19.5	19.0	14.5	9.4	4.1	-2.3
Normals$_{min}$	-9.8	-9.2	-5.3	0.6	5.6	10.4	14.0	13.6	9.5	4.9	0.3	-6.1
Normals$_{max}$	-1.3	-0.5	3.4	9.9	16.4	21.5	24.9	24.3	19.5	13.7	7.8	1.5

CLIMATIC CHANGE

According to average temperature increase scenarios for Kentville, Nova Scotia, average temperatures in summer (June to August) and in winter (December to February) would increase by approximately 2.3 ºC and 2.8 ºC, respectively, by the year 2080 from the present date (*NSE Climate Change Unit, 2021*).

3.2.2 PRECIPITATION

Mainland Nova Scotia is located in a temperate region and as such receives rainfall all year round. During the winter months it can be expected that the total precipitation will be a combination of both rainfall and snowfall.

The temperate climate helps maintain the moisture content in the air, and results in the consistently wet months all year long, with total average accumulations of 1181.2 mm. Snowfall accounts for approximately 22% of the total average accumulation and predominately falls between December and March with some snowfall appearing in the two shoulder months, November and April. This can be seen in **Table 3.2-2** below.

Table 3.2-2: ECCC Kentville Precipitation Normals

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall Normals	50.8	46.3	67.1	73.8	97.3	81.6	84.0	76.7	84.4	89.0	108.9	70.9	930.8
Snowfall Normals	71.4	59.2	45.2	17.2	4.0	0.0	0.0	0.0	0.0	0.0	12.9	53.1	263.0
Precip. Normals	116.1	101.3	109.8	92.7	102.1	81.6	84.0	76.7	84.4	89.0	121.5	122.0	1181.2

PLUVIOMETRY

As stated earlier, the Rainfall Normals for Kentville are a sample set of daily rainfall values for the period 1981 to 2010. Annual rainfall recorded over the last 30 years is 930.8 mm. Given the long period in which data are available, these values should be considered reliable. Liquid precipitation falls all year round with the highest monthly rainfalls occurring in May and between September and November. This predominately late, heavy rainfall pattern is consistent within the Maritime Region as this period commonly observes sub-tropical and tropical storms, with periodic hurricanes. The highest rainfall month is November, with an average of 108.9 mm. The month of May sees the most occurrences of rainfall events greater than 25mm, followed closely by a three way tie between July, September and December.

CLIMATIC CHANGE

According to average precipitation increase scenarios for Kentville, Nova Scotia, average precipitation in summer (June to August) and in winter (December to February) would change by approximately -0.4 mm and 29.9 mm, respectively, by the year 2080 from the present date. The winter is expected to have a higher precipitation ratio of rainfall to snow fall, resulting in fewer days with snow. Additionally, in the autumn (September to November) when Nova Scotia is at risk of severe rainfall events, average rainfall is expected to increase by 6.4mm (*NSE Climate Change Unit, 2021*). This is consistent with the SSP2-4.5 climate scenario for the Kentville CDA CS station.

3.3 SUMMARY OF CLIMATOLOGICAL CHARACTERISTICS

Overall, the climate of the study area is characterized as follows:

- An average annual temperature of about 7.1 ºC, the warmest and the coldest months being July and January with monthly averages of 24.9 ºC and -9.8 °C, respectively.
- Precipitation in the order of 1,181 mm per year, of which about 22% falls in the form of snow.
- With regard to climate change, total precipitation could increase by about 3.8% by 2080, with the majority of that change occurring for the winter months.
- A high frequency of freeze-thaw conditions during the winter but will decrease over time due to climate change.

4 HYDROLOGICAL ANALYSIS

4.1 OVERVIEW

This section describes the general hydrological conditions within the Study area and overall Coleman Brook watershed, and specifically on waterbodies, watersheds, and watercourses potentially affected by the roadway infrastructure. The hydrological analysis carried out concerns the determination peak flows to aid in the sizing and permitting of the proposed crossing structures. **Figure 3.1** shows the position of mining infrastructure as well as the position of the projected infrastructure in the river, i.e. culverts. Watersheds and their areas are also presented.

For the purposes of this study, four locations were considered to understand the effect the proposed Interchange would have on the surface water features in the area. Each of the four locations were modeled together to better understand their interconnected relationships and included the following.

4.1.1 HYDROGRAPHY

EXISTING CONDITIONS

The relief of the study area is primarily shallow due to this area being a river valley. The study area is located in the middle reaches of the Coleman Brook watershed and consists of multiple small watercourses, shallow waterbodies and wetlands. This configuration favours their enlargement rather than their enhancement during an increase in flow. The overall watershed area, Coleman Brook and its tributaries, flows from north to south, beginning in the hills north of the community of Grafton, then moving through in a valley of low vertical drop, generally at 0.5 - 1.0% slope. As it approaches and passes under Highway 101, the watercourse turns southeast and travels for approximately 6.5 km before discharging into the Cornwallis River. This river then discharges into the Minas Basin of the Bay of Fundy, approximately 18 km further downstream. The tributary area of Coleman Brook to the extent of the Highway 101 crossing is approximately 9.85 km^2.

4.2 MODELLING METHODOLOGY

4.2.1 GENERAL APPROACH

The mathematical models and procedures used in this analysis integrate precipitation data from neighbouring ECCC weather stations with site-specific data (topography, soil, and precipitation) in order to assess the Hydrological response of the Coleman Brook watershed, and its tributaries, which will be impacted by the Interchange. Peak flows within the Coleman Brook watershed were quantified using a Hydrological model developed using the HEC-HMS modelling software.

The process began with the delineation of the watershed for Coleman Brook, tributary to the point where the Creek passes under Highway 101. Subcatchment boundaries were further defined based on identified watercourses confluences.

Runoff values were estimated based on available provincial mapping and aerial photography and compared to industry standard runoff coefficients.

The Hydrological modelling analysis of the Coleman Brook watershed was performed using the HEC-HMS 4.7.1 modelling software, with input data from the ECCC IDF Curve for Kentville (Station ID 8202810).

Application of this modelling approach requires that specific assumptions be made such that the numerical model is representative of the physical realities within the area being analyzed. A number of parameters were selected based on available background data, resources, and engineering judgement to provide the most reasonable representation for the parameters in the model.

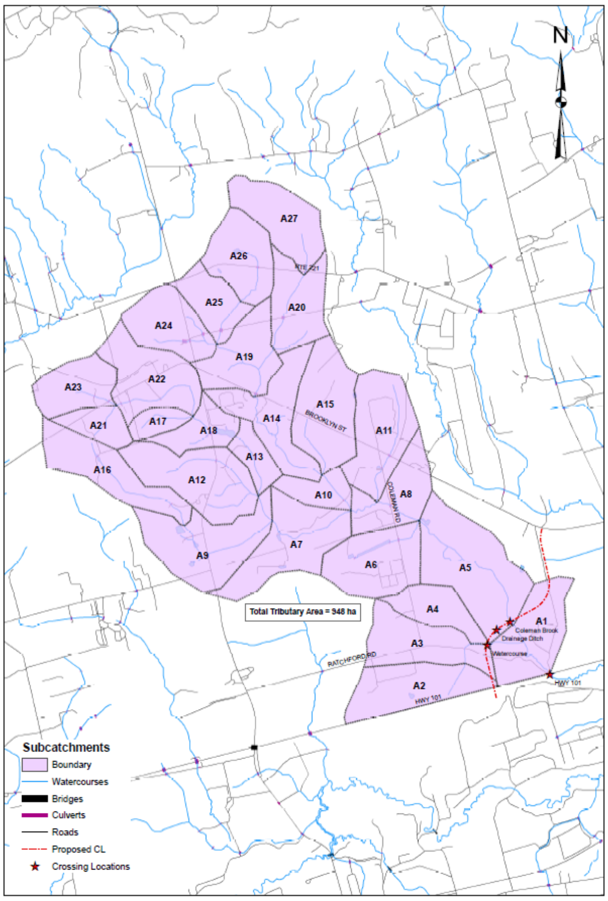
Existing conditions and assumptions for various aspects of the HEC-HMS model are outlined below. A detailed list of HEC-HMS Model Inputs can be found in Appendix A.

4.2.2 CATCHMENT AREAS

The area tributary to the stream gauge was sub-divided into 27 drainage areas based on natural topography, overland flow routes, and waterbodies. The size of these subcatchments was influenced by the data source used for delineation, with provincial 1:10,000 mapping being used to determine the catchment area boundaries. The delineated areas ranged from 10.4 to 68.7 hectares.

The Coleman Brook model subcatchments are shown on **Figure 4.2-1**. For full size figures, please refer to Appendix B.

Figure 4.2-1: Study Subcatchment Areas



4.2.3 SCS CURVE NUMBER LOSS MODEL

The subcatchment losses were based on SCS CN (Curve Number) values. These were selected by overlaying land use and soil conditions, Figure 4.2-2 and Figure 4.2-3 respectively.

Soil conditions are based on the Soil Map of Kings County, West Sheet, produced by the Canadian Department of Agriculture, 1963. The surface soil conditions within the subcatchments are comprised of the Avonport (Av), Cornwallis (Cn), Kingsport (Kp), Kentville (Kt), Millar (Mr), Pelton (Pn), Somerset (S), and Woodville (W) soil series, which primarily consist of various combinations of gravelly sandy loam, sandy loam over gravelly sandy loam, sandy loam, and friable sandy loam.

These soil series allowed for a specific Soil Horizon and CN value to be identified for each land use with a specific soil type underneath, within each subcatchment. The areas were then derived as observed using available provincial 1:10,000 mapping data and aerial photography. See **Table 4.2-1** for a summary of the subcatchment areas. For full size figures, please refer to Appendix B.

Figure 4.2-2: Study Land Use Areas

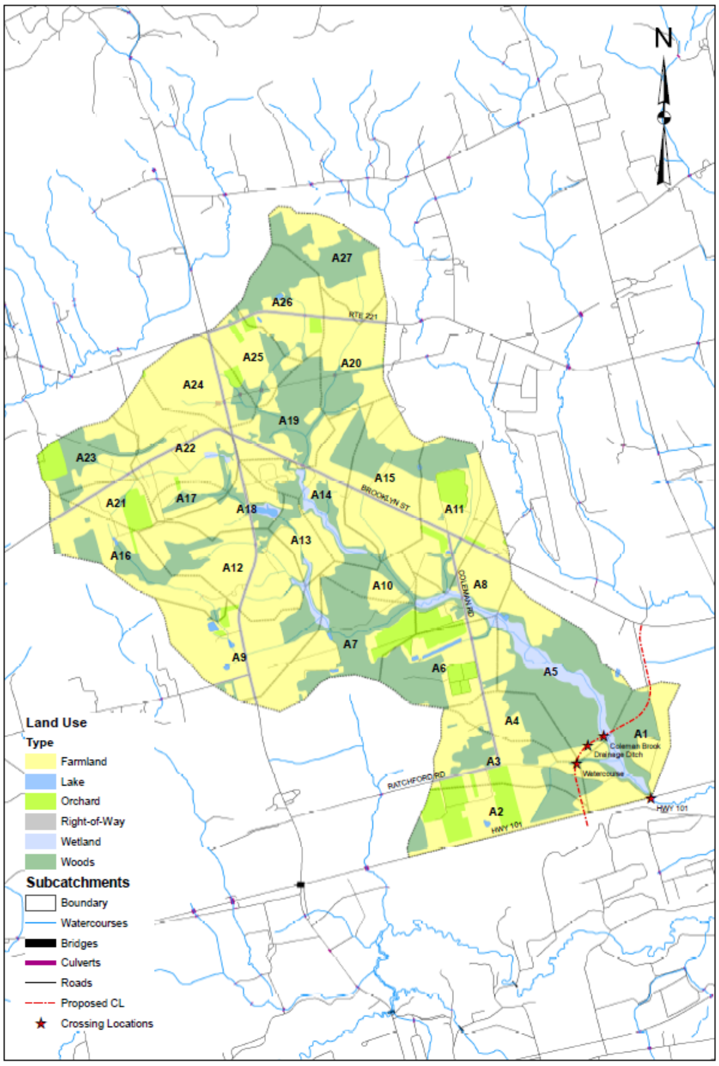


Figure 4.2-3: Study Soil Type Mapping

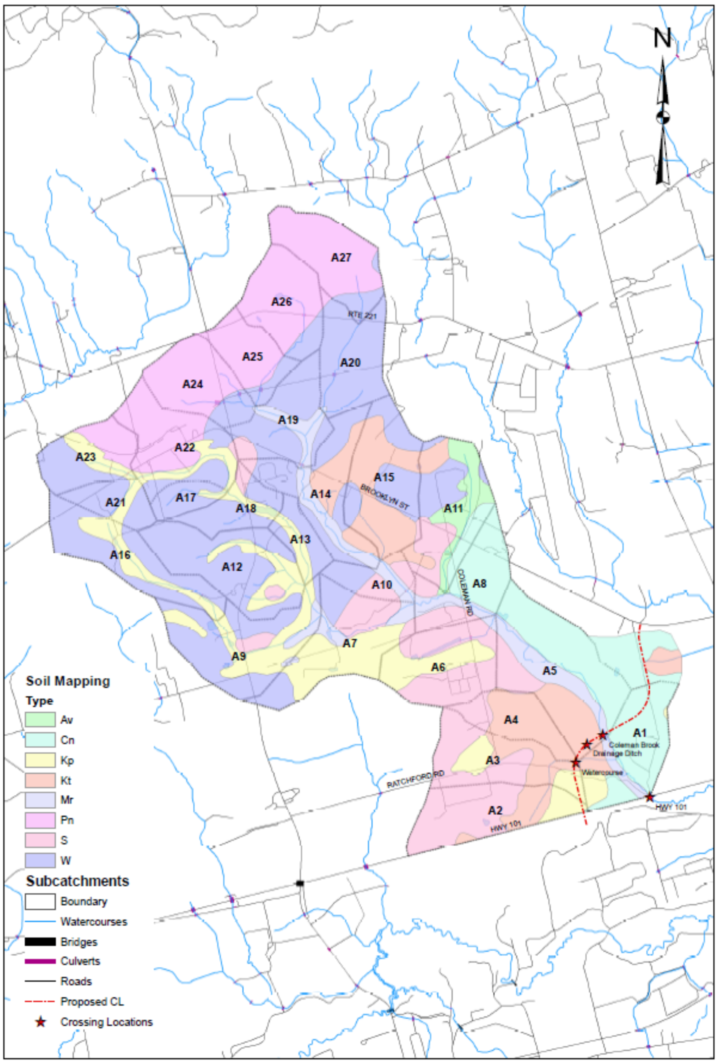


Table 4.2-1: Subcatchment Weighted CN Value by Land Use

Subcatchment	**Total Area (km^2)**	**Land Use (%)**						**Impervious Area (%)**	**Weighted CN**
		Farmland (CN=82)	ROW (CN=96)	Woods (CN=73)	Wetland (CN=98)	Orchard (CN=69)	Lake (CN=98)		
A1	0.41	54%	0%	37%	9%	0%	0%	8.7%	49
A2	0.42	48%	0%	18%	0%	34%	0%	0.3%	64
A3	0.40	57%	4%	31%	0%	8%	0%	0.2%	66
A4	0.23	52%	3%	46%	0%	0%	0%	0.1%	69
A5	0.69	22%	0%	60%	18%	0%	0%	18.1%	60
A6	0.44	41%	2%	37%	1%	18%	2%	2.8%	66
A7	0.51	37%	0%	48%	3%	11%	0%	3.0%	68
A8	0.33	66%	4%	9%	9%	12%	0%	9.4%	52
A9	0.55	81%	3%	11%	2%	2%	1%	3.5%	64
A10	0.16	50%	0%	50%	0%	0%	0%	0.0%	63
A11	0.48	61%	3%	22%	0%	14%	0%	0.5%	63
A12	0.52	82%	2%	14%	1%	0%	0%	0.9%	61
A13	0.14	71%	0%	25%	4%	0%	0%	4.1%	63
A14	0.43	55%	2%	35%	9%	0%	0%	8.6%	68
A15	0.49	78%	2%	20%	0%	0%	0%	0.2%	65
A16	0.42	71%	1%	26%	0%	1%	0%	0.3%	61
A17	0.10	71%	0%	27%	0%	2%	0%	0.0%	58
A18	0.21	71%	5%	17%	3%	0%	4%	7.6%	63
A19	0.36	37%	4%	59%	0%	0%	0%	0.2%	63
A20	0.35	71%	2%	26%	0%	0%	0%	0.1%	58
A21	0.16	59%	4%	8%	0%	29%	0%	0.2%	63
A22	0.45	88%	4%	6%	1%	0%	0%	1.5%	60
A23	0.29	45%	1%	38%	0%	16%	0%	0.0%	62
A24	0.34	84%	4%	9%	0%	3%	0%	0.2%	58
A25	0.24	65%	4%	25%	0%	6%	0%	0.2%	59
A26	0.36	50%	3%	43%	0%	4%	1%	0.8%	59
A27	0.38	54%	0%	45%	0%	0%	0%	0.0%	58

4.2.4 SCS UNIT HYDROGRAPH DIRECT RUNOFF MODEL

Hydrographs were developed for each of the 27 subcatchments, each based on their specific time of concentration, calculated using following equation.

$$T_c = \frac{L_o^{\,0.8}\left(\frac{25400}{CN} - 228.6\right)^{0.7}}{706.9S^{0.5}}$$

T_c Overland Time of Concentration (min)

L_o Length of overland flow path (m)

S Average catchment slope (m/m)

Catchment Lag was then determined by the industry accepted ratio of $T_L = 0.6T_C$.

Table 4.2-2: Subcatchment Runoff Characteristics

Subcatchment	Total Area (km²)	CN	Avg. Slope (m/m)	Tc (min)	T_L (min)
A1	0.41	49	0.010	139	83
A2	0.42	64	0.005	112	67
A3	0.40	66	0.024	47	28
A4	0.23	69	0.035	42	25
A5	0.69	60	0.015	31	18
A6	0.44	66	0.009	99	59
A7	0.51	68	0.009	111	67
A8	0.33	52	0.008	85	51
A9	0.55	64	0.039	31	18
A10	0.16	63	0.034	42	25
A11	0.48	63	0.018	69	42
A12	0.52	61	0.013	108	65
A13	0.14	63	0.028	47	28
A14	0.43	68	0.016	55	33
A15	0.49	65	0.019	90	54
A16	0.42	61	0.025	44	26
A17	0.10	58	0.041	43	26
A18	0.21	63	0.037	49	29
A19	0.36	63	0.043	41	25
A20	0.35	58	0.025	83	50
A21	0.16	63	0.021	83	50
A22	0.45	60	0.024	77	46
A23	0.29	62	0.025	39	24
A24	0.34	58	0.031	44	26
A25	0.24	59	0.018	93	56
A26	0.36	59	0.009	152	91
A27	0.38	58	0.016	60	36

4.2.5 STREAM ROUTING METHOD

Kinematic wave method was selected based on the limited information available for the upstream reaches outside of the survey extents. Inputs such as channel slope, width, side slopes and manning's values were all selected based on previous work in the region and aerial photography.

4.2.6 BOUNDARY CONDITIONS:

The downstream boundary condition of the Hydrological model was modelled as a simple outfall node to determine the peak flow rate of runoff produced by the watershed as well as to determine the peak flow reaching the Highway 101 culvert crossing.

4.2.7 RAINFALL

The ECCC Kentville CDA CS gauging station (Station ID 8202810) was chosen as the most appropriate representation of rainfall conditions, given it is the station's proximity to the proposed Interchange site and its acceptable period of record. Therefore, Chicago Distribution Design Storms were produced using the ECCC Kentville IDF information.

The data for this station was reviewed over the December through the end of February months to determine an appropriate 24 hour Winter Storm rainfall with a 1:100 year return period. This 24 hour rainfall was found to be approximately 65mm which was found to be similar to that of a 1:2 year peak rainfall event of 67mm. Therefore, the IDF data for a 1:2yr event IDF coefficients were adapted for the Winter Storm.

Climate change (CC) was incorporated as an additional Design Rainstorm Events, 1:100year+CC, based on the SSP 4.5 climate scenario IDF information produced by the Computerized IDF CC Tool v5.0 for the ECCC Kentville station. The Summer and Winter Storm values under the climate change scenario were both found to fall within the increase in precipitation range proposed by Richards and Daigle.

Table 4.2-3: Kentville IDF Coefficients

Design Storm	IDF Coefficients		
	a	b	c
1:100yr (Summer)	57.0	0.783	0.164
1:100yr (Winter)	17.6	0.590	0.038
1:50yr (Summer)	42.3	0.689	0.085
1:50yr (Winter)	15.8	0.584	0.037

Table 4.2-4: Kentville IDF Climate Change Coefficients

Design Storm	IDF Coefficients		
	a	b	c
1:100yr+CC (Summer)	64.0	0.786	0.167
1:100yr+CC (Winter)	19.4	0.591	0.038

4.2.8 MODEL ASSUMPTIONS

To produce a working model, additional assumptions were required due to limited data regarding soil composition, infiltration, groundwater flow, etc., such as:

- No evaporation of the brook or watershed within the 24hr design storm period beyond that incorporated in the SCS Curve Number Loss Model;
- No baseflow (from groundwater) into the system. It is acknowledged that baseflow could be a potential component in streamflow, however there is currently insufficient stream and water table information to adequately incorporate this component and is therefore outside the scope of this analysis. For the nature and purpose of this study, the conservative nature of the SCS runoff methodology was considered appropriate to estimate peak flows to the crossings during severe rainfall events.
- The Winter Storm scenario assumed all subcatchments had a CN value of 90 to simulate rainfall on frozen ground.

4.3 RESULTS AND DISCUSSION

The following section will discuss the impacts of the proposed crossing locations as well as propose approximate structure sizing and fish passage options. .

The following Table 4.3-1, Table 4.3-2, Table 4.3-3, and Table 4.3-4 summarizes the peak flow estimates resulting from the Hydrological model for the Coleman Brook Watershed at the approximate locations of the four proposed crossing structures. Flow values are estimates based on IDF information from ECCC Kentville climate station (8202810). Results are presented for analyses with- and without consideration of climate change.

It should be noted that to accommodate the flows, the two Coleman Brook crossing locations would require structures with spans greater than 3.0m at which point the structure is considered a bridge under the CHBDC. Therefore, to meet the CHBDC the 1:50 year flows need to be evaluated. The other two crossing locations can be accommodated by closed bottom structures, therefore only NSE's 1:100yr flow needs to be checked.

Table 4.3-1: Hydrological Modelling Analysis Summary – Upper Coleman Brook

1:50-Year Peak Flow (m^3/s)	1:50-Year Winter Peak Flow (m^3/s)	1:100-Year Peak Flow (m^3/s)	1:100-Year Winter Peak Flow (m^3/s)	1:100-Year Peak Flow + CC (m^3/s)	1:100-Year Winter Peak Flow + CC (m^3/s)
12.9	22.3	17.9	26.3	24.0	30.8

Table 4.3-2: Hydrological Modelling Analysis Summary – HWY 101 Crossing

1:50-Year Peak Flow (m^3/s)	1:50-Year Winter Peak Flow (m^3/s)	1:100-Year Peak Flow (m^3/s)	1:100-Year Winter Peak Flow (m^3/s)	1:100-Year Peak Flow + CC (m^3/s)	1:100-Year Winter Peak Flow + CC (m^3/s)
15.3	25.5	20.9	30.3	28.0	35.4

Table 4.3-3: Hydrological Modelling Analysis Summary – Unnamed Watercourse

1:100-Year Peak Flow (m^3/s)	1:100-Year Winter Peak Flow (m^3/s)	1:100-Year Peak Flow + CC (m^3/s)	1:100-Year Winter Peak Flow + CC (m^3/s)
1.7	3.0	2.6	3.7

Table 4.3-4: Hydrological Modelling Analysis Summary – Drainage Ditch

1:100-Year Peak Flow (m^3/s)	1:100-Year Winter Peak Flow (m^3/s)	1:100-Year Peak Flow + CC (m^3/s)	1:100-Year Winter Peak Flow + CC (m^3/s)
0.4	0.7	0.6	0.8

4.3.1 WATERCOURSE CROSSING LOCATIONS

Each crossing location was reviewed to see what structure and fish passage facilities would be necessary to meet all provincial and federal regulatory requirements. The following discussion describes each crossing and provides recommendations for each installation.

The proposed collector road width was assumed to be approximately 14.0m, including lane widths, shoulders and allowances for guardrail. Assuming the road height will be approximately 4.0m above the crossing channel's centerline, the resulting side slopes would need crossing structures approximately 30.0m long. It is recommended that the road profiles in the vicinity of the two smaller crossing structures be reviewed to minimize road heights, therefore allowing these closed bottom structures to fall below 25.0m long.

The area adjacent to the upper section of Coleman Brook is made up of mostly heavy forest and some areas of wetland surrounding sections of the river. The lower section of Coleman Brook at the Highway 101 crossing consists of farmland and some wooded areas. The unnamed watercourse has a narrow row of trees on either side of the water course with farmland beyond the tree lines. Finally, the drainage ditch is located along the edge of a section of farmland with heavy trees on the north side of the watercourse.

Table 4.3-5: Channel Dimensions

Crossing	Watercourse Slope	Channel Width	Bank Full Depth
HWY 101	0.4%	≈ 9.8m	≈ 0.8m
Coleman Brook Crossing	0.4%	≈ 4.8m	≈ 0.6m
Unnamed Watercourse	0.4%	≈ 1.9m	≈ 0.4m
Drainage Ditch	0.3%	≈ 4.0m	≈ 0.8m

Flow profiles for the three watercourse crossings can be found in Appendix C. For the two Coleman Brook crossings only the maximum flow profile and the governing 1:50 year profile are shown for clarity.

4.3.2 HWY 101 CROSSING

The existing Coleman Brook crossing at HWY 101 with twin 1800mm culverts does not have sufficient capacity to accommodate any of the 1:100 year design flows. Additionally, as multi-barrel crossings are not preferred by NSE, it is recommended this structure be replaced and upgraded.

The proposed structure should be sized to span the estimated channel width at a minimum at the crossing location. For the purposes of this study a 12.0m width was assumed to accommodate the peak flows, with no change in the hydraulic grade line of the Brook. The rise of the structure being dictated by the 1:50 year Winter flow plus 1.0m freeboard. This open area, as a result of the CHBDC freeboard requirement, has more than sufficient capacity to pass all design flows.

Table 4.3-6: Potential Crossing Structure Options

Crossing	1:50yr Winter Peak Flow (m^3/s)	1:50yr Winter Elev. (m)	1:100-Year Winter Peak Flow + CC (m^3/s)	1:100-Year Winter + CC Elev. (m)	Approx. CHBDC Min. Elev. (m)[1]
HWY 101	25.5	19.1	35.4	19.6	20.1

Note: [1] This value is strictly a vertical offset from the hydrological flow elevations assuming the structure spans past the banks (12.0m opening width) and is intended as a scoping exercise, further hydraulic modelling will be required for detailed design of the structure.

4.3.3 UPPER COLEMAN BROOK

The new Coleman Brook crossing along the proposed collector road should be sized to span the estimated channel width at a minimum at the crossing location. For the purposes of this study a 10.0m width was assumed to accommodate the peak flows, with no change in the hydraulic grade line of the Brook. The rise of the structure being dictated by the 1:50 year Winter flow plus 1.0m freeboard. This open area, as a result of the CHBDC freeboard requirement, has more than sufficient capacity to pass all design flows.

Table 4.3-7: Potential Crossing Structure Options

Crossing	1:50yr Winter Peak Flow (m^3/s)	1:50yr Winter Elev. (m)	1:100-Year Winter Peak Flow + CC (m^3/s)	1:100-Year Winter + CC Elev. (m)	Approx. CHBDC Min. Elev. (m)[1]
Upper Coleman Brook	22.3	20.4	30.8	20.9	21.4

Note: [1] This value is strictly a vertical offset from the hydrological flow elevations assuming the structure spans past the banks (10.0m opening width) and is intended as a scoping exercise, further hydraulic modelling will be required for detailed design of the structure.

4.3.4 UNNAMED WATERCOURSE

The new Unnamed Watercourse crossing along the proposed collector road is a culvert sized to freely pass the 1:100 year Winter flow plus climate change, with a $H_w/D = 1.0$, to meet NSE's opening requirements. This structure would require a downstream energy dissipation pool to meet NSE's watercourse alteration requirements, however, due to the watercourse slope fish baffles are not required.

Table 4.3-8: Potential Culvert Crossing Structures

Crossing	1:100yr Design Flow (m^3/s)[1]	Min. Opening Size	Proposed Structure	Baffles (Y/N)	Downstream Pool Min. Base Dimensions
Unnamed Watercourse	3.7	1500mm Dia.	Circular Culvert	N	4.50m x 3.00m

4.3.5 DRAINAGE DITCH

The new Drainage Ditch crossing along the proposed collector road is a culvert sized to pass the 1:100 year Winter flow plus climate change with a $H_w/D = 1.1$, as this is a drainage cross culvert and would need to only meet NSDPW cross culvert sizing with a 1:100 year flow and maximum $H_w/D = 1.5$. With an $H_w/D = 1.5$ and the design peak flow, the required standard culvert size does not change.

Table 4.3-9: Drainage Ditch Crossing Structure

Crossing	1:100yr Design Flow (m^3/s)[2]	Min. Opening Size	Proposed Structure	Baffles (Y/N)	Downstream Pool Min. Base Dimensions
Drainage Ditch	0.8	750mm Dia.	Circular Culvert	N	N/A[1]

Note: [1] It is recommended that this location be review by an NSE Inspector as this drainage ditch characteristics do not seem to meet NSE's watercourse characteristic requirements.

5 CONCLUSION

The Cambridge Interchange site is located adjacent to Coleman Brook, where the brook crosses Highway 101 within the Cornwallis River Valley of Nova Scotia, approximately 96 km northwest of Halifax. The southern portions of the site are accessed via municipally owned and Annapolis First Nations roads. The northern portion of the site is not serviced by any roads, primarily consisting of farmland with vegetated tree bands along Coleman Brook.

There are four proposed crossings that are currently impacted by the proposed Cambridge Interchange alignment. The first is an existing crossing of Coleman Brook at HWY101 were there is currently a twin 1800mm culvert arrangement. The second crossing occurs where the alignment of the proposed collector road, connecting the proposed Interchange to Brooklyn Road, crosses Coleman Brook north of the current crossing. There are two other smaller crossings along this alignment, one, a small unnamed watercourse crossing and the second, what is believed to be a drainage ditch adjacent to farmland. Flows are significantly lower in the two tributary crossings to Coleman Brook.

After the completion of HEC-HMS modelling, the following 1:100 year Winter +CC peak design flows were found at each structure location and are accompanied by a minimum opening size.

Crossing	Peak Design Flow (m^3/s)	Min. Opening Size	Proposed Structure	Baffles (Y/N)	Downstream Pool Min. Base Dimensions
HWY 101	35.4	12.0m (span) x 3.25m (rise)	Clear Span Structure	N	N/A[1]
Coleman Brook Crossing	30.8	10.0m (span) x 3.35m (rise)	Clear Span Structure	N	N/A[1]
Unnamed Watercourse	3.7	1500mm Dia.	Circular Culvert	N	4.50m x 3.00m
Drainage Ditch	0.8	750mm Dia.	Circular Culvert	N	N/A[2]

Exact sizing, placement and rock armour sizing should be considered during detailed design of these structures, once final alignment and side slopes of the proposed collector road have been chosen. All crossing structures are to be aligned parallel to the watercourse or ditch they are crossing

The Unnamed Watercourse did not have a watercourse slope of $\geq$ 0.5% so there is no need for baffles to be installed in this culvert, as per DFO fish passage guidelines.

The proposed collector road width was assumed to be approximately 14.0m, including lane widths, shoulders and allowances for guardrail. Assuming the road height will be approximately 4.0m above the crossing channel’s centerline, the resulting side slopes would need crossing structures approximately 30.0m long. It is recommended that the road profiles in the vicinity of the two smaller crossing structures be reviewed to minimize road heights, therefore allowing these closed bottom structures to fall below 25.0m long.

Only two of the four structures are closed bottom structures, the Unnamed Watercourse crossing and the Drainage Ditch crossing. The Unnamed Watercourse crossing is on a watercourse and will need downstream dissipation pool to meet NSE requirements however the second crossing, the Drainage Ditch, may not need a dissipation pool. This particular crossing does not seem to meet NSE watercourse designation requirements, therefore it is highly recommended that NSDPW have this location be reviewed by an NSE Inspector.

6 REFERENCES

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APPENDIX

A

HEC-HMS MODEL INPUT PARAMETERS

CATCHMENT AREAS

Subbasin	Total Area (sq.m)	Total Area (sq.km)
A1	410281.8	0.41
A2	423277.5	0.42
A3	398962.4	0.40
A4	230049.5	0.23
A5	687395.1	0.69
A6	434939.3	0.43
A7	505478.5	0.51
A8	333472.0	0.33
A9	547045.6	0.55
A10	160193.3	0.16
A11	476741.0	0.48
A12	517344.1	0.52
A13	140799.5	0.14
A14	433729.2	0.43
A15	494449.8	0.49
A16	419434.8	0.42
A17	103619.4	0.10
A18	205417.0	0.21
A19	356892.3	0.36
A20	352230.4	0.35
A21	159468.5	0.16
A22	445278.8	0.45
A23	287954.9	0.29
A24	343202.5	0.34
A25	241115.2	0.24
A26	358969.7	0.36
A27	377411.4	0.38

SCS CURVE NUMBER LOSS MODEL (SUMMER)

Subbasin	CN	Imperv %
A1	49	13.7
A2	64	5.3
A3	66	5.2
A4	69	5.1
A5	60	23.1
A6	66	7.8
A7	68	8.0
A8	52	14.4
A9	64	8.5
A10	63	5.0
A11	63	5.5
A12	61	5.9
A13	63	9.1
A14	68	13.6
A15	65	5.2
A16	61	5.3
A17	58	5.0
A18	63	12.6
A19	63	5.2
A20	58	5.1
A21	63	5.2
A22	60	6.5
A23	62	5.0
A24	58	5.2
A25	59	5.2
A26	59	5.8
A27	58	5.0

SCS CURVE NUMBER LOSS MODEL (WINTER)

Subbasin	CN	Imperv %
A1	90	13.7
A2	90	5.3
A3	90	5.2
A4	90	5.1
A5	90	23.1
A6	90	7.8
A7	90	8.0
A8	90	14.4
A9	90	8.5
A10	90	5.0
A11	90	5.5
A12	90	5.9
A13	90	9.1
A14	90	13.6
A15	90	5.2
A16	90	5.3
A17	90	5.0
A18	90	12.6
A19	90	5.2
A20	90	5.1
A21	90	5.2
A22	90	6.5
A23	90	5.0
A24	90	5.2
A25	90	5.2
A26	90	5.8
A27	90	5.0

SCS UNIT HYDROGRAPH DIRECT RUNOFF MODEL

Subbasin	Graph Type	Lag (min)
A1	Standard	83
A2	Standard	67
A3	Standard	28
A4	Standard	25
A5	Standard	18
A6	Standard	59
A7	Standard	67
A8	Standard	51
A9	Standard	18
A10	Standard	25
A11	Standard	42
A12	Standard	65
A13	Standard	28
A14	Standard	33
A15	Standard	54
A16	Standard	26
A17	Standard	26
A18	Standard	29
A19	Standard	25
A20	Standard	50
A21	Standard	50
A22	Standard	46
A23	Standard	24
A24	Standard	26
A25	Standard	56
A26	Standard	91
A27	Standard	36

KINEMATIC WAVE ROUTING METHOD

Name	Length (m)	Slope (m/m)	Mannings	Shape	Base (m)	Side (xH:1V)	Invert (m)
Reach-1	372.9	0.013	0.035	Trapezoid	1	5	44.0
Reach-2	724.1	0.013	0.035	Trapezoid	1	5	40.0
Reach-3	626.8	0.020	0.035	Trapezoid	1	5	44.0
Reach-4	448.7	0.011	0.035	Trapezoid	1	5	40.0
Reach-5	581.8	0.026	0.035	Trapezoid	1	5	40.0
Reach-6	726.1	0.014	0.035	Trapezoid	1	5	35.0
Reach-7	492.8	0.010	0.035	Trapezoid	2	5	35.0
Reach-8	388.9	0.013	0.035	Trapezoid	1	5	50.0
Reach-9	334.0	0.015	0.035	Trapezoid	1	5	50.0
Reach-10	990.1	0.010	0.035	Trapezoid	1.5	5	40.0
Reach-11	508.3	0.03	0.035	Trapezoid	1	5	40.0
Reach-12	223.3	0.011	0.035	Trapezoid	1.5	5	35.0
Reach-13	1124.4	0.011	0.035	Trapezoid	2.5	5	30.0
Reach-14	569.5	0.009	0.035	Trapezoid	2	5	30.0
Reach-15	611.6	0.008	0.035	Trapezoid	2	5	32.5
Reach-17	669.8	0.015	0.035	Trapezoid	1.5	5	24.0
Reach-18	1009.6	0.012	0.035	Trapezoid	1	5	40.0
Reach-19	1044.9	0.010	0.035	Trapezoid	1.5	5	30.0
Reach-20	259.8	0.020	0.035	Trapezoid	2.5	5	30.0
Reach-21	875.7	0.006	0.035	Trapezoid	2.5	5	25.0
Reach-22	406.6	0.012	0.035	Trapezoid	2.5	5	25.0
Reach-23	287.7	0.006	0.035	Trapezoid	3	5	24.0
Reach-24	429.0	0.006	0.035	Trapezoid	3	5	23.0
Reach-25	369.7	0.014	0.035	Trapezoid	1	5	23.0
Reach-26	1361.4	0.0015	0.035	Trapezoid	3.5	5	21.0
Reach-27	314.6	0.005	0.035	Trapezoid	1	5	23.0
Reach-28	198.5	0.005	0.035	Trapezoid	1	5	22.0
Reach-29	166.8	0.005	0.035	Trapezoid	1	5	21.0
Reach-30	304.4	0.005	0.035	Trapezoid	1	5	20.5
Reach-31	129.0	0.004	0.035	Trapezoid	3.5	5	20.5
Reach-32	433.0	0.004	0.035	Trapezoid	3.5	5	20.0.
Reach-33	30.0	0.005	0.035	Trapezoid	1	5	22.5
Reach-34	297.6	0.005	0.035	Trapezoid	1	5	210

RAINFALL

Chicago Distribution Equations

(Keifer, C.J. and H.h. Chu. 1957)

$$i_{\tau\neq 0}=\frac{a\left[(1-b)\left(\frac{\tau}{\rho}\right)+c\right]}{\left(\frac{\tau}{\rho}+c\right)^{(1+b)}}\qquad i_{\tau=0}=\frac{a}{(\Delta t+c)^{b}}\qquad {}^{3}/_{8}\leq r\leq {}^{5}/_{8}\qquad r=\frac{t_p}{t_d}$$

$$for\,t>t_p:\quad \tau=t-t_p;\ \rho=1-r\qquad for\,t\leq t_p:\quad \tau=t_p-t;\ \rho=r$$

$i = average\ intensity\ (mm/hr)$
$t_d = duration\ of\ rainfall\ (hr)$
$\Delta t = storm\ time\ step\ (min)$
$t_p = time\ to\ peak\ of\ storm\ (hr)$
$a, b, c = IDF\ constants\ dependent\ on\ storm\ return\ period\ (requires\ units\ of\ mm\ \&\ hrs)$

IDF Constants & Chicago Storm Parameters

Table 1 - 1:50 Year Design Storm

IDF Constants (IDF Tool v5.0)		Chicago Storm Parameters			Results		
a	42.3	Δt	5	min	Peak Intensity	144.4	mm/hr
b	0.689	r	0.5		Total Depth	112.8	mm
c	0.085	t_d	24	hr			
		t_p	12	hr			

Table 2 - 1:50 Year Winter Design Storm

IDF Constants (IDF Tool v5.0)		Chicago Storm Parameters			Results		
a	15.8	Δt	5	min	Peak Intensity	54.5	mm/hr
b	0.584	r	0.5		Total Depth	59.2	mm
c	0.037	t_d	24	hr			
		t_p	12	hr			

Table 3 - 1:100 Year Design Storm

IDF Constants (IDF Tool v5.0)		Chicago Storm Parameters			Results		
a	47.0	Δt	5	min	Peak Intensity	161.1	mm/hr
b	0.696	r	0.5		Total Depth	122.6	mm
c	0.087	t_d	24	hr			
		t_p	12	hr			

Table 4 - 1:100 Year Winter Design Storm

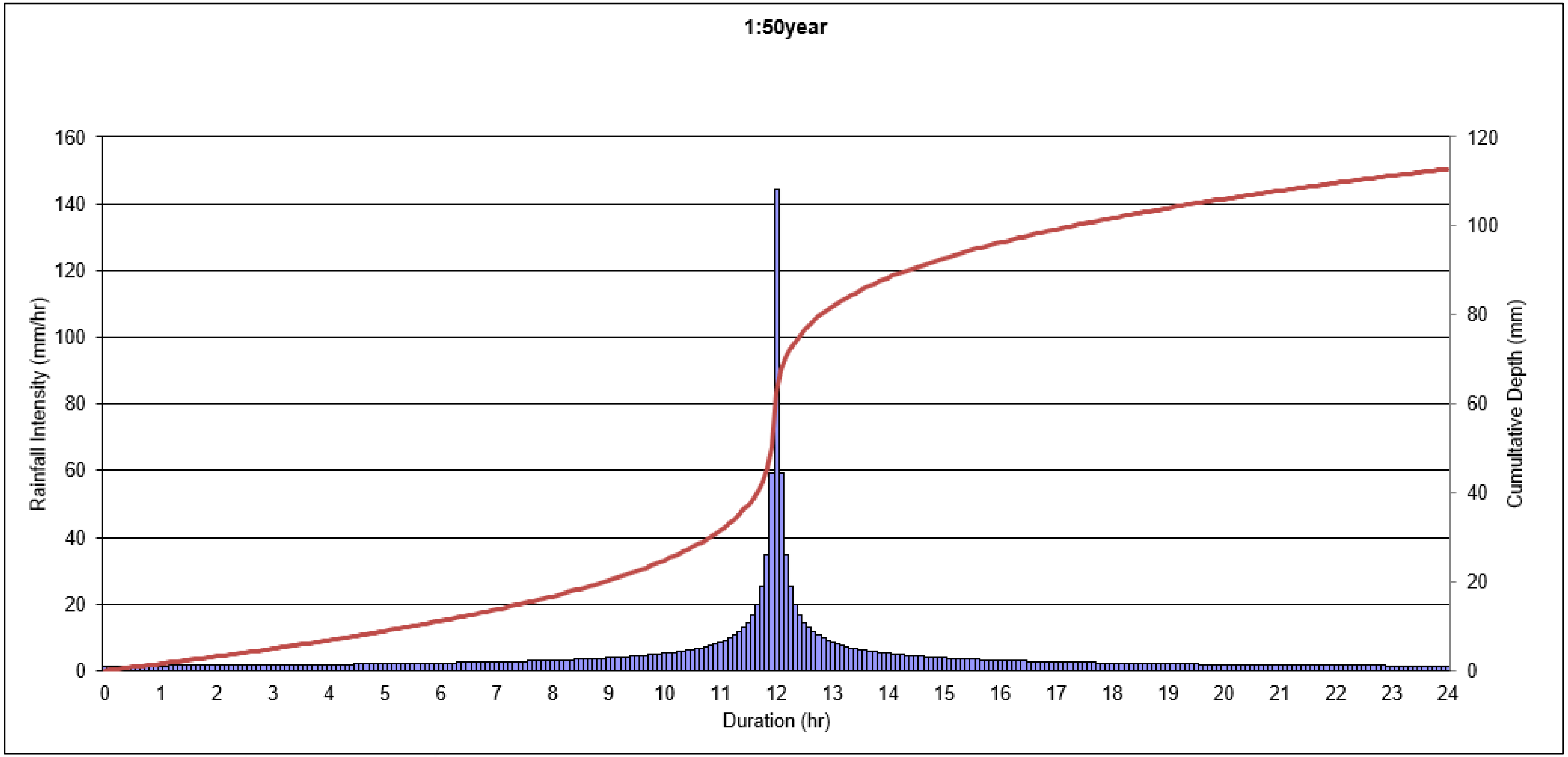
IDF Constants (IDF Tool v5.0)		Chicago Storm Parameters			Results		
a	17.6	Δt	5	min	Peak Intensity	61.1	mm/hr
b	0.59	r	0.5		Total Depth	64.6	mm
c	0.038	t_d	24	hr			
		t_p	12	hr			

Table 5 - 1:100 Year + CC Design Storm

IDF Constants (IDF Tool v5.0)		Chicago Storm Parameters			Results		
a	64	Δt	5	min	Peak Intensity	190.1	mm/hr
b	0.786	r	0.5		Total Depth	124.9	mm
c	0.167	t_d	24	hr			
		t_p	12	hr			

Table 6 - 1:100 Year Winter + CC Design Storm

IDF Constants (IDF Tool v5.0)		Chicago Storm Parameters			Results		
a	19.4	Δt	5	min	Peak Intensity	67.5	mm/hr
b	0.591	r	0.5		Total Depth	70.9	mm
c	0.038	t_d	24	hr			
		t_p	12	hr			


1:50year
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140
120
100
80
60
40
20
0
Rainfall Intensity (mm/hr)
120
100
80
60
40
20
0
Cumultative Depth (mm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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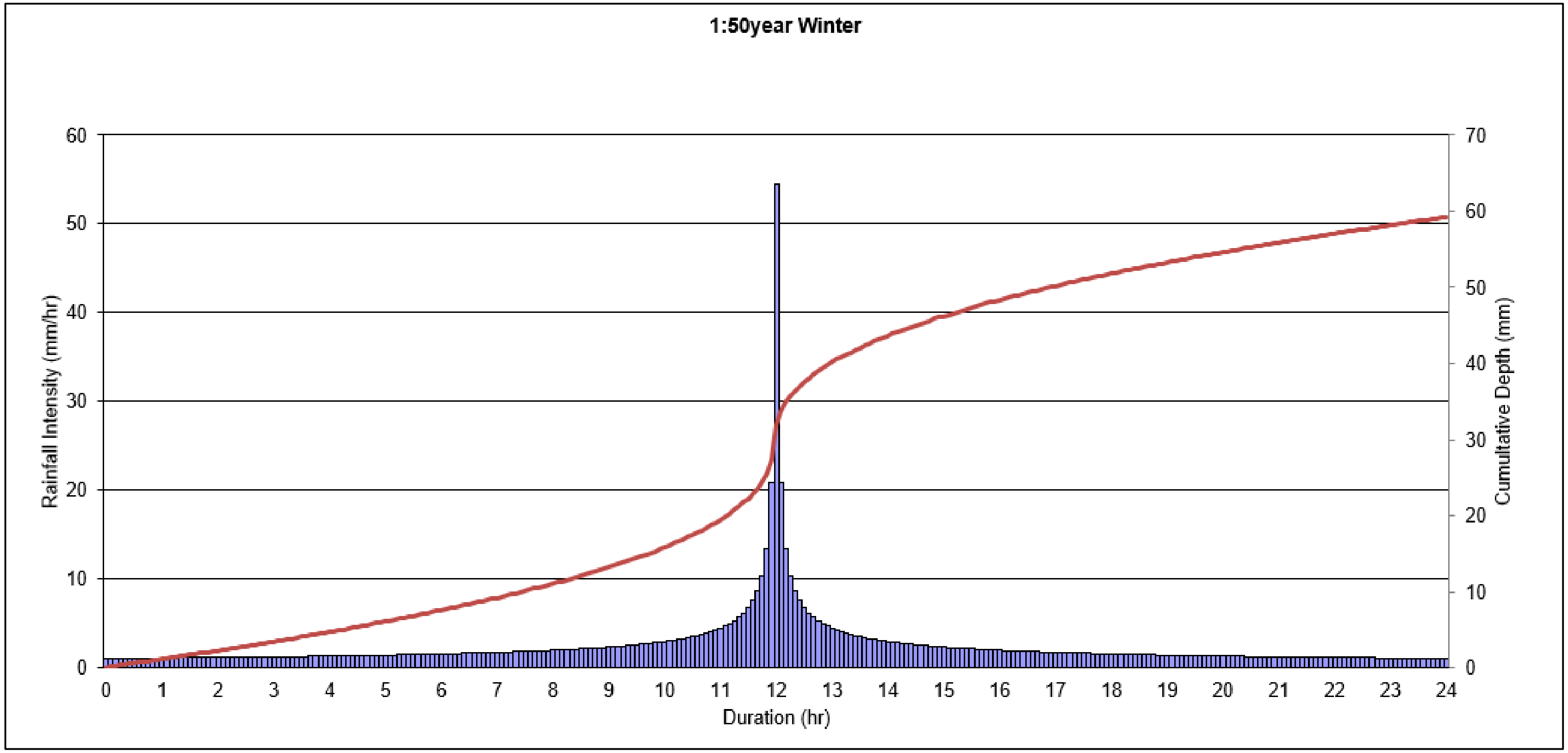
17
18
19
20
21
22
23
24
Duration (hr)

1:50year Winter
Rainfall Intensity (mm/hr)
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10
20
30
40
50
60
Cumultative Depth (mm)
0
10
20
30
40
50
60
70
Duration (hr)
0
1
2
3
4
5
6
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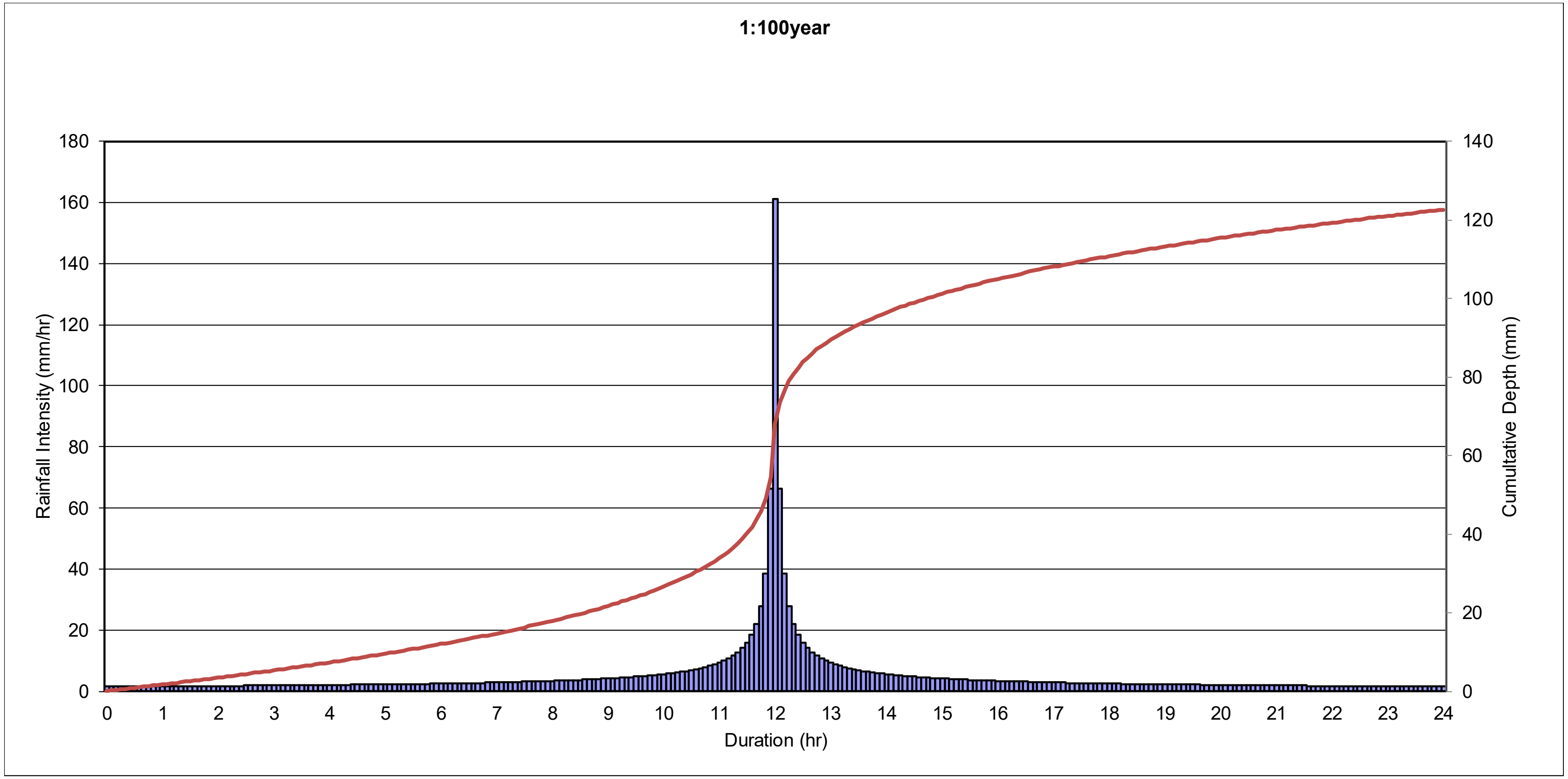
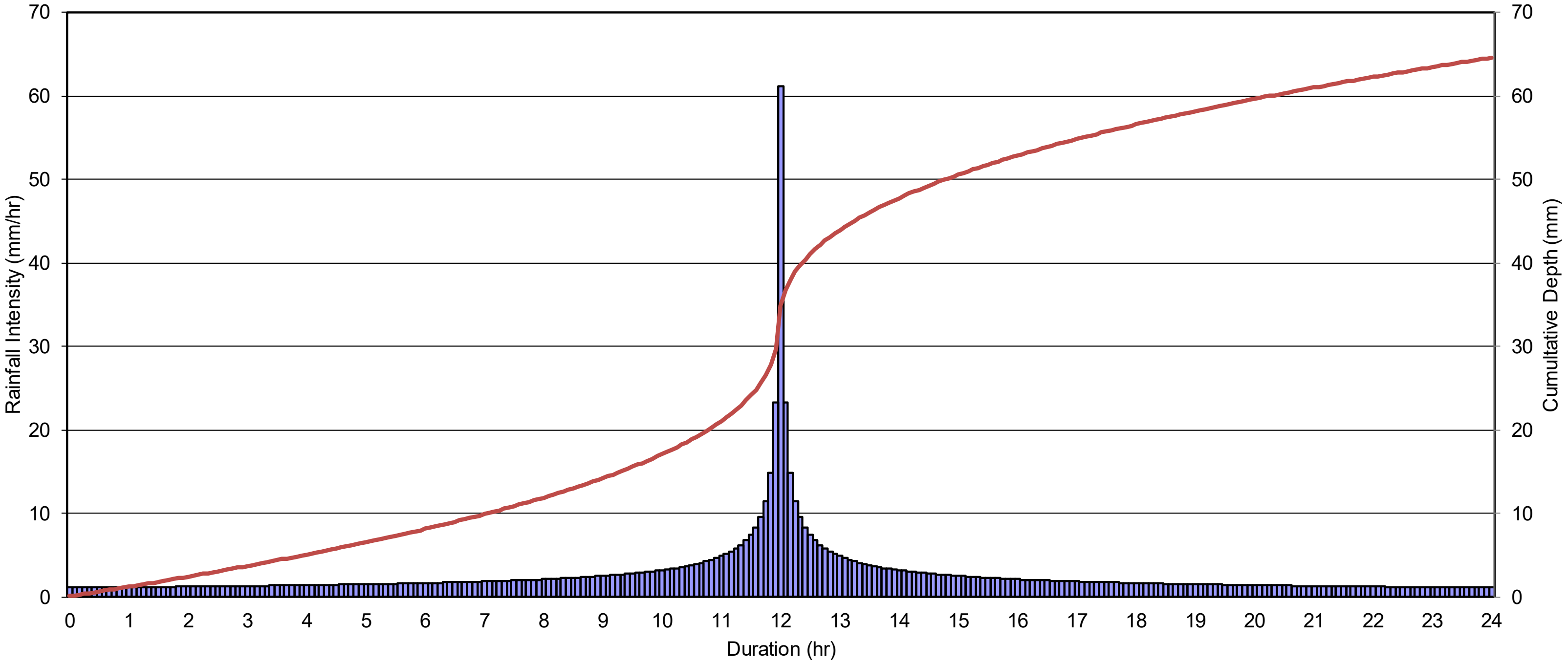
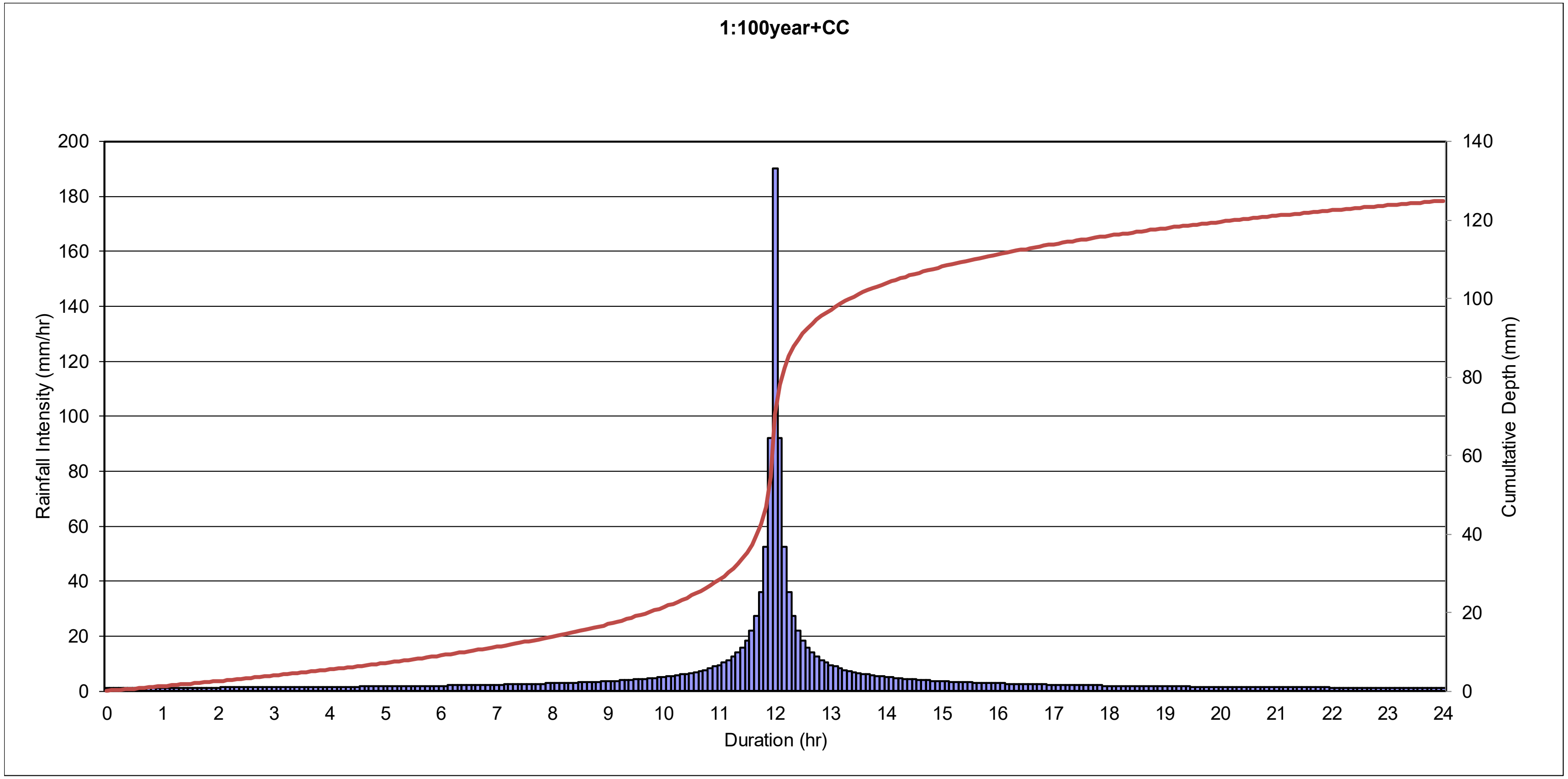
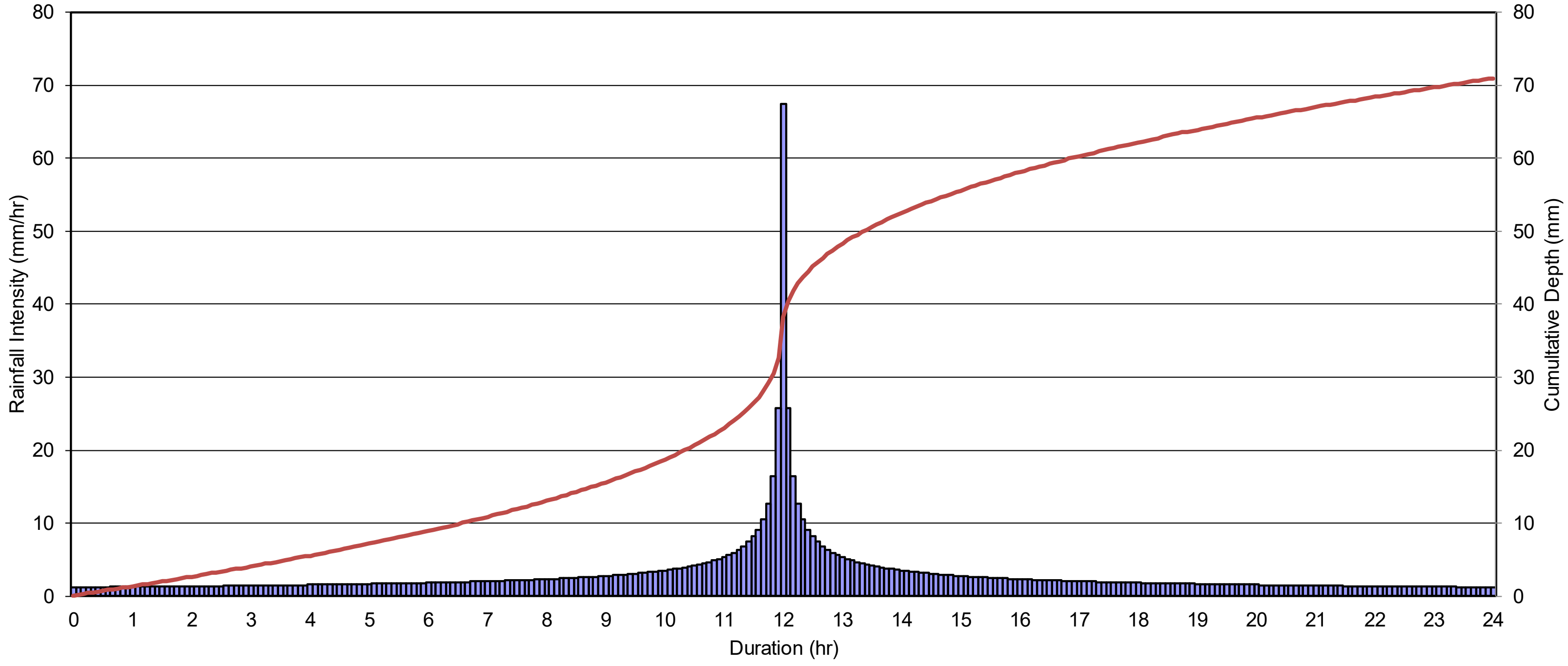

1:100year
Rainfall Intensity (mm/hr)
180
160
140
120
100
80
60
40
20
0
Cumultative Depth (mm)
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Duration (hr)

1:100year Winter



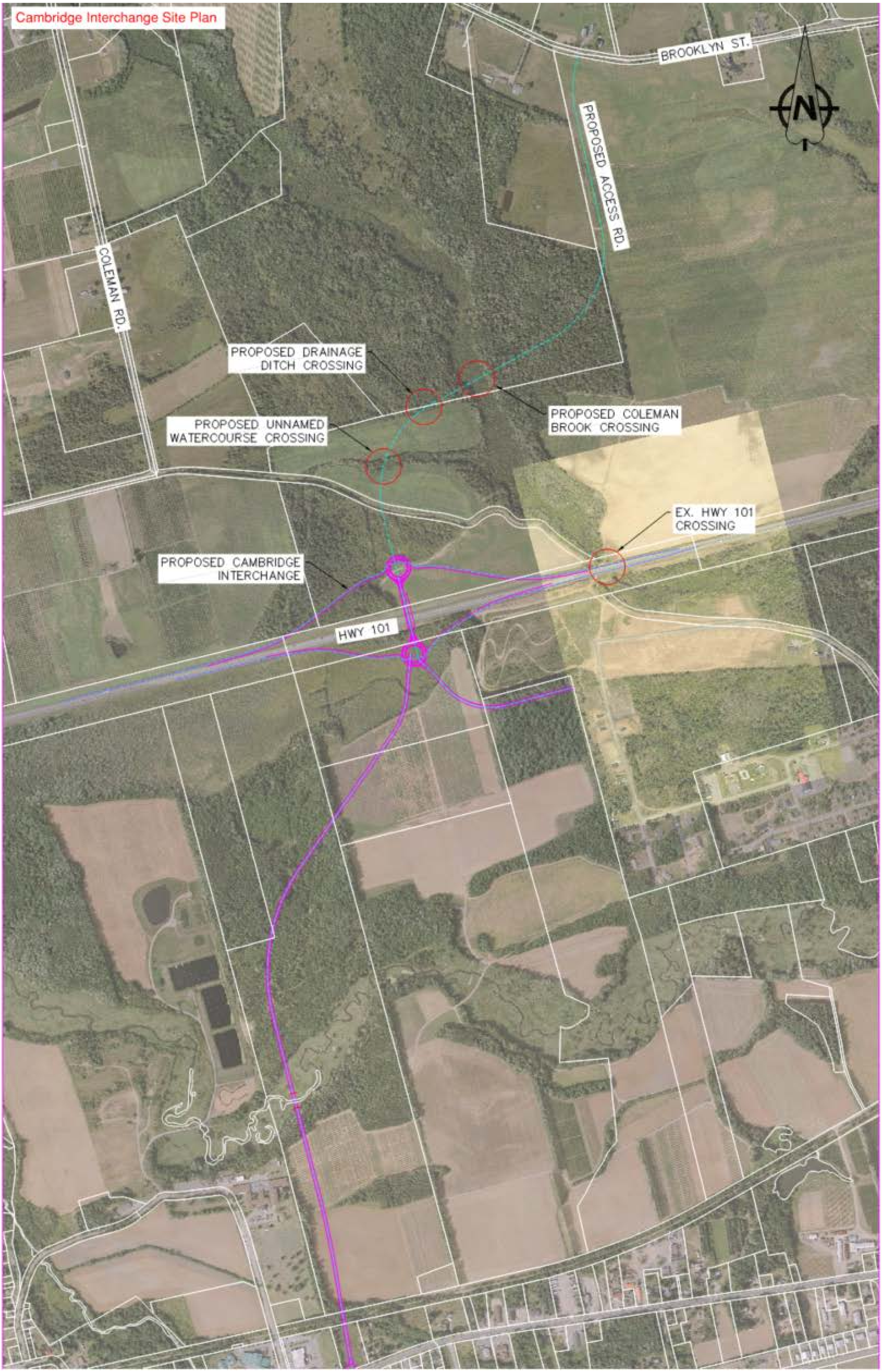

1:100year+CC
Rainfall Intensity (mm/hr)
200
180
160
140
120
100
80
60
40
20
0
Cumultative Depth (mm)
140
120
100
80
60
40
20
0
Duration (hr)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

1:100year+CC Winter
Rainfall Intensity (mm/hr)
Cumultative Depth (mm)
Duration (hr)
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

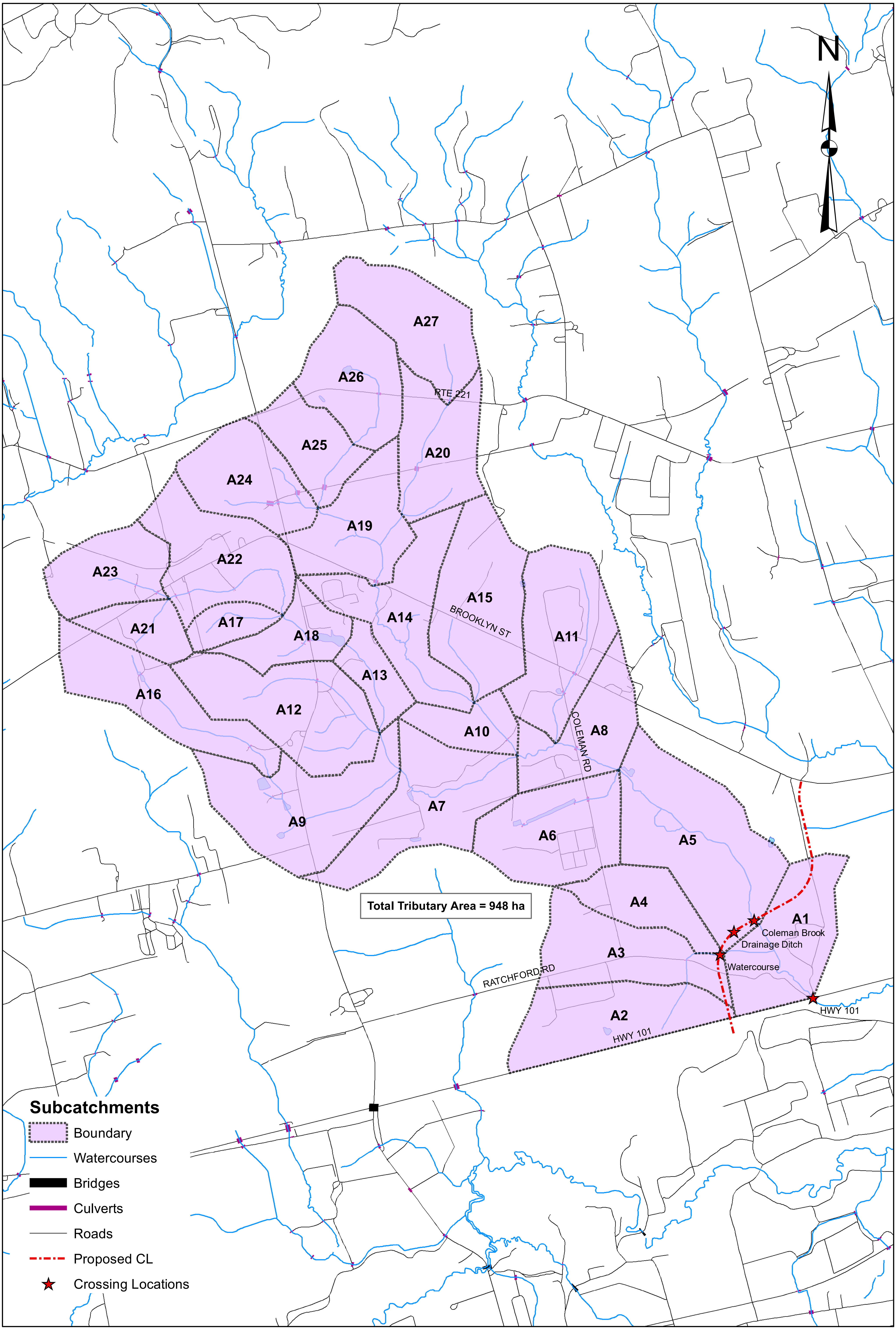
APPENDIX

B FIGURES

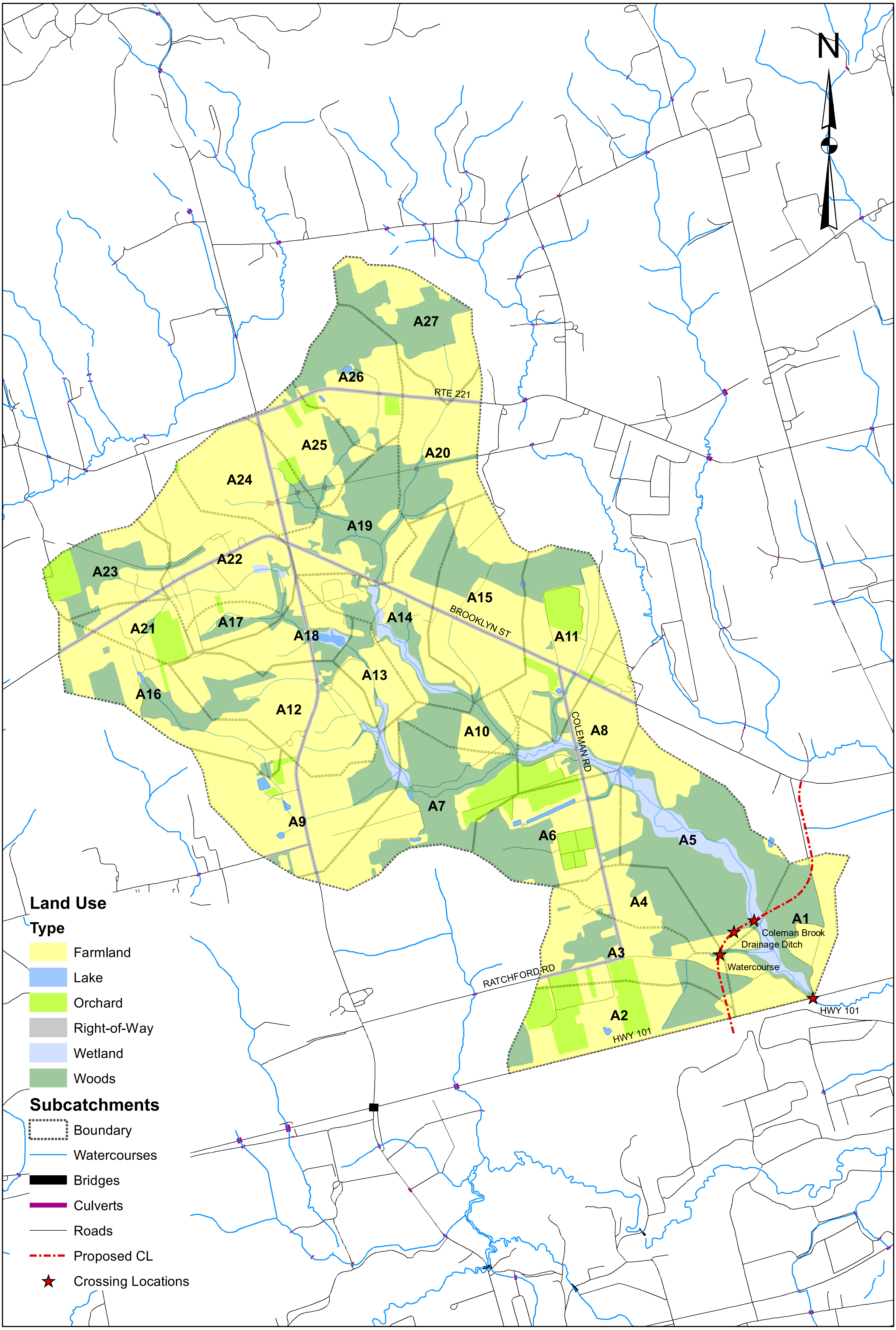
Cambridge Interchange Site Plan



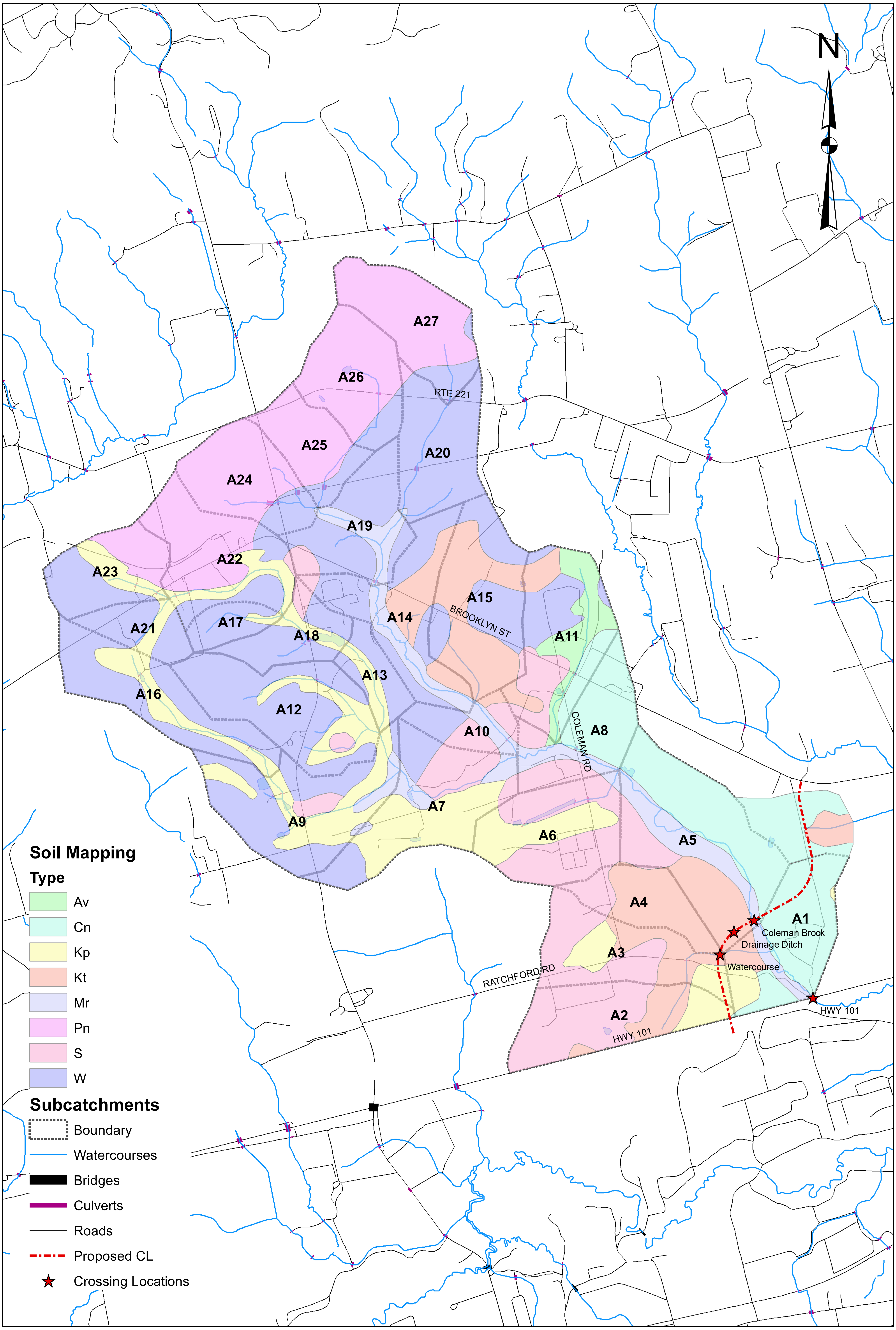
Cambridge Interchange



Cambridge Interchange



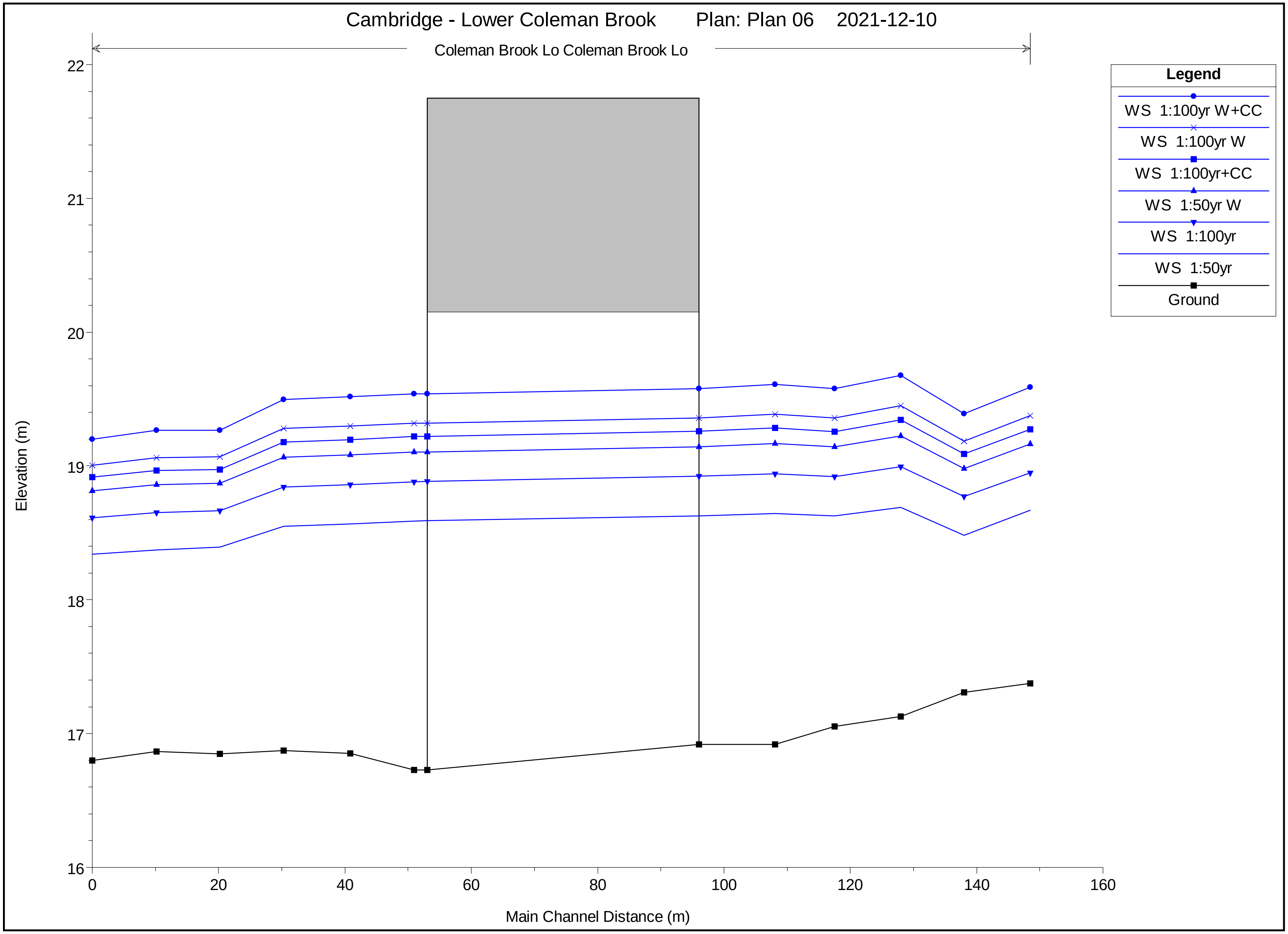
Cambridge Interchange



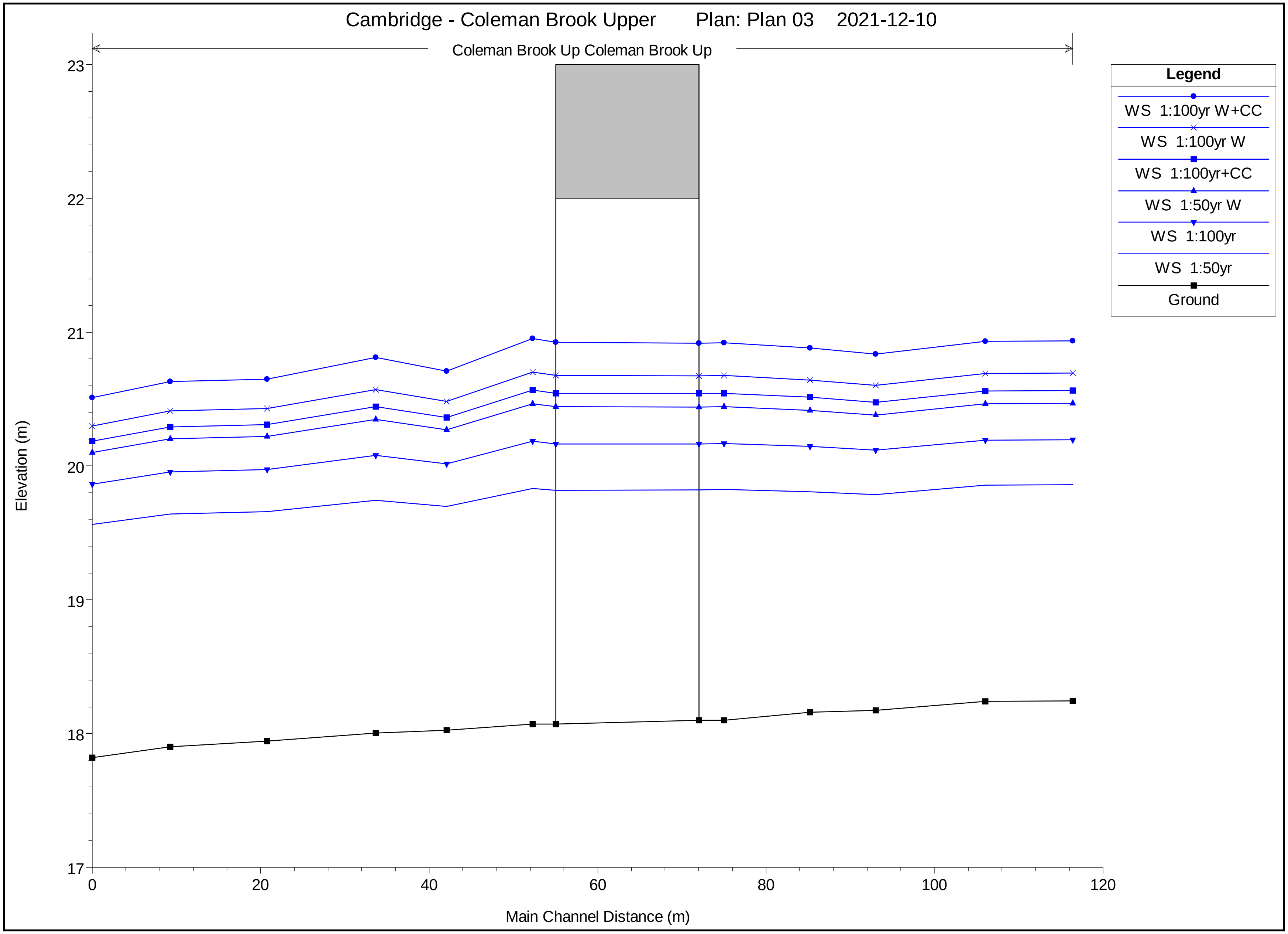
APPENDIX

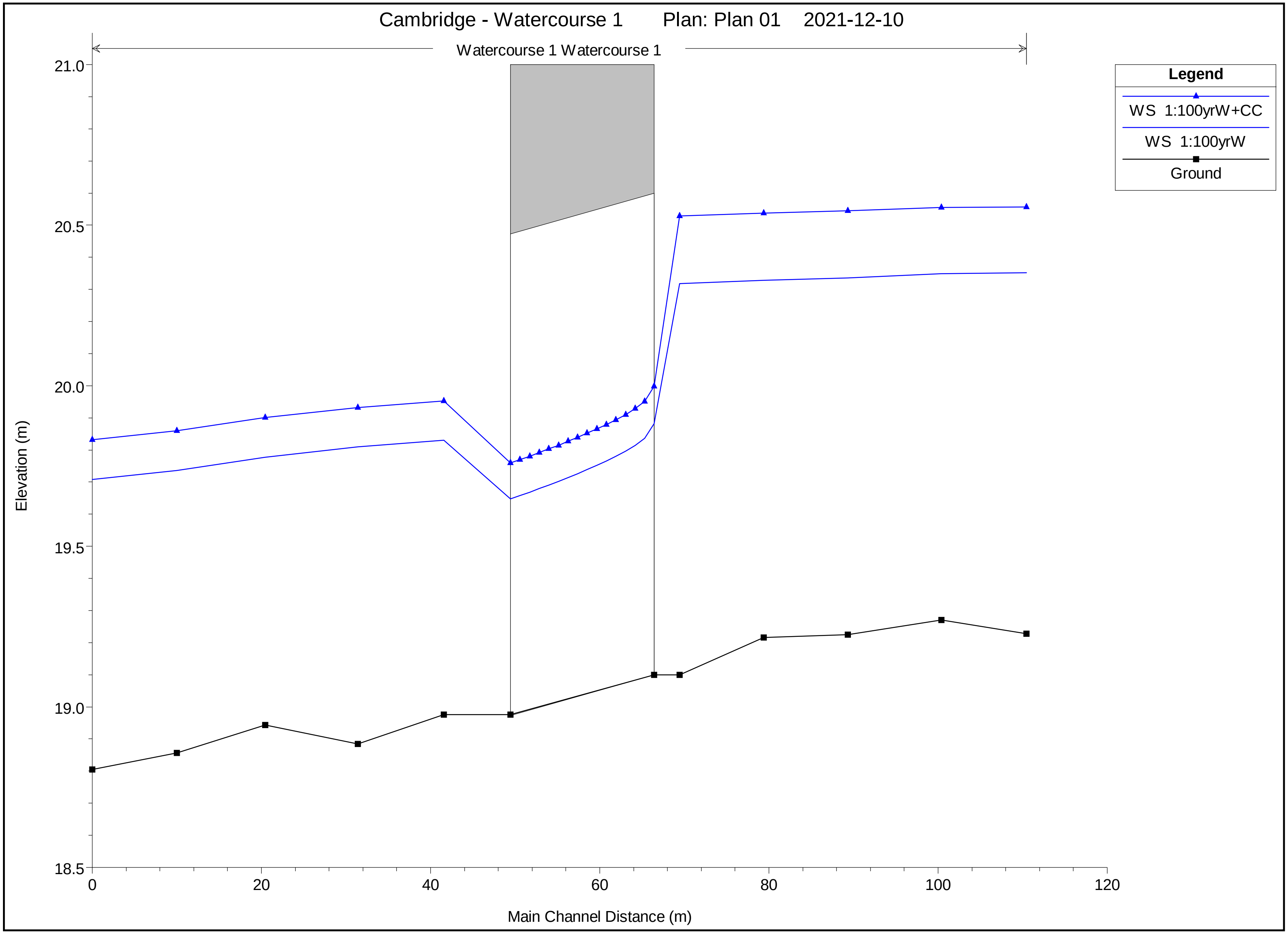
C

FLOW PROFILES



Cambridge - Lower Coleman Brook Plan: Plan 06 2021-12-10
Coleman Brook Lo Coleman Brook Lo
Legend
WS 1:100yr W+CC
WS 1:100yr W
WS 1:100yr+CC
WS 1:50yr W
WS 1:100yr
WS 1:50yr
Ground
Elevation (m)
22
21
20
19
18
17
16
0
20
40
60
80
100
120
140
160
Main Channel Distance (m)


Cambridge - Coleman Brook Upper Plan: Plan 03 2021-12-10
Coleman Brook Up Coleman Brook Up
Legend
WS 1:100yr W+CC
WS 1:100yr W
WS 1:100yr+CC
WS 1:50yr W
WS 1:100yr
WS 1:50yr
Ground
Elevation (m)
17
18
19
20
21
22
23
0
20
40
60
80
100
120
Main Channel Distance (m)


Cambridge - Watercourse 1 Plan: Plan 01 2021-12-10
Watercourse 1 Watercourse 1
Legend
WS 1:100yrW+CC
WS 1:100yrW
Ground
Elevation (m)
21.0
20.5
20.0
19.5
19.0
18.5
0
20
40
60
80
100
120
Main Channel Distance (m)