

Appendix A Field Program Report





**2023-2024 CLIMATE CHANGE FLOOD
RISK MAPPING STUDY FOR THE CITY OF
ST. JOHN'S**
Field Program Report

August 14, 2024

Prepared for:
Government of Newfoundland and Labrador
and City of St. John's

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2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's

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2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's

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1.0 Introduction

Stantec has been retained by the City of St. John's and the Government of Newfoundland and Labrador to conduct the 2023 -2024 Climate Change Flood Risk Mapping Study for the City of St. John's. The study includes providing flood risk maps for current climate and climate change conditions for the following seven study areas:

1. Barrows Road Stream,
2. Holes in Marsh Brook,
3. Kitty Gaul Brook,
4. Mundy Pond Brook,
5. Outer Cove Brook,
6. South Brook, and
7. Virginia River.

The collection of accurate and complete field data is important for the development of representative hydrologic and hydraulic models for floodplain development. The Field Program consisted of three major components: Hydrological and Hydraulic Reconnaissance, Water Level and Flow Monitoring and Ground Survey. Data collected during the hydrological and hydraulic reconnaissance task informed the selection of water level and flow monitoring sites and aided with the delineation of drainage areas. The water level and flow monitoring program was conducted over a 1 month period with the aim of capturing water levels and flows during a higher than normal conditions. The monitoring data will be used to calibrate the hydrologic and hydraulic models. The ground survey is used to build the hydraulic models to include the bathymetry portion of the rivers and the geometry of hydraulic structures. Stantec team members completed the hydrological and hydraulic reconnaissance and water level and flow monitoring portions of the field program and developed a detailed Ground Survey Plan (**Appendix A**) to ensure the necessary survey data was collected.

Additionally, the City provided LiDAR data for development of digital elevation models (DEM) for the flood plains and watersheds. A LiDAR verification exercise was completed by comparing ground survey check points (points of known elevation that are used throughout a survey for data validation), and monuments from the ground survey to evaluate the accuracy of the LiDAR data.

The following sections describe the three major field program components, as well as the results of the LiDAR verification.



2.0 Hydrological and Hydraulic Reconnaissance

Representatives of Stantec's hydrotechnical team traversed the main watercourses in the seven study areas, including the tributaries for the Virginia river area, to identify features of hydrologic and hydraulic interest. Such features included hydraulic structures, locations of storm sewer discharge, significant grade changes such as rapids or waterfalls, bank features such as berms, areas of significant roughness change and storage features such as ponds, pools, and wetlands. These items were identified in the Ground Survey Plan for further data collection for the survey team.

This task also informed the selection of level logger installation locations. Generally, Stantec searched for channels that were relatively straight by nature with little turbulence for an average daily flow and free of large rocky areas. The reconnaissance was also useful in determining channel bottom conditions and the effort needed for each flow monitoring station.

Prior to conducting this task, Stantec reviewed the City's LiDAR and as-built drawings, and identified areas requiring further field investigation. These included:



1. Weir location at Kelsey Drive for Holes in Marsh Brook study area as seen in **Figure 1**.

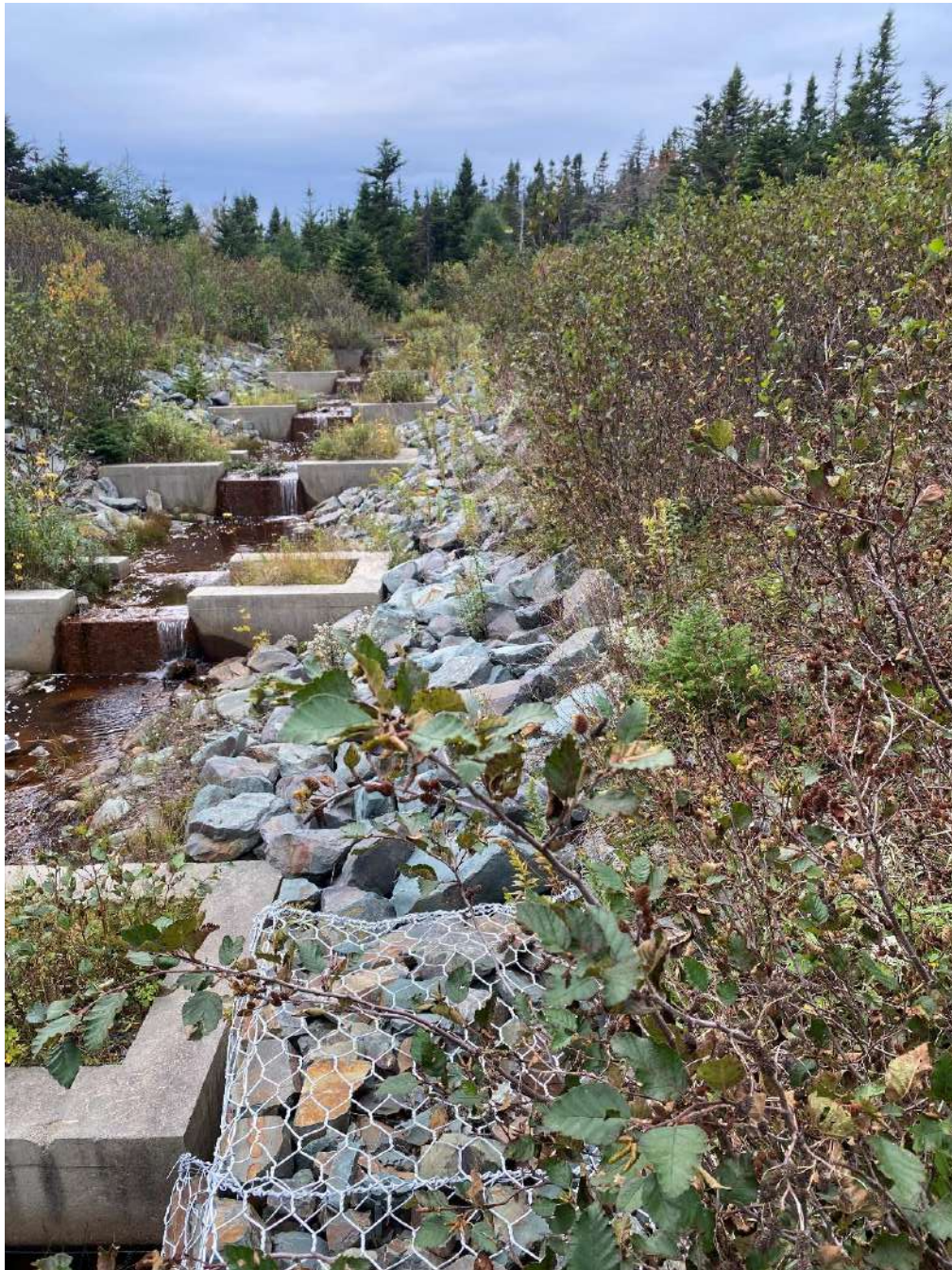


Figure 1 - Weir Location at Kelsey Drive within Holes in Marsh Brook

2. The outlet weir structure for Virginia Lake as seen in **Figure 2**.



Figure 2 - Outlet Weir Structure for Virginia Lake within Virginia River

3. Virginia River supplemental flow from the tributaries as seen in **Figure 3**.



Figure 3 - Virginia River Tributary Flow at Guzzwell Drive

4. The storm pipe network for Barrows Road Stream as seen in **Figure 4**.



Figure 4 - Outlet for Storm Pipe Network from Cuckholds Cove Road

5. The outlet structure for Mundy Pond as seen in **Figure 5**.



Figure 5 - Outlet Structure for Mundy Pond within Mundy Pond Brook

6. Suitable placement for the level logger installations for all seven study areas as seen in Section 3.0.

Each location can be seen in **Figure 6** below.



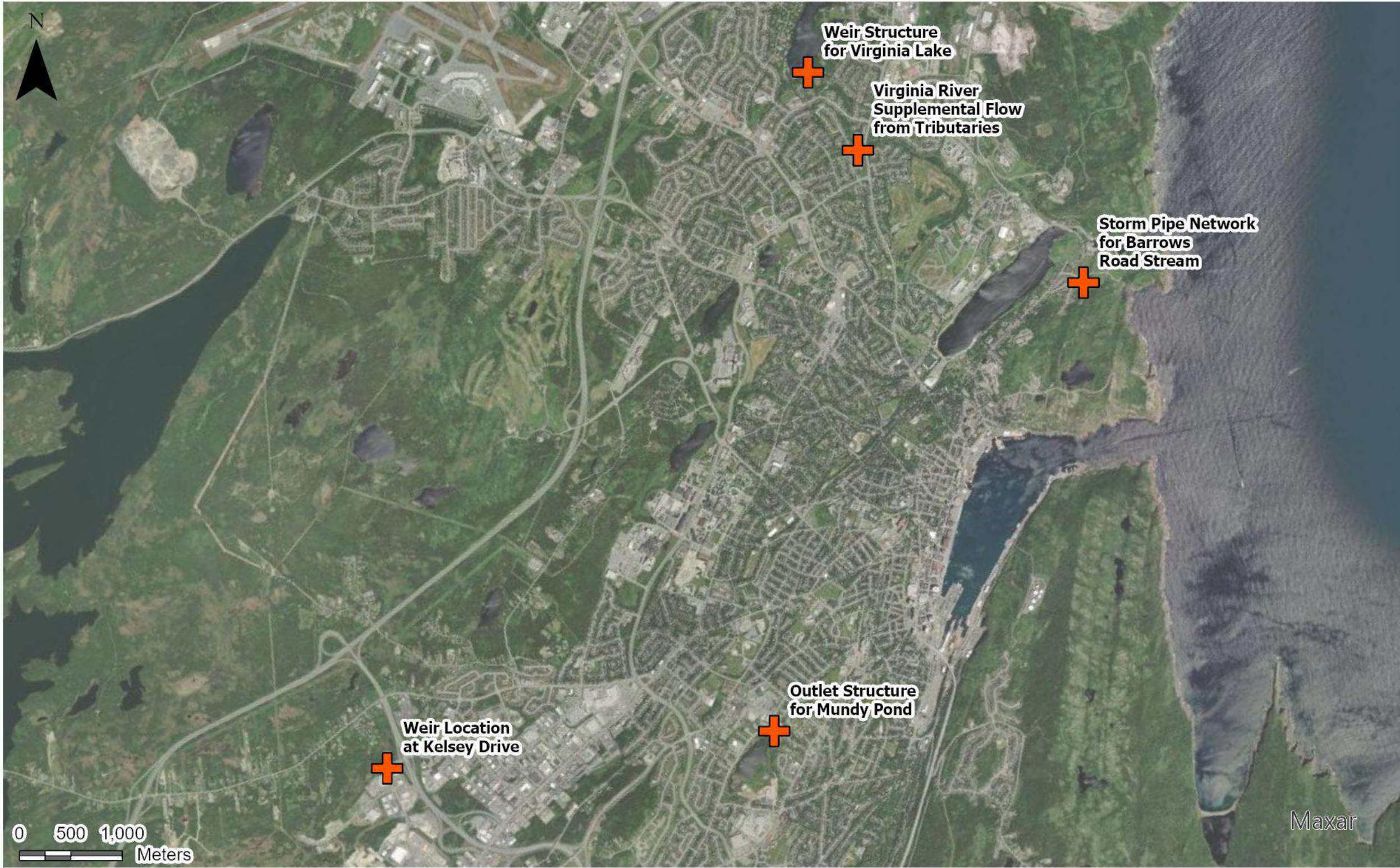


Figure 6 - Areas Requiring Further Field Investigation



3.0 Water Level and Flow Monitoring

Following the hydrological and hydraulic reconnaissance task, Stantec's hydrotechnical team identified a total of 16 water level monitoring sites within seven study areas listed below and shown in **Figure 7**. The monitoring locations were selected based on the portion of the drainage area that the level logger would capture as well as adequate water depth, absence of excess turbulence, streambed conditions and channel geometry. The selection of monitoring locations also considered the location of existing real-time Water Survey of Canada (WSC) hydrometric stations to supplement the data available from those stations.

- Barrows Road Stream
 - Barrows Road Stream near Cuckholds Cove Road
 - Barrows Road Stream near Barrows Road
- Holes in Marsh Brook
 - Holes in Marsh Brook near Kelsey Drive
 - Holes in Marsh Brook near Pippy Place
- Kitty Gaul Brook
 - Kitty Gaul Brook at Downstream of Blackmarsh Road
 - Kitty Gaul Brook near Greenwood Crescent
- Mundy Pond Brook
 - Mundy Pond Brook near Coefield Street
 - Mundy Pond Brook at Mundy Pond Outlet
- Outer Cove Brook
 - Outer Cove Brook at Virginia River Trail
 - Outer Cove Brook at Torbay Road
- South Brook
 - South Brook at Southlands Boulevard Upper Crossing
 - South Brook at Tree Top Drive
- Virginia River and its Tributaries
 - Virginia River at Penny Crescent
 - Virginia River at Virginia Lake Outlet Weir
 - Virginia River Tributary at Guzzwell Drive
 - Virginia River at Logy Bay Road



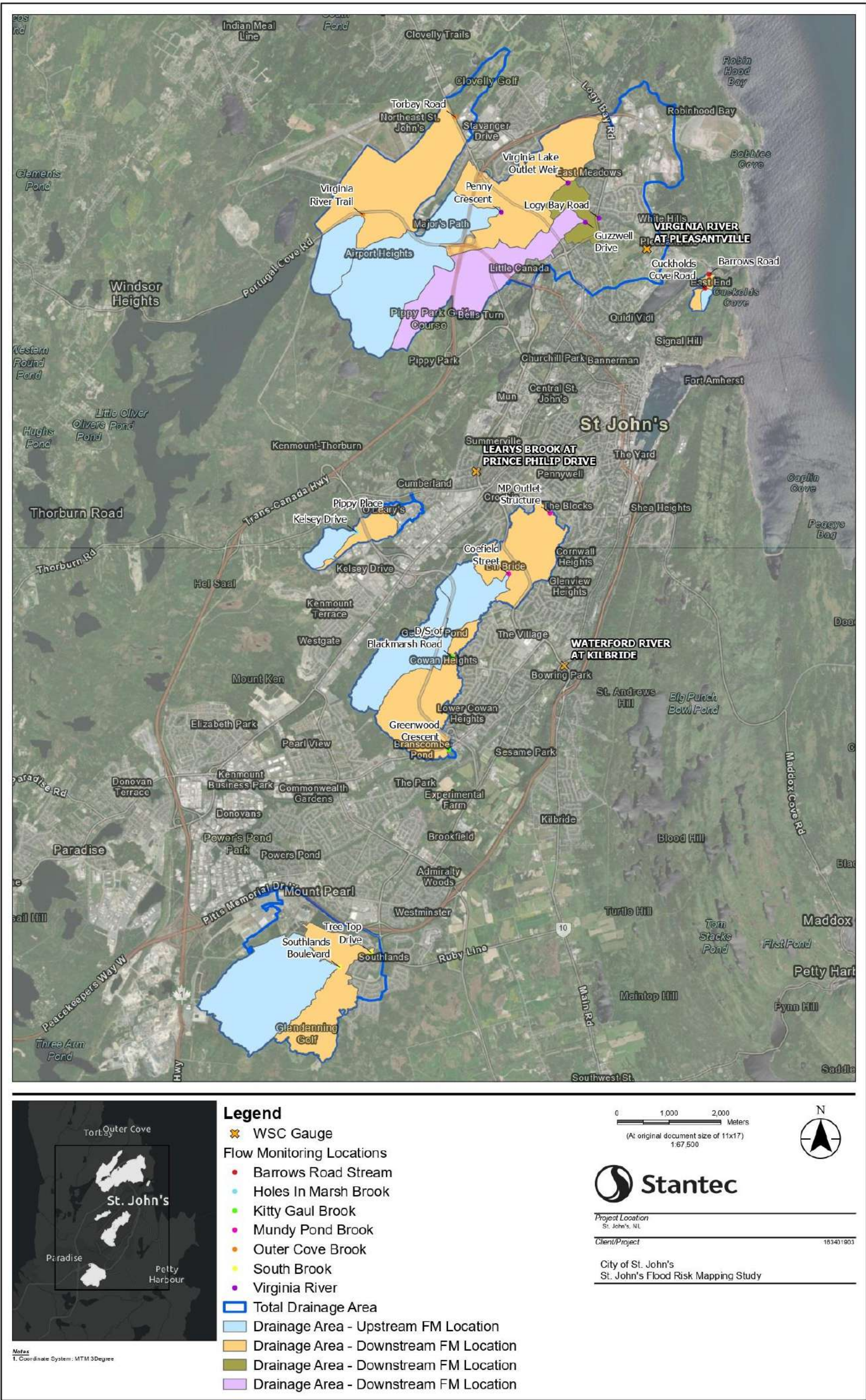


Figure 7 - Water Level Monitoring Locations



3.1 Water Level Logger Programming, Installation and Retrieval

The water level monitoring was carried out from October 17th, 2023 to November 23rd, 2023. Two types of water level metres were deployed: U-20 series HOBO loggers (**Figure 8**) were installed at 10 locations, and Solinst 3001 Levellogger 5 (**Figure 9**) were installed at 6 locations. **Appendix B** contains manufacturers data sheets for both the HOBO and Solinst level loggers used. Data was recorded at 5-minute intervals. In addition to the level loggers, the following materials were used in the installation process.

- Three to four inch perforated PVC standpipe – Used to contain the level loggers and prevent lateral movement while deployed.
- Metal T-post – The perforated PVC standpipe was attached to the T-post for structural stability.

An example of a typical level logger set up can be seen in **Figure 10** Error! Reference source not found., for Virginia River near Logy Bay Road.



Figure 8 - U20 Series Water Level Logger



Figure 9 - Solinst 3001 Level Logger 5 Series

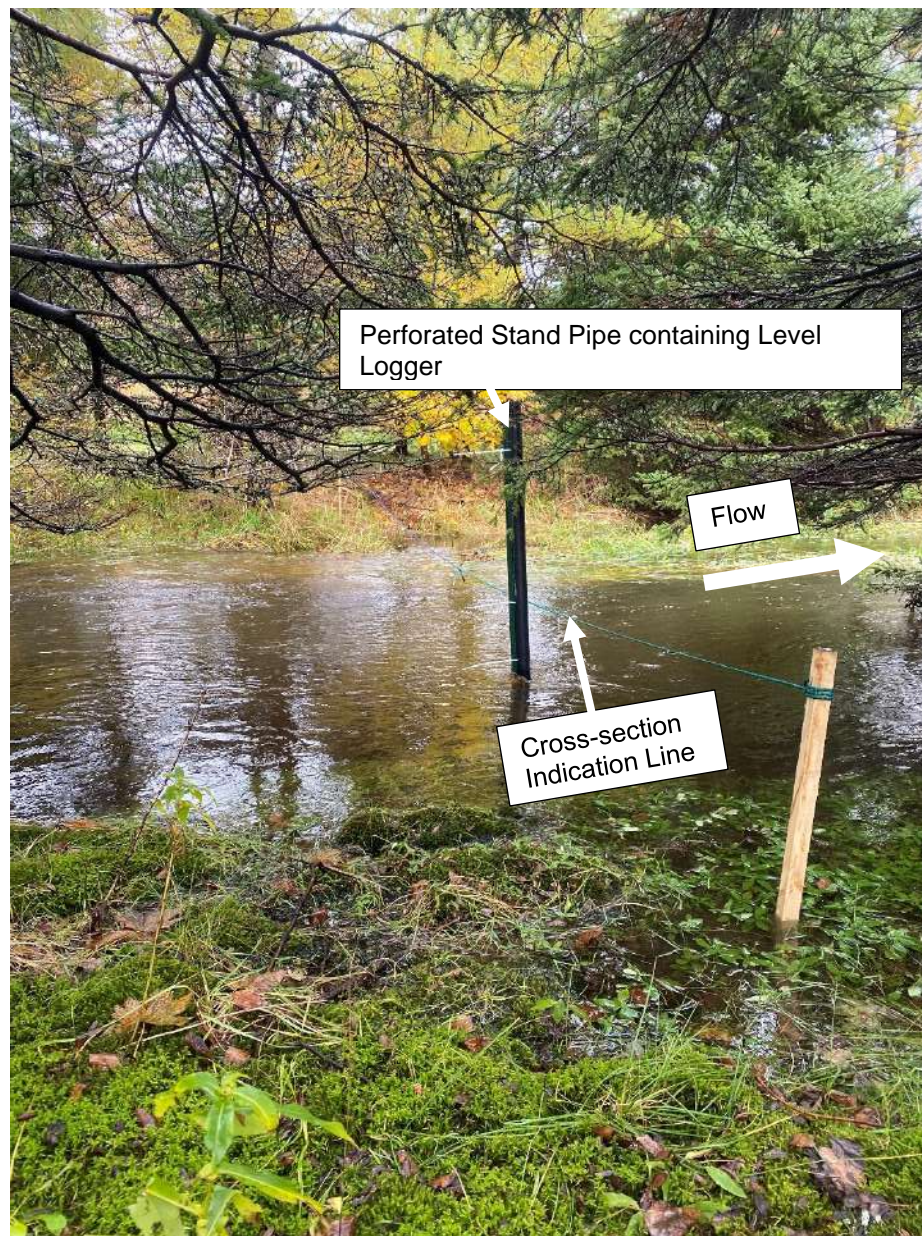


Figure 10 - Water Level Monitoring Station on Virginia River near Logy Bay Road

The date, time, and depth of water at the logger was noted at each level logger deployment and retrieval. This information is necessary for the data correction process. The level loggers record the pressure of the water at the logger location. To convert the pressure to depth, the logger data is corrected against barometric data retrieved from environment Canada. The St. John's International Airport Class A Meteorological Station was used to obtain barometric data. This station is within 15 km of each of the monitoring locations and has hourly atmospheric data available. The pressures read by the loggers were then converted to equivalent metres of water and referenced to the recorded installation water level at

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3.0 Water Level and Flow Monitoring

each site. The plots of the depth measurements during high flow precipitation events can be seen in the figures below.

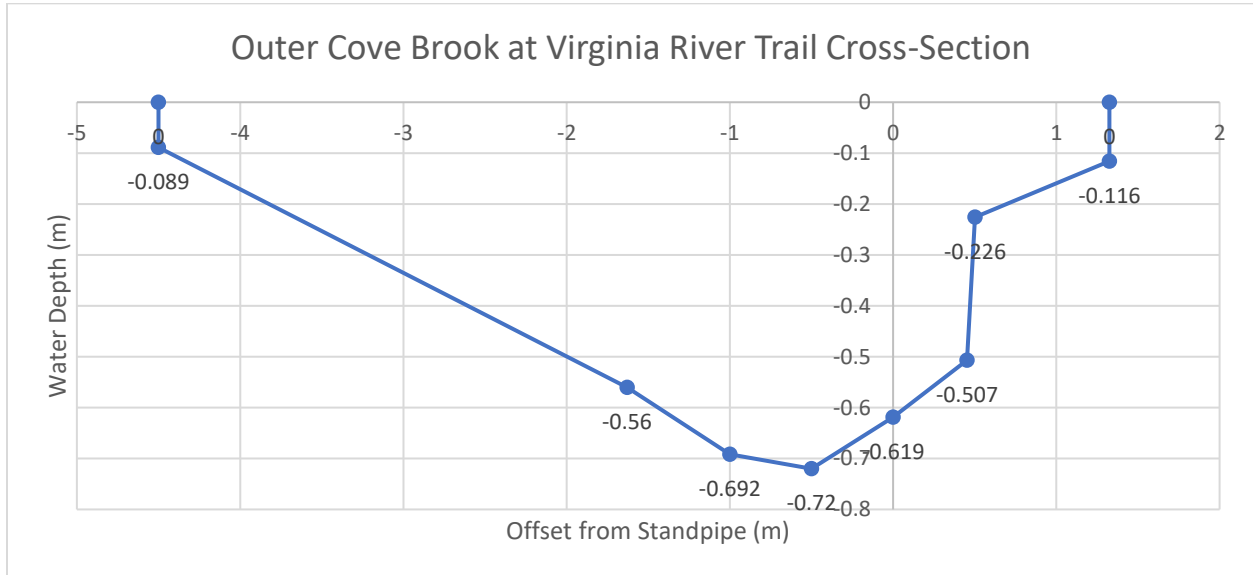


Figure 11 - Virginia River Trail High Flow Cross-Section

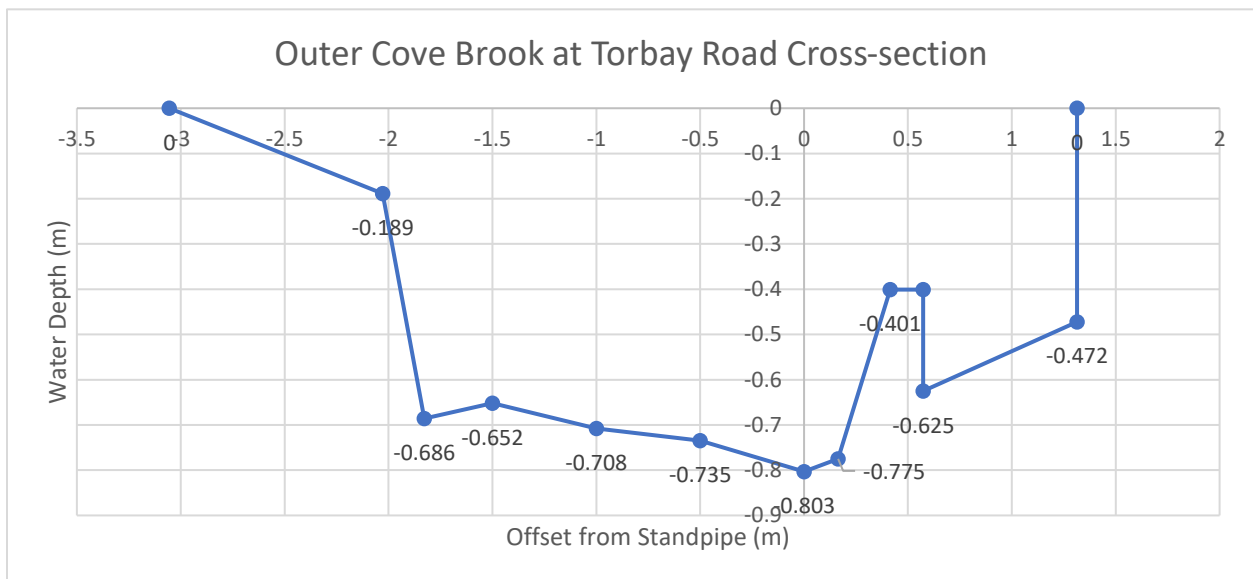


Figure 12 - Torbay Road High Flow Cross-Section



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3.0 Water Level and Flow Monitoring

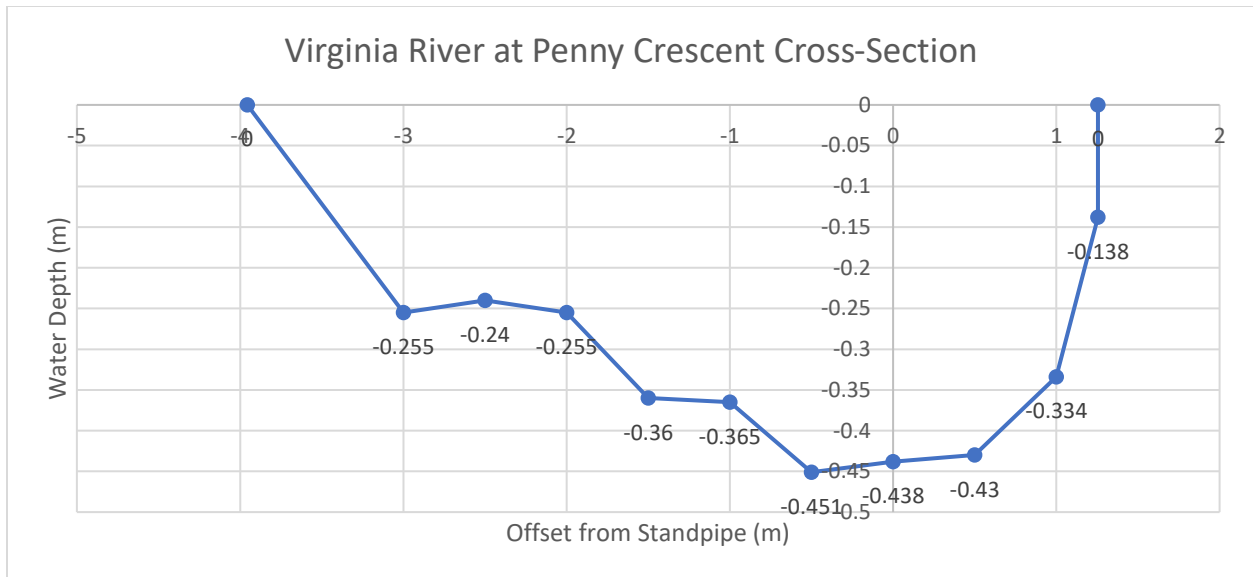


Figure 13 - Penny Crescent High Flow Cross-Section

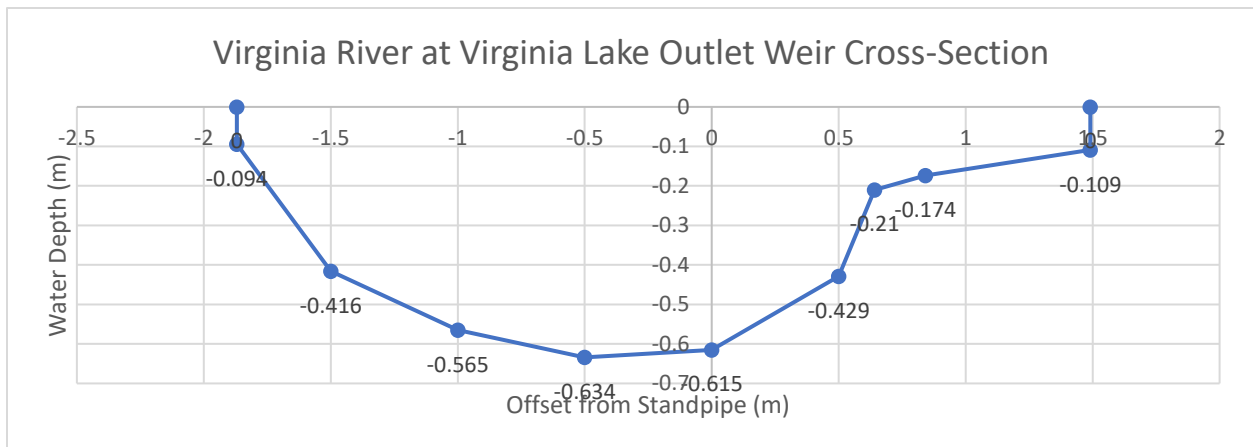


Figure 14 - Virginia Lake Outlet Weir High Flow Cross-Section



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3.0 Water Level and Flow Monitoring

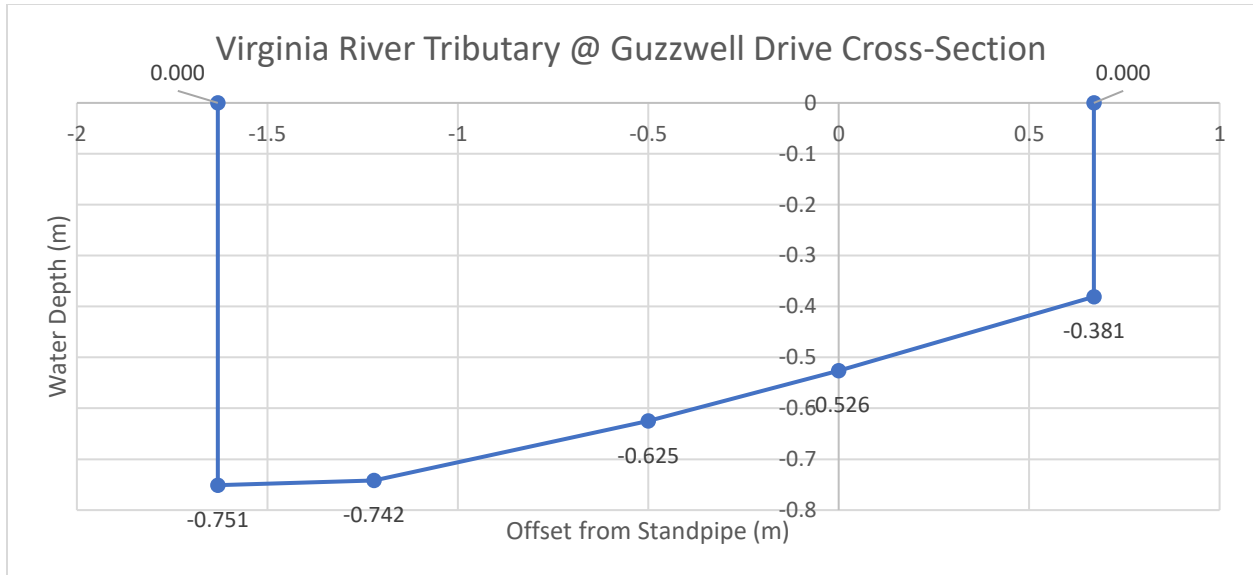


Figure 15 - Tributary at Guzzwell Drive High Flow Cross-Section

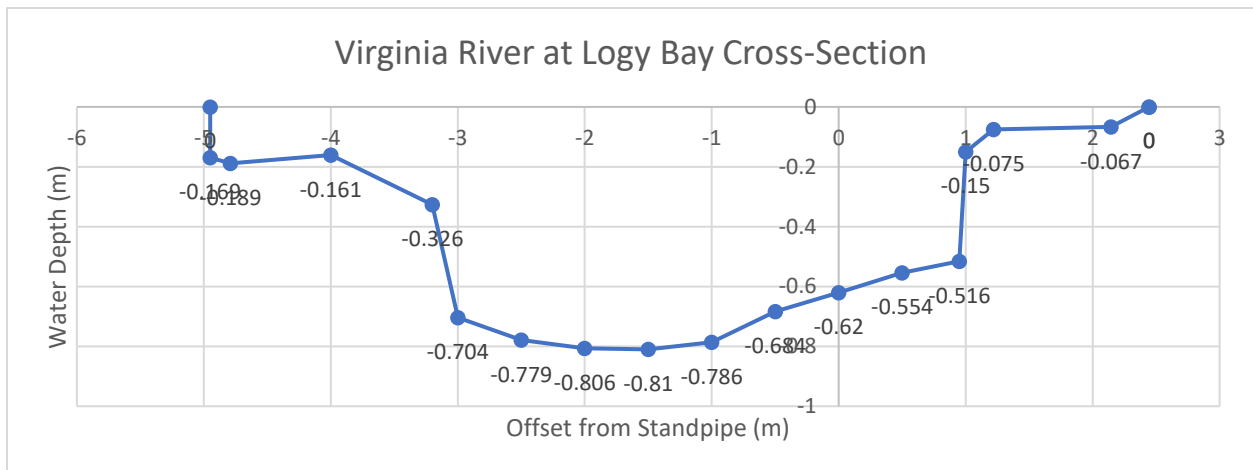


Figure 16 - Logy Bay Road High Flow Cross-Section



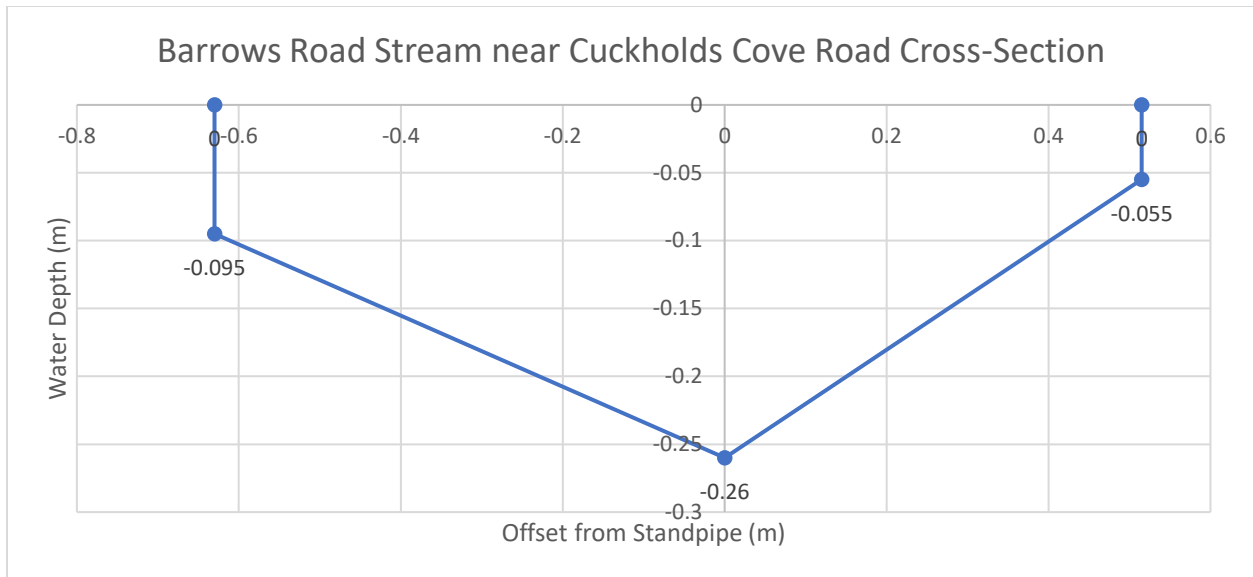


Figure 17 - Cuckholds Cove Road High Flow Cross-Section

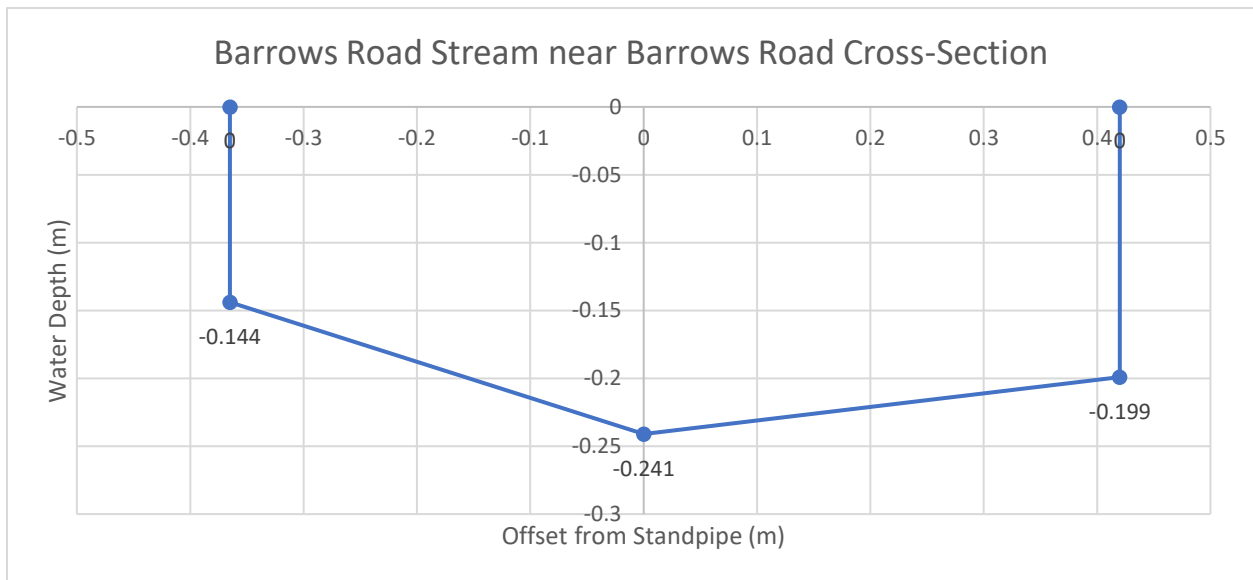


Figure 18 - Barrows Road High Flow Cross-Section



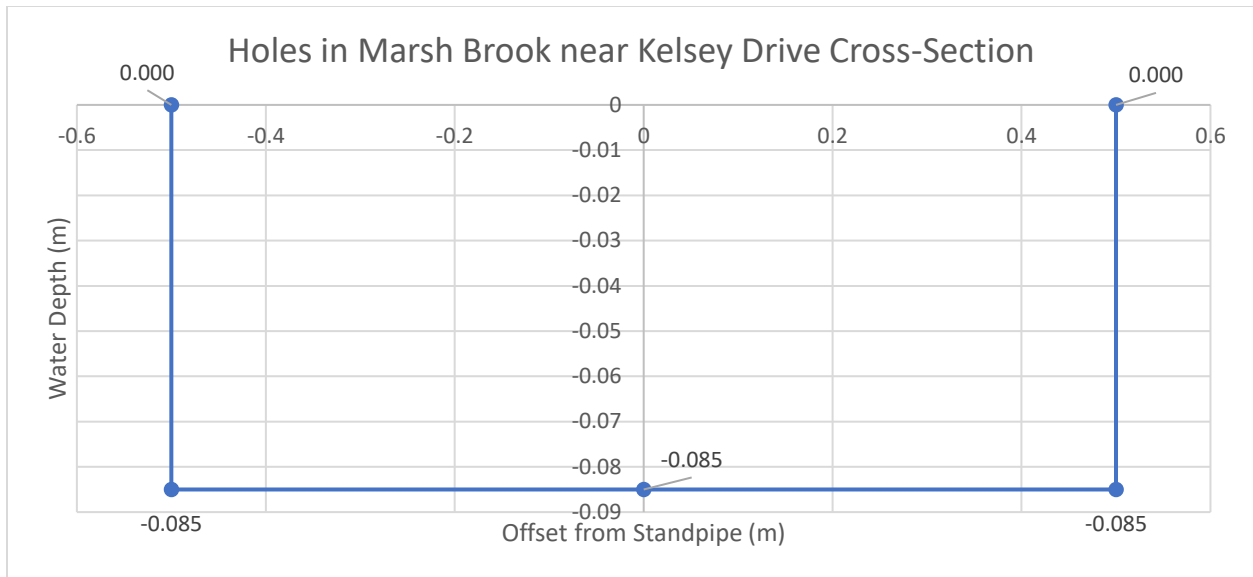


Figure 19 - Kelsey Drive High Flow Cross-Section

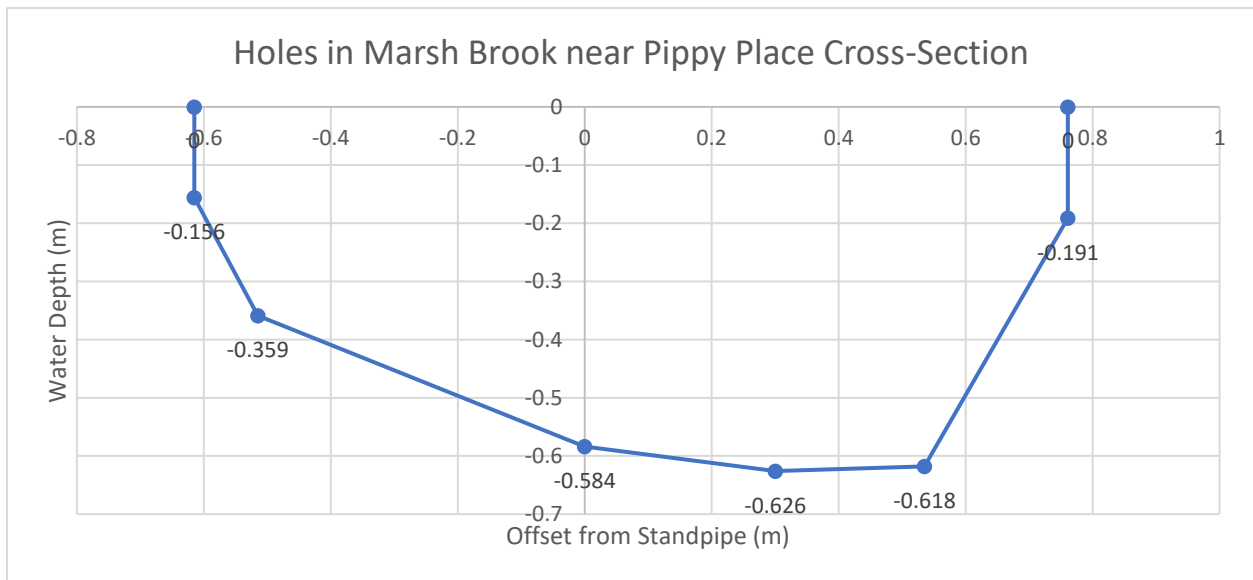


Figure 20 - Pippy Place High Flow Cross-Section

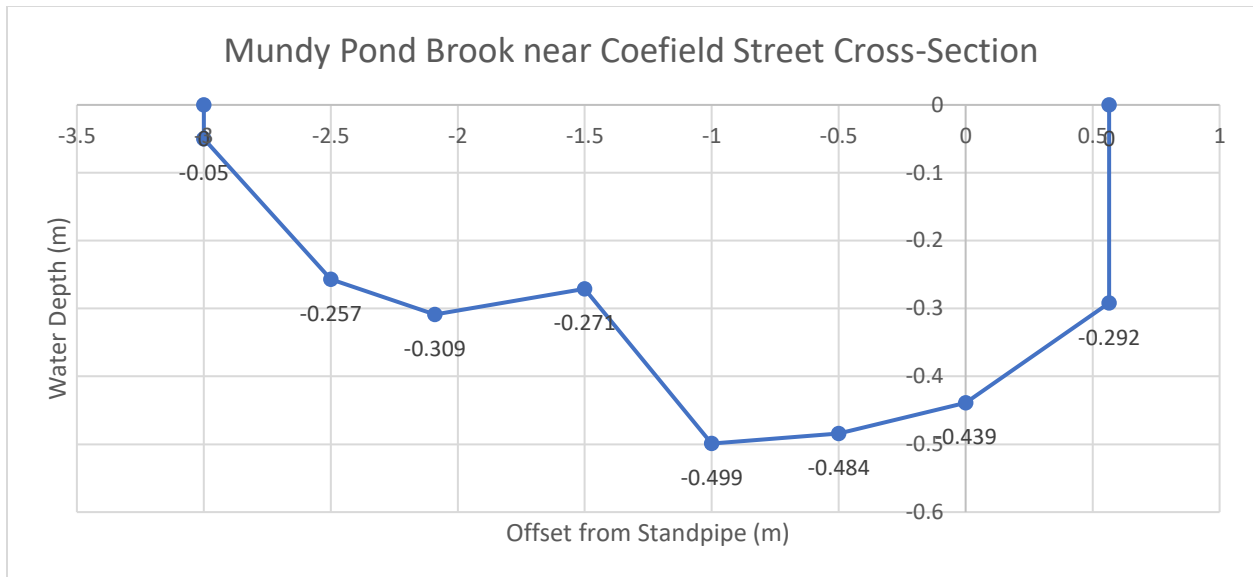


Figure 21 - Coefield Street High Flow Cross-Section

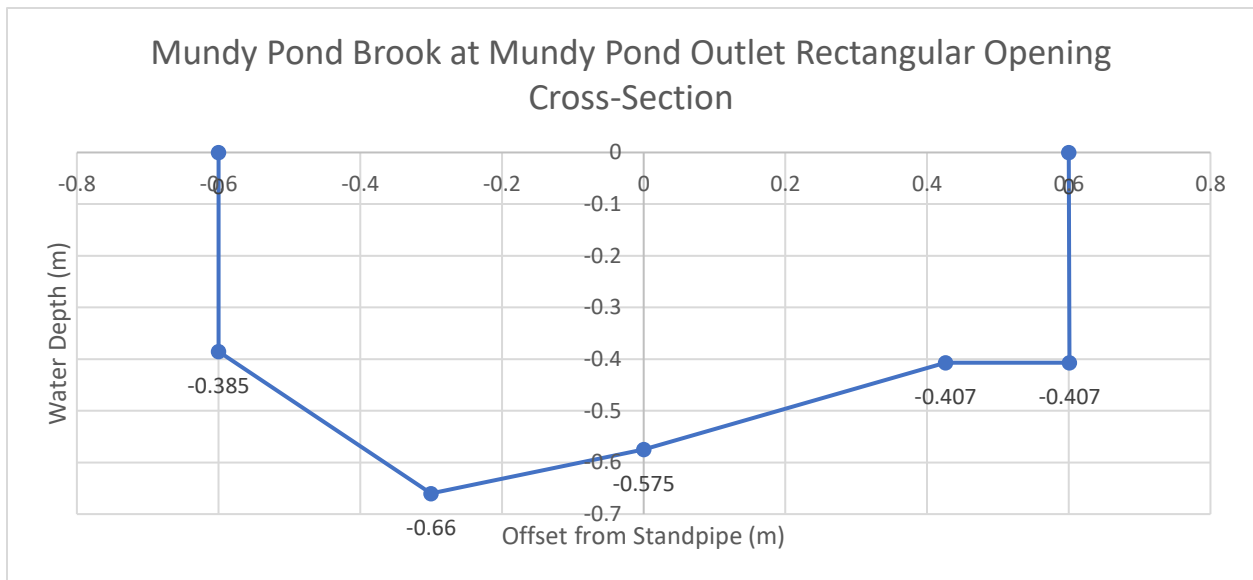


Figure 22 - Mundy Pond Outlet High Flow Cross-Section

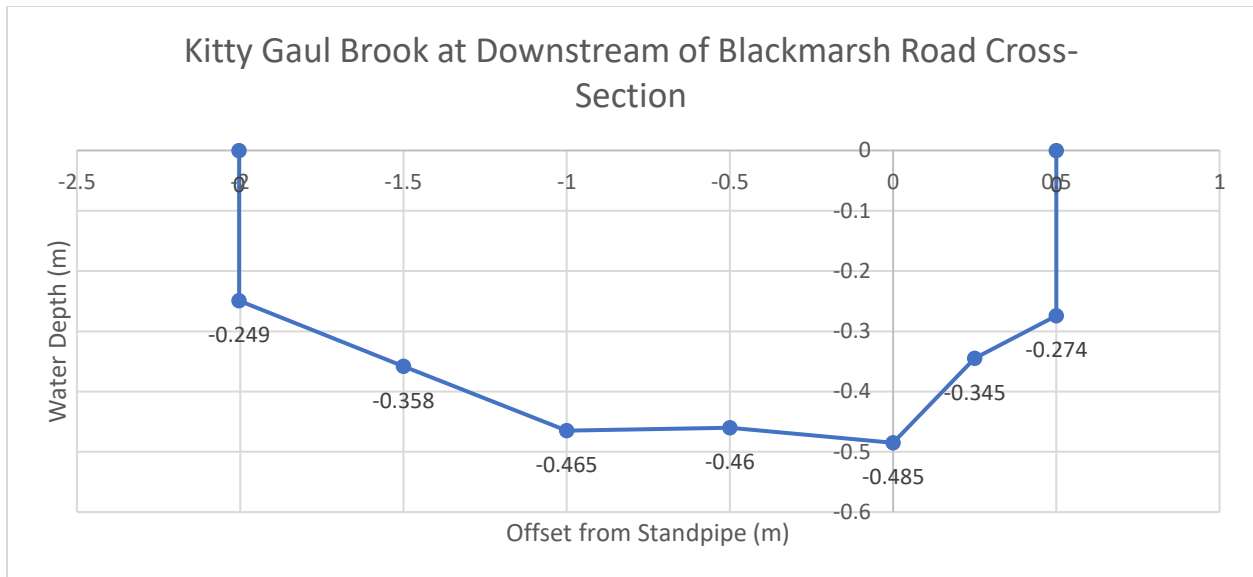


Figure 23 - Downstream of Blackmarsh Road High Flow Cross-Section

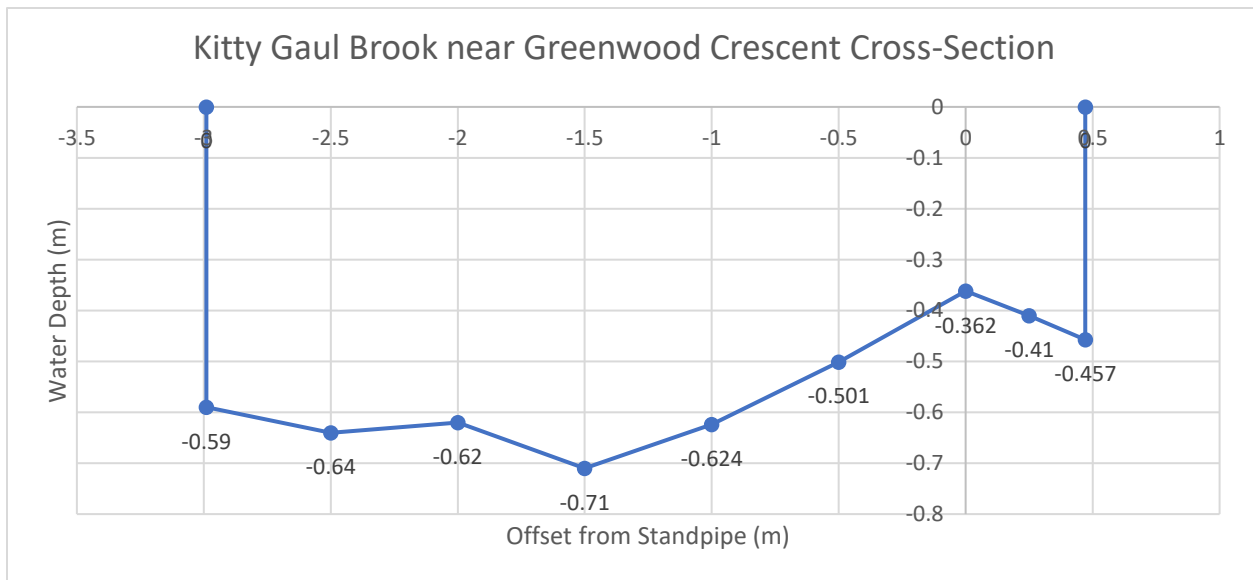


Figure 24 - Greenwood Crescent High Flow Cross-Section



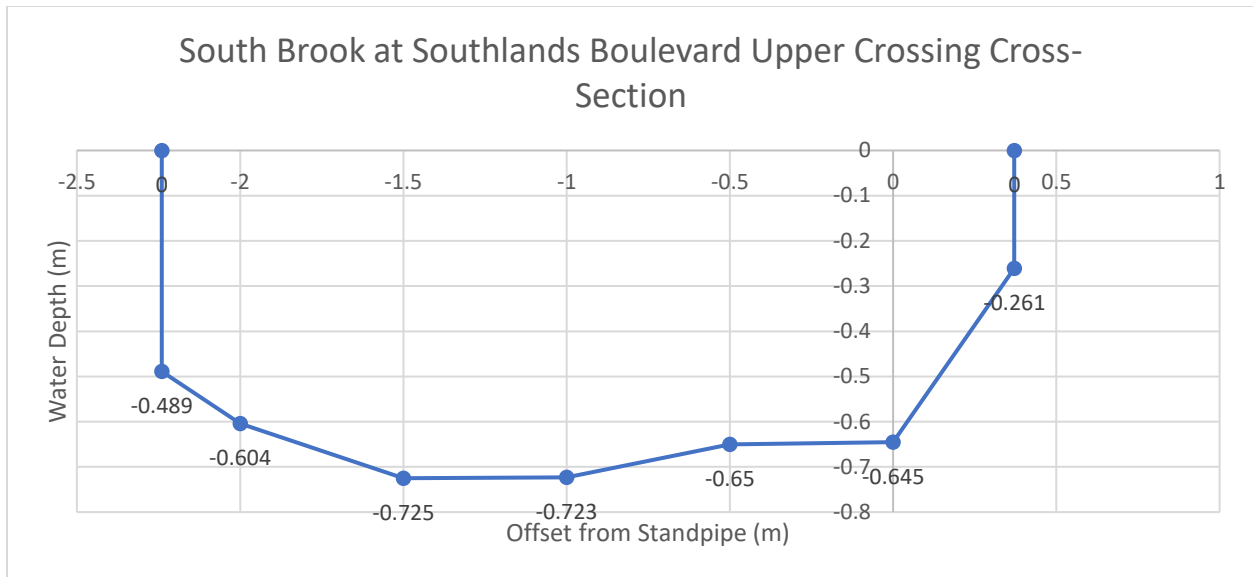


Figure 25 - Southlands Boulevard Upper Crossing High Floe Cross-Section

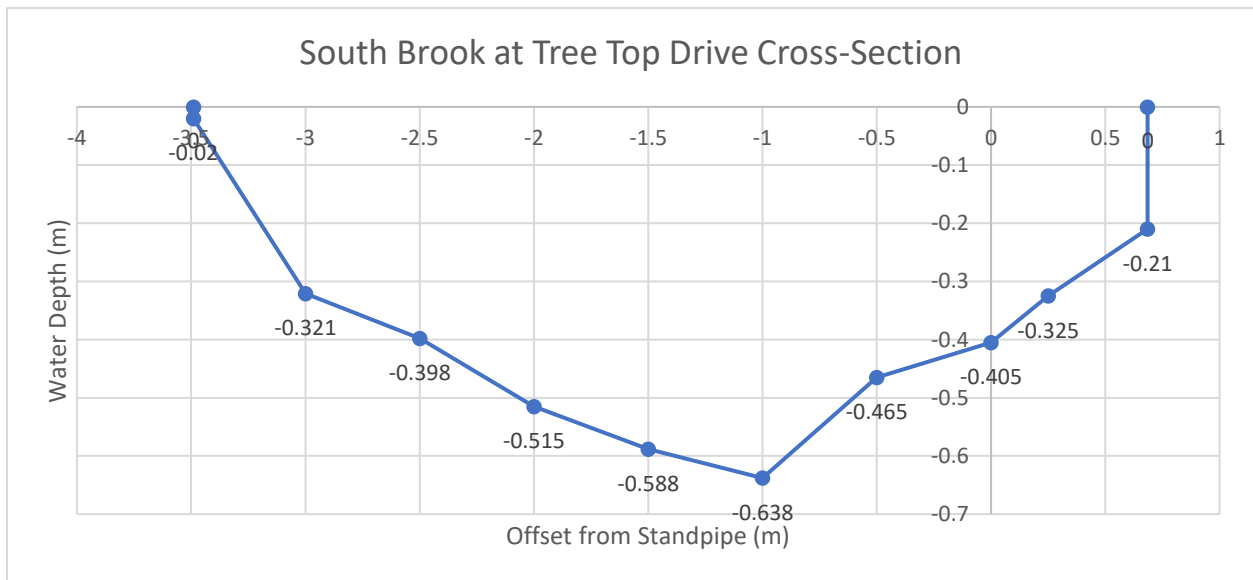


Figure 26 - Tree Top Drive High Flow Cross-Section



3.2 Velocity Metre Measurements

Velocity measurements at the level logger locations were obtained using the Xylem FP111 Digital Handheld Water Velocity Metre (see **Appendix C** for specifications). Cross section data obtained at the time of the velocity measurement (including depth and area) and used to estimate channel flow following the procedure described in Section V – Average Velocity (point b on page 7) of the FP111 Flow Probe User Manual, included in **Appendix C**.

In addition to the Xylem FP111 Digital Handheld Water Velocity Metre, the following materials (as seen in **Figure 10**) were used for this task:

- Rope and wooden stakes – wooden stakes were driven in the left and right banks of the cross-section and the rope strung between the two stakes. The rope was used as a cross-section indication line, such that the velocity measurements were recorded at the same location, and to divide the cross section into subsections.
- Metre stick – To measure the water depth along the cross-section.

Members of Stantec's hydrotechnical team conducted the velocity measurements. Per the procedure described in **Appendix C**, each cross-section was divided into subsections of 0.5 m widths, and a velocity measurement was collected in each subsection. The water depth was recorded at the 0.5 m increments, and at any areas of interest, such as marked changes in depth or flow obstructions. The start and end time of each measurement was also noted. To minimize uncertainty in the velocity measurements, methodical and consistent techniques were used, ensuring that the unit's propeller is aligned correctly, and the probe is moved consistently along the cross-section. Measurements were along the cross-sections were repeated to improve reliability in the results.

Two velocity measurements were collected at each level logger location. The dates and times of velocity measurements are included in **Table 1**. The first occasion was conducted from October 23rd, 2023, to October 25th, 2023, during normal day conditions, (i.e., little or no precipitation in the preceding 2-3 days), to develop a low flow baseline. The velocity measurements were conducted on November 2, 2023, following 35.8mm of rain which occurred from November 1st, 2023 to November 2nd, 2023 with 11cm of snow on the ground from a previous snowfall that occurred on October 31st, 2023. Actual snowfall did not occur during this event. Ideally, the measurements should be recorded during the storm event, or one day after as the water levels would be elevated and not yet normalized to develop a high flow data set.

3.2.1 WATERCOURSE FLOW RATE CALCULATIONS

The velocity recorded for each subsection was multiplied by the cross-sectional area of that subsection to obtain the flow rate. This calculation was performed for each subsection. The total flow for each cross-section was calculated from the sum of subsection flow rates.



The flow and depth measurements were used to create rating curves at each level logger location. Since the level logger data was used to produce water depths, the rating curves were then used to estimate flows corresponding to each water depth.

3.3 Summary of Level and Flow Monitoring

The following sections summarize the level and flow monitoring data collection. Photos taken during the monitoring period at each location during low and high precipitation events can be seen in **Appendix D**.

3.3.1 BARROWS ROAD STREAM

Barrows Road Stream consists of two flow monitoring locations and a total drainage area of approximately 17.9ha. The subdrainage area for Cuckholds Cove Road flow monitoring location is approximately 5.3ha as seen in **Figure 27**. The flow monitoring location at Barrows Road captures the entire drainage area for Barrows Road Stream. This area is predominantly covered with open vegetated land, with some residential development. The placement of the flow monitoring locations for this area was intended to capture the daily flow rate as it discharges into the Quidi Vidi Harbour.



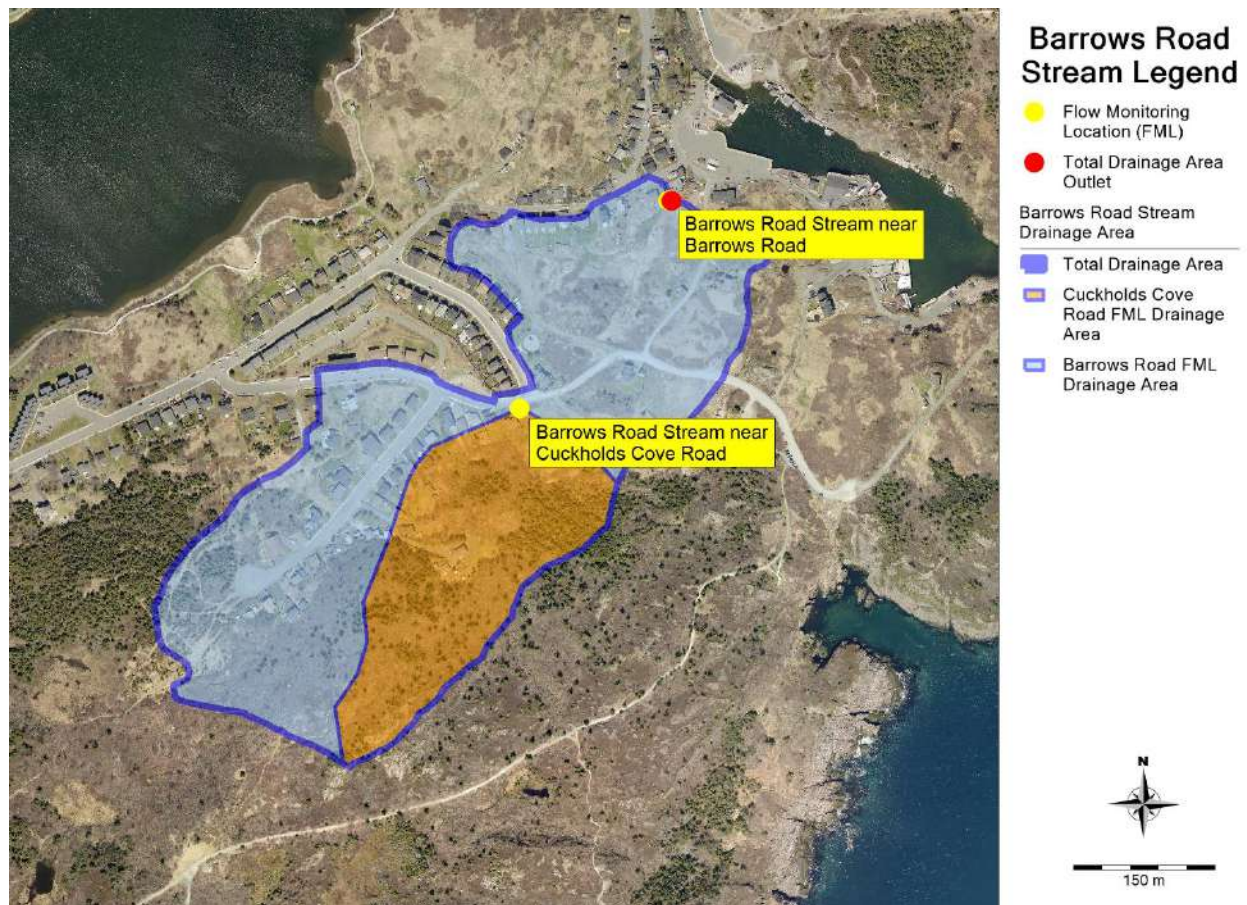


Figure 27 - Barrows Road Stream Drainage Area and Flow Monitoring Locations

Barrows Road Stream near Cuckholds Cove Road Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.197m**
- Area weighted low velocity – **0.050m/s**
- Total low cross-sectional area – **0.095m²**
- Estimated low flow rate – **0.005m³/s**
- Field measured high water level at the stand pipe – **0.260m**
- Area weighted high velocity – **0.050m/s**
- Total high cross-sectional area – **0.193m²**
- Estimated high flow rate – **0.010m³/s**

Barrows Road Stream near Barrows Road Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.201m**
- Area weighted low velocity – **0.050m/s**
- Total low cross-sectional area – **0.154m²**
- Estimated low flow rate – **0.008m³/s**
- Field measured high water level at the stand pipe – **0.241m**
- Area weighted high velocity – **0.265m/s**
- Total high cross-sectional area – **0.163m²**
- Estimated high flow rate – **0.043m³/s**

3.3.2 OUTER COVE BROOK

Outer Cove Brook consists of two flow monitoring locations and a total drainage area of approximately 449.7ha. The flow monitoring locations at Virginia River Trail and Torbay Road have drainage areas of approximately 83.0ha and 394.9ha, respectively, as seen in **Figure 28**. The drainage area for Outer Cove Brook encompasses a majority residential and industrial landscapes. The flow monitoring location at Virginia River Trail was intended to capture flow upstream of the St. John's International Airport's stormwater drainage system. The flow monitoring location at Torbay Road was intended to capture the total flow discharging from the airport.



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3.0 Water Level and Flow Monitoring

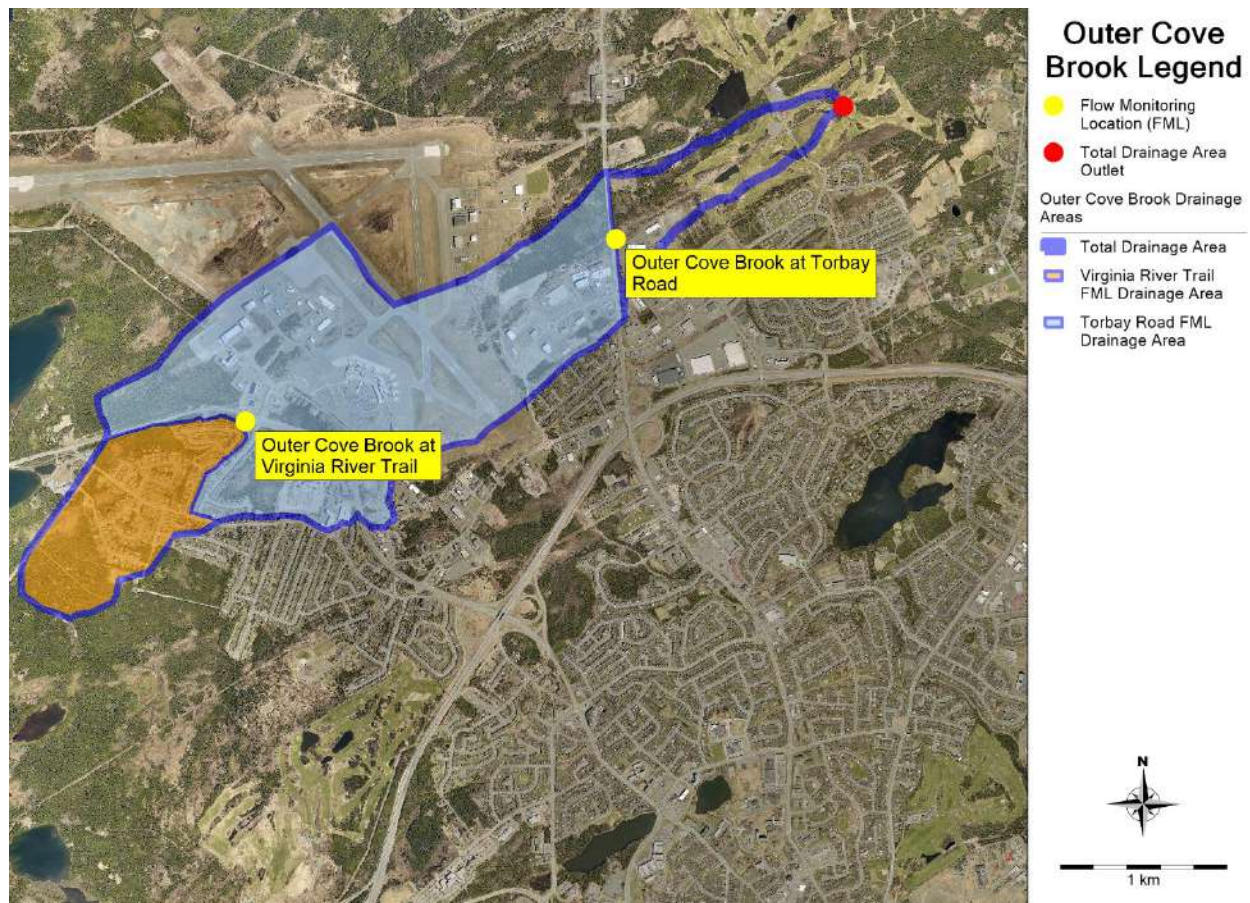


Figure 28 - Outer Cove Brook Drainage Area and Flow Monitoring Locations

Outer Cove Brook at Virginia River Trail Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.472m**
- Area weighted low velocity – **0.177m/s**
- Total low cross-sectional area – **0.967m²**
- Estimated low flow rate – **0.171m³/s**
- Field measured high water level at the stand pipe – **0.619m**
- Area weighted high velocity – **0.167m/s**
- Total high cross-sectional area – **2.427m²**
- Estimated high flow rate – **0.406m³/s**

Outer Cove Brook at Torbay Road Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.457m**
- Area weighted low velocity – **0.251m/s**
- Total low cross-sectional area – **1.100m²**
- Estimated low flow rate – **0.277m³/s**



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3.0 Water Level and Flow Monitoring

- Field measured high water level at the stand pipe – **0.803m**
- Area weighted high velocity – **0.539m/s**
- Total high cross-sectional area – **2.236m²**
- Estimated high flow rate – **1.205m³/s**

3.3.3 VIRGINIA RIVER

Virginia River consists of four flow monitoring locations and a total drainage area of approximately 1417.3ha. The flow monitoring drainage areas for Penny Crescent, Virginia Lake Outlet Weir, Logy Bay Road and the Tributary at Guzzwell Drive is approximately, 352.0ha, 656.2ha, 944.4ha and 227.4ha, respectively, as seen in **Figure 29**.

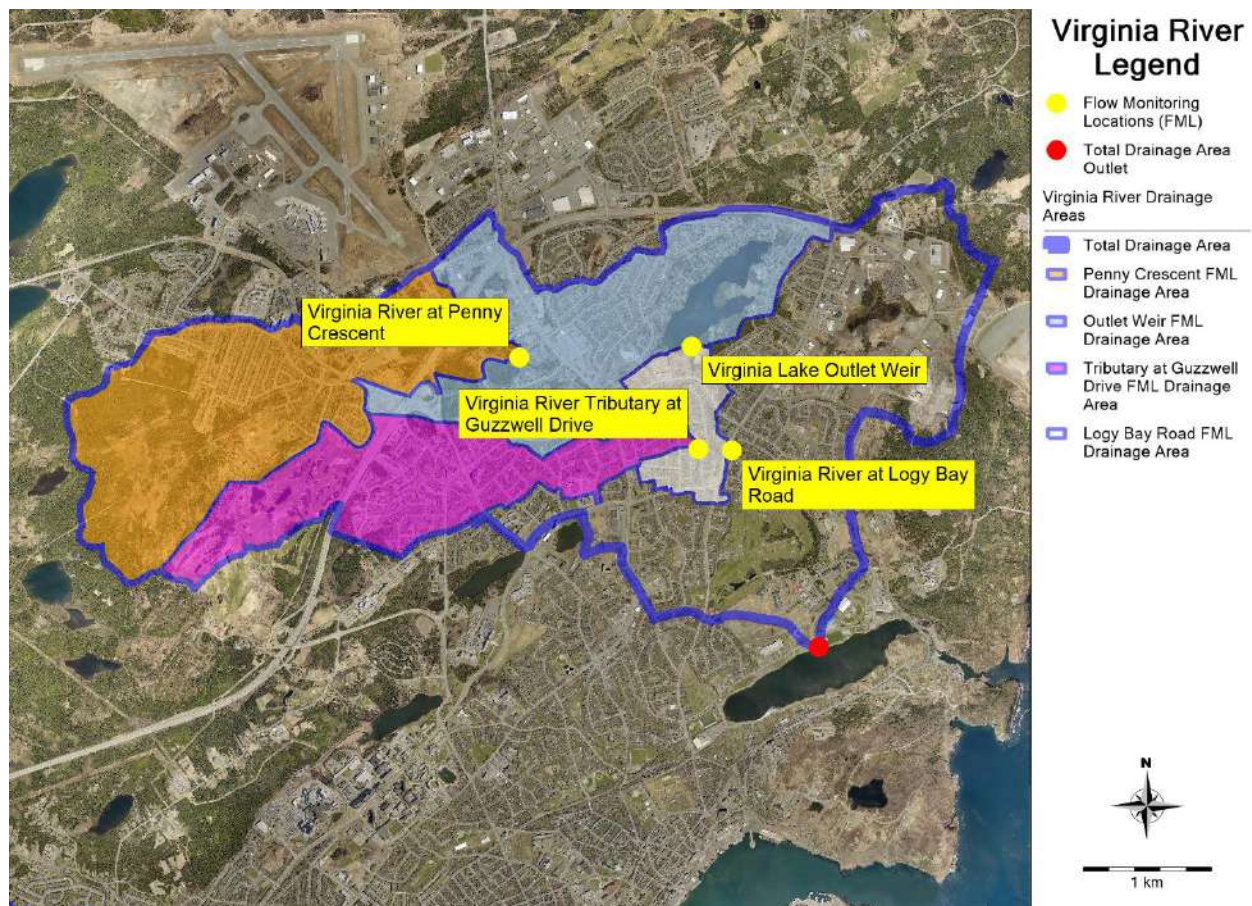


Figure 29 - Virginia River Drainage Area and Flow Monitoring Locations

Virginia River at Penny Crescent Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.307m**
- Area weighted low velocity – **0.336m/s**
- Total low cross-sectional area – **0.777m²**



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3.0 Water Level and Flow Monitoring

- Estimated low flow rate – **0.261m³/s**
- Field measured high water level at the stand pipe – **0.438m**
- Area weighted high velocity – **0.472m/s**
- Total high cross-sectional area – **1.599m²**
- Estimated high flow rate – **0.755m³/s**

Virginia Lake Outlet Weir Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.598m** (level logger measurement)
- Area weighted low velocity – **0.415m/s**
- Total low cross-sectional area – **1.045m²**
- Estimated low flow rate – **0.434m³/s**
- Field measured high water level at the stand pipe – **0.703m** (level logger measurement)
- Area weighted high velocity – **0.581m/s**
- Total high cross-sectional area – **1.492m²**
- Estimated high flow rate – **0.866m³/s**

It is important to note that the flow monitoring location was placed in between a diverging stream to capture hydrometric data for the Virginia River and the contributing supplemental flow that the outlet weir produces during high precipitation events. The outlet weir generally does not produce any additional flow during low precipitation events.

Virginia River Tributary at Guzzwell Drive Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.334m**
- Area weighted low velocity – **0.171m/s**
- Total low cross-sectional area – **1.119m²**
- Estimated low flow rate – **0.191m³/s**
- Field measured high water level at the stand pipe – **0.526m**
- Area weighted high velocity – **0.535m/s**
- Total high cross-sectional area – **1.390m²**
- Estimated high flow rate – **0.743m³/s**

Virginia River at Logy Bay Road Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.298m**
- Area weighted low velocity – **0.268m/s**
- Total low cross-sectional area – **1.376m²**
- Estimated low flow rate – **0.369m³/s**
- Field measured high water level at the stand pipe – **0.620m**
- Area weighted high velocity – **0.488m/s**
- Total high cross-sectional area – **3.382m²**
- Estimated high flow rate – **1.651m³/s**



3.3.4 HOLES IN MARSH BROOK

Holes in Marsh Brook consists of two flow monitoring locations and a total drainage area of approximately 97.3ha. The flow monitoring location drainage areas for Kelsey Drive and Pippy Place is approximately 33.2ha and 77.3ha, respectively as seen in **Figure 30**.

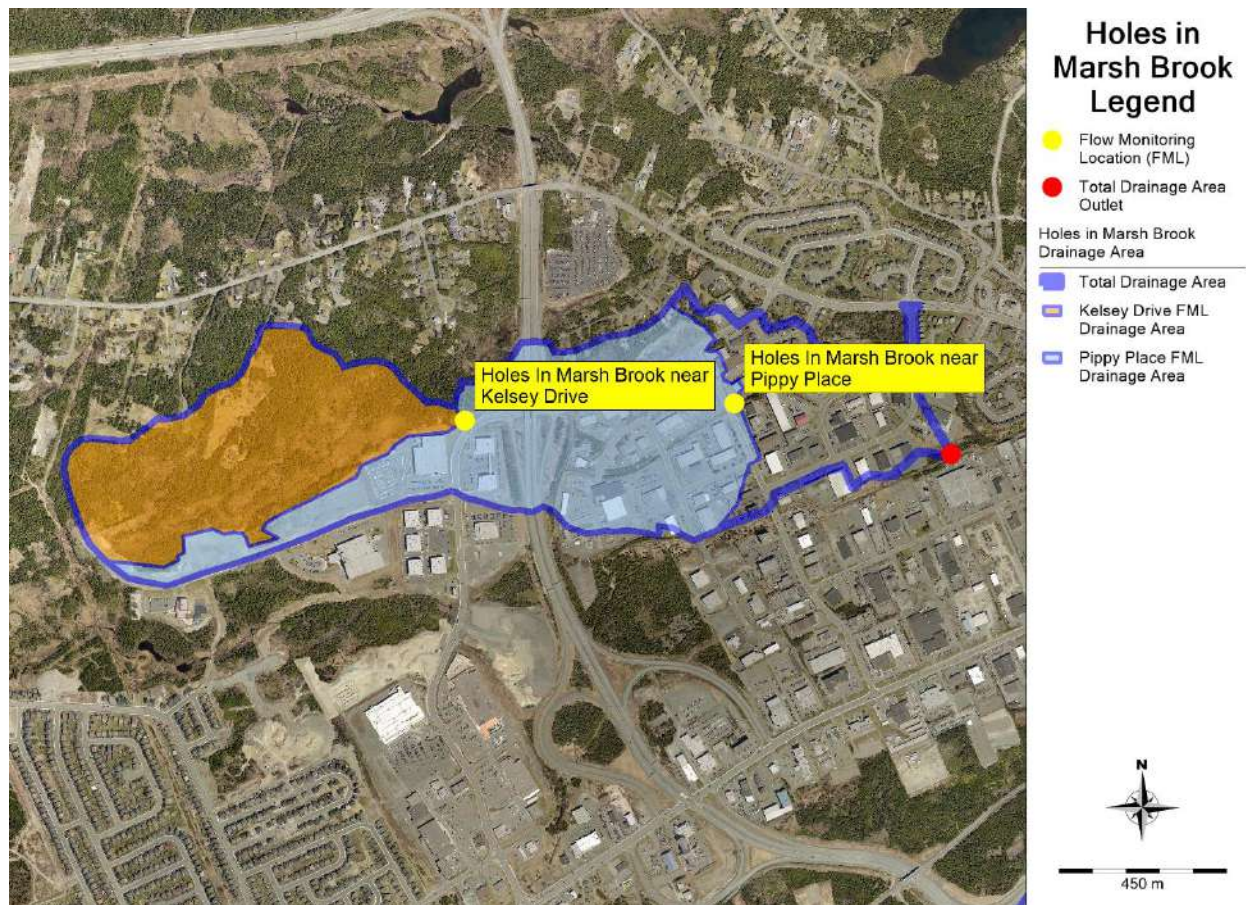


Figure 30 - Holes in Marsh Brook Drainage Area and Flow Monitoring Locations

Holes in Marsh Brook near Kelsey Drive Estimated Hydrometric Properties:

- Field measured low water level at weir centre – **0.036m**
- Area weighted low velocity – **0.200m/s**
- Total low cross-sectional area – **0.036m²**
- Estimated low flow rate – **0.0072m³/s**
- Field measured high water level at weir centre – **0.085m**
- Area weighted high velocity – **0.850m/s**
- Total high cross-sectional area – **0.085m²**
- Estimated high flow rate – **0.0723m³/s**

The weir centre was considered the datum for the Kelsey Drive hydrometric study as the geometry of weir during low and high flow remained the same. This approach allowed for greater accuracies when estimating the flow rate at the weir itself. Generally, the datum was at the stand pipe for most of the flow monitoring locations; however, because the geometry of the weir is consistent, Stantec elected to use that geometry to develop estimated flow rates rather than recording a cross-section across the channel.

Holes in Marsh Brook near Pippy Place Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.391m**
- Area weighted low velocity – **0.165m/s**
- Total low cross-sectional area – **0.389m²**
- Estimated low flow rate – **0.064m³/s**

- Field measured high water level at the stand pipe – **0.584m**
- Area weighted high velocity – **0.416m/s**
- Total high cross-sectional area – **0.675m²**
- Estimated high flow rate – **0.281m³/s**

3.3.5 MUNDY POND BROOK

Mundy Pond Brook consists of two flow monitoring locations and a total drainage area of approximately 246.6ha. The flow monitoring drainage areas for Coefield Street is approximately 68.5ha and the Outlet Structure flow monitoring location captures the entire drainage area for Mundy Pond Brook as seen in **Figure 31**.



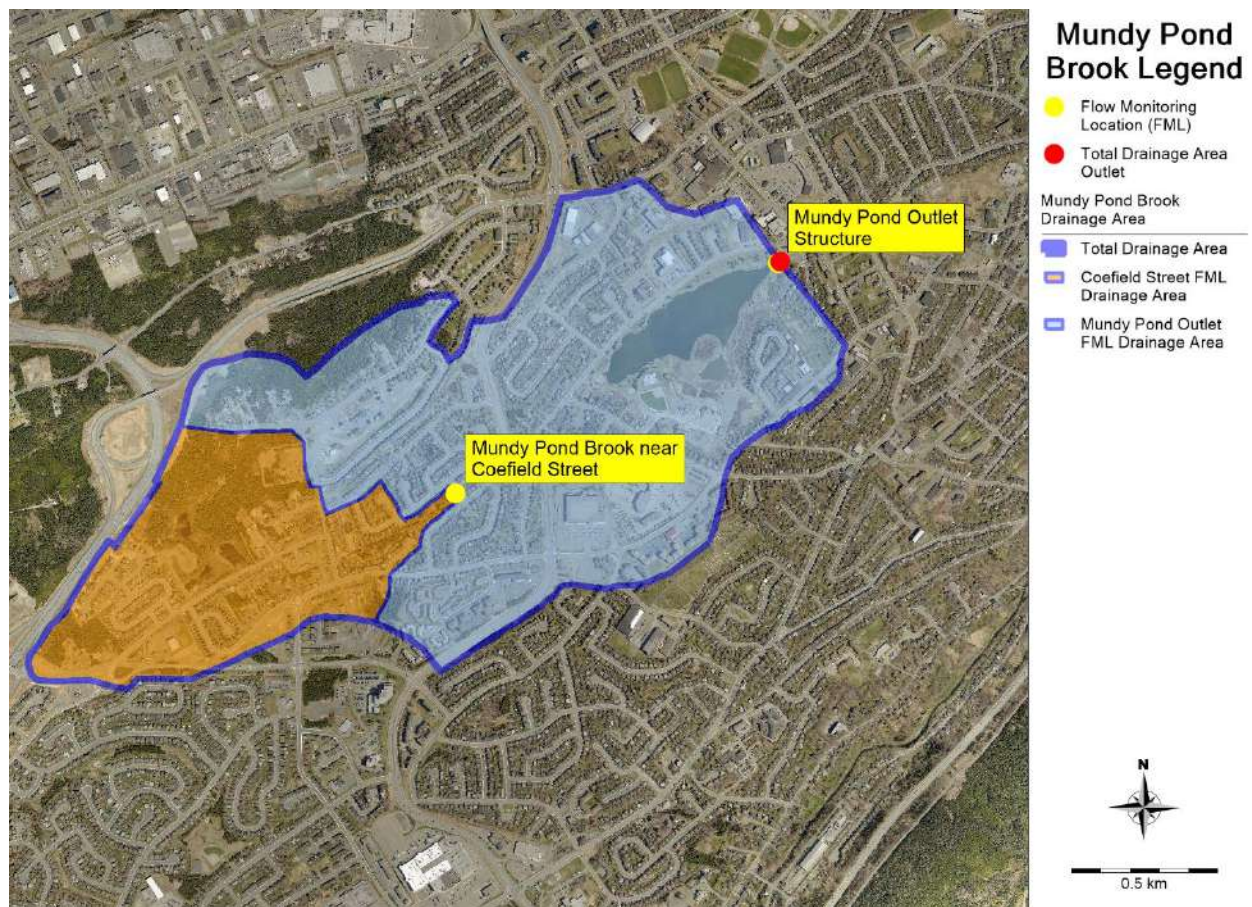


Figure 31 - Mundy Pond Brook Drainage Area and Flow Monitoring Locations

Mundy Pond Brook near Coefield Street Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.307m**
- Area weighted low velocity – **0.133m/s**
- Total low cross-sectional area – **0.821m²**
- Estimated low flow rate – **0.109m³/s**
- Field measured high water level at the stand pipe – **0.439m**
- Area weighted high velocity – **0.294m/s**
- Total high cross-sectional area – **1.239m²**
- Estimated high flow rate – **0.364m³/s**

Mundy Pond Outlet Structure Opening Estimated Hydrometric Properties:

- Field measured low water level at the centre of opening – **0.320m**
- Area weighted low velocity – **0.811m/s**
- Total low cross-sectional area – **0.375m²**
- Estimated low flow rate – **0.304m³/s**



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- Field measured high water level at the centre of opening – **0.575m**
- Area weighted high velocity – **1.199m/s**
- Total high cross-sectional area – **0.622m²**
- Estimated high flow rate – **0.746m³/s**

3.3.6 KITTY GAUL BROOK

Kitty Gaul Brook consists of two flow monitoring locations and a total drainage area of approximately 294.8ha. The flow monitoring drainage areas for Downstream of Blackmarsh Road and Greenwood Crescent is approximately 156.4ha and 293.6ha, respectively, as seen in **Figure 32**.

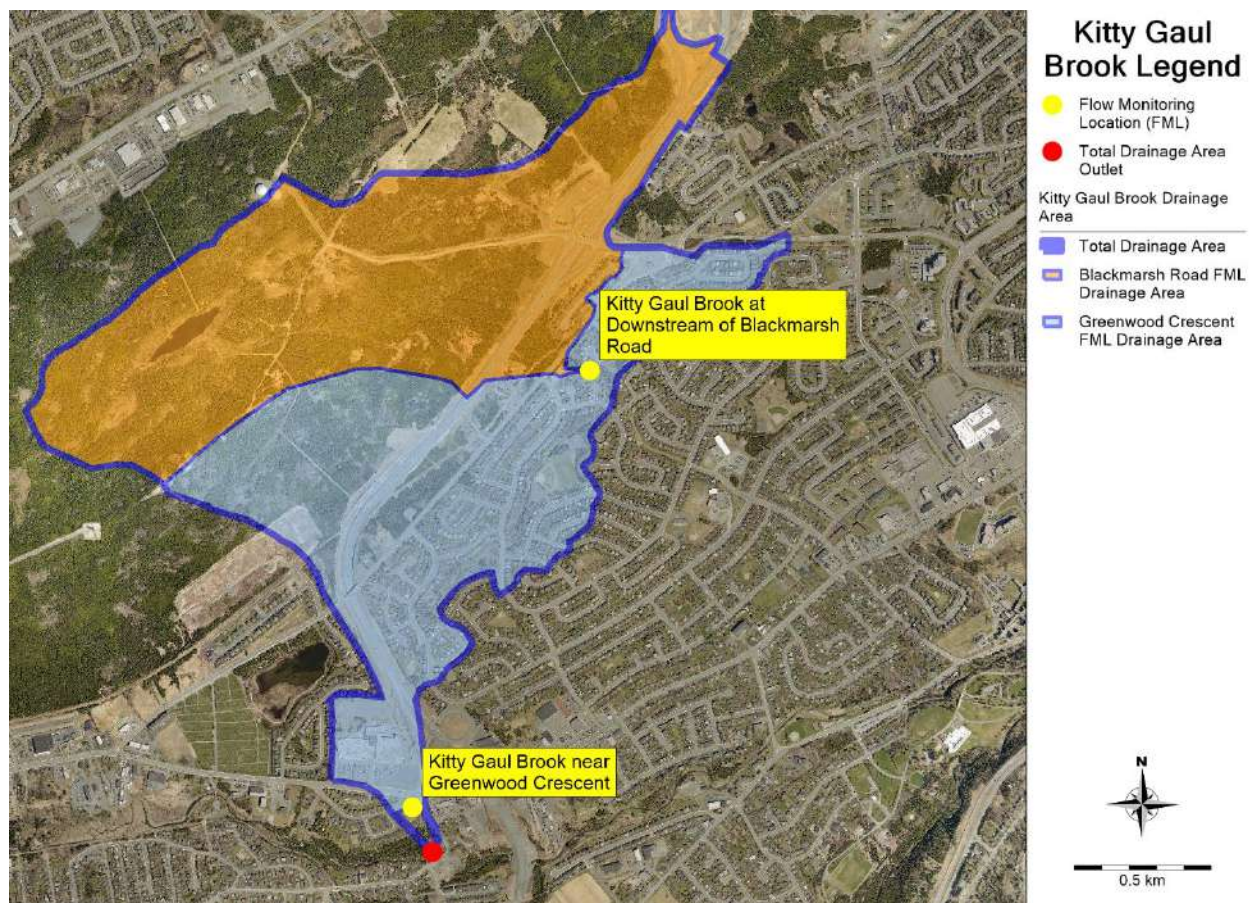


Figure 32 - Kitty Gaul Brook Drainage Area and Flow Monitoring Locations

Kitty Gaul Brook near Greenwood Crescent Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.182m**
- Area weighted low velocity – **0.254m/s**
- Total low cross-sectional area – **1.329m²**
- Estimated low flow rate – **0.338m³/s**



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- Field measured high water level at the stand pipe – **0.362m**
- Area weighted high velocity – **0.564m/s**
- Total high cross-sectional area – **1.972m²**
- Estimated high flow rate – **1.112m³/s**

Kitty Gaul Brook at Downstream of Blackmarsh Road Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.304m**
- Area weighted low velocity – **0.159m/s**
- Total low cross-sectional area – **0.655m²**
- Estimated low flow rate – **0.104m³/s**
- Field measured high water level at the stand pipe – **0.485m**
- Area weighted high velocity – **0.368m/s**
- Total high cross-sectional area – **1.037m²**
- Estimated high flow rate – **0.381m³/s**

3.3.7 SOUTH BROOK

South Brook consists of two flow monitoring locations and a total drainage area of approximately 731.7ha. The flow monitoring drainage areas for Southlands Boulevard (upper crossing) and Tree Top Drive is approximately 297.4ha and 444.7ha, respectively, as seen in **Figure 33**.



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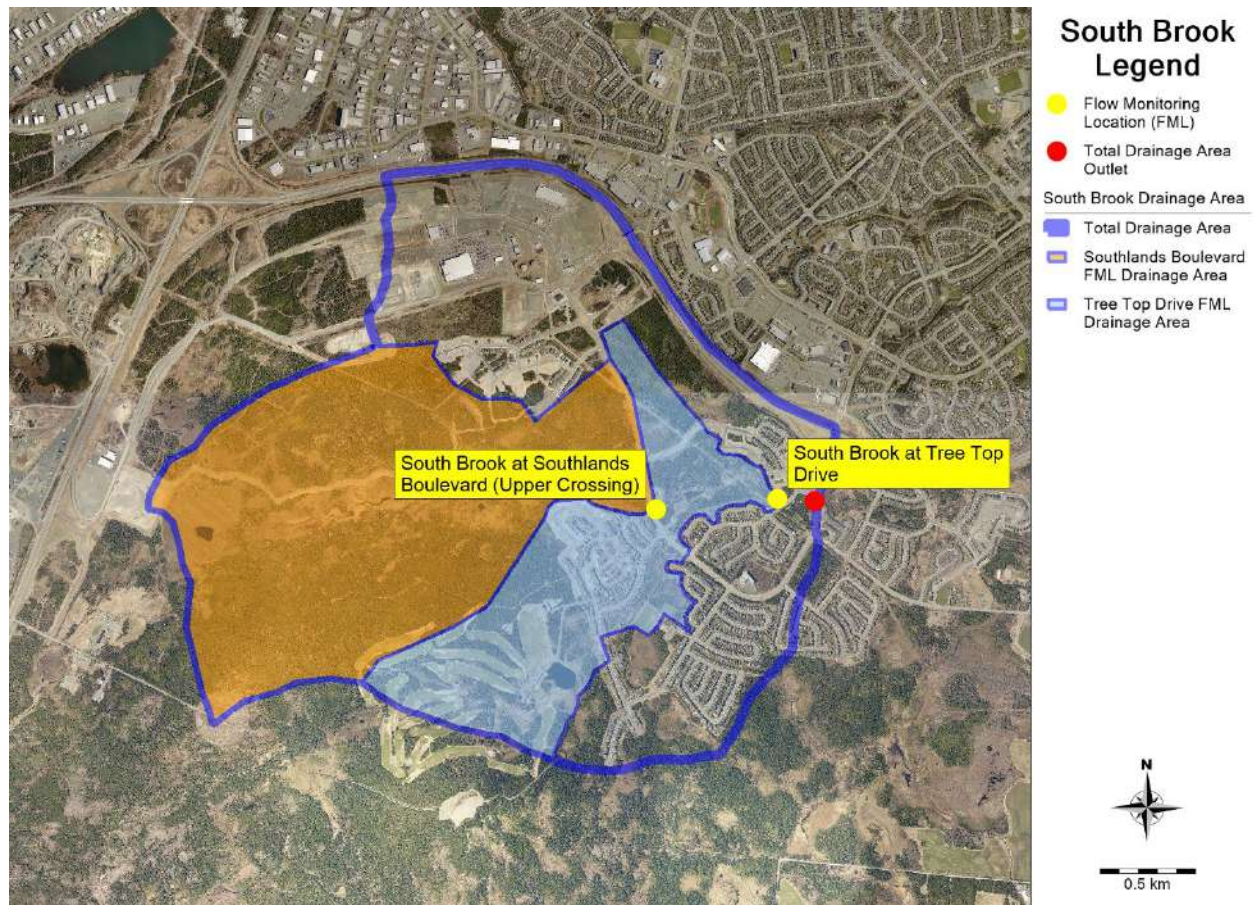


Figure 33 - South Brook Drainage Area and Flow Monitoring Locations

South Brook at Southlands Boulevard (Upper Crossing) Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.562m**
- Area weighted low velocity – **0.195m/s**
- Total low cross-sectional area – **1.169m²**
- Estimated low flow rate – **0.228m³/s**
- Field measured high water level at the stand pipe – **0.645m**
- Area weighted high velocity – **0.578m/s**
- Total high cross-sectional area – **1.660m²**
- Estimated high flow rate – **0.960m³/s**

South Brook at Tree Top Drive Estimated Hydrometric Properties:

- Field measured low water level at the stand pipe – **0.192m**
- Area weighted low velocity – **0.429m/s**
- Total low cross-sectional area – **0.913m²**
- Estimated low flow rate – **0.392m³/s**



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- Field measured high water level at the stand pipe – **0.405m**
- Area weighted high velocity – **0.653m/s**
- Total high cross-sectional area – **1.775m²**
- Estimated high flow rate – **1.158m³/s**

The estimated flows corresponding to the measured velocities are summarized in **Table 1**.



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Table 1 - Summary of Estimated Low and High Flow

Description	Flow Rate (m³/s)	Measuring Start Time	Measuring End Time	Date
<i>Outer Cove Brook at Virginia River Trail Cross-Section</i>	0.171	10:39:00 AM	10:54:00 AM	Monday, October 23, 2023
	0.406	10:15:00 AM	10:30:00 AM	Thursday, November 2, 2023
<i>Outer Cove Brook at Torbay Road Cross-section</i>	0.277	9:54:00 AM	10:15:00 AM	Monday, October 23, 2023
	1.205	10:40:00 AM	11:00:00 AM	Thursday, November 2, 2023
<i>Virginia River at Penny Crescent Cross-Section</i>	0.261	11:00:00 AM	11:30:00 AM	Monday, October 23, 2023
	0.755	11:14:00 AM	11:27:00 AM	Thursday, November 2, 2023
<i>Virginia River at Virginia Lake Outlet Weir Cross-Section</i>	0.434	11:47:00 AM	12:10:00 PM	Monday, October 23, 2023
	0.866	11:53:00 AM	12:00:00 PM	Thursday, November 2, 2023
<i>Virginia River Tributary @ Guzzwell Drive Cross-Section</i>	0.191	12:45:00 PM	12:53:00 PM	Monday, October 23, 2023
	0.743	12:30:00 PM	12:41:00 PM	Thursday, November 2, 2023
<i>Virginia River at Logy Bay (Old) Cross-Section</i>	0.652	1:00:00 PM	1:30:00 PM	Monday, October 23, 2023
	N/A			
<i>Virginia River at Logy Bay (New) Cross-Section</i>	0.369	10:05:00 AM	10:20:00 AM	Wednesday, October 25, 2023
	1.651	12:53:00 PM	1:10:00 PM	Thursday, November 2, 2023
<i>Barrows Road Stream near Cuckholds Cove Road Cross-Section</i>	0.005	2:14:00 PM	2:16:00 PM	Monday, October 23, 2023
	0.010	1:30:00 PM	1:32:00 PM	Thursday, November 2, 2023
<i>Barrows Road Stream near Barrows Road Cross-Section</i>	0.008	1:55:00 PM	2:10:00 PM	Monday, October 23, 2023
	0.043	1:23:00 PM	1:25:00 PM	Thursday, November 2, 2023
<i>Holes in Marsh Brook near Kelsey Drive Cross-Section</i>	0.007	2:55:00 PM	3:00:00 PM	Monday, October 23, 2023
	0.072	2:10:00 PM	2:12:00 PM	Thursday, November 2, 2023
<i>Holes in Marsh Brook near Pippy Place Cross-Section</i>	0.064	2:45:00 PM	2:50:00 PM	Monday, October 23, 2023
	0.281	1:55:00 PM	2:00:00 PM	Thursday, November 2, 2023
<i>Mundy Pond Brook near Coefield Street Cross-Section</i>	0.109	9:14:00 AM	9:22:00 AM	Tuesday, October 24, 2023
	0.364	2:30:00 PM	2:40:00 PM	Thursday, November 2, 2023
<i>Mundy Pond Brook at Mundy Pond Outlet Rectangular Opening Cross-Section</i>	0.304	9:40:00 AM	9:55:00 AM	Tuesday, October 24, 2023
	0.746	2:45:00 PM	2:52:00 PM	Thursday, November 2, 2023
<i>Mundy Pond Brook at Mundy Pond Outlet Cross-Section</i>	0.288	9:40:00 AM	9:55:00 AM	Tuesday, October 24, 2023
	N/A			
<i>Kitty Gaul Brook at Downstream of Blackmarsh Road Cross-Section</i>	0.104	10:10:00 AM	10:20:00 AM	Tuesday, October 24, 2023
	0.381	3:06:00 PM	3:15:00 PM	Thursday, November 2, 2023
<i>Kitty Gaul Brook near Greenwood Crescent Cross-Section</i>	0.338	10:35:00 AM	10:55:00 AM	Tuesday, October 24, 2023
	1.112	3:20:00 PM	3:34:00 PM	Thursday, November 2, 2023
<i>South Brook at Southlands Boulevard Upper Crossing Cross-Section</i>	0.228	11:35:00 AM	11:41:00 AM	Tuesday, October 24, 2023
	0.960	4:00:00 PM	4:10:00 PM	Thursday, November 2, 2023
<i>South Brook at Tree Top Drive Cross-Section</i>	0.392	11:10:00 AM	11:30:00 AM	Tuesday, October 24, 2023
	1.158	3:50:00 PM	3:56:00 PM	Thursday, November 2, 2023



3.4 Hydrometric Data Comparison

The flow series developed for the monitoring period were also compared to active real-time WSC hydrometric station data. The Leary's Brook at Prince Philip Drive (02ZM020; 1,780 ha), Virginia River at Pleasantville (02ZM018, 1,070 ha), and Waterford River at Kilbride (02ZM008, 5,270 ha) were compared to the monitored flow series to validate the monitored flow series. Flow data from the WSC hydrometric stations were prorated to the level logger locations by ratio of drainage areas and graphed with the monitored flow to conduct the comparison. The locations of these hydrometric stations, in relation to the level loggers is presented in **Figure 7**. Note that the watersheds included as part of this study are typically smaller compared to other flood risk mapping studies that were previously completed in Newfoundland.

3.4.1 HOLES IN MARSH BROOK

Flow from the Leary's Brook at Prince Philip Drive (02ZM020) hydrometric station were prorated to the Holes in Marsh Brook monitoring locations. Holes in Marsh Brook is a tributary to Leary's Brook. The comparisons for the Kelsey Drive and Pippy Place monitoring locations are shown in **Figure 34** and **Figure 35**, respectively.

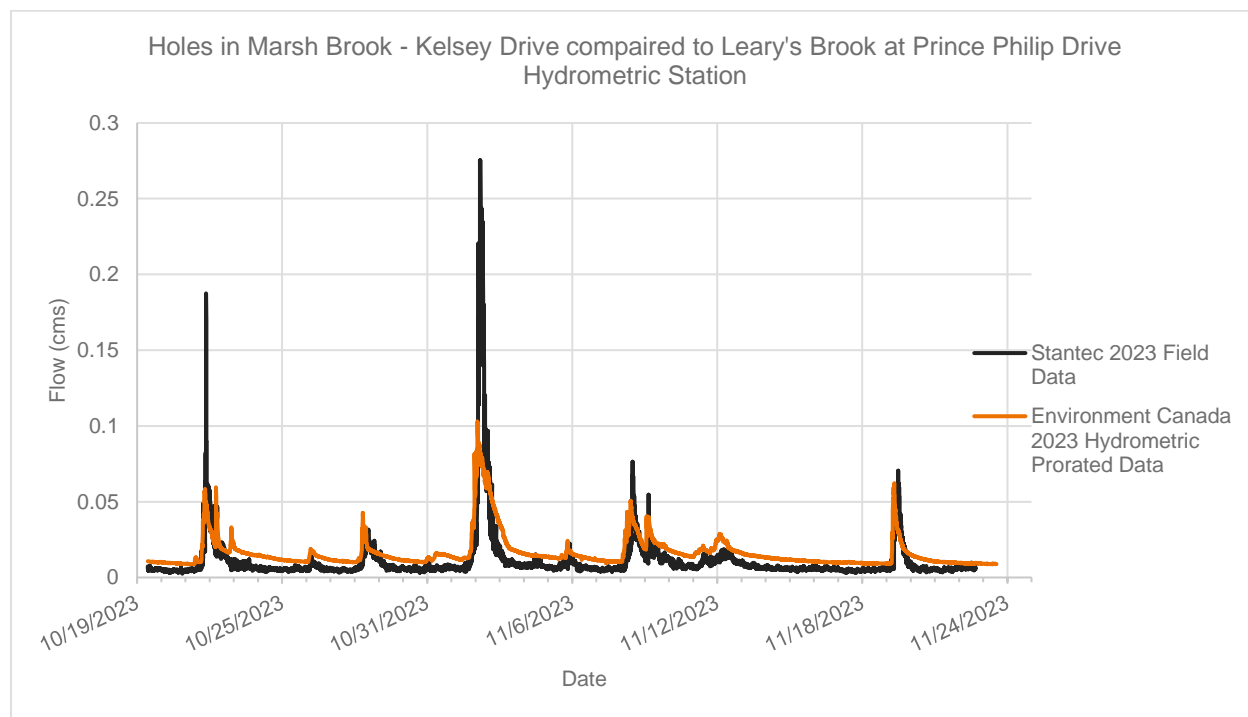


Figure 34 - Kelsey Drive Flow Monitoring Location Comparison



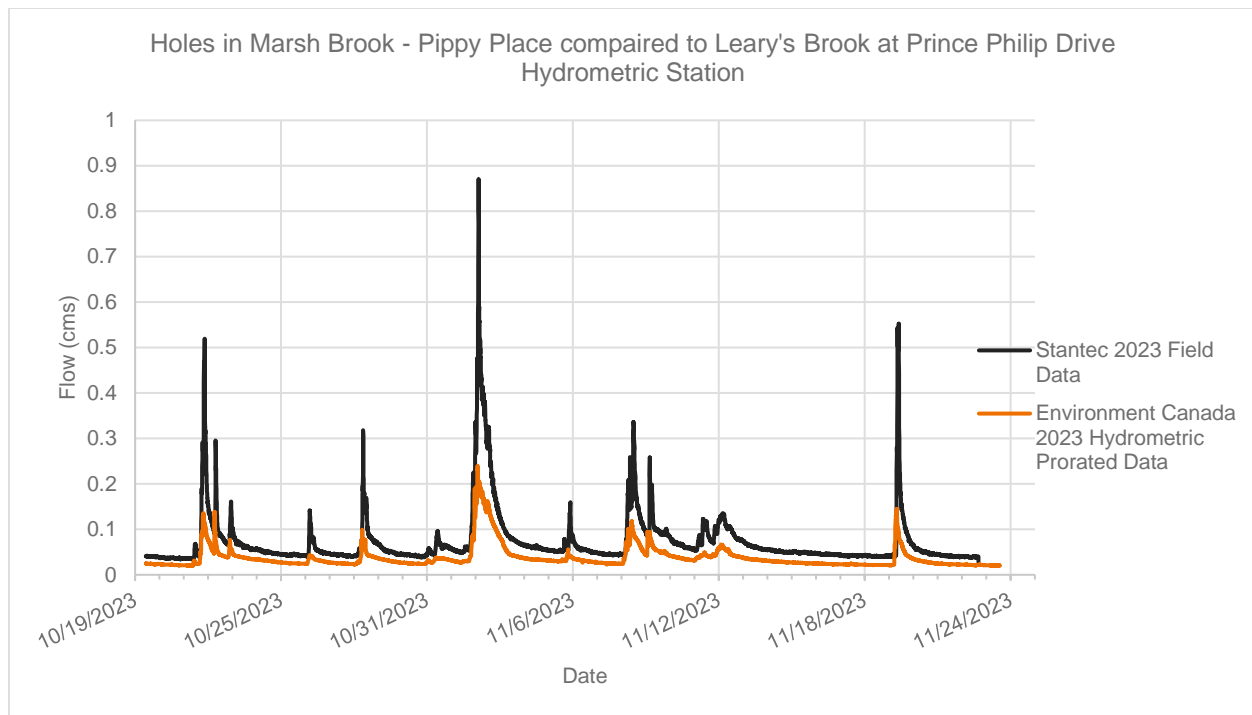


Figure 35 - Pippy Place Flow Monitoring Location Comparison

The drainage areas are not comparable as Leary's Brook hydrometric station drainage area is significantly larger than the flow monitoring station's drainage area for Kelsey Drive and Pippy Place. Generally, the data for the Holes in Marsh Brook monitoring locations corresponded well to the 02ZM020 hydrometric station as the data is consistent with detecting noticeable precipitation events.

3.4.2 OUTER COVE BROOK

The Virginia River at Pleasantville (02ZM018) hydrometric station was compared to three study areas for this report; Outer Cove Brook, Virginia River and its tributaries, and Barrow's Road Stream. The graphical comparison for the Virginia River Trail and at Torbay Road monitoring locations are presented in **Figure 36** and **Figure 37**, respectively.

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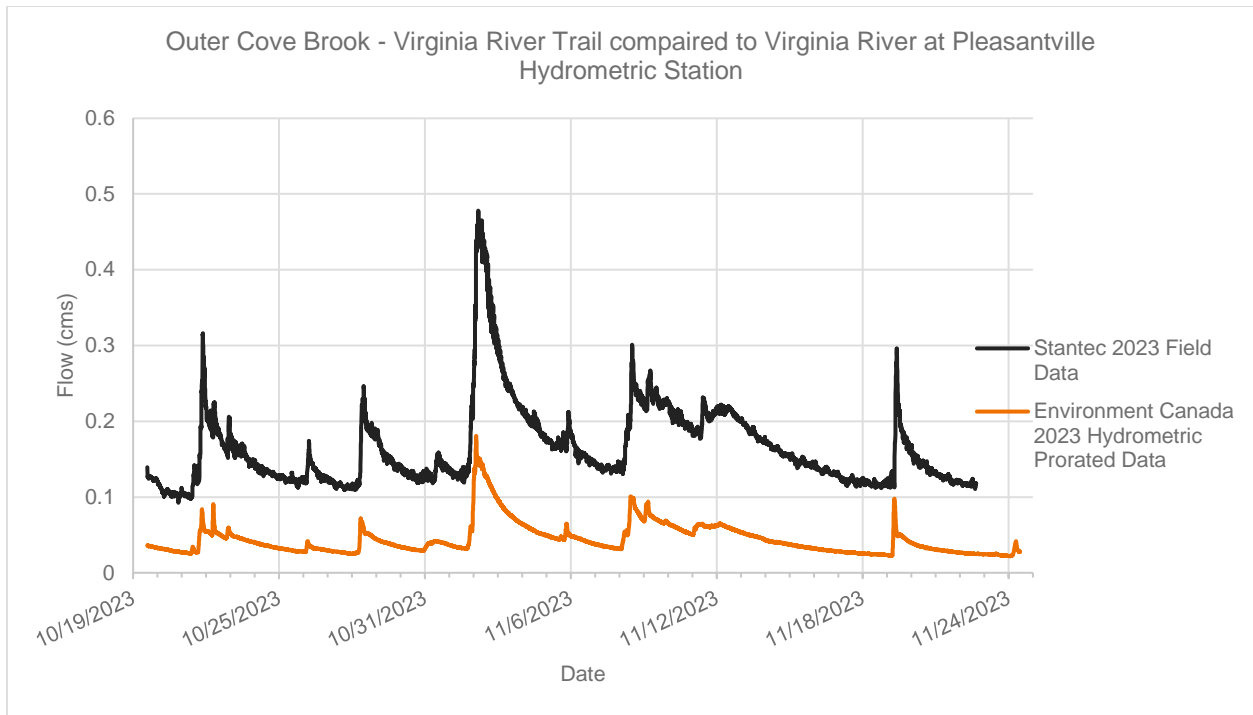


Figure 36 - Virginia River Trail Flow Monitoring Location Comparison

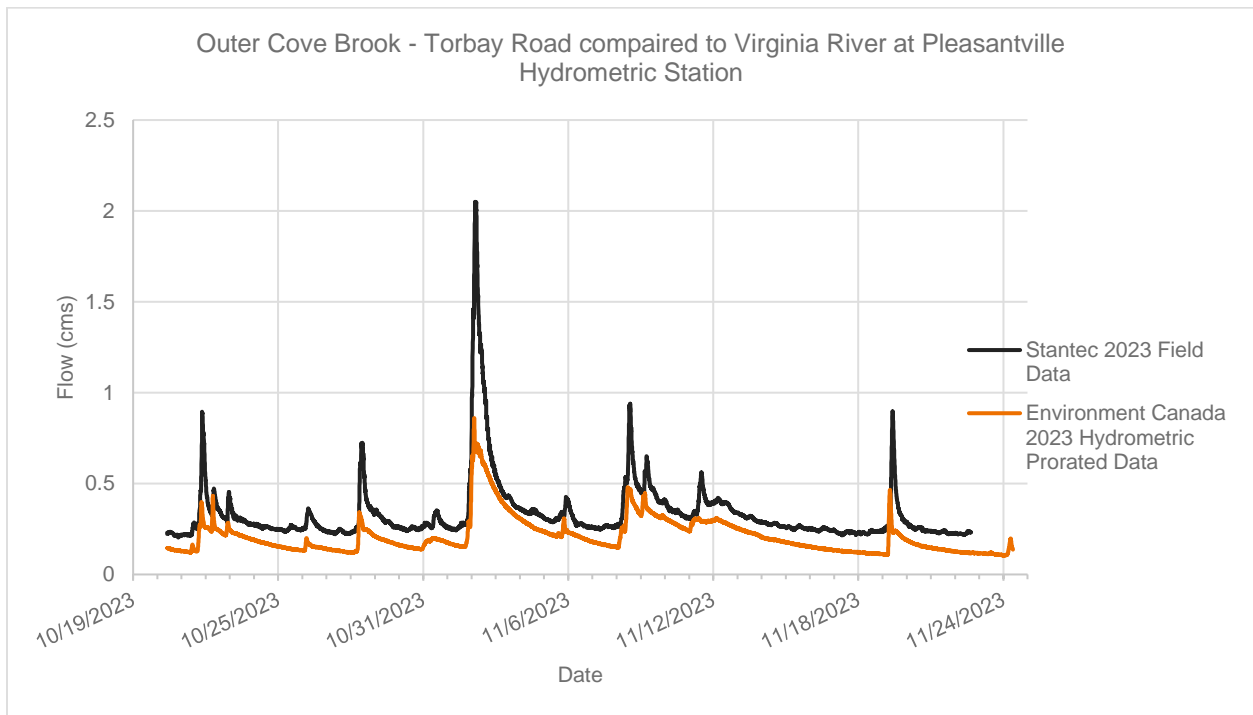


Figure 37 - Torbay Road Flow Monitoring Location Comparison



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Similar to Holes in Marsh Brook, the shape of the comparison graphs for Outer Cove Brook indicates that the field data is comparable with Environment Canada's data for detecting precipitation events; however, as previously mentioned, both flow monitoring drainage areas are not comparable with the Virginia River drainage area thus will not produce the same peak flow rates. The Virginia River at Pleasantville gauge is also located downstream of the large attenuating feature of Virginia Lake which may cause the flow peaks to be less pronounced than those on Outer Cove Brook.

3.4.3 VIRGINIA RIVER

The flows at the Virginia River monitoring locations showed the closest comparison to the prorated hydrometric station data. This is a good comparison as all 4 measurement locations in the Virginia River system are located within the drainage area of the WSC station. The graphical comparison for the Penny Crescent, Outlet Weir, Logy Bay Road and Guzzwell Drive monitoring locations are presented in **Figure 38**, **Figure 39**, **Figure 40** and **Figure 41**, respectively.

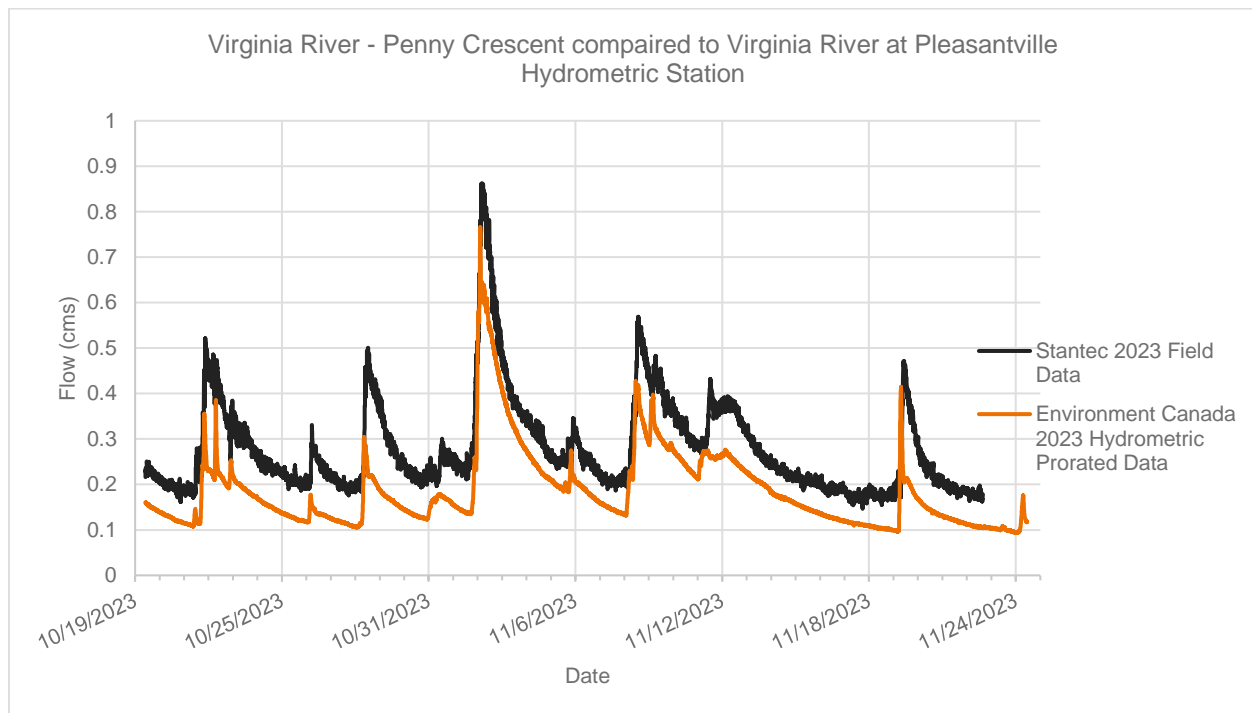


Figure 38 – Penny Crescent Flow Monitoring Location Comparison



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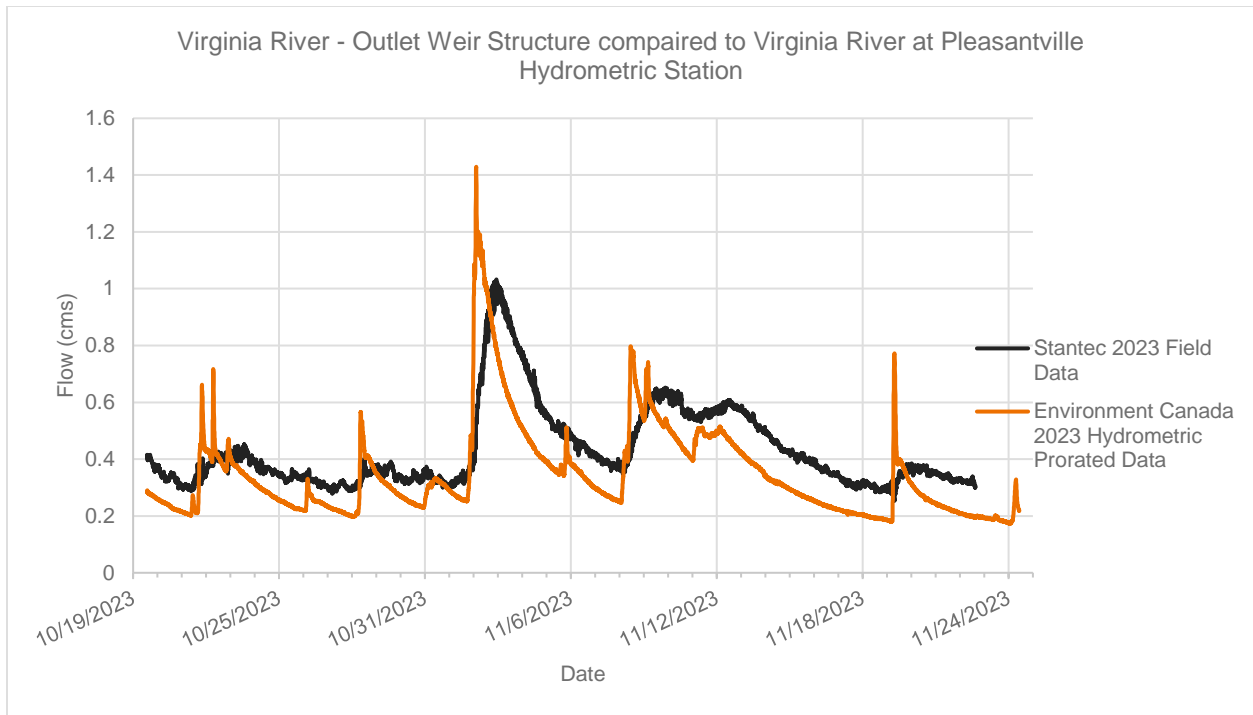


Figure 39 – Outlet Weir Structure Flow Monitoring Location Comparison

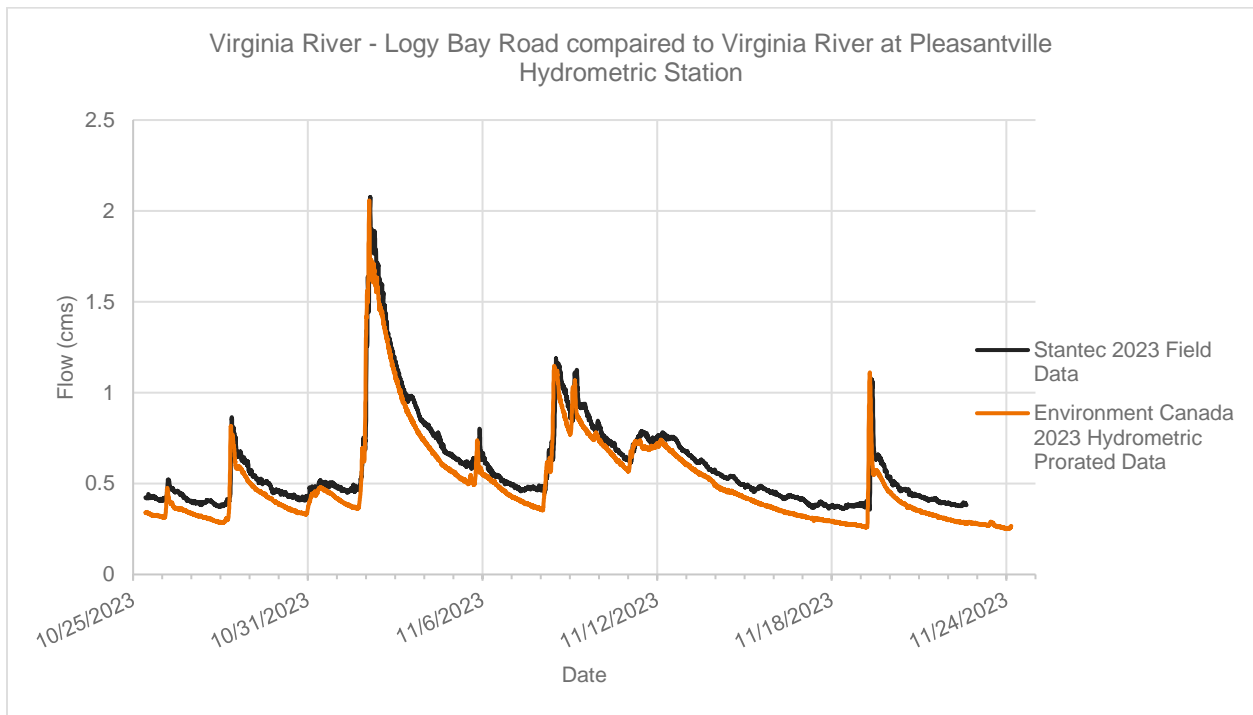


Figure 40 – Logy Bay Road Flow Monitoring Location Comparison



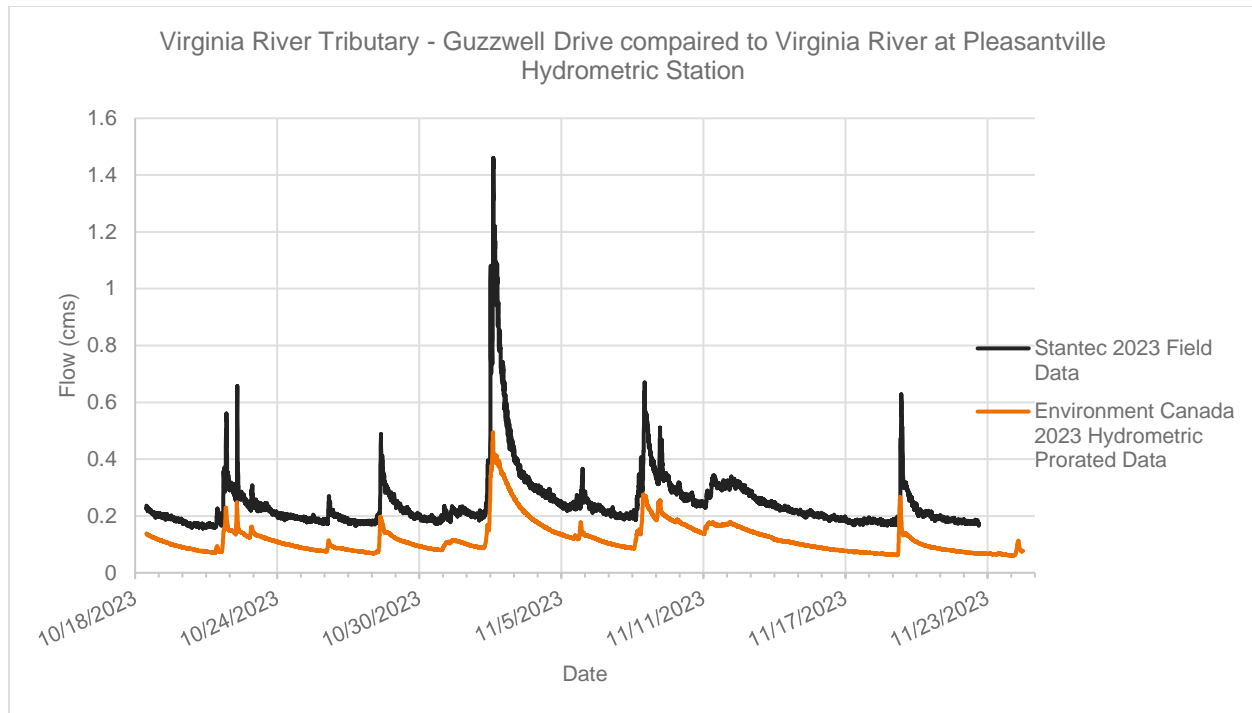


Figure 41 – Tributary at Guzzwell Drive Flow Monitoring Location Comparison

As evident in **Figure 40**, the comparison between Logy Bay Road flow monitoring location and Environment Canada’s Virginia River at Pleasantville hydrometric station is near identical as the drainage areas are similar. It is important to note that the distance between the Logy Bay flow monitoring location and Environment Canada’s Virginia River at Pleasantville hydrometric station is 1.2km thus this comparison was crucial to this study as it indicates that the field measured data was being collected and corrected accurately to use for the flood modelling component. It was expected that the outlet weir structure to have varying results for flow measurements as the river diverges at that section. The outlet weir structure had very little involvement during the peak precipitation event on November 2nd, 2023. Most of the water bypasses the weir and is directed downstream. The flow monitoring location at Guzzwell Drive collects the discharge from the tributary watercourse that feeds into Virginia River.

3.4.4 BARROWS ROAD STREAM

The observed water levels, and hence flows, at the Barrows Road stream monitoring locations were very low. The flow data recorded at the WSC station 02ZM018 was prorated to the Cuckholds Cove Road and Barrows Road level logger locations for comparison, as shown in **Figure 42** and **Figure 43**.

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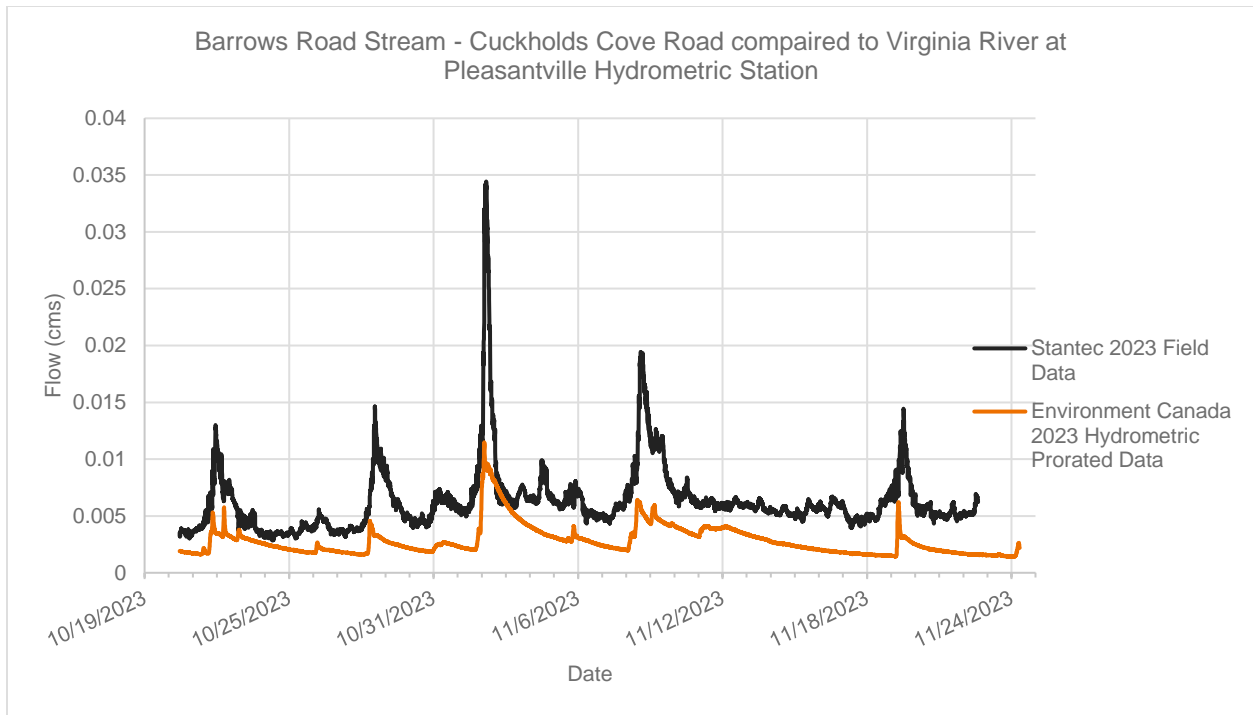


Figure 42 – Cuckholds Cove Road Flow Monitoring Location Comparison

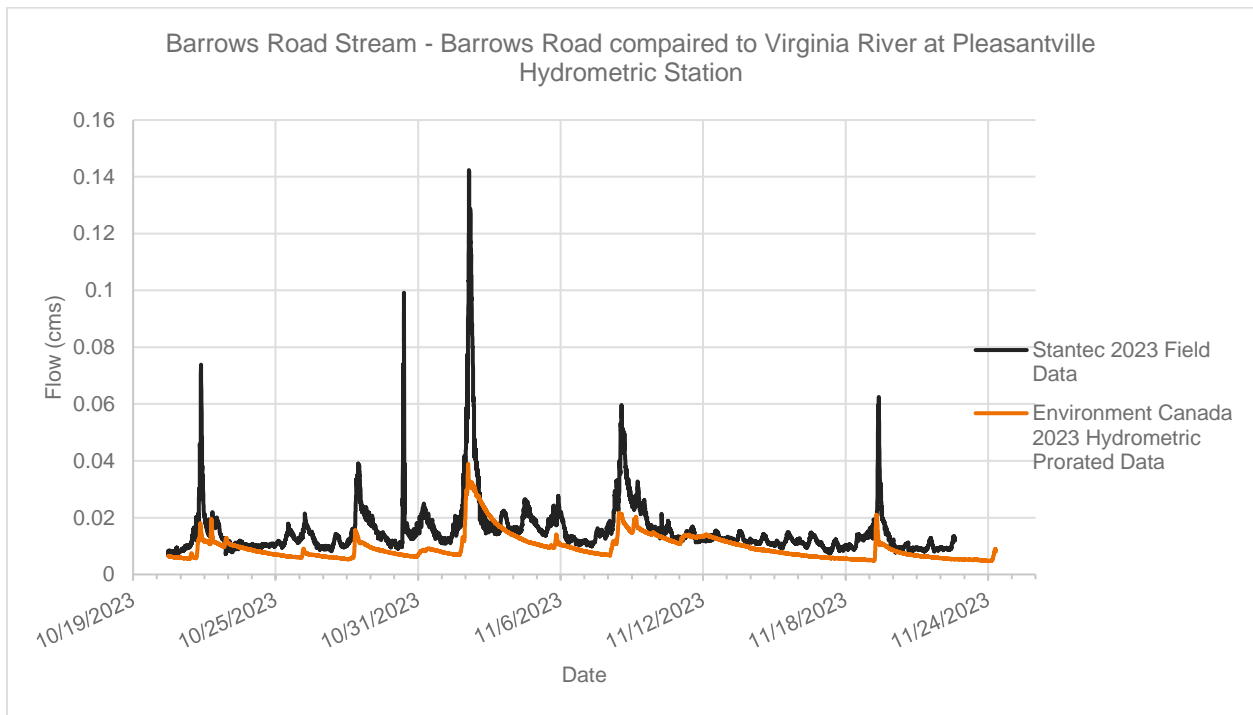


Figure 43 – Barrows Road Flow Monitoring Location Comparison



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As depicted in the above figures, the proration between drainage areas is not comparable. Similar to the other datasets that were compared, both hydrometric show when a significant precipitation storm occurred.

Additionally, the drainage area for Barrow's Road stream is comparatively small and contains significant areas of barren/rocky Land cover that tends to generate faster and higher runoff peaks.

3.4.5 KITTY GAUL BROOK

The Waterford River at Kilbride (02ZM008) hydrometric station flow data was compared to the flow data recorded at monitoring stations installed on Kitty Gaul Brook, Mundy Pond Brook, and South Brook. The graphical comparison for the Kitty Gaul Brook Downstream of Blackmarsh Road and Greenwood Crescent monitoring locations are presented in **Figure 44** and **Figure 45**, respectively.

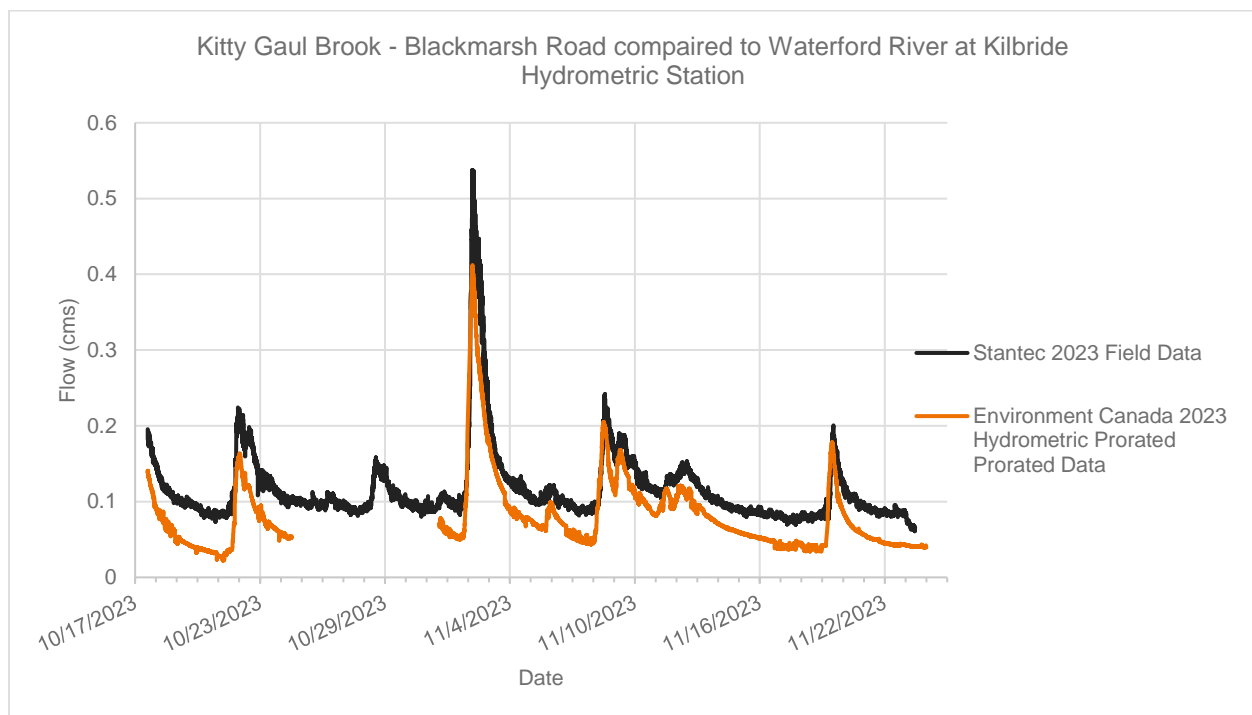


Figure 44 – Downstream of Blackmarsh Road Flow Monitoring Location Comparison

The drainage areas for WSC station 02ZM008 is large and the drainage areas for the Kitty Gaul Brook flow monitoring stations are not suitable for comparison even with a proration factor; however, Stantec does have a level of comfort with respect to both data sets recording major and minor precipitation events. The hydrometric comparison graph for Greenwood Crescent can be seen in **Figure 45**, and yields the same results as the Blackmarsh Road flow monitoring station.



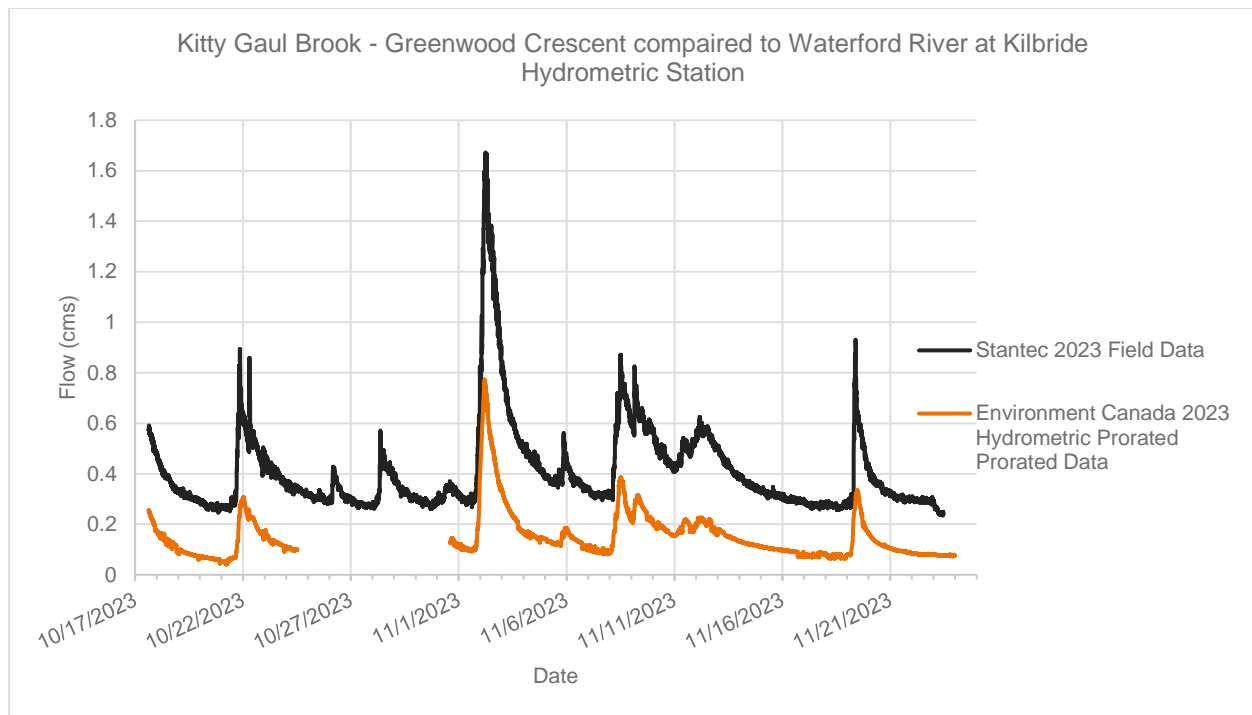


Figure 45 - Greenwood Crescent Flow Monitoring Location Comparison

3.4.6 MUNDY POND BROOK & SOUTH BROOK

The hydrometric data comparison varied between Mundy Pond Brook and South Brook. Similarly, the drainage area is minimal and is not comparable to produce related results in terms of flow; however, the same general shape is seen in the below mentioned figures thus recording similarities in data in terms of major and minor precipitation events.

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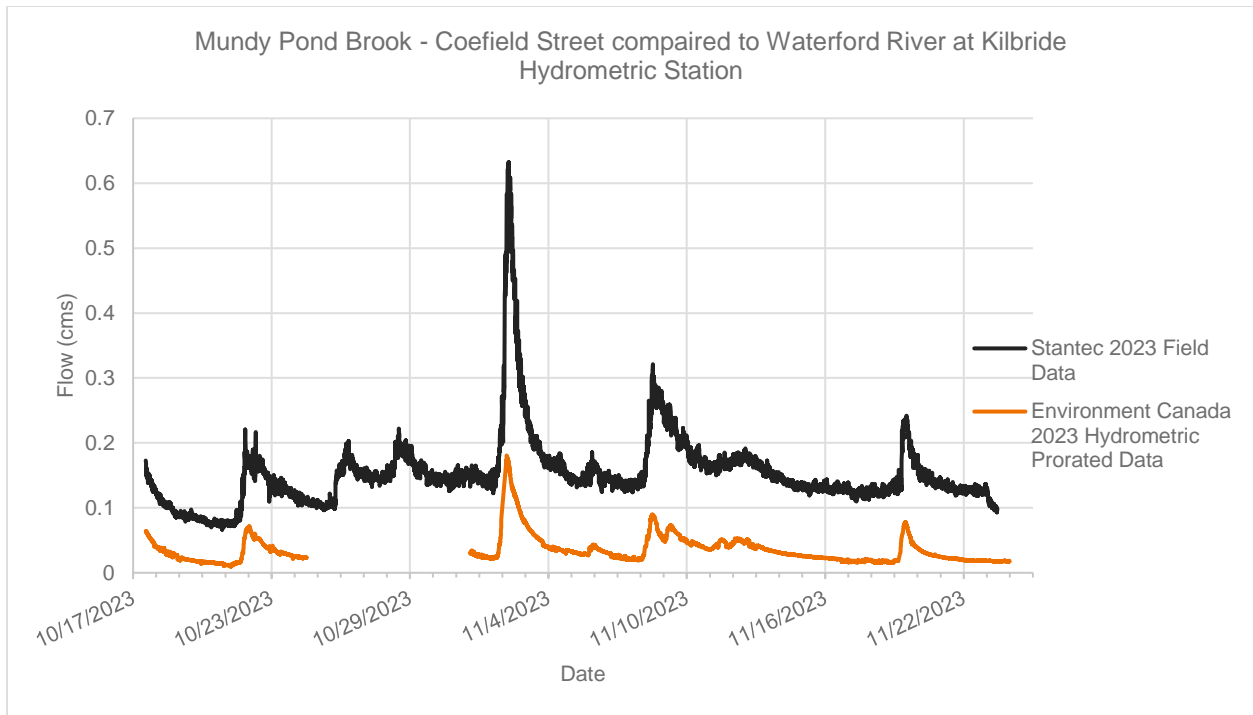


Figure 46 - Coefield Street Flow Monitoring Location Comparison

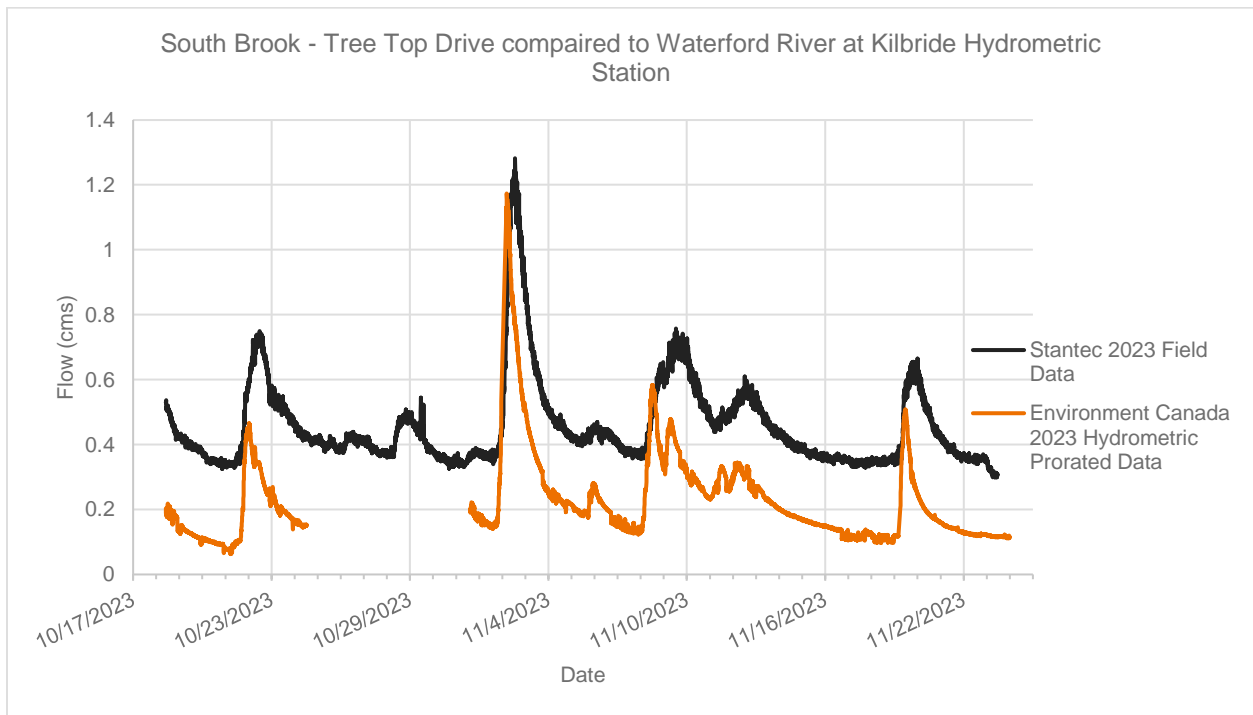


Figure 47 - Tree Top Drive Flow Monitoring Location Comparison



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It should be noted that although the flow rates from WSC hydrometric stations are prorated to the flow monitoring drainage area, some differences are expected, especially when taking data from a hydrometric station that is within a different drainage area (difference land use, slope, etc.). Based on the comparisons, it was determined that the data recorded in the field produced reliable results as the level loggers recorded major and minor precipitation events alike the WSC stations. The results are appropriate to develop hydrologic and hydraulic models.

A summary of the peak flow rates estimated at the monitoring locations and WSC's hydrometric stations is included in **Table 2**.



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Table 2: Estimated Peak Flow Rates

Description	Estimated Peak Flow Rate (m³/s)	2023 Environment Canada Prorated Peak Flow Rate (m³/s)	Δ (m³/s)	% Difference	Environment Canada Hydrometric Station	Time (Field)	Time (Environment Canada)	Date
Outer Cove Brook at Virginia River Trail Cross-Section	0.48	0.18	0.30	90.19	Virginia River at Pleasantville	4:40:00 AM	2:35:00 AM	Thursday, November 2, 2023
Outer Cove Brook at Torbay Road Cross-section	2.05	0.86	1.19	81.79	Virginia River at Pleasantville	3:30:00 AM	2:35:00 AM	Thursday, November 2, 2023
Virginia River at Penny Crescent Cross-Section	0.86	0.77	0.10	11.75	Virginia River at Pleasantville	4:40:00 AM	2:35:00 AM	Thursday, November 2, 2023
Virginia River at Virginia Lake Outlet Weir Cross-Section	1.03	1.43	0.40	32.15	Virginia River at Pleasantville	10:25:00 PM	2:35:00 AM	Thursday, November 2, 2023
Virginia River Tributary @ Guzzwell Drive Cross-Section	1.46	0.50	0.96	98.71	Virginia River at Pleasantville	3:00:00 AM	2:35:00 AM	Thursday, November 2, 2023
Virginia River at Logy Bay (New) Cross-Section	2.08	2.06	0.02	0.93	Virginia River at Pleasantville	3:15:00 AM	2:35:00 AM	Thursday, November 2, 2023
Barrows Road Stream near Cuckholds Cove Road Cross-Section	0.03	0.01	0.02	100.02	Virginia River at Pleasantville	4:35:00 AM	2:35:00 AM	Thursday, November 2, 2023
Barrows Road Stream near Barrows Road Cross-Section	0.14	0.04	0.10	114.02	Virginia River at Pleasantville	3:30:00 AM	2:35:00 AM	Thursday, November 2, 2023
Holes in Marsh Brook near Kelsey Drive Cross-Section	0.28	0.10	0.17	91.18	Leary's Brook at Prince Philip Drive	4:30:00 AM	1:57:00 AM	Thursday, November 2, 2023
Holes in Marsh Brook near Pippy Place Cross-Section	0.87	0.24	0.63	113.60	Leary's Brook at Prince Philip Drive	2:55:00 AM	1:57:00 AM	Thursday, November 2, 2023
Mundy Pond Brook near Coefield Street Cross-Section	0.63	0.18	0.45	111.10	Waterford River at Kilbride	6:40:00 AM	4:45:00 AM	Thursday, November 2, 2023
Mundy Pond Brook at Mundy Pond Outlet Rectangular Opening Cross-Section	0.82	0.65	0.17	22.88	Waterford River at Kilbride	1:25:00 PM	4:45:00 AM	Thursday, November 2, 2023
Kitty Gaul Brook at Downstream of Blackmarsh Road Cross-Section	0.54	0.41	0.13	26.33	Waterford River at Kilbride	4:35:00 AM	4:45:00 AM	Thursday, November 2, 2023
Kitty Gaul Brook near Greenwood Crescent Cross-Section	1.67	0.77	0.90	73.44	Waterford River at Kilbride	5:45:00 AM	4:45:00 AM	Thursday, November 2, 2023
South Brook at Southlands Boulevard Upper Crossing Cross-Section	1.26	0.78	0.47	46.14	Waterford River at Kilbride	12:20:00 PM	4:45:00 AM	Thursday, November 2, 2023
South Brook at Tree Top Drive Cross-Section	1.28	1.17	0.11	8.89	Waterford River at Kilbride	1:20:00 PM	4:45:00 AM	Thursday, November 2, 2023



4.0 Ground Survey

Stantec retained Allnorth Consultants Ltd. to conduct the topographic and bathymetric surveys. Stantec outlined specific survey requirements for each watercourse during the field planning phase. **Appendix A** contains Stantec's Ground Survey Plan. The field program includes ground surveys to determine the nature and extent of the features which affect the exchange of water between the river and the flood plain.

The ground survey primarily focused on hydraulic structures and channel cross sections of the watercourses being analyzed. A total of 106 hydraulic structures were surveyed. There are a wide variety of hydraulic structures in the study areas including road, bridges, pedestrian bridges, culverts, outlet structures, weirs and fish passage structures among others. The ground survey is intended to capture the geometry of structure openings as well as associated infrastructure including headwalls/tailwalls, inlet/outlet pools and weir dimensions such that they can be accurately represented in the hydraulic model(s).

The ground survey also included cross sections of the watercourse channels. The channel cross sections capture bathymetric points within the watercourse, shorelines, banks and other geometric features such that the interaction between the watercourse and its associated floodplain can be modeled. Sections were taken in the near vicinity of the upstream and downstream ends of hydraulic structures (two sections at each end) as well as at other points of interest where changes in flow and water level are expected such as the confluence of tributaries, pond outlets or severe grade changes as seen in **Appendix E**.

The coordinate system utilized for the St. John's, NL area was CSRS MTM Zone 1 and the vertical datum was CGVD2013. The ground survey is used to supplement the LiDAR data received from the City of St. John's.

The following sections discuss the findings from Allnorth Consultants Ltd. and potential implications to the flood study and current hydrology and hydraulic limitations. Note that uncertainty in the ground survey is addressed in **Section 5.0**, where ground survey data is compared to LiDAR data.

4.1 Barrows Road Stream

Stantec identified 5 hydraulic structures for Barrow's Road Stream and Allnorth Consultants Ltd. provided cross-sections for all five hydraulic structures as per the Ground Survey Plan report. An important aspect for Barrow's Road Stream is where stormwater is discharged from Inlet Structure 1 to the Outlet Structure as identified in Figure 1 of the Ground Survey Plan report, and as seen in **Figure 48** and **Figure 49** below. Stantec utilized the ground survey data and storm sewer shapefile geometry from the City of St. John's to refine the storm pipe alignment from Inlet Structure 1 to the Outlet Structure.





Figure 48 – Inlet Structure 1 for Barrows Road Stream



Figure 49 – Outlet Structure for Barrows Road Stream

4.2 Outer Cove Brook

All 20 identified hydraulic structures and corresponding cross-sections were captured for Outer Cove Brook. The ground survey data and photographs as seen in **Figure 50** are used to help define the channel geometry.



Figure 50 - Channel Located at Torbay Road in Outer Cove Brook

4.3 Virginia River

Virginia River is the largest study area of the seven study areas. The ground survey included 38 hydraulic structures and corresponding cross sections. While all 38 hydraulic structures were located in the field, the upstream inlet/obvert for the culvert present at the Tributary Crossing at Paddy Dobbin Drive was completely buried in ice/snow as seen in **Figure 51**. The downstream end of the culvert was located and provides a good indication of the diameter and material for use in the PCSWMM model. The invert was estimated based on the expected slope (based on the difference between the channel's elevation upstream and downstream of the hydraulic structure).



Figure 51 - Paddy Dobbin Drive Inlet

4.4 Holes in Marsh Brook

Holes in Marsh Brook has a unique hydraulic structure; a fish ladder upstream of Kelsey Drive (**Figure 52**). There was a total of 10 hydraulic structures, including the fish ladder, and corresponding cross sections collected during the ground survey.



Figure 52 - Fish Ladder at Kelsey Drive



4.5 Mundy Pond Brook

Fourteen hydraulic structures, including many driveway culverts, were identified and surveyed along with the corresponding cross sections along Mundy Pond Brook. The residential housing is built within close proximity to the Mundy Pond Brook. Allnorth Consultants Ltd were unable to collect survey data of the structure crossing at Jensen Camp Road due to no trespassing signs in the area. Stantec will supplement the survey with as-built drawings in this area.

Another unique feature of the Mundy Pond study area is the Outlet Structure on Mundy Pond, as shown in **Figure 53**.





Figure 53 - Mundy Pond Outlet Structure

4.6 Kitty Gaul Brook

There were a total of 16 hydraulic structures and corresponding cross sections surveyed for Kitty Gaul Brook. Examples of the channel geometry is presented in **Figure 54** and **Figure 55**.



Figure 54 - Channel near Blackmarsh Road for Kitty Gaul Brook Study Area





Figure 55 - Channel near Greenwood Crescent for Kitty Gaul Brook Study Area

4.7 South Brook

Three hydraulic structures and corresponding cross sections were surveyed for South Brook. Examples of the channel geometry is presented in **Figure 56** and **Figure 57**.



Figure 56 - Channel near Tree Top Drive for South Brook Study Area



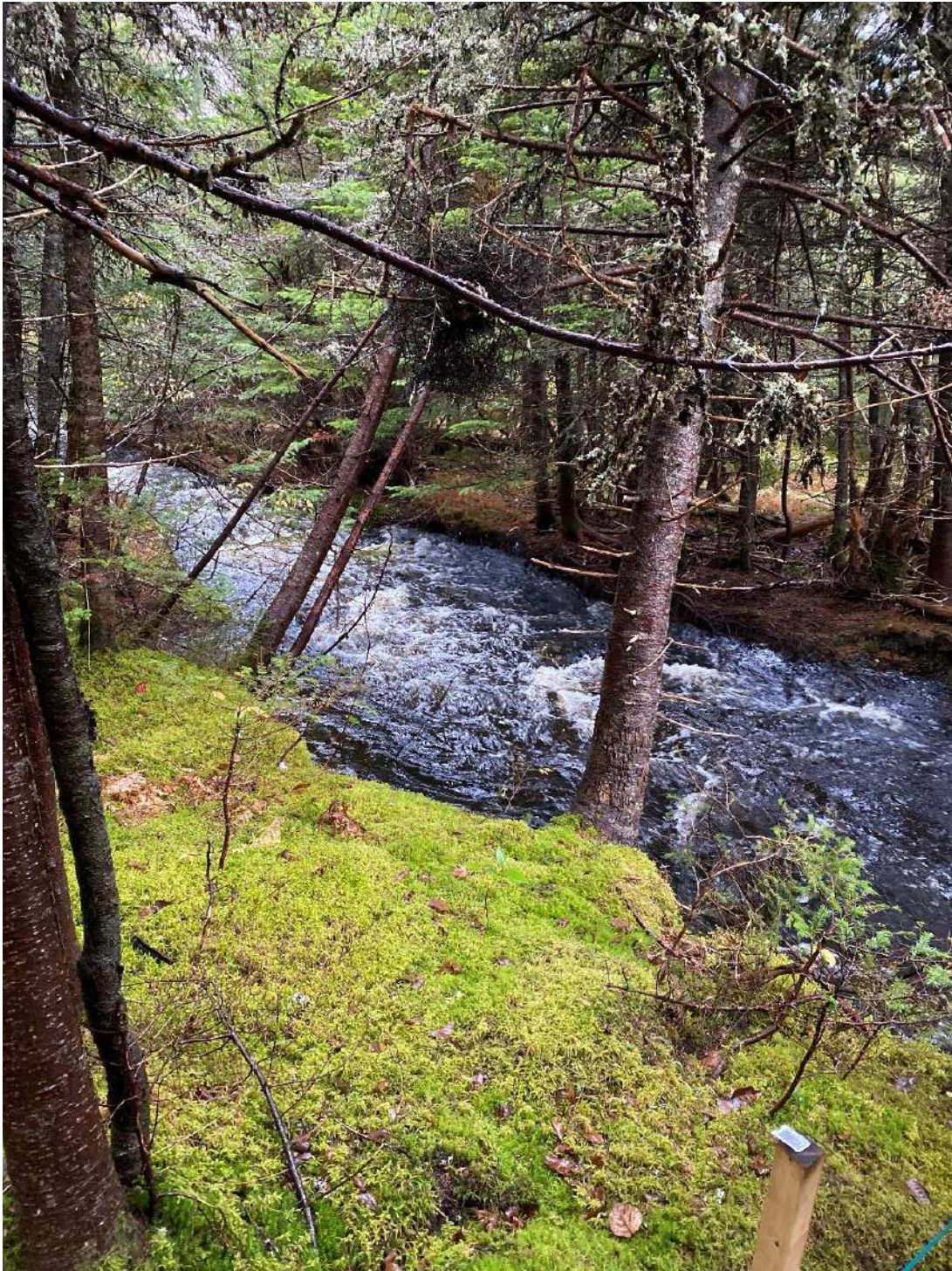


Figure 57 - Intermediate Channel between Southlands Boulevard (Upper Crossing) and Tree Top Drive



5.0 LiDAR Verification

Stantec obtained the LiDAR (2020) data for this project from the City of St. John's geomatics department and tested the data using three monuments and 53 checks points that were surveyed using Real Time Kinetic (RTK) equipment. The vertical datum that was used for both data sets are CGVD2013 and projected to MTM Zone 1 NAD83 CSRS. Generally, both data sets varied +/- 0.150m on average. The comparison between the RTK survey check points/monuments and the LiDAR was analyzed using ArcGIS Pro's spatial analyst tool.

5.1 Analysis

Stantec utilized the Federal Airborne LiDAR Data Acquisition Guideline Version 3.1, 2022 to assess the LiDAR's accuracy. The guideline can be seen in **Appendix F**. The LiDAR was assessed to meet the 95% confidence level for vertical accuracy regarding non-vegetated and vegetated surfaces. The RTK survey check points that were used in this study were well distributed across the entire area of interest. **Table 3** below shows the requirements for the Canadian Quality Level 1 (CQL1) 95% confidence level for vertical accuracy.

Table 3 - CQL1 Requirements Summary

<i>Requirements</i>	Generic Specifications	Example for the CQL1	Category
<i>Non-vegetated Vertical Accuracy – 95% confidence level</i>	$\leq 1.96 \times \text{RMSEZ}$	$\leq 1.96 \times 10 \rightarrow 19.6 \text{ cm}$	Acquisition
<i>Vegetated Vertical Accuracy (VVA) – 95th percentile</i>	$\leq 3 \times \text{RMSEZ}$	$\leq 3 \times 10 \rightarrow 30 \text{ cm}$	Acquisition

There was a combination of non-vegetated and vegetated areas throughout each study area and



Table 4 summarizes the elevation difference below. Although the difference are larger in some watersheds, for instance for Barrow's Road Stream which is characterized by wetlands, the agreement between the two datasets are generally good and complying with the requirements. Based on the results from the **Table 4**, the LiDAR that was provided from the City of St. John's is adequate.



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Table 4 - LiDAR Accuracy Summary

<i>Survey ID Number</i>	<i>Northing (m)</i>	<i>Easting (m)</i>	<i>Survey Elev. (m)</i>	<i>Description</i>	<i>LiDAR Elev. (m)</i>	<i>Elev. Difference (m)</i>	<i>Absolute Elev. Difference (m)</i>	<i>Monument/Check Point Area</i>
1_231212BC	5268497.38	322331.6	113.393	CHK	113.587	-0.194	0.194	Holes in Marsh Brook
21G0001	5268497.38	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_231214BC	5268497.38	322331.61	113.387	CHK	113.587	-0.200	0.200	Holes in Marsh Brook
21G0001	5268497.38	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_231215BC	5268497.37	322331.61	113.393	CHK	113.587	-0.194	0.194	Holes in Marsh Brook
21G0001	5268497.38	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_240110BC	5268497.38	322331.62	113.398	CHK	113.587	-0.189	0.189	Holes in Marsh Brook
1_240124BC	5268497.37	322331.62	113.394	CHK	113.587	-0.193	0.193	Holes in Marsh Brook
21G0001	5268497.39	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_231102KP	5268497.37	322331.61	113.371	CHK	113.587	-0.216	0.216	Holes in Marsh Brook
21G0001	5268497.39	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_231108KP	5268497.37	322331.6	113.387	CHK	113.587	-0.200	0.200	Holes in Marsh Brook
21G0001	5268497.39	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_231109KP	5268497.38	322331.61	113.385	CHK	113.587	-0.202	0.202	Holes in Marsh Brook
1_231114KP	5268497.37	322331.61	113.372	CHK	113.587	-0.215	0.215	Holes in Marsh Brook
21G0001	5268497.39	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_231120KP	5268497.36	322331.61	113.388	CHK	113.587	-0.199	0.199	Holes in Marsh Brook
21G0001	5268497.39	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_231212KP	5268497.37	322331.61	113.397	CHK	113.587	-0.190	0.190	Holes in Marsh Brook
21G0001	5268497.38	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
21G0001	5268497.38	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1000_231214KP	5268497.38	322331.61	113.387	CHK	113.587	-0.200	0.200	Holes in Marsh Brook
21G0001	5268497.38	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1000_231215KP	5268497.37	322331.61	113.394	CHK	113.587	-0.193	0.193	Holes in Marsh Brook
1_240110KP	5268497.4	322331.62	113.405	CHK	113.587	-0.182	0.182	Holes in Marsh Brook
21G0001	5268497.39	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook



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<i>Survey ID Number</i>	<i>Northing (m)</i>	<i>Easting (m)</i>	<i>Survey Elev. (m)</i>	<i>Description</i>	<i>LiDAR Elev. (m)</i>	<i>Elev. Difference (m)</i>	<i>Absolute Elev. Difference (m)</i>	<i>Monument/Check Point Area</i>
1_240109ML	5268497.36	322331.6	113.376	CHK	113.587	-0.211	0.211	Holes in Marsh Brook
21G0001	5268497.39	322331.62	113.393	MON	113.587	-0.194	0.194	Holes in Marsh Brook
1_240124ML	5268497.37	322331.61	113.381	CHK	113.587	-0.206	0.206	Holes in Marsh Brook
1_231218BC	5271566.7	328848.21	35.506	CHK	35.226	0.280	0.280	Barrows Road Stream
1_231025KP	5271566.7	328848.2	35.491	CHK	35.226	0.265	0.265	Barrows Road Stream
80G2252	5271566.72	328848.22	35.49	MON	35.226	0.264	0.264	Barrows Road Stream
1000_231213KP	5271566.71	328848.2	35.482	CHK	35.226	0.256	0.256	Barrows Road Stream
1_231218KP	5271566.71	328848.2	35.495	CHK	35.226	0.269	0.269	Barrows Road Stream
80G2252	5271566.72	328848.22	35.49	MON	35.226	0.264	0.264	Barrows Road Stream
1_231221BC	5272789.54	327052.64	67.559	CHK	67.433	0.126	0.126	Virginia River
1_240108BC	5272789.56	327052.65	67.553	CHK	67.433	0.120	0.120	Virginia River
1_231213CB	5272789.53	327052.64	67.55	CHK	67.433	0.117	0.117	Virginia River
1_240102CB	5272789.54	327052.65	67.538	CHK	67.433	0.105	0.105	Virginia River
1_231221KP	5272789.55	327052.64	67.544	CHK	67.433	0.111	0.111	Virginia River
1_240102KP	5272789.54	327052.65	67.543	CHK	67.433	0.110	0.110	Virginia River
1_240108KP	5272789.55	327052.65	67.558	CHK	67.433	0.125	0.125	Virginia River
1_240109BC	5274153.9	322778.87	162.463	CHK	162.484	-0.021	0.021	Outer Cove Brook
1_240116BC	5274153.92	322778.88	162.492	CHK	162.484	0.008	0.008	Outer Cove Brook
97G7250	5274153.94	322778.87	162.563	MON	162.484	0.079	0.079	Outer Cove Brook
1_231220KP	5274153.91	322778.87	162.477	CHK	162.484	-0.007	0.007	Outer Cove Brook
97G7250	5274153.94	322778.87	162.563	MON	162.484	0.079	0.079	Outer Cove Brook
1_240109KP	5274153.91	322778.88	162.469	CHK	162.484	-0.015	0.015	Outer Cove Brook
97G7250	5274153.94	322778.87	162.563	MON	162.484	0.079	0.079	Outer Cove Brook
1_240116KP	5274153.91	322778.87	162.489	CHK	162.484	0.005	0.005	Outer Cove Brook
1_231212ML	5274153.92	322778.87	162.499	CHK	162.484	0.015	0.015	Outer Cove Brook
1_231213ML	5274153.88	322778.87	162.482	CHK	162.484	-0.002	0.002	Outer Cove Brook
1_231214ML	5274153.92	322778.88	162.485	CHK	162.597	-0.112	0.112	Outer Cove Brook
1_231215ML	5274153.91	322778.87	162.464	CHK	162.484	-0.020	0.020	Outer Cove Brook
1_231218ML	5274153.91	322778.88	162.473	CHK	162.484	-0.011	0.011	Outer Cove Brook
1_231220ML	5274153.92	322778.88	162.487	CHK	162.484	0.003	0.003	Outer Cove Brook
					Average =	-0.057	0.153	



APPENDICES



Appendix A – Ground Survey Plan





**2023-2024 CLIMATE CHANGE FLOOD
RISK MAPPING FOR THE CITY OF ST.
JOHN'S**
Ground Survey Plan

September 27, 2023

Prepared for:
Government of Newfoundland and Labrador
and the City of St. John's

Prepared by:
Stantec Consulting Limited

Project Number:
163401903

2023-2024 Climate Change Flood Risk Mapping for the City of St. John's

Revision	Description	Author	Date	Quality Check	Date	Independent Review	Date
Draft		DE	9/27/23	JB	9/27/23		



2023-2024 Climate Change Flood Risk Mapping for the City of St. John's

The conclusions in the Report titled 2023-2024 Climate Change Flood Risk Mapping for the City of St. John's are Stantec's professional opinion, as of the time of the Report, and concerning the scope described in the Report. The opinions in the document are based on conditions and information existing at the time the scope of work was conducted and do not take into account any subsequent changes. The Report relates solely to the specific project for which Stantec was retained and the stated purpose for which the Report was prepared. The Report is not to be used or relied on for any variation or extension of the project, or for any other project or purpose, and any unauthorized use or reliance is at the recipient's own risk.

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Printed Name

Reviewed by:


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Printed Name

Approved by:

Signature



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1 Introduction

This document outlines Stantec's Plan for the execution of the Ground Survey program associated with Climate Change Flood Risk Mapping Study for the City of St. John's. The collection of accurate and complete survey data is important for the development of representative hydrologic and hydraulic models for floodplain development.

The ground survey will be conducted within the seven study areas that are to be analyzed as part of this study. These areas include:

1. Barrows Road Stream
2. Holes in Marsh Brook
3. Kitty Gaul Brook
4. Mundy Pond Brook
5. Outer Cover Brook
6. South Brook
7. Virginia River and its tributaries

The ground survey will primarily focus on hydraulic structures and channel cross sections of the watercourses being analyzed.

Following a desktop review of the seven study areas, Stantec has identified approximately 106 hydraulic structures to be surveyed. There are a wide variety of hydraulic structures in the study areas including road bridges, pedestrian bridges, culverts, outlet structures, weirs and fish passage structures among others. The ground survey is intended to capture the geometry of structure openings as well as associated infrastructure including headwalls/tailwalls, inlet/outlet pools and weir dimensions such that they can be accurately represented in the hydraulic model(s).

Prior to initiation of the ground survey, Stantec representatives will visit each of the study areas to conduct hydrological and hydraulic reconnaissance. During this exercise we will traverse the watercourses to identify hydraulic structures that may not have been visible through the aerial/ satellite imagery and have them added to the topographic survey scope. Additionally, during this exercise Stantec will identify areas requiring cross section survey, such as at severe grade changes, wetland inlets/ outlets, large pools, or other significant features with significant hydraulic influence. During this exercise Stantec will assess the potential locations for level and flow monitoring. Tentative potential monitoring locations are discussed below in Section 4.

2 Survey Requirements

The topographic survey will be used to inform the flood mapping study, and will require the surveying of hydraulic structures including bridges and culverts. Additionally, river and stream channels cross sections will need to be surveyed. The survey requirements include the following:



2023-2024 Climate Change Flood Risk Mapping for the City of St. John's

2 Survey Requirements

1. The topographic survey will include 7 areas as follows. Section 3 below lists hydraulic structures and sections to be surveyed and includes maps of those locations.:
 - a. Barrows Road Stream
 - b. Holes in Marsh Brook
 - c. Kitty Gaul Brook
 - d. Mundy Pond Brook
 - e. Outer Cover Brook
 - f. South Brook
 - g. Virginia River
2. Surveying of hydraulic structures is to capture the following information:
 - a. For culverts:
 - i. Upstream and downstream invert elevations and obvert elevations.
 - ii. Include pipe diameter and material.
 - iii. Survey points such that the geometry of headwall and wingwall infrastructure is captured.
 - iv. If inlet and/or outlet pools are present, survey the waterline of the pools as well provide 3 bathymetric points within the pools.
 - v. For irregular culver shapes such as elliptical pipe survey points such that the cross-sectional geometry of the pipe is captured.
 - vi. Cross section of the channel at upstream and downstream ends of the culvert as well as 10m upstream and downstream. Cross sections to capture information noted in item 3 below.
 - b. For bridges and box culverts:
 - i. Invert elevations in the centre of the channel at the upstream and downstream faces of the bridge
 - ii. Ground elevations at the extremities of both the upstream and downstream openings
 - iii. Elevation of the underside and top of the bridge deck
 - iv. If inlet and/or outlet pools are present survey the waterline of the pools as well provide 3 bathymetric points within the pools.
 - v. Cross section of the channel at upstream and downstream ends of the culvert as well as 10m upstream and downstream. Cross sections to capture information noted in in item 3 below.
 - c. For Miscellaneous Hydraulic Structures such as weirs and outlet structures
 - i. Weir profile including any notches such that the geometry of all potential flow contact area is captured.
 - ii. Invert elevation, top elevation and sides such that the geometry of hydraulic openings is captured.
 - iii. Associated infrastructure geometry such as wing walls and gabion wall extents.
 - iv. Cross section of the channel at upstream and downstream ends (if applicable) of structure as well as 10m upstream and downstream. Cross sections to capture information noted in in item 3 below.
3. Cross sections of watercourse channels and banks to be surveyed where there can be expected change in water level and flow. Cross sections to contain the following information:
 - a. Shoreline on each side of the watercourse
 - b. Bathymetric point at the channel centreline
 - c. Bathymetric point at the channel thalweg
 - d. Minimum of two intermediate bathymetric points between the centre line and the shoreline
 - e. High water marks, if visible
 - f. Top and toe of channel banks



4. Cross sections and hydraulic structures surveyed must also be photographed from both the upstream and downstream directions and photos referenced to the associated survey points.
5. Survey to be provided in MTM Zone 1 NAD83 CSRS Projection with all elevations referenced to CGVD2013.
6. Survey to be provided in AutoCAD Format with accompanying point text file in Point Number, Northing, Easting, Elevation, Description, photo reference format.

3 Study Area Hydraulic Structures and Cross Sections

Stantec will create a database of the hydraulic structures and cross sections within the study areas in GIS such that structure and section information and location can be easily accessed once surveyed. The structures and sections identified for surveying in each study area are detailed in the sections below. Note that, as described above, the survey at each hydraulic structure will include 4 cross sections including at the upstream and downstream face of the structure and 10m up/downstream. The sections noted below are in addition to those sections.

3.1 Barrows Road Stream

For Barrows Road Stream we have identified 5 hydraulic structures and 2 cross sections to be surveyed shown below in Figure 1 and Figure 2 respectively.



2023-2024 Climate Change Flood Risk Mapping for the City of St. John's
3 Study Area Hydraulic Structures and Cross Sections



Figure 1: Barrows Road Stream Structures





Figure 2: Barrows Road Stream Sections

3.2 Holes in Marsh Brook

For Holes in Marsh Brook, we have identified 10 hydraulic structures and 5 cross sections to be surveyed shown below in Figure 3 and Figure 4 respectively.

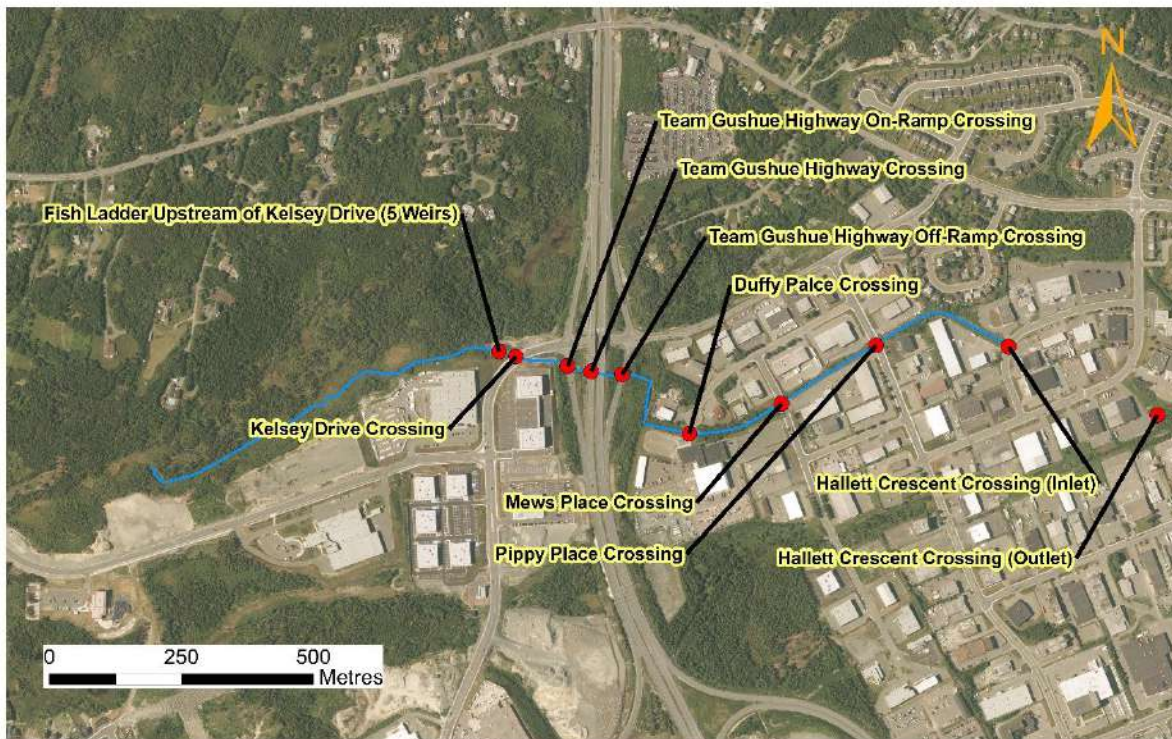


Figure 3: Holes in Marsh Brook Structures

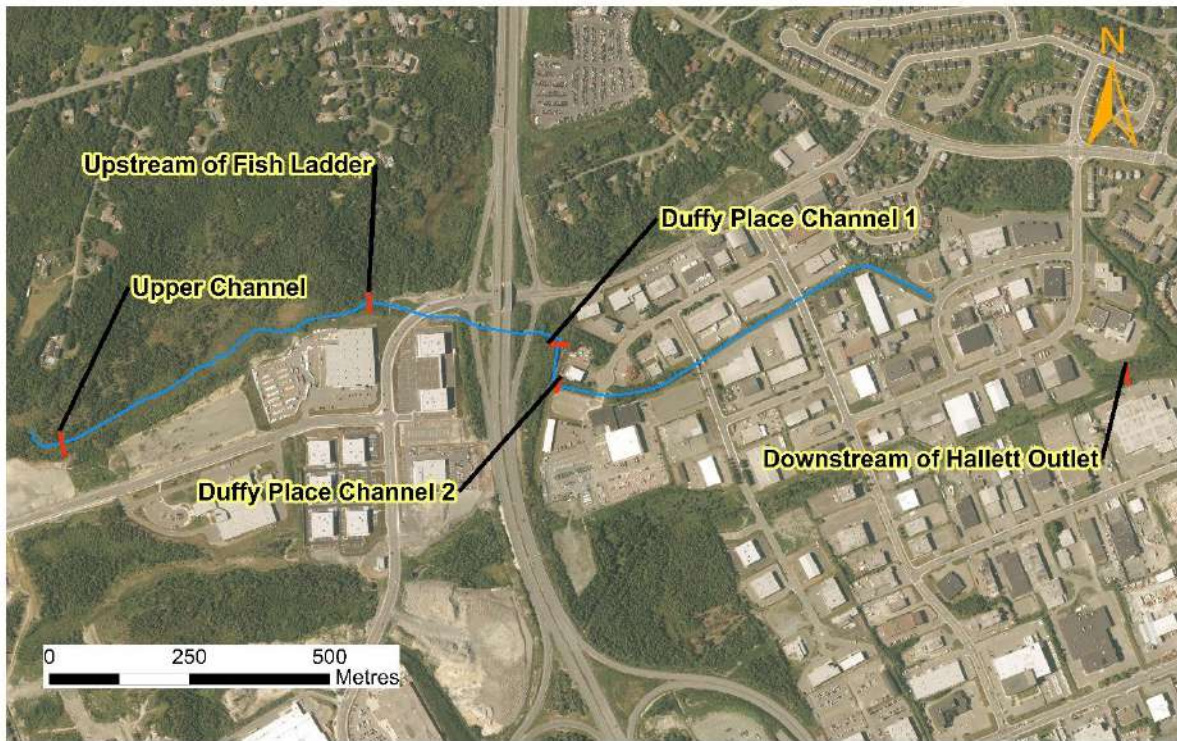


Figure 4: Holes in Marsh Brook Sections

3.3 Kitty Gaul Brook

For Kitty Gaul Brook we have identified 16 hydraulic structures and 5 cross sections to be surveyed shown below in Figure 5 and Figure 6 respectively.

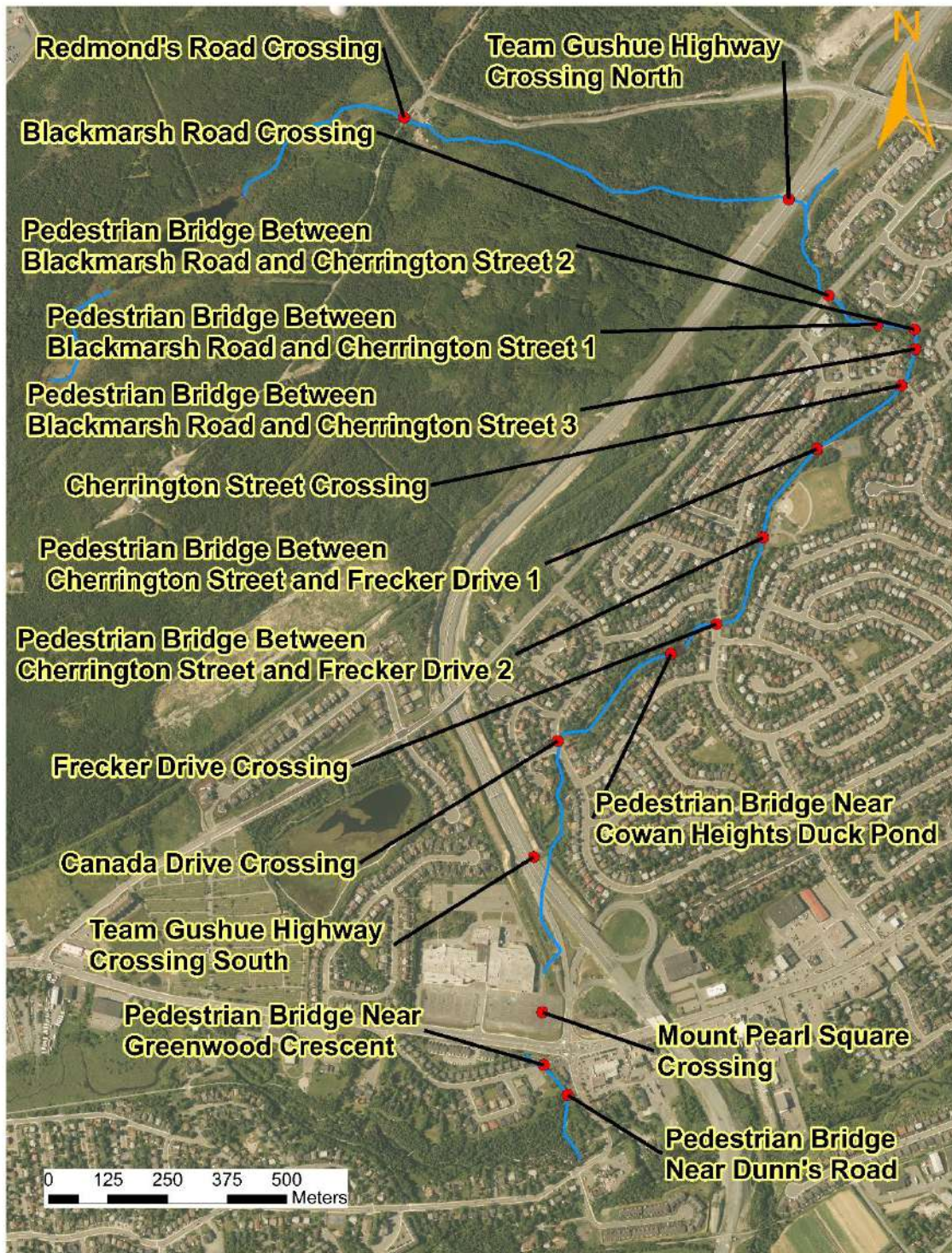


Figure 5: Kitty Gaul Brook Structures





Figure 6: Kitty Gaul Brook Sections

3.4 Mundy Pond Brook

For Mundy Pond Brook we have identified 14 hydraulic structures and 4 cross sections to be surveyed shown below in Figure 7 and Figure 8 respectively.

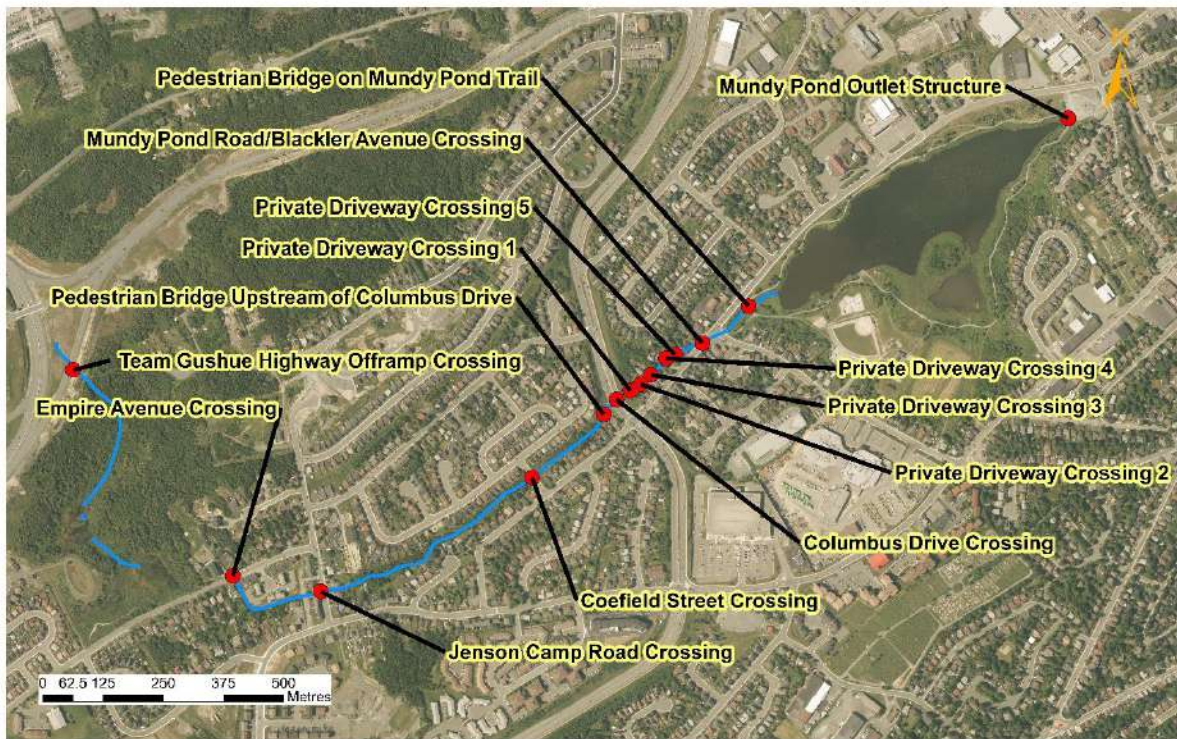


Figure 7: Mundy Pond Brook Structures

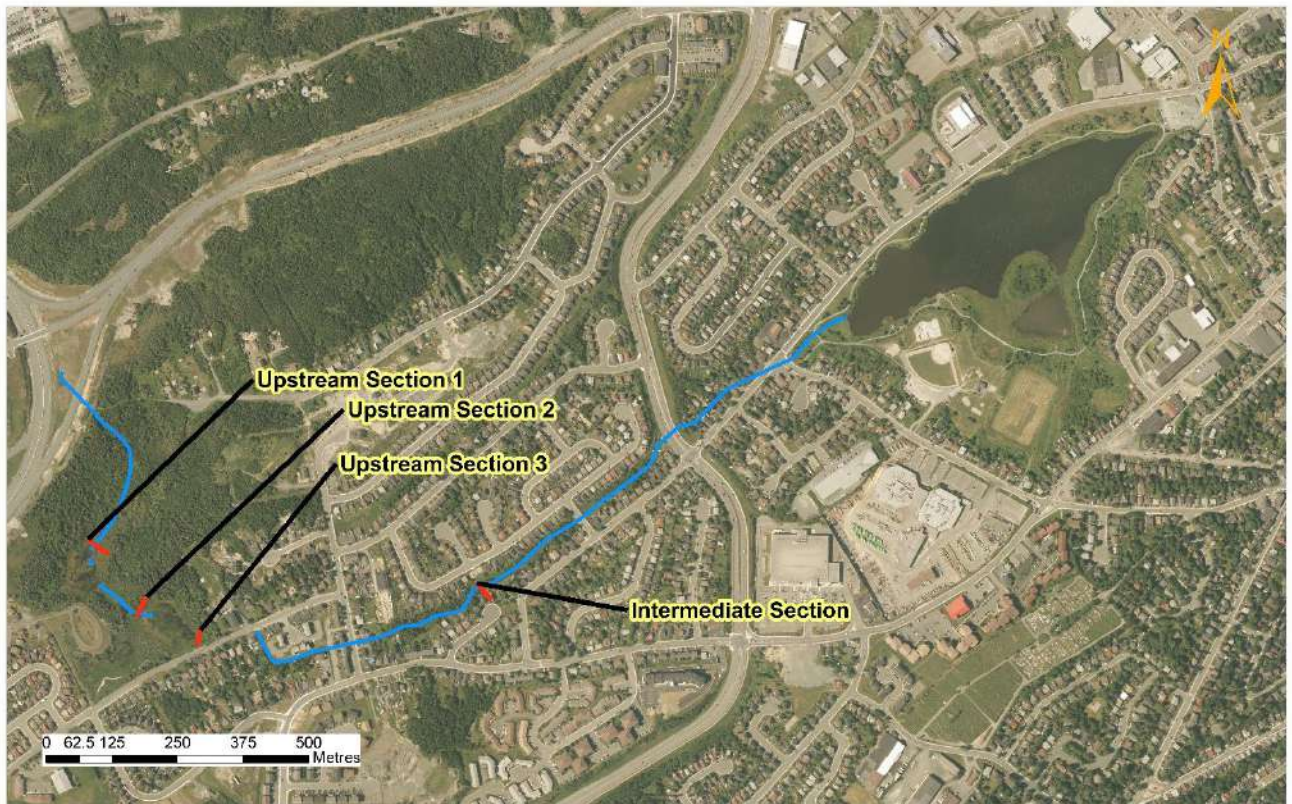


Figure 8: Mundy Pond Brook Sections

3.5 Outer Cove Brook

For Outer Cove Brook we have identified 20 hydraulic structures and 6 cross sections to be surveyed shown below in Figure 9 and Figure 10 respectively.

2023-2024 Climate Change Flood Risk Mapping for the City of St. John's
3 Study Area Hydraulic Structures and Cross Sections

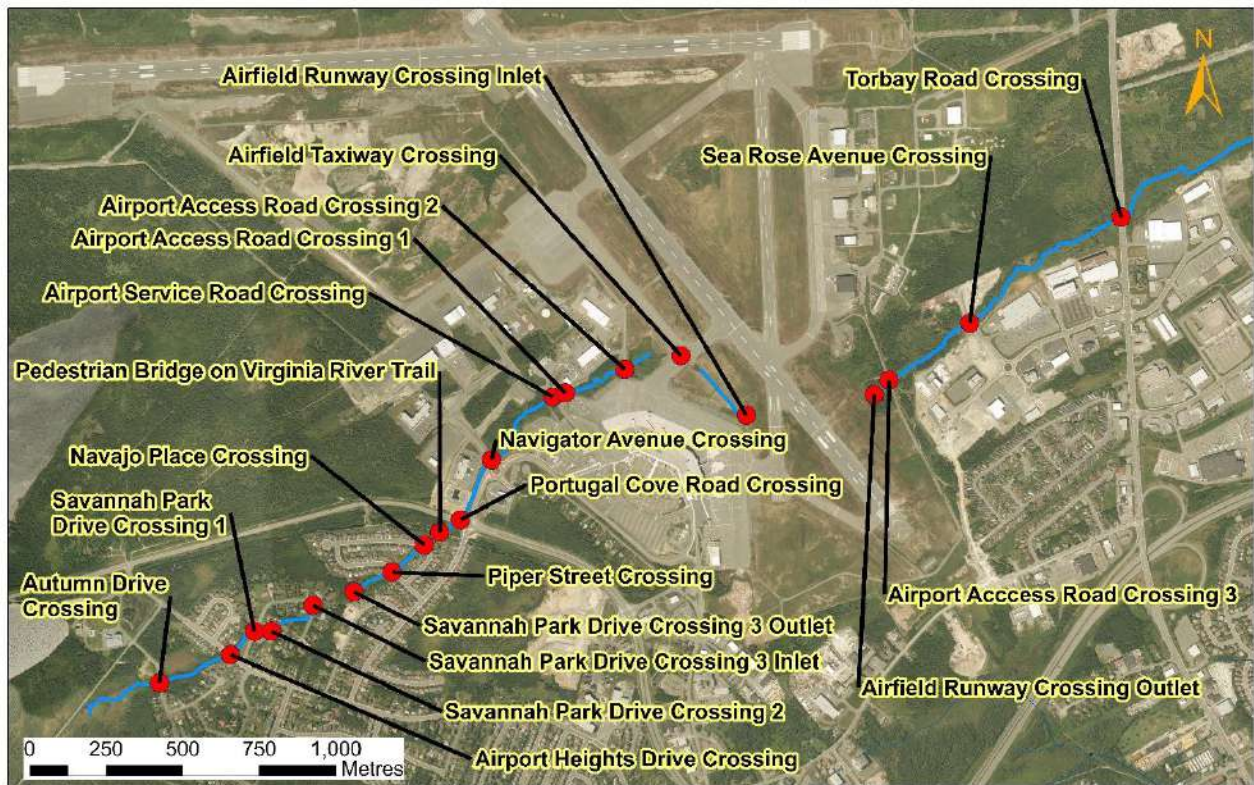


Figure 9: Outer Cover Brook Structures

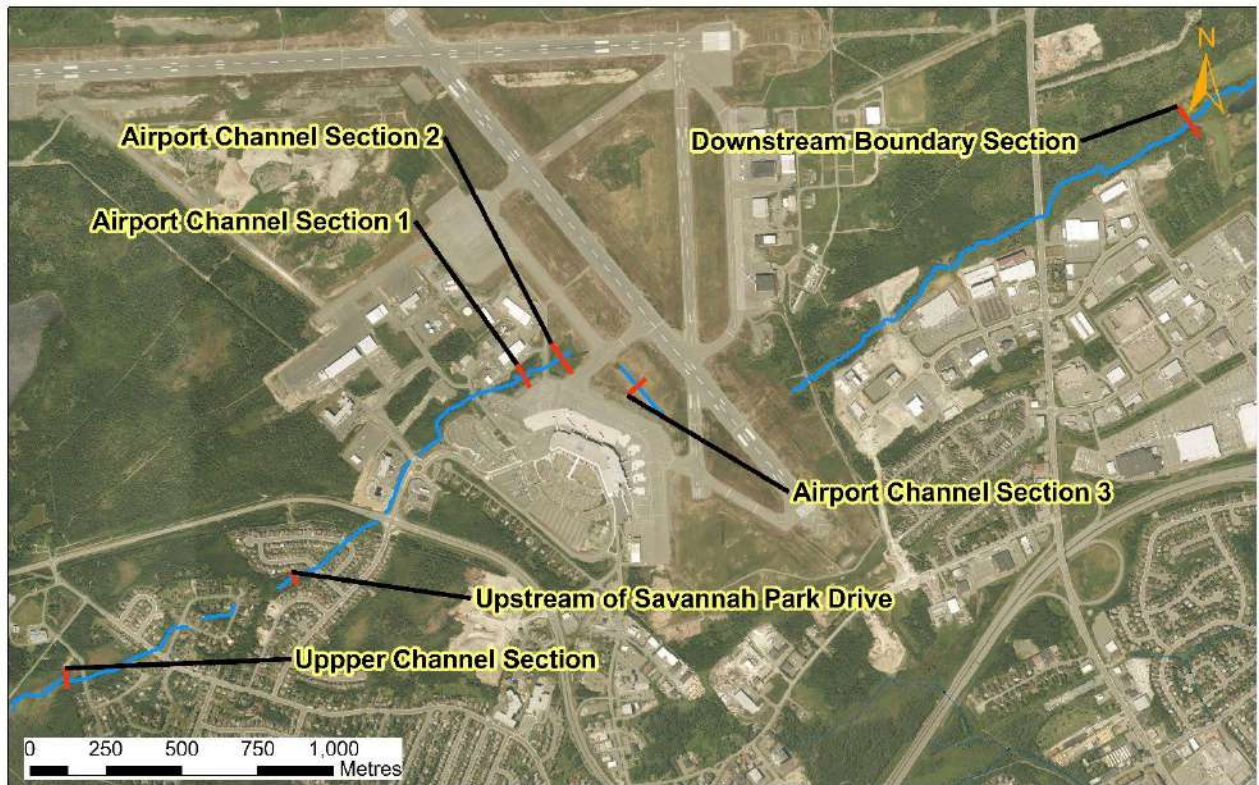


Figure 10: Outer Cove Brook Sections

3.6 South Brook

For South Brook we have identified 3 hydraulic structures and 9 cross sections to be surveyed shown below in Figure 11 and Figure 12 respectively.

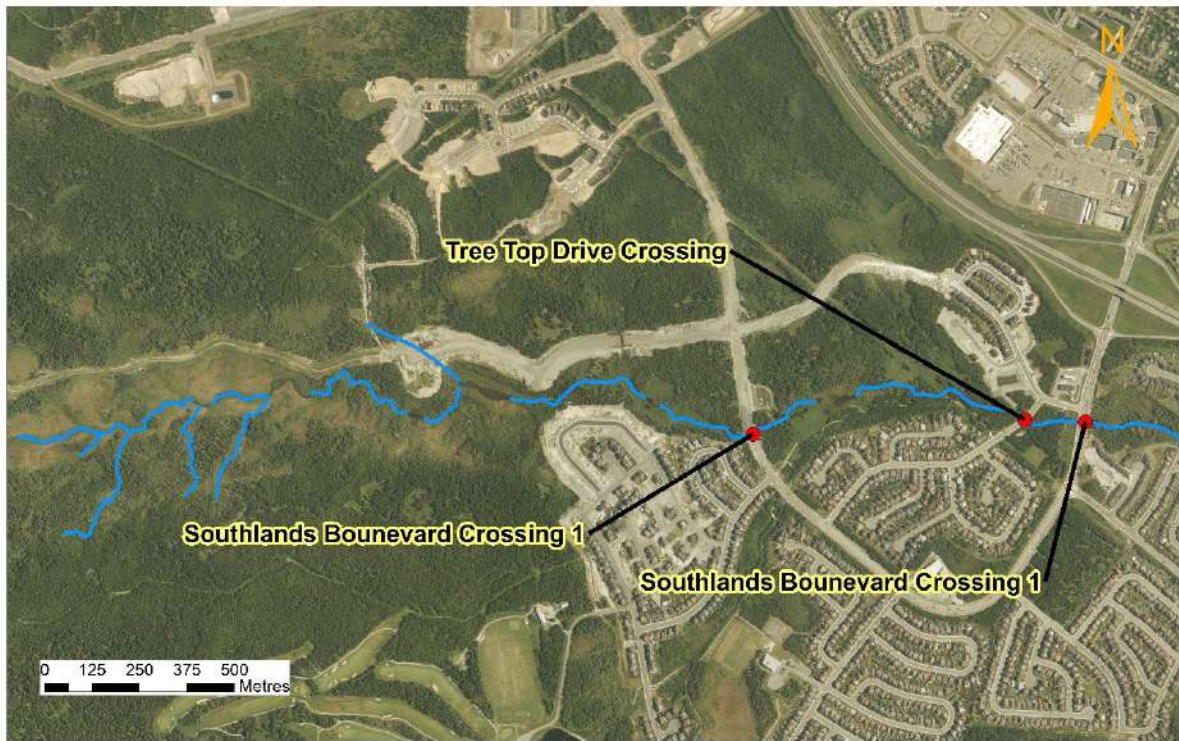


Figure 11: South Brook Structures

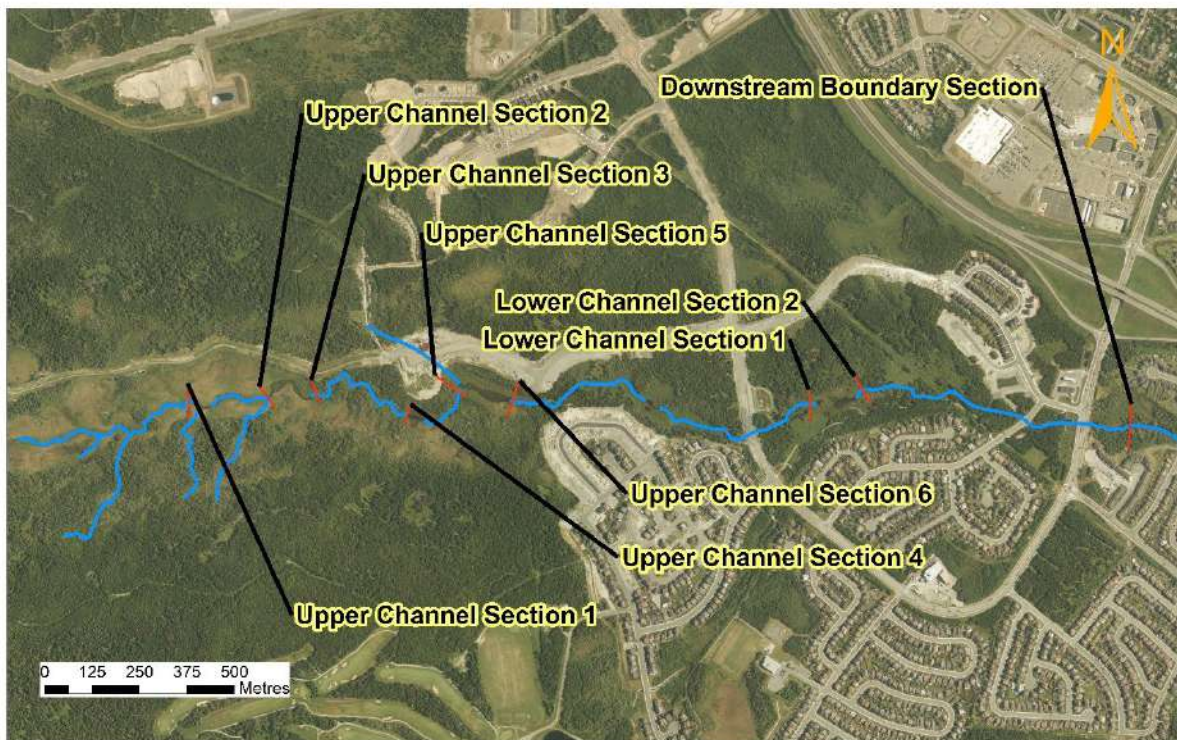


Figure 12: South Brook Sections

3.7 Virginia River

For Virginia River we have identified 38 hydraulic structures and 14 cross sections to be surveyed shown below in Figure 13 and Figure 14 respectively.

2023-2024 Climate Change Flood Risk Mapping for the City of St. John's

3 Study Area Hydraulic Structures and Cross Sections

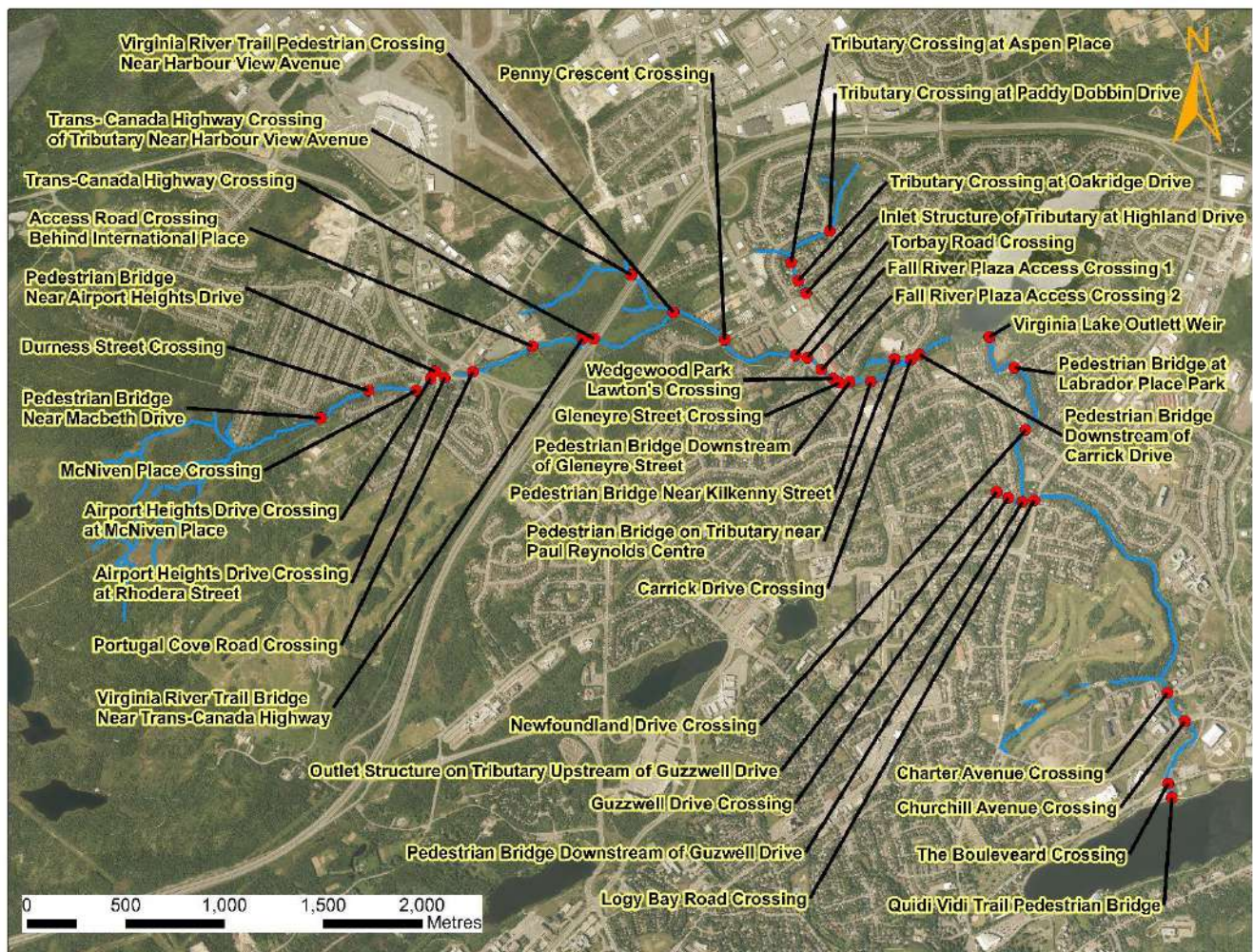


Figure 13: Virginia River Structures

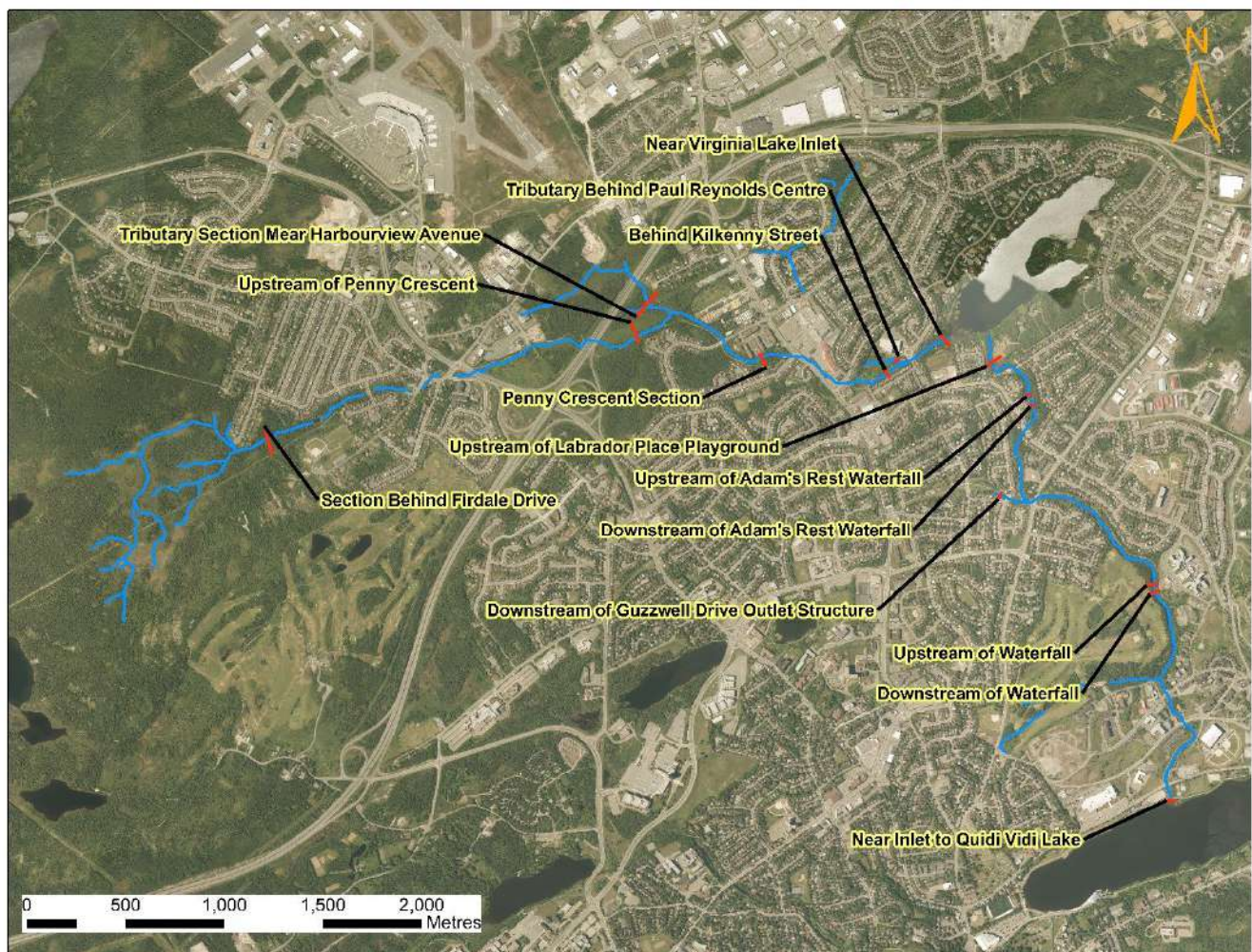


Figure 14: Virginia River Sections

4 Level and Flow Monitoring

For the purposes of model calibration, Stantec will conduct water level and flow monitoring on the 7 subject watercourses. During the initial hydraulic reconnaissance, Stantec will visit potential monitoring sites to assess their suitability for the installation of monitoring equipment. Stantec has identified 16 potential monitoring locations for investigation, two for each study area with the exception of Virginia River which has 4 monitoring locations. The monitoring locations for investigation are shown in Figure 15 below:

2023-2024 Climate Change Flood Risk Mapping for the City of St. John's
4 Level and Flow Monitoring

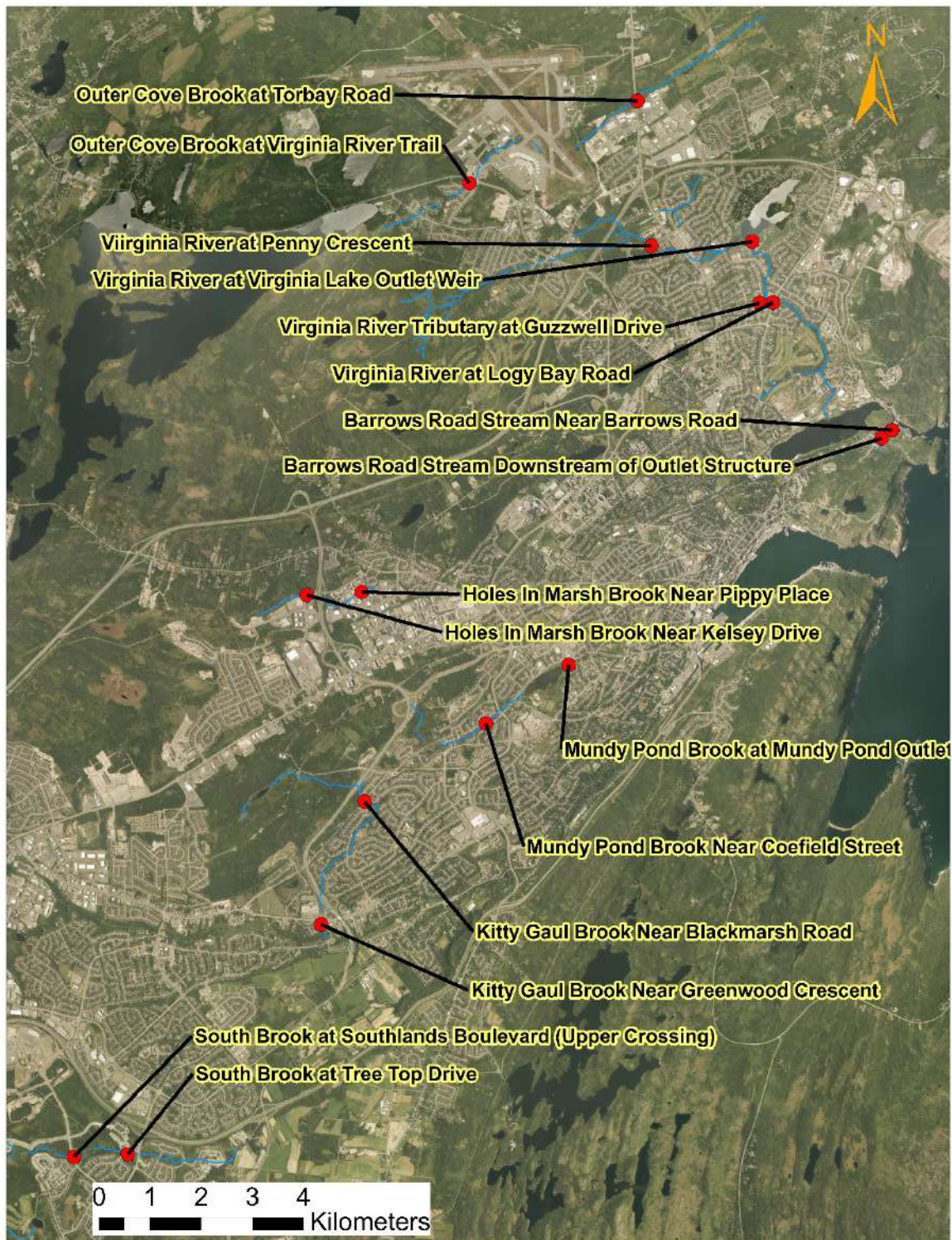


Figure 15: Potential Level and Flow Monitoring Locations



Appendix B – Level Logger and Velocity Metre Data Sheets





HOBO® U20 Series Water Level Loggers

Accurate, affordable water level monitoring

HOBO Water Level data loggers offer high accuracy at an affordable price, with no cumbersome vent tubes or desiccants to maintain. These data loggers are ideal for recording water levels and temperatures in wells, streams, lakes, wetlands and tidal estuaries.

Supported Measurements: Water Level, Barometric Pressure, Pressure (Absolute), Temperature

Key Advantages:

- Available in 4 depth ranges
- No-vent-tube design for easy and reliable deployment
- Available in stainless steel and titanium* versions
- Durable ceramic pressure sensor for reliable performance
- Calibration certificate included

Minimum System Requirements:



Software



Base Station¹



Coupler²



Water Level Logger Kits:

Deluxe Kit includes a carrying case, two HOBO Water Level Loggers (one 13 foot for barometric pressure and one 13 foot, 30 foot, or 100 foot), HOBOWare Pro software, and a HOBO Waterproof Data Shuttle with coupler. The Starter Kit includes a HOBO Water Level Logger, HOBOWare Pro Software, and an Optic USB Base Station. Available in 13 foot, 30 foot, and 100 foot depths.



Deluxe Kit



Starter Kit

*Titanium version recommended for saltwater deployment.

¹HOBO Base Station or HOBO Waterproof Shuttle required.

²Coupler included with HOBO Base Station or HOBO Waterproof Shuttle.

► For complete information and accessories, please visit: www.onsetcomp.com

Part number	U20-001-04/ U20-001-04-Ti	U20-001-01/ U20-001-01-Ti	U20-001-02/ U20-001-02-Ti	U20-001-03/ U20-001-03-Ti
HOBO Water Level Specifications				
Range	0-4 m (0-13 ft) 0-145 kPa (0-21 psia)	0-9 m (0-30 ft) 0-207 kPa (0-30 psia)	0-30 m (0-100 ft) 0-400 kPa (0-58 psia)	0-76 m (0-250 ft) 0-850 kPa (0-123 psia)
Factory Calibrated Range (0° to 40°C; 32° to 104°F)	69 to 145 kPa (10-21 psia)	69 to 207 kPa (10-30 psia)	69 to 400 kPa (10-58 psia)	69 to 850 kPa (10-123 psia)
Water Level Accuracy (Typical Error)	± 0.3 cm (0.01 ft) (± 0.075% FS)	± 0.5 cm (0.015 ft) (± 0.05% FS)	± 1.5 cm (0.05 ft) (± 0.05% FS)	± 3.8 cm (0.125 ft) (± 0.05% FS)
Resolution	0.14 cm (0.005 ft)	0.21 cm (0.007 ft)	0.41 cm (0.013 ft)	0.87 cm (0.028 ft)
Burst Pressure	310 kPa (45 psia) 18 m (60 ft) depth		500 kPa (72.5 psia) 40.8 m (134 ft) depth	1200 kPa (174 psia) 112 m (368 ft) depth
Temperature Specifications (all models)				
Range	-20° to 50°C (-4° to 122°F)			
Accuracy	± 0.37° @ 20°C (± 0.67° @ 68°F) ± 0.44° from 0° to 50°C (± 0.79° from 32° to 122°F)			
Resolution (10 bit)	0.1° @ 20°C (0.18° @ 68°F)			
Response time	5 minutes (to 90% in water)			
Dimensions	2.46 cm diameter x 15 cm (0.97 x 5.9 in) hole in mounting bail 6.3 mm (0.25 in)			
CE compliant	Yes			

Contact Us

Sales (8am to 5pm ET, Monday through Friday)

- Email sales@onsetcomp.com
- Call 1-508-759-9500
- In U.S. toll free 1-800-564-4377
- Fax 1-508-759-9100

Technical Support (8am to 8pm ET, Monday through Friday)

- Contact Product Support onsetcomp.com/support/contact
- Call 1-508-759-9500
- In U.S. toll free 1-877-564-4377

Onset Computer Corporation
470 MacArthur Boulevard
Bourne, MA 02532



Levellogger® 5

Model 3001

The Levellogger 5 records highly accurate groundwater and surface water level and temperature measurements. It combines a pressure sensor, temperature detector, 10-year lithium battery, and datalogger, sealed within a 22 mm x 160 mm (7/8" x 6.3") stainless steel housing with a corrosion-resistant coating baked-on using polymerization technology.

The Levellogger 5 measures absolute pressure using a Hastelloy® pressure sensor, offering high resolution and an accuracy of 0.05% FS. Readings are stable in extreme pressure and temperature conditions. The Hastelloy sensor can withstand 2 times over-pressure without permanent damage. Combined with the durable coating inside and out, the Levellogger 5 has high corrosion and abrasion resistance in harsh environments.

The Levellogger 5 uses a Faraday cage design, which protects against power surges or electrical spikes caused by lightning. Its durable maintenance-free design, high accuracy and stability, make the Levellogger 5 the most reliable instrument for long-term, continuous water level recording.

Levellogger 5 Features

- Highly stable communication: single-eye optical interface—easier to clean, more scratch resistant
- Large memory: 150,000 sets of data
- Strong, robust design: double o-ring seals for increased leakage protection
- High thermistor sensitivity: accurate platinum RTD
- Superior protection in harsh environments: corrosion and abrasion resistant coating—inside and out
- Intuitive Levellogger Software: Diagnostic Utility for more proactive user “self-tests”



Single-eye optical interface

The Levellogger 5 features a smooth, single-eye optical interface, which allows for easy cleaning and more reliable, faster communication. Using a Solinst USB device, including the Field Reader 5 and Levellogger PC Software, programming and data downloading speeds are 57,600 bps.



Fast communication and downloading speeds with a high speed Field Reader 5

Applications

- Aquifer characterization: pumping tests, slug tests, etc.
- Watershed, drainage basin and recharge monitoring
- Stream gauging, lake and reservoir management
- Harbour and tidal fluctuation measurement
- Wetlands and stormwater run-off monitoring
- Water supply and tank level measurement
- Mine water and landfill leachate management
- Long-term water level monitoring in wells, surface water bodies and seawater environments

Flexible Communication

Levellogger Software is streamlined, making it easy to program dataloggers, and view and compensate data in the office or the field. Data compensation is made simple; multiple data files can be barometrically compensated at once.

The Levellogger 5 App Interface on your in-field Levelloggers creates a *Bluetooth®* connection between your dataloggers and the Solinst Levellogger App on your smart device. The Solinst Readout Unit (SRU) connects to your deployed Levelloggers

to display and save real-time water level readings that are automatically barometrically compensated. Also an option, the DataGrabber 5 is a field-ready USB data transfer unit.

Remote monitoring options include the LevelSender 5, a simple and compact device that fits right in a 2" well, SolSat 5 Satellite Telemetry, STS Telemetry Systems, and the RRL Remote Radio Link. In addition, Levellogger 5 Series dataloggers are SDI-12 compatible.

Levellogger Setup

Programming Levelloggers is extremely intuitive. Simply connect to a PC using an Optical Reader (Desktop Reader 5 or Field Reader 5) or PC Interface Cable. Use a single screen to fill in your project information and sampling regime. Templates of settings can be saved for easy re-use.

The Levellogger time may be synchronized to the computer clock. There are options for immediate start or future start and stop times. The percentage battery life remaining and the amount of free memory are indicated on the settings screen.

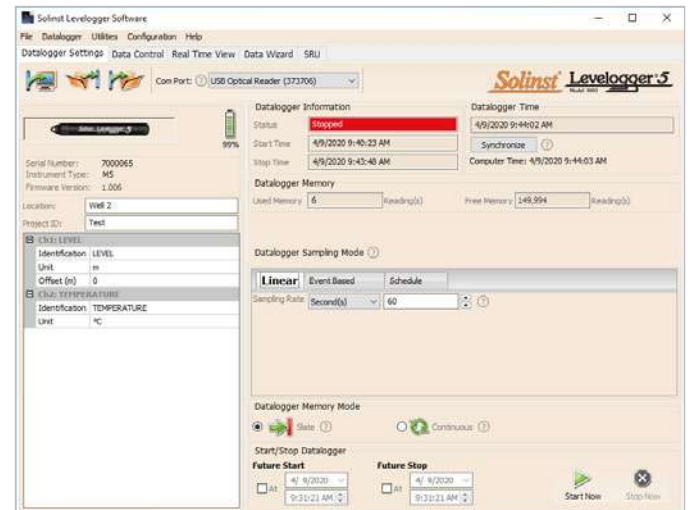
Levelloggers can also be programmed with a sampling regime and start/stop times using the Solinst Levellogger App on your smart device.

Convenient Sampling Options

Levelloggers can be programmed with linear, event-based, or a user-selectable sampling schedule. Linear sampling can be set from 1/8 second to 99 hours.

Event-based sampling can be set to record when the level changes by a selected threshold. Readings are checked at the selected time interval, but only recorded in memory if the condition has been met. A default reading is taken every 24 hours if no "event" occurs.

The Schedule option allows up to 30 schedule items, each with its own sampling rate and duration. For convenience, there is an option to automatically repeat the schedule.



Data Download, Viewing and Export

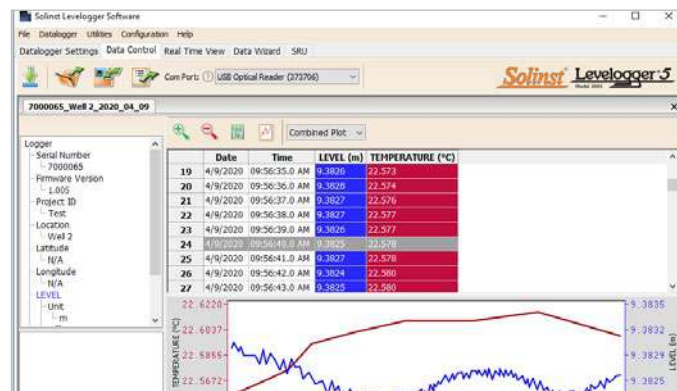
Data is downloaded to a PC with the click of a screen icon. There are multiple options for downloading data, including 'Append Data' and 'All Data'. The software also allows immediate viewing of the data in graph or table format using 'Real Time View'.

Level data is automatically compensated for temperature; the temperature data is also downloaded. Barometric compensation of Levellogger data is performed using the Data Wizard, which can also be used to input manual data adjustments, elevation, offsets, density, and adjust for Barometric efficiency. The Levellogger Software allows easy export of the data into a spreadsheet or database for further processing.

The Solinst Levellogger App also allows you to view and save real-time or logged data right on your smart device, or you can view and save the data using an SRU.

Helpful Utilities

The Diagnostic Utility can be used in case of an unexpected problem. It checks the functioning of the program, calibration, backup and logging memories, the pressure transducer, temperature sensor and battery voltage, as well as enabling a complete Memory Dump, if required. A firmware upgrade will be available from time to time, to allow upgrading of the Levellogger 5, as new features are added.



Levellogger 5 App Interface

The Levellogger 5 App Interface uses *Bluetooth®* technology to connect your Levellogger to your smart device. With the Solinst Levellogger App, you can download data, view real-time data, and program your Levelloggers. Data can be e-mailed from your smart device directly to your office (see Model 3001 Levellogger 5 App Interface data sheets).

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Solinst Readout Unit (SRU)

Connect an SRU to an in-field Levellogger via an L5 Direct Read Cable or L5 Threaded or Slip Fit Adaptor to display instant water level readings, Levellogger status, save a real-time logging session, and download data to the SRU memory.



DataGrabber 5

The DataGrabber 5 is a field-ready data transfer device that allows you to copy data from a Levellogger onto a USB flash key (Dual USB & USB-C key provided). The DataGrabber 5 is compact and very easy to transport. It connects to the top end of a Levellogger's Direct Read Cable, or directly to a Levellogger using an adaptor. One push-button is used to download all of the data in a Levellogger's memory to a USB device.



LevelSender 5 Telemetry

The LevelSender 5 is a simple, low cost telemetry system designed to send data from Levelloggers in the field, to your smart device and PC database via cellular communication. There is two-way communication between the LevelSender 5 and Home Station, allowing remote updates. LevelSender 5 stations are compact in design, which allows them to be discreetly installed inside a 2" (50 mm) well (see Model 9500 data sheet).



STS Telemetry

STS Telemetry provides an efficient method to send Levellogger data from the field to your desktop. Cellular communication options give the flexibility to suit any project. STS Systems are designed to save costs by enabling the self-management of data. Alarm notification, remote firmware upgrades and diagnostic reporting make system maintenance simple (see Model 9100 data sheet).



SolSat 5 Satellite Telemetry

The SolSat 5 Satellite Telemetry uses Iridium satellite technology to provide global connectivity for your remote water monitoring projects. The SolSat 5 is simple to set up with Solinst dataloggers using an intuitive and secure Wi-Fi App on your smart device. The SolSat 5 features a built-in barometer, solar panel and a compact weatherproof enclosure for deployment almost anywhere.



RRL Remote Radio Link

The RRL Remote Radio Link is ideal for closed-loop, short range applications up to 30 km (20 miles). The RRL can be linked to an STS telemetry station to change from a closed-loop telemetry system to one which can be accessed from anywhere through internet connectivity. (see Model 9200 data sheet).

Standard Cable Deployment

Levelloggers may be suspended on a stainless steel wireline or Kevlar® cord. This is a very inexpensive method of deployment, and if in a well, allows the Levellogger to be easily locked out of sight and inaccessible. Solinst offers wireline and cord assemblies in a variety of lengths.

Solinst 3001 Well Cap Assembly

The 2" Locking Well Caps are designed for both standard and Direct Read Cable deployment options.

The well cap has a convenient eyelet for suspending Levelloggers using wireline or Kevlar cord. The Well Cap insert has two openings to accommodate direct read cables for both a Levellogger and Barologger. Adaptors are available to fit 4" wells.

The cap is vented to equalize atmospheric pressure in the well. It slips over the casing, and can be secured using a lock with a 9.5 mm (3/8") shackle diameter.



*Levellogger 2" Locking Well Cap Installations
(see Well Caps data sheet for more details)*

L5 Direct Read Cables

When it is desired to get real-time data and communicate with Levelloggers without removal from the water, they can be deployed using L5 Direct Read Cables. This allows viewing of data, downloading, and programming in the field using a portable PC, or Solinst Levellogger 5 App Interface. You can view and save data to an SRU, or just download data with a DataGrabber 5.

Levelloggers can be connected to an SDI-12 datalogger using the Solinst SDI-12 Interface Cable attached to a L5 Direct Read Cable.

Cable Specifications

L5 Direct Read Cables are available for attachment to any Levellogger in lengths up to 1500 ft. The 3.175 mm dia. (1/8") coaxial cable has an outer polyurethane jacket for strength and durability. The stranded stainless steel conductor gives non-stretch accuracy.

*Barologger 5 and Levellogger 5
installed in Well Using
L5 Direct Read Cables*



Accurate Barometric Compensation

Levelloggers measure absolute pressure (water pressure + atmospheric pressure) expressed in feet, meters, centimeters, psi, kPa, or bar.

The most accurate method of obtaining changes in water level is to compensate for atmospheric pressure fluctuations using a Barologger 5, avoiding time lag in the compensation.

The Barologger 5 is set above high water level in one location on site. One Barologger can be used to compensate all Levelloggers in a 30 km (20 mile) radius and/or with every 300 m (1000 ft.) change in elevation.

The Levellogger Software Data Compensation Wizard automatically produces compensated data files using the synchronized data files from the Barologger and Levelloggers on site.

The Barologger 5 uses pressure algorithms based on air rather than water pressure, giving superior accuracy.

The recorded barometric information can also be very useful to help determine barometric lag and/or barometric efficiency of the monitored aquifer.

The Barologger 5 records atmospheric pressure in psi, kPa, or mbar. When compensating submerged Levellogger 5, Edge, Gold or Junior data, Levellogger Software can recognize the type of Levellogger and compensate using the same units found in the submerged data file (e.g. feet or meters). This makes the Barologger 5 backwards compatible.

*Synchronize and Simplify
Barometric Compensation
Across Entire Site*



Levellogger 5 Specifications

Level Sensor:	Piezoresistive Silicon with Hastelloy Sensor
Accuracy:	± 0.05% FS (Barologger 5: ± 0.05 kPa)
Stability of Readings:	Superior, low noise
Resolution:	0.002% FS to 0.0006% FS
Units of Measure:	m, cm, ft., psi, kPa, bar, °C, °F (Barologger 5: psi, kPa, mbar, °C, °F)
Normalization:	Automatic Temperature Compensation
Temp. Comp. Range:	0° to 50°C (Barologger 5: -10 to +50°C)
Temperature Sensor:	Platinum Resistance Temperature Detector (RTD)
Temp. Sensor Accuracy:	± 0.05°C
Temp. Sensor Resolution:	0.003°C
Battery Life:	10 Years – based on 1 reading/minute
Clock Accuracy (typical):	± 1 minute/year (-20°C to 80°C)
Operating Temperature:	-20°C to 80°C
Maximum # Readings:	150,000 sets of readings
Memory Mode:	Slate and Continuous
Communication:	Optical high-speed: USB, SDI-12 57,600 bps with USB
Size:	22 mm x 160 mm (7/8" x 6.3")
Weight:	146 grams (5.2 oz)
Corrosion Resistance:	Baked-on coating using polymerization technology (inside and out)
Other Wetted Materials:	Delrin®, Viton®, 316L stainless steel, Hastelloy, PFAS-free PTFE coating
Sampling Modes:	Linear, Event & User-Selectable with Repeat Mode, Future Start, Future Stop, Real-Time View
Measurement Rates:	1/8 sec to 99 hrs
Barometric Compensation:	Software Wizard and one Barologger 5 in local area (approx. 30 km/20 miles radius)

Models	Full Scale (FS)	Accuracy	Resolution
Barologger	Air only	± 0.05 kPa	0.002% FS
M5	5 m (16.4 ft.)	± 0.3 cm (0.010 ft.)	0.001% FS
M10	10 m (32.8 ft.)	± 0.5 cm (0.016 ft.)	0.0006% FS
M20	20 m (65.6 ft.)	± 1 cm (0.032 ft.)	0.0006% FS
M30	30 m (98.4 ft.)	± 1.5 cm (0.064 ft.)	0.0006% FS
M100	100 m (328.1 ft.)	± 5 cm (0.164 ft.)	0.0006% FS
M200	200 m (656.2 ft.)	± 10 cm (0.328 ft.)	0.0006% FS

Low Cost Datalogging: See Levellogger 5 Junior data sheet.
Vented Dataloggers: See LevelVent 5 & AquaVent 5 data sheets.
Conductivity Datalogging: See Levellogger 5 LTC data sheet.

Appendix C – FP111 Flow Probe User Manual





Flow Probes - FP111, FP211, and FP311

DIGITAL HANDHELD WATER VELOCITY METERS

Highly-accurate, easy flow monitoring for surface water, stormwater, wastewater, and other open flowing water sources.

The **FP111, FP211, and FP311 Flow Probes** are highly accurate water velocity instruments for measuring flows in open channels and partially filled pipes. The water velocity probe consists of a protected water turbo prop positive displacement sensor coupled with an expandable probe handle ending in a digital readout display. The water flow meter incorporates true velocity averaging for the most accurate flow measurements.



◀ FP111



Records 30 data sets, and readings are in feet or meters per second.



Telescoping handles ranging from 3 feet to 14 feet



Rain-proof digital computer and display with 5 year shelf life



Lightweight, rugged and reliable



a **xylem** brand

Flow Probes FP111, FP211, FP311



Digital Display ▶



◀ Optional Swivel Tee



◀ Flow probe propeller with magnetic sensor

Flow Probe Specifications	
Range	0.3 - 19.9 FPS (0.1 - 6.1 MPS)
Accuracy	0.1 FPS
Averaging	True digital running average. Updated once per second.
Display	LCD, Glare, and UV Protected
Control	4 button
Datalogger	30 sets, MIN, MAX, and AVG
Features	Timer, Low battery warning
Sensor Type	Protected Turbo-Prop propeller with magnetic pickup.
Weight	Instrument: 2 lbs (0.9 kg) (FP111); 3 lbs (1.4 kg) (FP211); 2.8 lbs (1.3 kg) (FP311) Shipping: 13 lbs (5.9 kg) (FP111); 23 lbs (10.4 kg) (FP211); 19 lbs (8.6 kg) (FP311)
Expandable Length	3.7 to 6 ft (1.1 to 1.8 m) (FP111); 5.5 to 14 ft (1.7 to 4.3 m) (FP211); 2.5 to 5.5 ft (0.76 to 1.7 m) (FP311)
Materials	Probe: PVC and anodized aluminum with stainless steel water bearing Computer: ABS/Polycarbonate housing with polyester overlay
Power	Internal Lithium Battery, Approx 5 years life with typical use, Non-Replaceable
Auto Shutoff	After 5 minutes of inactivity
Operating Temperature	-4 °F to 158 °F (-20 °C to 70 °C)
Storage Temperature	-22 °F to 176 °F (-30 °C to 80 °C)
Carrying Case	The Flow Probe is shipped in a padded carrying case.
Certificates	CE



YSI, a Xylem brand
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Yellow Springs, OH 45387

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YSI.com

Who's
Minding
the Planet?®



YSI.com/Flow-Probe

Appendix D – Low and High Precipitation Field Photos

Barrows Road Stream

Flow monitoring location during low precipitation events near Barrows Road:



Figure D1

Flow monitoring location during low precipitation events near Cuckholds Cove Road:

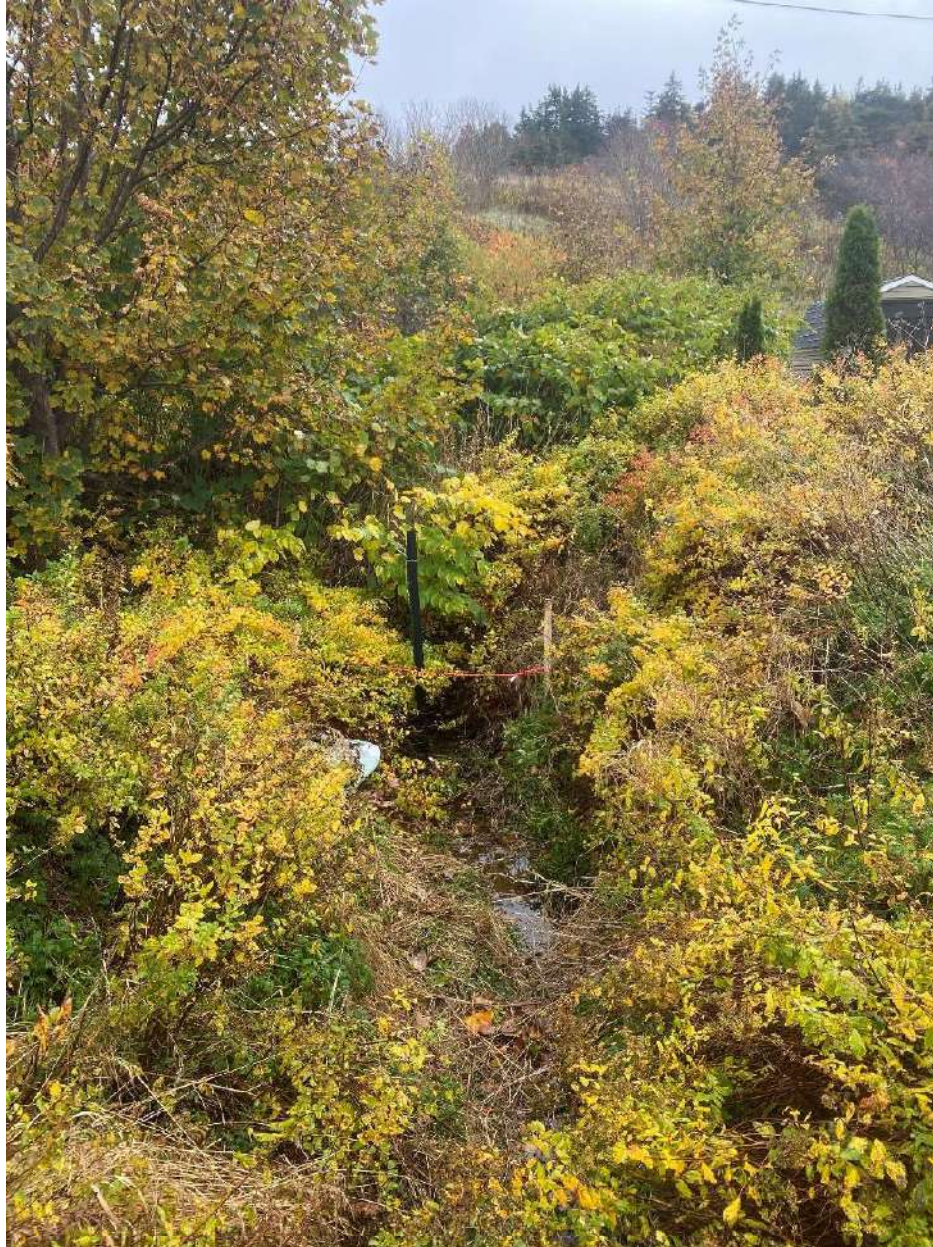


Figure D2

Outer Cove Brook

Flow monitoring location during low precipitation events at Virginia River Trail:



Figure D3



Figure D4

Flow monitoring location during high precipitation events at Virginia River Trail:



Figure D5

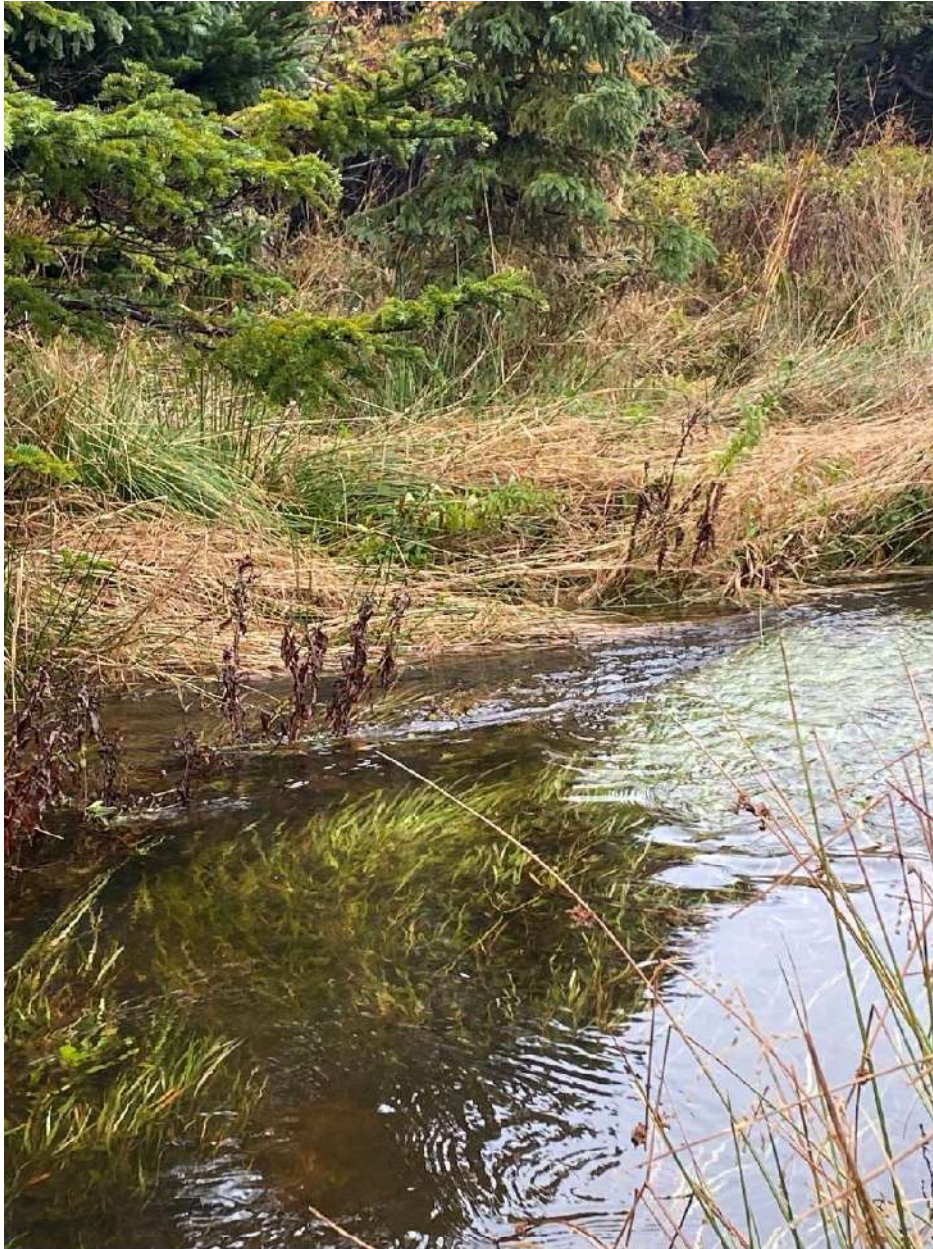


Figure D6

Flow monitoring location during low precipitation events at Torbay Road:



Figure D7

Flow monitoring location during high precipitation events at Torbay Road:



Figure D8

Virginia River

Flow monitoring location during low precipitation events at Penny Crescent:



Figure D9

Flow monitoring location during high precipitation events at Penny Crescent:



Figure D10

Flow monitoring location during low precipitation events at Virginia Lake Outlet Weir:



Figure D11

Flow monitoring location during low precipitation events at Virginia River Tributary at Guzzwell Drive:



Figure D12

Flow monitoring location during high precipitation events at Virginia River Tributary at Guzzwell Drive:



Figure D13

Flow monitoring location during low precipitation events at Virginia River at Logy Bay Road:



Figure D14

Flow monitoring location during high precipitation events at Virginia River at Logy Bay Road:



Figure D15

Holes in Marsh Brook

Flow monitoring location during low precipitation events near Kelsey Drive:



Figure D16

Flow monitoring location during high precipitation events near Kelsey Drive:

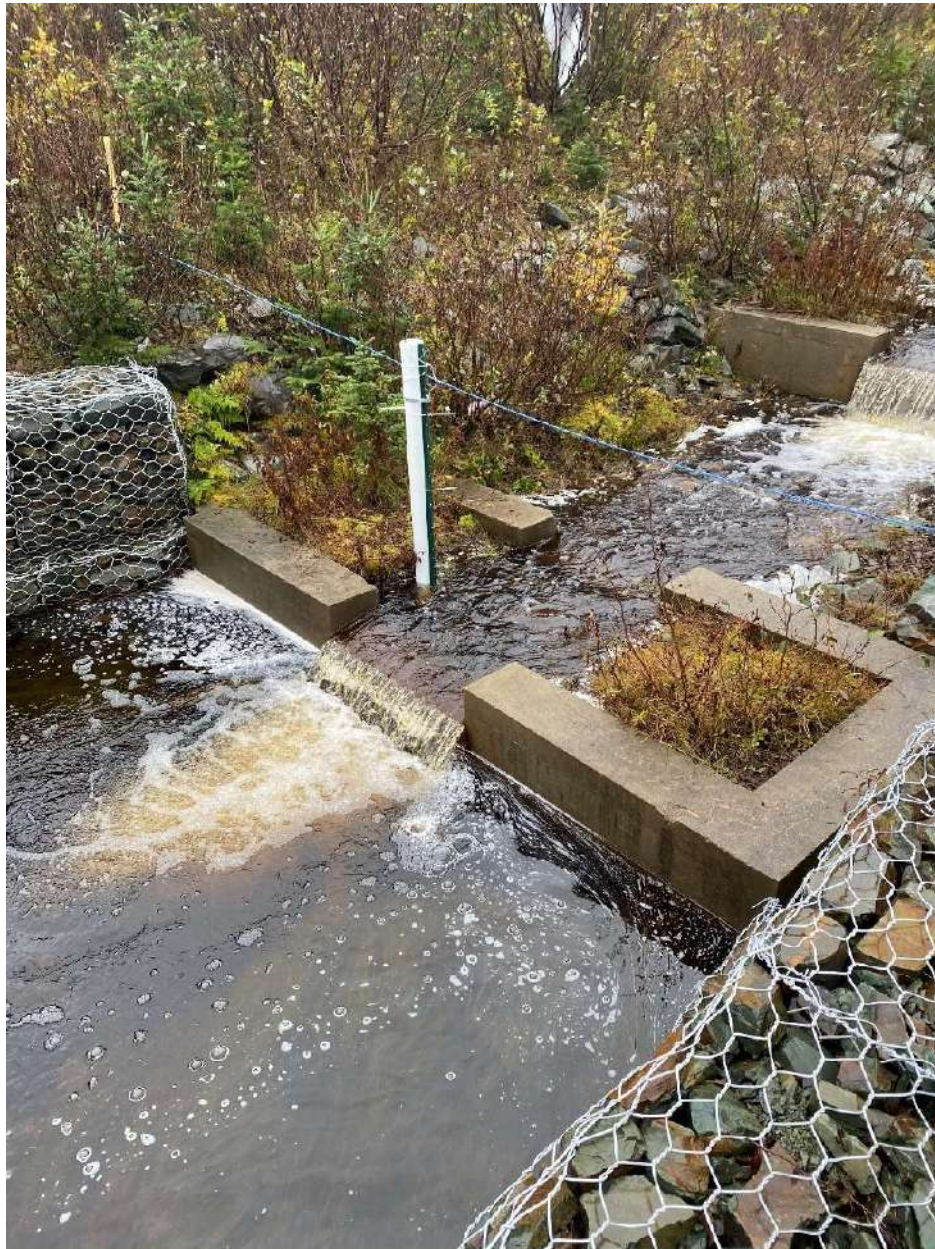


Figure D17

Flow monitoring location during low precipitation events near Pippy Place:



Figure D18

Mundy Pond Brook

Flow monitoring location during low precipitation events near Coefield Street:



Figure D19

Flow monitoring location during high precipitation events near Coefield Street:



Figure D20

Flow monitoring location during low precipitation events at Mundy Pond Outlet Structure:



Figure D21



Figure D22

Flow monitoring location during high precipitation events at Mundy Pond Outlet Structure:



Figure D23



Figure D24

Kitty Gaul Brook

Flow monitoring location during low precipitation events near Blackmarsh Road:



Figure D25

Flow monitoring location during high precipitation events near Blackmarsh Road:



Figure D26



Figure D27

Flow monitoring location during low precipitation events near Greenwood Crescent:



Figure D28

Flow monitoring location during high precipitation events near Greenwood Crescent:



Figure D29

South Brook

Flow monitoring location during low precipitation events at Southlands Boulevard (Upper Crossing):

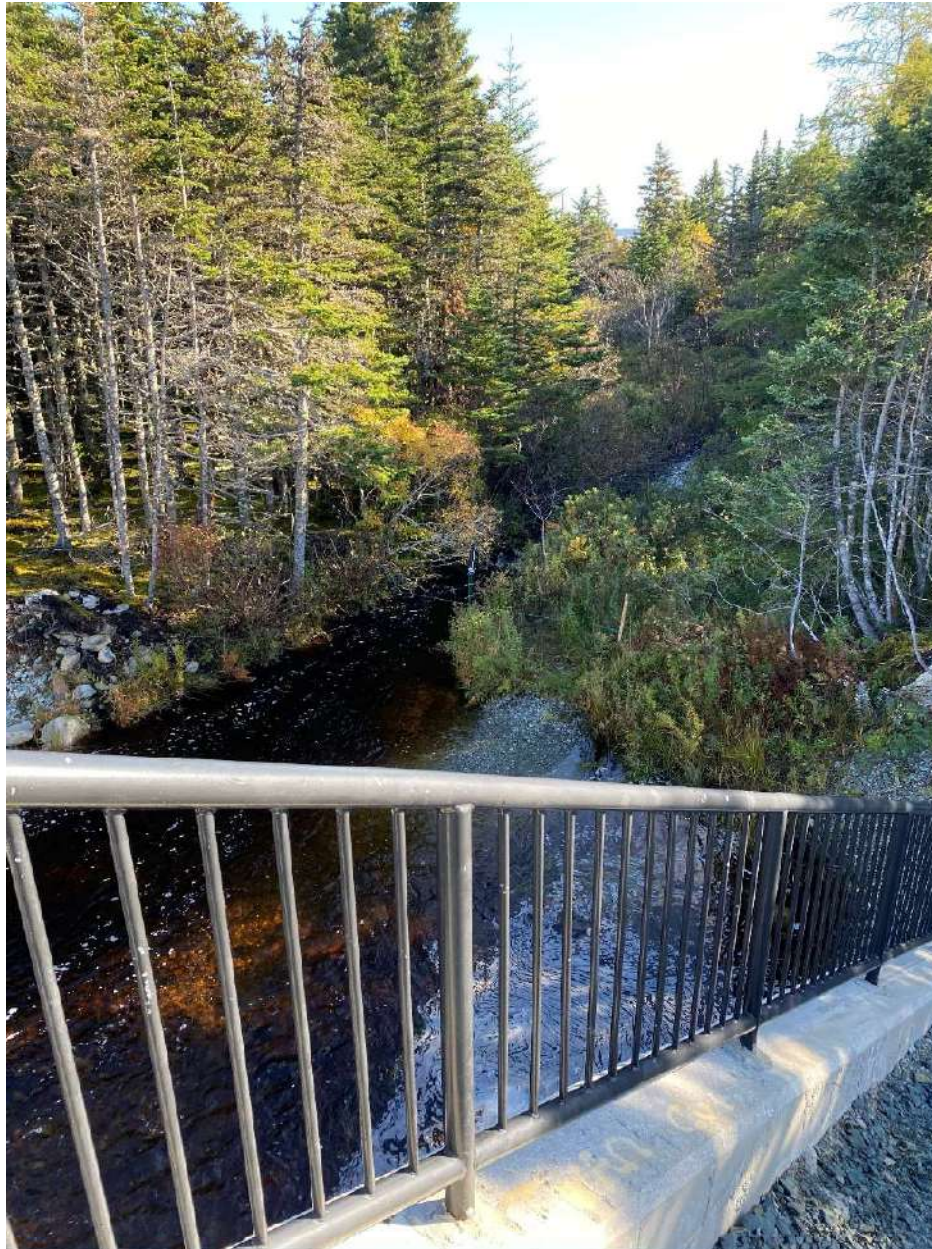


Figure D30

Flow monitoring location during high precipitation events at Southlands Boulevard (Upper Crossing):

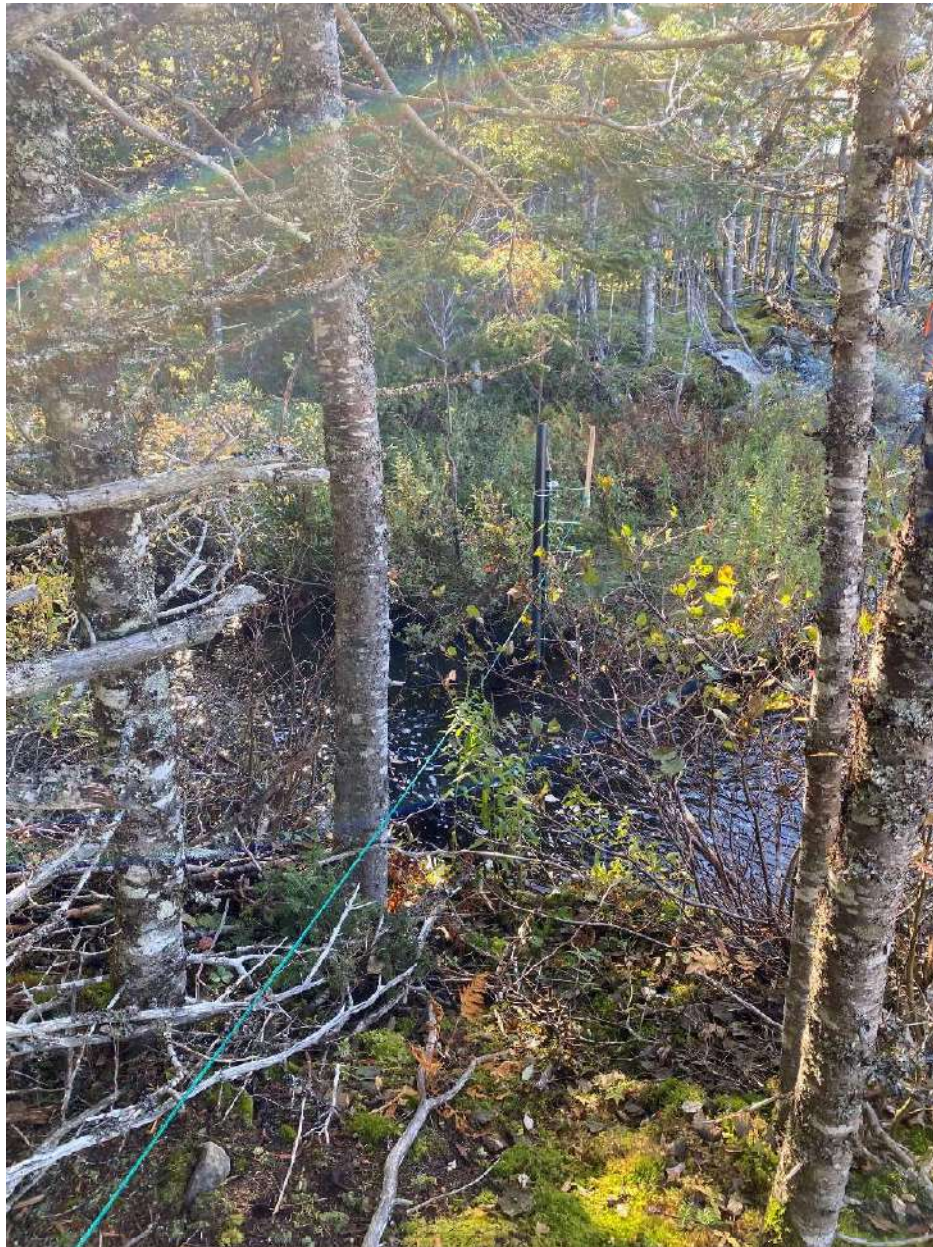


Figure D31

Flow monitoring location during low precipitation events at Tree Top Drive:



Figure D32

Flow monitoring location during high precipitation events at Tree Top Drive:

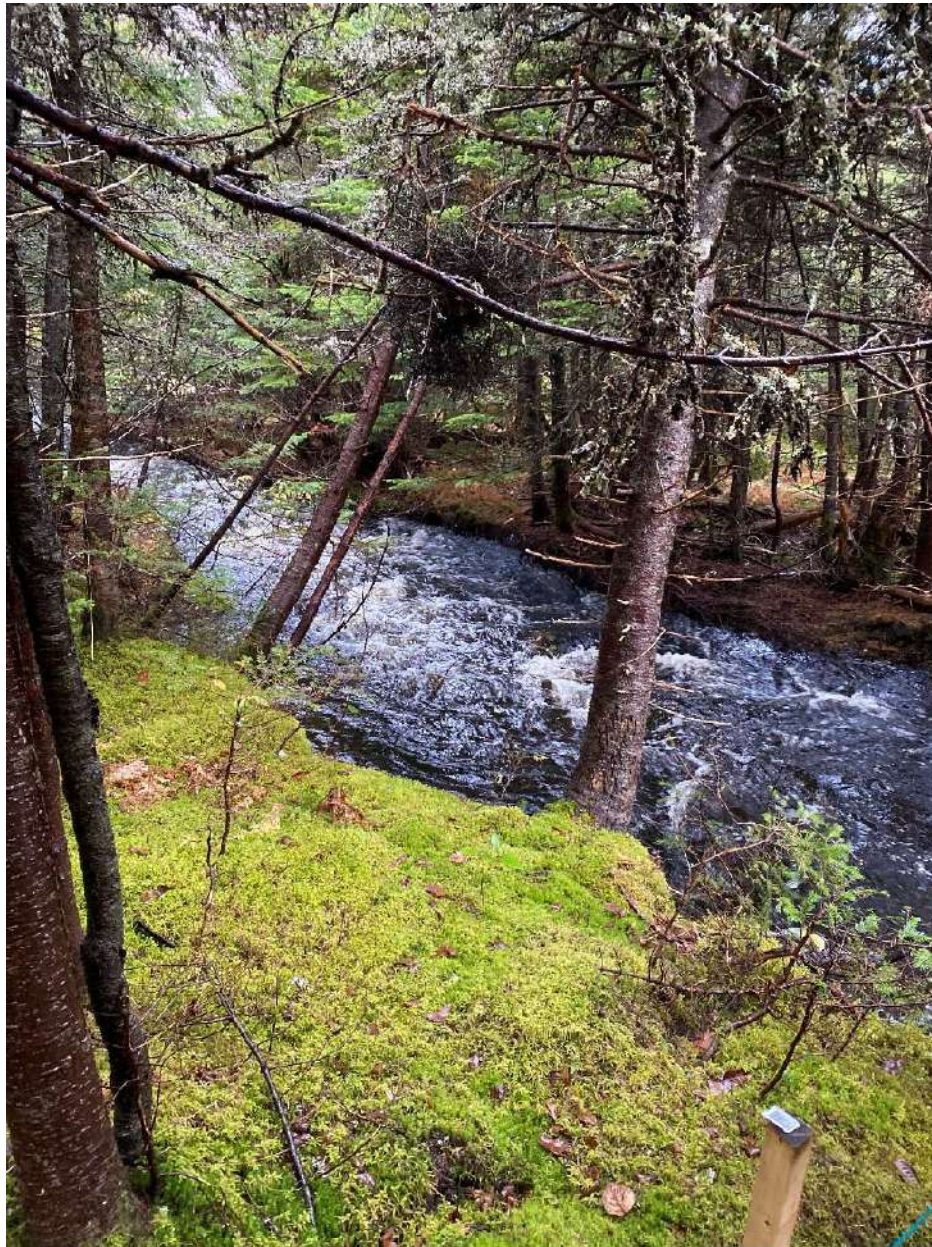






Figure D33


Appendix E – Structure Data Sheets









Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/16/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	324367.332	5275036.569	
Culvert ID:	OCB-C15	U/S Invert Elevation (m):	129.752
Size (m):	Unknown	D/S Invert Elevation (m):	118.293
Shape:	Circular	Culvert Slope (m/m):	0.025538905
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	448.688
Wingwall Angle(°):	45	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Significant weathering observed.
Photos			
Upstream:			
			
Downstream:			



Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/16/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	324110.799	5275233.356	
Culvert ID:	OCB-C14	U/S Invert Elevation (m):	132.032
Size (m):	2.790	D/S Invert Elevation (m):	132.056
Shape:	Rectangular	Culvert Slope (m/m):	-0.000248216
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	96.69
Wingwall Angle(°):	45	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			
<div></div>			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/16/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323962.065	5275171.995	
Culvert ID:	OCB-C13	U/S Invert Elevation (m): 132.7	
Size (m):	2.000	D/S Invert Elevation (m): 132.402	
Shape:	Square	Culvert Slope (m/m): 0.011355409	
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m): 26.243	
Wingwall Angle(°):	0	Watercourse: Outer Cove Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/16/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	324830.143	5275161.129	
Culvert ID:	OCB-C16	U/S Invert Elevation (m):	114.161
Size (m):	Unknown	D/S Invert Elevation (m):	115.218
Shape:	Circular	Culvert Slope (m/m):	-0.088083333
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	3	Water Level (m):	
Headwall Material:	Rock	Length (m):	12
Wingwall Angle(°):	0	Watercourse:	
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			
<div></div> <div></div>			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	322692.993		5274205.151
Culvert ID:	OCB-C-02	U/S Invert Elevation (m):	156.435
Size (m):	1.500	D/S Invert Elevation (m):	156.132
Shape:	Circular	Culvert Slope (m/m):	0.007760674
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:		Water Level (m):	155.778
Headwall Material:	Concrete	Length (m):	39.043
Wingwall Angle(°):	45	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation growth observed upstream and downstream, pooling water observed at inlet and outlet
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/15/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323730.658	5275075.542	
Culvert ID:	OCB-C12	U/S Invert Elevation (m): 135.229	
Size (m):	1.500	D/S Invert Elevation (m): 134.935	
Shape:	Circular	Culvert Slope (m/m): 0.013534665	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	3	Water Level (m):	
Headwall Material:	Concrete	Length (m): 21.722	
Wingwall Angle(°):	N/A	Watercourse: Outer Cove Brook	
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Rusting observed. Crack in headwall at upstream invert.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/15/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323772.806	5275089.485	
Culvert ID:	OCB-C12	U/S Invert Elevation (m):	134.064
Size (m):	2.000	D/S Invert Elevation (m):	134.178
Shape:	Rectangular	Culvert Slope (m/m):	-0.0038
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Rock	Length (m):	30
Wingwall Angle(°):	90	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Low lying Vegetation observed, some blocking inlet grate.
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Culverts

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322476.311	5274113.964	
Culvert ID:	OCB-C01	U/S Invert Elevation (m):	157.158
Size (m):	0.600	D/S Invert Elevation (m):	157.589
Shape:	Circular	Culvert Slope (m/m):	-0.034337157
Material:	HDPE	Road Top Elevation (m):	
No. of Barrels:		Water Level (m):	157.249
Headwall Material:	Rock	Length (m):	12.552
Wingwall Angle:	N/A	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Water observed, low vegetation observed on downstream, mature vegetation observed on upstream

Photos

Upstream:



Downstream:



Survey Data Sheet - Culverts

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date:	12/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)	
	323319.958		5274582.188	
Culvert ID:	OCB-C08	U/S Invert Elevation (m): 144.227		
Size (m):	2.200	D/S Invert Elevation (m): 144.105		
Shape:	Circular	Culvert Slope (m/m): 0.005497972		
Material:	CMP	Road Top Elevation (m):		
No. of Barrels:	1	Water Level (m): 144.677		
Headwall Material:	Concrete	Length (m): 22.19		
Wingwall Angle(°):	40	Watercourse: Outer Cove Brook		
Comments:	Condition:	Date of Construction:	Description:	
	Good		Water Observed. Vegetation growth in water channel at inlet and outlet.	





Photos





Upstream:












Downstream:






Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/15/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323537.613	5274859.003	
Culvert ID:	OCB-C10	U/S Invert Elevation (m):	139.316
Height (m):	0.800	D/S Invert Elevation (m):	140.651
Shape:	Arch	Culvert Slope (m/m):	-0.048429224
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Rock	Length (m):	27.566
Wingwall Angle(°):	N/A	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Low lying vegetation growth observed at both inverts.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323384.297	5274627.342	
Culvert ID:	OCB-C08	U/S Invert Elevation (m):	143.584
Size (m):	1.400	D/S Invert Elevation (m):	143.604
Shape:	Circular	Culvert Slope (m/m):	-0.002815315
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Rock	Length (m):	7.104
Wingwall Angle(°):	N/A	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Rusting Observed.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323229.194	5274491.817	
Culvert ID:	OCB-C06	U/S Invert Elevation (m): 146.728	
Size (m):	2.200	D/S Invert Elevation (m): 146.506	
Shape:	Circular	Culvert Slope (m/m): 0.013443139	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	146.878
Headwall Material:	Concrete	Length (m):	16.514
Wingwall Angle(°):	50	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation growth at mouth of upstream inlet. Water Observed.
Photos			
Upstream:			
			
Downstream:			
		 	

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/15/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323433.769	5274660.676	
Culvert ID:	OCB-C09	U/S Invert Elevation (m):	143.369
Size (m):	0.800	D/S Invert Elevation (m):	143.066
Shape:	Circular	Culvert Slope (m/m):	0.009172368
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	
Headwall Material:	N/A	Length (m):	33.034
Wingwall Angle(°):	N/A	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Poor		Significant rust observed. Downstream invert has partially collapsed. Vegetation and rock observed obstructing U/S and
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322780.477	5274292.855	
Culvert ID:	OCB-C03	U/S Invert Elevation (m):	156.167
Size (m):	0.900	D/S Invert Elevation (m):	155.145
Shape:	Circular	Culvert Slope (m/m):	0.056095285
Material:	HDPE	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	155.267
Headwall Material:	Rock	Length (m):	18.219
Wingwall Angle(°):	N/A	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation growth at inlet and outlet
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322821.485	5274294.525	
Culvert ID:	OCB-C04	U/S Invert Elevation (m):	155.132
Size (m):	0.900	D/S Invert Elevation (m):	155.015
Shape:	Circular	Culvert Slope (m/m):	0.007919854
Material:	HDPE	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	N/A
Headwall Material:	Rock	Length (m):	14.773
Wingwall Angle(°):	N/A	Watercourse:	Outer Cove Brook

Comments:	Condition:	Date of Construction:	Description:
	Good		Inlet clear of debris, low vegetation and fallen leaves at outlet No water observed.





Photos





Upstream:











Downstream:





Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date:
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322973.301	5274374.025	
Culvert ID:	OCB-C05	U/S Invert Elevation (m): 152.338	
Size (m):	0.900	D/S Invert Elevation (m): 149.72	
Shape:	Circular	Culvert Slope (m/m): 0.017998694	
Material:	HDPE	Road Top Elevation (m):	
No. of Barrels:		Water Level (m):	
Headwall Material:	Concrete	Length (m): 145.455	
Wingwall Angle(°):	80	Watercourse: Outer Cove Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation growth surrounding inlet. Overgrowth of vegetation at outlet.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/12/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	325108.214	5275366.998	
Culvert ID:	OCB-C17	U/S Invert Elevation (m):	109.019
Size (m):	Unknown	D/S Invert Elevation (m):	108.322
Shape:	Rectangular	Culvert Slope (m/m):	0.026807692
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	26
Wingwall Angle(°):	45	Watercourse:	Outer Cove Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/12/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	325569.142	5275710.966	
Culvert ID:	OCB-C18	U/S Invert Elevation (m): 98.935	
Size (m):	Unknown	D/S Invert Elevation (m): 98.376	
Shape:	Rectangular	Culvert Slope (m/m): 0.019950036	
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m): 28.02	
Wingwall Angle(°):	45	Watercourse: Outer Cove Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Rusting observed.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/09/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	324814.44	5273772.72	
Culvert ID:	VR-C06	U/S Invert Elevation (m):	129.27
Size (m):	4.000	D/S Invert Elevation (m):	129.212
Shape:	Arch	Culvert Slope (m/m):	0.006627814
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	8.751
Wingwall Angle(°):	0	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		Weathering observed
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/20/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	324301.74	5273581.056	
Culvert ID:	VR-C03	U/S Invert Elevation (m):	145.774
Size (m):	4.682	D/S Invert Elevation (m):	144.203
Shape:	Arch	Culvert Slope (m/m):	0.059938955
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	26.21
Wingwall Angle(°):		Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation growth observed.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	01/09/24
NAD83 MTM Zone 1 Coordinates:	Easting (m) 324369.937	Northing (m) 5273607.298	
Culvert ID:	VR-C04	U/S Invert Elevation (m):	145.204
Size (m):	3.426	D/S Invert Elevation (m):	142.853
Shape:	Arch	Culvert Slope (m/m):	0.04879922
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	48.177
Wingwall Angle(°):	65	Watercourse:	Virginia River
Comments:	Condition: Good	Date of Construction:	Description: No debris observed


Photos





Upstream:









Downstream:




Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/21/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326727.365	5273744.596	
Culvert ID:	VR-C17	U/S Invert Elevation (m):	73.854
Size (m):	3.000	D/S Invert Elevation (m):	74.134
Shape:	Arch	Culvert Slope (m/m):	-0.01148294
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	
Headwall Material:	N/A	Length (m):	24.384
Wingwall Angle(°):	N/A	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation Growth observed.
Photos			
Upstream:			
Downstream:			
			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	328075.246	5272102.405	
Culvert ID:	VR-C23	U/S Invert Elevation (m): 23.364	
Size (m):	6.300	D/S Invert Elevation (m): 22.927	
Shape:	Rectangular	Culvert Slope (m/m): 0.032921501	
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m): 13.274	
Wingwall Angle(°):	60	Watercourse: Virginia River	
Comments:	Condition:	Date of Construction:	Description:
	Good		No debris or vegetation observed in waterbed. Wingwall in good condition
Photos			
Upstream:			
			
Downstream:			
			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/18/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	328160.079	5271959.526	
Culvert ID:	VR-C24	U/S Invert Elevation (m): 19.444	
Size (m):	9.593	D/S Invert Elevation (m): 19.033	
Shape:	Rectangular	Culvert Slope (m/m): 0.025531122	
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m): 16.098	
Wingwall Angle(°):	70 & 15	Watercourse: Virginia River	
Comments:	Condition:	Date of Construction:	Description:
	Good		Weathering of headwall observed.
Photos			
Upstream:			
			
Downstream:			
			





Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/18/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	323986.23		5273516.405
Culvert ID:	VR-C01	U/S Invert Elevation (m): 150.314	
Size (m):	1.600	D/S Invert Elevation (m): 149.862	
Shape:	Arch	Culvert Slope (m/m): 0.018151153	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m): 24.902	
Wingwall Angle(°):	45	Watercourse: Virginia River	
Comments:	Condition:	Date of Construction:	Description:
	Good		Little to no debris observed at inlets.
Photos			
Upstream:			
			
Downstream:			
			



Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date:
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
Culvert ID:	VR-C12	U/S Invert Elevation (m):	90.513
Size (m):	7.973	D/S Invert Elevation (m):	90.303
Shape:		Culvert Slope (m/m):	0.010733453
Material:		Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:		Length (m):	19.565
Wingwall Angle(°):		Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
Photos			
Upstream:			
Downstream:			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/02/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326278.203	5273692.974	
Culvert ID:	VR-C13	U/S Invert Elevation (m):	86.826
Size (m):	7.973	D/S Invert Elevation (m):	87.553
Shape:	Rectangular	Culvert Slope (m/m):	-0.060502663
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	12.016
Wingwall Angle(°):	75	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Weathering and vegetation observed.
Photos			
Upstream:			
			
Downstream:			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/02/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326414.624	5273625.71	
Culvert ID:	VR-C15	U/S Invert Elevation (m):	82.715
Size (m):	Unknown	D/S Invert Elevation (m):	81.663
Shape:	Rectangular	Culvert Slope (m/m):	0.02209295
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	
Headwall Material:	Concrete	Length (m):	47.617
Wingwall Angle(°):		Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good	2023	Two additional outlets in the wingwalls.
Photos			
Upstream:			
			
Downstream:			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 02/13/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	327239.639	5273067.32	
Culvert ID:	VR-C21	U/S Invert Elevation (m):	58.955
Size (m):	9.592	D/S Invert Elevation (m):	58.91
Shape:	Rectangular	Culvert Slope (m/m):	0.002279404
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	19.742
Wingwall Angle(°):	90	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		Clear of debris and vegetation.
Photos			
Upstream:			
Downstream:			
			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/08/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326193.993	5274082.303	
Culvert ID:	VR-C30	U/S Invert Elevation (m):	93.024
Size (m):	Various	D/S Invert Elevation (m):	
Shape:	Square	Culvert Slope (m/m):	#VALUE!
Material:		Road Top Elevation (m):	
No. of Barrels:	4	Water Level (m):	
Headwall Material:		Length (m):	N/A
Wingwall Angle(°):		Watercourse:	Virginia River Tributary
Comments:	Condition:	Date of Construction:	Description:
Photos			
Upstream:			
			
Downstream:			
			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/18/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	327367.153		5273047.941
Culvert ID:	VR-C22	U/S Invert Elevation (m): 58.042	
Size (m):	5.750	D/S Invert Elevation (m): 57.983	
Shape:	Rectangular	Culvert Slope (m/m): 0.001608638	
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m): 36.677	
Wingwall Angle(°):	90	Watercourse: Virginia River	
Comments:	Condition:	Date of Construction:	Description:
	Good		Clear of debris, vegetation observed in water bed.
Photos			
Upstream:			
			
Downstream:			
			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/18/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323757.718	5273380.644	
Culvert ID:	VR-C02	U/S Invert Elevation (m):	145.199
Size (m):	4.375	D/S Invert Elevation (m):	145.41
Shape:	Rectangular	Culvert Slope (m/m):	-0.005185167
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	40.693
Wingwall Angle(°):	60	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation observed at outlet.
Photos			
Upstream:			
Downstream:			
			


Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/18/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	327329.188	5273426.004	
Culvert ID:	VR-C19	U/S Invert Elevation (m):	61.068
Size (m):	5.993	D/S Invert Elevation (m):	61.038
Shape:	Rectangular	Culvert Slope (m/m):	0.00114771
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	26.139
Wingwall Angle(°):	45	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		Weathering observed. Vegetation at inlet.
Photos			
Upstream:			
			
Downstream:			
<div></div>			

Survey Data Sheet - Culverts					
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: December 18, 2023		
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)			
	327184.944	5273096.712			
Culvert ID:	VR-C20	U/S Invert Elevation (m):	92.582		
Size (m):	2.150	D/S Invert Elevation (m):	60.893		
Shape:	Square	Culvert Slope (m/m):	0.022672247		
Material:	Concrete	Road Top Elevation (m):			
No. of Barrels:	1	Water Level (m):			
Headwall Material:	Concrete	Length (m):	1397.7		
Wingwall Angle(°):	90	Watercourse:	Virginia River		
Comments:	Condition:	Date of Construction:	Description:		
Photos Upstream: <table border="1" style="width: 100%; height: 200px;"> <tr> <td style="width: 50%;"></td> <td style="width: 50%;"></td> </tr> </table>					
Downstream:					

Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/21/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	327262.025	5273725.635	
Structure ID:	VR-B08	U/S Underside Elevation (m):	69.347
Span (m)	12.343	D/S Underside Elevation (m):	69.338
Height (m):	2.192	Top Deck Elevation (m):	69.607
Material:	Timber	Water Level (m):	67.415
Structure Type:	Bridge	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
Downstream:			
			

Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/21/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326779.426	5273778.241	
Structure ID:	VR-B07	U/S Underside Elevation (m):	75.431
Span (m)	33.014	D/S Underside Elevation (m):	75.449
Height (m):	2.287	Top Deck Elevation (m):	75.736
Material:	Timber	Water Level (m):	73.449
Structure Type:	Bridge	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/02/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326429.685	5273631.706	
Structure ID:	VR-B05	U/S Underside Elevation (m):	82.087
Span (m)	24.258	D/S Underside Elevation (m):	82.069
Height (m):	2.345	Top Deck Elevation (m):	83.475
Material:	Timber	Water Level (m):	79.742
Structure Type:	Bridge	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/18/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	327319.01		5273048.78
Structure ID:	VR-C09	U/S Underside Elevation (m):	58.702
Span (m)	12.770	D/S Underside Elevation (m):	58.707
Height (m):	1.881	Top Deck Elevation (m):	59.009
Material:	Timber	Water Level (m):	57.128
Structure Type:	Bridge	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation overgrowth observed.
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	12/20/23
NAD83 MTM Zone 1 Coordinates:	Easting (m) 324330.516	Northing (m) 5273613.899	
Structure ID:	VR-B02	U/S Underside Elevation (m):	145.303
Span (m)	10.538	D/S Underside Elevation (m):	145.286
Height (m):	1.038	Top Deck Elevation (m):	145.698
Material:	Timber	Water Level (m):	144.265
Structure Type:	Bridge	Watercourse:	Virginia River
Comments:	Condition: Good	Date of Construction:	Description: Flowing water and vegetation observed


Photos

Upstream:



Downstream:



Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/21/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	326539.089		5273636.658
Structure ID:	VR-C16	U/S Underside Elevation (m):	78.685
Span (m)	53.371	D/S Underside Elevation (m):	78.696
Height (m):	1.934	Top Deck Elevation (m):	79.056
Material:	Timber	Water Level (m):	77.122
Structure Type:	Bridge	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		Excess vegetative growth observed
Photos			
Upstream:			
			
Downstream:			
<div></div> <div></div>			

Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	12/18/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323757.155	5273380.345	
Structure ID:	VR-B01	U/S Underside Elevation (m):	159.877
Span (m)	30.212	D/S Underside Elevation (m):	159.89
Height (m):	2.109	Top Deck Elevation (m):	160.247
Material:	Steel	Water Level (m):	157.781
Structure Type:	Bridge	Watercourse:	Virginia River

Comments:	Condition:	Date of Construction:	Description:
	Good		Flowing water observed.


Photos




Upstream:





Downstream:



Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/21/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326655.658	5273753.94	
Structure ID:	VR-B06	U/S Underside Elevation (m):	76.834
Span (m)	25.506	D/S Underside Elevation (m):	76.813
Height (m):	3.219	Top Deck Elevation (m):	77.273
Material:	Timber	Water Level (m):	74.054
Structure Type:	Bridge	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		No water observed beneath bridge.
Photos			
Upstream:			
			
Downstream:			
<div></div> <div></div>			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 04/14/00
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	325786.284	5273833.937	
Culvert ID:	VR-C10	U/S Invert Elevation (m):	105.517
Size (m):	1.333	D/S Invert Elevation (m):	105.522
Shape:	Square	Culvert Slope (m/m):	-0.000275619
Material:		Road Top Elevation (m):	
No. of Barrels:		Water Level (m):	
Headwall Material:		Length (m):	18.141
Wingwall Angle(°):		Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
Photos Upstream: <div>   </div>			
Downstream: <div>  </div>			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/09/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	324497.358	5273621.183	
Culvert ID:	VR-C05	U/S Invert Elevation (m):	140.436
Size (m):	1.600	D/S Invert Elevation (m):	139.328
Shape:	Arch	Culvert Slope (m/m):	0.021163213
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	N/A	Length (m):	52.355
Wingwall Angle(°):	N/A	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	328112.482	5271569.382	
Structure ID:	VR-B10	U/S Underside Elevation (m):	12.372
Span (m)	15.357	D/S Underside Elevation (m):	12.372
Height (m):	2.105	Top Deck Elevation (m):	12.459
Material:	Timber	Water Level (m):	10.354
Structure Type:	Bridge	Watercourse:	Virginia River

Comments:	Condition:	Date of Construction:	Description:
	Good		Clear of debris.



Photos



Upstream:





Downstream:








Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/08/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	325309.067	5274144.683	
Culvert ID:	VR-C08	U/S Invert Elevation (m):	119.327
Size (m):	1.366	D/S Invert Elevation (m):	117.949
Shape:	Circular	Culvert Slope (m/m):	0.020257258
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	N/A	Length (m):	68.025
Wingwall Angle(°):	N/A	Watercourse:	
Comments:	Condition:	Date of Construction:	Description:
	Poor		Outlet collapsing. Vegetation growth observed.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	328093.252	5271646.364	
Culvert ID:	VR-C25	U/S Invert Elevation (m): 12.598	
Size (m):	9.612	D/S Invert Elevation (m): 12.627	
Shape:	Rectangular	Culvert Slope (m/m): -0.002157899	
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	4	Water Level (m):	
Headwall Material:	Concrete	Length (m): 13.439	
Wingwall Angle(°):	90	Watercourse: Virginia River	
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Weathering/ deteriorationn of wingwall. Rock and other debris in waterbed.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/02/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326136.27	5273766.839	
Culvert ID:	VR-C11	U/S Invert Elevation (m):	92.546
Size (m):	7.481	D/S Invert Elevation (m):	90.89
Shape:	Rectangular	Culvert Slope (m/m):	0.02669676
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	62.03
Wingwall Angle(°):		Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Weathering and cracking observed in concrete.
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/08/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	325100.637	5273817.369	
Culvert ID:	VR-C07	U/S Invert Elevation (m):	121.833
Size (m):	2.800	D/S Invert Elevation (m):	
Shape:	Circular	Culvert Slope (m/m):	1.885405221
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	N/A	Length (m):	64.619
Wingwall Angle(°):	N/A	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Rusting observed at bottom of barrel.
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/08/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326113.553	5274240.988	
Culvert ID:	VR-C27	U/S Invert Elevation (m):	104.882
Size (m):	1.442	D/S Invert Elevation (m):	102.908
Shape:	Circular	Culvert Slope (m/m):	0.041963394
Material:	HDPE	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	47.041
Wingwall Angle(°):		Watercourse:	Virginia River Tributary
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/08/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326150.996	5274147.281	
Culvert ID:	VR-C28	U/S Invert Elevation (m):	96.497
Size (m):		D/S Invert Elevation (m):	95.236
Shape:	Circular	Culvert Slope (m/m):	0.042709568
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	29.525
Wingwall Angle(°):		Watercourse:	Virginia River Tributary
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos Upstream: <div>   </div>			
Downstream: <div>  </div>			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date:
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
Culvert ID:		U/S Invert Elevation (m):	
Size (m):		D/S Invert Elevation (m):	
Shape:		Culvert Slope (m/m):	#DIV/0!
Material:		Road Top Elevation (m):	
No. of Barrels:		Water Level (m):	
Headwall Material:		Length (m):	
Wingwall Angle(°):		Watercourse:	
Comments:	Condition:	Date of Construction:	Description:
Photos			
Upstream:			
Downstream:			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/21/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
Culvert ID:		U/S Invert Elevation (m):	
Size (m):		D/S Invert Elevation (m):	
Shape:		Culvert Slope (m/m):	#DIV/0!
Material:		Road Top Elevation (m):	
No. of Barrels:		Water Level (m):	
Headwall Material:		Length (m):	
Wingwall Angle(°):		Watercourse:	
Comments:	Condition:	Date of Construction:	Description:
Photos			
Upstream:			
Downstream:			

Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	01/02/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	325527.501	5273961.734	
Structure ID:	VR-B04	U/S Underside Elevation (m):	113.351
Span (m)	5.000	D/S Underside Elevation (m):	113.429
Height (m):	1.089	Top Deck Elevation (m):	113.445
Material:	Timber	Water Level (m):	112.356
Structure Type:	Bridge	Watercourse:	Virginia River

Comments:	Condition:	Date of Construction:	Description:
	Good		Flowing water free of debris observed.


Photos



Upstream:








Downstream:



Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/08/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	325070.966	5273812.813	
Structure ID:	VR-B03	U/S Underside Elevation (m):	123.228
Span (m)	19.120	D/S Underside Elevation (m):	123.192
Height (m):	1.073	Top Deck Elevation (m):	123.665
Material:	Timber	Water Level (m):	122.881
Structure Type:	Bridge	Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/02/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	326340.528	5273646.994	
Culvert ID:	VR-C14	U/S Invert Elevation (m):	82.252
Size (m):	4.259	D/S Invert Elevation (m):	83.044
Shape:	Rectangular	Culvert Slope (m/m):	-0.065693431
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	12.056
Wingwall Angle(°):		Watercourse:	Virginia River
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Weathering and cracking observed
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 10/25/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	328832.8	5271189.348	
Culvert ID:	BRS-C03	U/S Invert Elevation (m): 28.792	
Size (m):	0.485	D/S Invert Elevation (m): 20.566	
Shape:	Circular	Culvert Slope (m/m): 0.08144877	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Rock	Length (m): 100.996	
Wingwall Angle(°):	N/A	Watercourse: Barrows Road Stream	
Comments:	Condition:	Date of Construction:	Description:
	Poor		Heavy rusting at inlet and outlet, vegetation growth observed.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	328990.778	5271405.347	
Culvert ID:	BRS-C04	U/S Invert Elevation (m):	0.804
Size (m):	0.445	D/S Invert Elevation (m):	N/A
Shape:	Circular	Culvert Slope (m/m):	N/A
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Rock	Length (m):	N/A
Wingwall Angle(°):	N/A	Watercourse:	Barrows Road Stream
Comments:	Condition:	Date of Construction:	Description:
	Poor		Significant rusting, and collapse.
Photos			
Upstream:			
			
Downstream:			
<div></div> <div></div>			

Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	10/25/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	328930.858	5269178.086	
Structure ID:	BRS-B01	U/S Underside Elevation (m):	1.841
Span (m)	5.890	D/S Underside Elevation (m):	1.795
Height (m):	0.084	Top Deck Elevation (m):	2.131
Material:	Timber	Water Level (m):	1.711
Structure Type:	Bridge	Watercourse:	Barrows Road Stream


Comments:	Condition:	Date of Construction:	Description:
	Moderate		Bridge spans over a bog with excess tall grass growth.



Photos



Upstream:





Downstream:

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	328839.257	5271178.187	
Culvert ID:	BRS-C02	U/S Invert Elevation (m):	28.94
Size (m):	0.285	D/S Invert Elevation (m):	28.915
Shape:	Circular	Culvert Slope (m/m):	0.004144562
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	29.058
Headwall Material:	Rock	Length (m):	6.032
Wingwall Angle(°):	N/A	Watercourse:	Barrows Road Stream
Comments:	Condition:	Date of Construction:	Description:
	Poor		Rusting and extensive vegetation growth observed.
Photos			
Upstream:			
			
Downstream:			
<div></div> <div></div>			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	328820.888		5271156.621
Culvert ID:	BRS-C01	U/S Invert Elevation (m):	29.607
Size (m):	0.600	D/S Invert Elevation (m):	29.629
Shape:	Circular	Culvert Slope (m/m):	-0.001037981
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	29.589
Headwall Material:	N/A	Length (m):	21.195
Wingwall Angle(°):	N/A	Watercourse:	Barrows Road Stream
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Outvert partially concealed by vegetation and debris. Vegetation at invert.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	323627.714		5267511.152
Culvert ID:	MPB-C04	U/S Invert Elevation (m):	108.126
Size (m):	4.000	D/S Invert Elevation (m):	108.276
Shape:	Rectangular	Culvert Slope (m/m):	-0.0085832
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	17.476
Wingwall Angle(°):	15	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Weathering and minor sagging of top of arch observed.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323627.714	5267511.152	
Culvert ID:	MPB-C04	U/S Invert Elevation (m):	108.126
Size (m):	1.400	D/S Invert Elevation (m):	108.276
Shape:	Circular	Culvert Slope (m/m):	-0.0085832
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1 U/S, 2D/S	Water Level (m):	
Headwall Material:	Concrete	Length (m):	17.476
Wingwall Angle(°):		Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Vegetation blocking invert grate
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	11/20/23
NAD83 MTM Zone 1 Coordinates:	Easting (m) 322940.154	Northing (m) 5267265.822	
Culvert ID:	MPB-C02	U/S Invert Elevation (m):	134.555
Size (m):	0.740	D/S Invert Elevation (m):	132.876
Shape:	Circular	Culvert Slope (m/m):	0.019699636
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	133.951
Headwall Material:	Concrete	Length (m):	85.23
Wingwall Angle(°):	90	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Cracked Headwall at outlet

Photos


Upstream:



Downstream:



Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323213.366	5267273.571	
Culvert ID:	MPB-C03	U/S Invert Elevation (m):	131.71
Size (m):	Unknown	D/S Invert Elevation (m):	130.959
Shape:	Circular	Culvert Slope (m/m):	0.036801098
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	20.407
Wingwall Angle(°):	50	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Poor		Lots of debirs observed, blocking flow.
Photos			
Upstream:			
Downstream:			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	324724.659		5268286.576
Culvert ID:	MPB-C07	U/S Invert Elevation (m):	
Size (m):	2.188	D/S Invert Elevation (m):	86.114
Shape:	Square	Culvert Slope (m/m):	#VALUE!
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	85.75
Headwall Material:	N/A	Length (m):	N/A
Wingwall Angle(°):	N/A	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Lots of debris trapped in and surrounding grate.
Photos			
Upstream:			
Downstream:			
			

Survey Data Sheet - Culverts

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m) 323950.429	Northing (m) 5267788.916	
Culvert ID:	MPB-C06	U/S Invert Elevation (m):	93.039
Size (m):	2.069	D/S Invert Elevation (m):	88.643
Shape:	Circular	Culvert Slope (m/m):	0.048163203
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	91.273
Wingwall Angle(°):	35	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Buildup of debris at grates.

Photos


Upstream:





Downstream:





Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	324075.141		5267880.033
Structure ID:	MPB-B09	U/S Underside Elevation (m):	87.629
Span (m)	7.729	D/S Underside Elevation (m):	87.757
Height (m):	1.484	Top Deck Elevation (m):	88.418
Material:	Timber	Water Level (m):	86.934
Structure Type:	Bridge	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Lots of vegetation growth in waterbed.
Photos			
Upstream:			
			
Downstream:			
<div></div>			


Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/20/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	323768.605		5267652.716
Structure ID:	MPB-B02	U/S Underside Elevation (m):	104.019
Span (m)	15.836	D/S Underside Elevation (m):	104.033
Height (m):	2.167	Top Deck Elevation (m):	104.295
Material:	Timber	Water Level (m):	102.128
Structure Type:	Bridge	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Excess Vegetation observed at upstream and downstream of bridge
Photos			
Upstream:			
			
Downstream:			
<div></div> <div></div>			



Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	323836.722		5267702.43
Structure ID:	MPB-B02	U/S Underside Elevation (m):	97.458
Span (m)	4.800	D/S Underside Elevation (m):	99.5
Height (m):	0.807	Top Deck Elevation (m):	99.681
Material:	Timber	Water Level (m):	98.874
Structure Type:	Bridge	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Waterbed free of visible debris
Photos			
Upstream:			
			
Downstream:			



Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: January 24, 2024
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	323856.96		5267717.773
Structure ID:	MPB-B03	U/S Underside Elevation (m):	98.618
Span (m):	3.597	D/S Underside Elevation (m):	98.526
Height (m):	1.46	Top Deck Elevation (m):	98.848
Material:	Timber	Water Level (m):	97.388
Structure Type:	Bridge	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			


Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/24/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323874.077	5267738.092	
Structure ID:	MPB-B04	U/S Underside Elevation (m):	96.937
Span (m)	3.981	D/S Underside Elevation (m):	96.836
Height (m):	1.177	Top Deck Elevation (m):	97.202
Material:	Timber	Water Level (m):	96.025
Structure Type:	Bridge	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			



Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323896.524	5267759.171	
Structure ID:	MPB-B05	U/S Underside Elevation (m):	95.434
Span (m)	3.037	D/S Underside Elevation (m):	95.244
Height (m):	0.977	Top Deck Elevation (m):	95.475
Material:	Timber	Water Level (m):	94.498
Structure Type:	Bridge	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	323903.961	5267766.199	
Structure ID:	MPB-B06	U/S Underside Elevation (m):	94.824
Span (m)	4.251	D/S Underside Elevation (m):	94.721
Height (m):	0.898	Top Deck Elevation (m):	95.132
Material:	Timber	Water Level (m):	94.234
Structure Type:	Bridge	Watercourse:	Mundy Pond Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		
Photos			
Upstream:			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/12/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	322648.502		5267754.479
Culvert ID:	MPB-C01	U/S Invert Elevation (m): 155.641	
Size (m):	0.615	D/S Invert Elevation (m): 155.346	
Shape:	Circular	Culvert Slope (m/m): 0.004110696	
Material:	HDPE	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	N/A	Length (m): 71.764	
Wingwall Angle(°):	N/A	Watercourse: Mundy Pond Brook	
Comments:	Condition:	Date of Construction:	Description:
	Poor		Outvert nearly completely covered in with rock.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/08/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321601.923	5269058.376	
Culvert ID:	HMB-C05	U/S Invert Elevation (m):	103.443
Size (m):	1.000	D/S Invert Elevation (m):	103.007
Shape:	Circular	Culvert Slope (m/m):	0.020336769
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	21.439
Wingwall Angle(°):	35	Watercourse:	Holes in Marsh Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		High water levels and excess vegetation observed.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/02/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	321244.6		5269203.51
Structure ID:	HMB-W01	U/S Underside Elevation (m):	N/A
Span (m)		D/S Underside Elevation (m):	N/A
Height (m):	N/A	Top Deck Elevation (m):	N/A
Material:	Concrete	Water Level (m):	
Structure Type:	Weir	Watercourse:	Holes in Marsh Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		7 successive weirs.
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322202.641	5269245.276	
Culvert ID:	HMB-C08	U/S Invert Elevation (m):	93.974
Size (m):	1.450	D/S Invert Elevation (m):	90.253
Shape:	Circular	Culvert Slope (m/m):	0.011696734
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	318.123
Wingwall Angle(°):	65	Watercourse:	Holes in Marsh Brook
Comments:	Condition:	Date of Construction:	Description:
	Poor		Major rusting and debris observed at inlet.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m) 321268.696	Northing (m)	
Culvert ID:	HMB-C01	U/S Invert Elevation (m):	125.065
Size (m):	2.285	D/S Invert Elevation (m):	123.299
Shape:	Rectangular	Culvert Slope (m/m):	0.04384963
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	121.416
Headwall Material:	Concrete	Length (m):	40.274
Wingwall Angle(°):	55	Watercourse:	Holes in Marsh Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Waterbed clear of vegetation and debris.




Photos



Upstream:








Downstream:







Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	321777.29		5269114.586
Culvert ID:	HMB-C06	U/S Invert Elevation (m): 100.141	
Span (m):	2.900	D/S Invert Elevation (m): 99.489	
Shape:	Arch	Culvert Slope (m/m): 0.03047441	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m): 21.395	
Wingwall Angle(°):	45	Watercourse: Holes in Marsh Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Arch shaped with 2.9m span and 1.45m height.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	321949.9		5269229.394
Culvert ID:	HMB-C07	U/S Invert Elevation (m): 95.184	
Size (m):	1.400	D/S Invert Elevation (m): 94.726	
Shape:	Arch	Culvert Slope (m/m): 0.016661816	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m): 27.488	
Wingwall Angle(°):	51	Watercourse: Holes in Marsh Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation observed at outlet.
Photos			
Upstream:			
			
Downstream:			
			



Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/02/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	321473.28		5269167.859
Culvert ID:	HMB-C04	U/S Invert Elevation (m): 113.086	
Size (m):	2.000	D/S Invert Elevation (m): 110.947	
Shape:	Circular	Culvert Slope (m/m): 0.096394772	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Rock	Length (m): 22.19	
Wingwall Angle(°):	N/A	Watercourse: Holes in Marsh Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation growth observed at inlet.
Photos			
Upstream:			
			
Downstream:			
			



Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321357.313	5269190.251	
Culvert ID:	HMB-C02	U/S Invert Elevation (m):	119.308
Size (m):		D/S Invert Elevation (m):	117.14
Shape:	Circular	Culvert Slope (m/m):	0.060078701
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	36.086
Wingwall Angle(°):	60	Watercourse:	Holes in Marsh Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Debris observed against metal grate at inlet.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/13/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321407.105	5269169.675	
Culvert ID:	HMB-C03	U/S Invert Elevation (m):	116.783
Size (m):	2.000	D/S Invert Elevation (m):	112.445
Shape:	Circular	Culvert Slope (m/m):	0.077786544
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	N/A	Length (m):	55.768
Wingwall Angle(°):	N/A	Watercourse:	Holes in Marsh Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		High waterlevel observed at outlet.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322001.728	5266494.862	
Culvert ID:	KGB-C04	U/S Invert Elevation (m): 137.63	
Size (m):	1.625	D/S Invert Elevation (m): 136.382	
Shape:	Circular	Culvert Slope (m/m): 0.051355911	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	
Headwall Material:	N/A	Length (m): 24.301	
Wingwall Angle(°):	N/A	Watercourse: Kitty Gaul Brook	
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Slight discolouration noted inside barrel. Very minor exterior damage.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322001.728	5266494.862	
Culvert ID:	KGB-C05	U/S Invert Elevation (m):	138.099
Size (m):	0.850	D/S Invert Elevation (m):	136.799
Shape:	Circular	Culvert Slope (m/m):	0.054078789
Material:	HDPE	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	
Headwall Material:	N/A	Length (m):	24.039
Wingwall Angle(°):	N/A	Watercourse:	Kitty Gaul Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Tall grass observed at upstream inlet.

Photos	
Upstream:	
	
Downstream:	
	

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/20/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321473.004	5265553.159	
Culvert ID:	KGB-C08	U/S Invert Elevation (m):	Unknown
Size (m):	Unknown	D/S Invert Elevation (m):	Unknown
Shape:	Square	Culvert Slope (m/m):	Unknown
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	107.93
Headwall Material:	Concrete	Length (m):	Unknown
Wingwall Angle(°):	55	Watercourse:	Kitty Gaul Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation observed at U/S inlet
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	11/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m) 322179.051	Northing (m) 5266312.89	
Culvert ID:	KGB-C06	U/S Invert Elevation (m):	122.879
Size (m):	1.180	D/S Invert Elevation (m):	123.504
Shape:	Rectangular	Culvert Slope (m/m):	-0.037490253
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	16.671
Wingwall Angle(°):	45	Watercourse:	Kitty Gaul Brook
Comments:	Condition: Good	Date of Construction:	Description: High water level observed.




Photos

Upstream:



Downstream:



Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321787.619	5265799.871	
Culvert ID:	KGB-C07	U/S Invert Elevation (m):	Unknown
Size (m):	Unknown	D/S Invert Elevation (m):	114.378
Shape:	Rectangular	Culvert Slope (m/m):	Unknown
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	113.49
Headwall Material:	Concrete	Length (m):	18.037
Wingwall Angle(°):	60	Watercourse:	Kitty Gaul Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Secondary D/S outlet does not have inlet U/S.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/08/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321455.623	5265051.454	
Culvert ID:	KGB-C10	U/S Invert Elevation (m):	93.935
Size (m):	1.100	D/S Invert Elevation (m):	85.836
Shape:	Circular	Culvert Slope (m/m):	0.042477867
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	93.919
Headwall Material:	Concrete	Length (m):	190.664
Wingwall Angle(°):	45	Watercourse:	Kitty Gaul Brook
Comments:	Condition:	Date of Construction:	Description:
	Moderate		Significant rusting observed.

Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	11/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322199.997	5266384.423	
Structure ID:	KGB-B03	U/S Underside Elevation (m):	126.964
Span (m)	8.751	D/S Underside Elevation (m):	126.996
Height (m):	1.646	Top Deck Elevation (m):	127.169
Material:	Timber	Water Level (m):	125.35
Structure Type:	Bridge	Watercourse:	Kitty Gaul Brook

Comments:	Condition:	Date of Construction:	Description:
	Good		

Photos

Upstream:



Downstream:



Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	11/15/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322118.295	5266429.043	
Structure ID:	KGB-B01	U/S Underside Elevation (m):	130.905
Span (m)	9.311	D/S Underside Elevation (m):	130.836
Height (m):	2.364	Top Deck Elevation (m):	131.145
Material:	Timber	Water Level (m):	128.536
Structure Type:	Bridge	Watercourse:	Kitty Gaul Brook

Comments:	Condition:	Date of Construction:	Description:
	Good		Wood has weathered. No visible deterioration.

Photos

Upstream:



Downstream:



Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	11/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	322196.354	5266422.129	
Structure ID:	KGB-B-02	U/S Underside Elevation (m):	127.598
Span (m)	8.748	D/S Underside Elevation (m):	127.618
Height (m):	1.246	Top Deck Elevation (m):	127.707
Material:	Timber	Water Level (m):	126.372
Structure Type:	Bridge	Watercourse:	Kitty Gaul Brook

Comments:	Condition:	Date of Construction:	Description:
	Good		

Photos

Upstream:



Downstream:



Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	11/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321995.977	5266170.08	
Structure ID:	KGB-B04	U/S Underside Elevation (m):	125.273
Span (m)	10.015	D/S Underside Elevation (m):	125.257
Size (m):	1.836	Top Deck Elevation (m):	125.416
Material:	Timber	Water Level (m):	123.096
Structure Type:	Bridge	Watercourse:	Kitty Gaul Brook

Comments:	Condition:	Date of Construction:	Description:
	Good		

Photos

Upstream:



Downstream:



Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	11/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m) 321889.94	Northing (m) 5265977.826	
Structure ID:	KGB-B05	U/S Underside Elevation (m):	124.307m
Span (m)	9.998	D/S Underside Elevation (m):	124.258
Size (m):	1.666	Top Deck Elevation (m):	124.795
Material:	Timber	Water Level (m):	
Structure Type:	Bridge	Watercourse:	Kitty Gaul Brook
Comments:	Condition: Good	Date of Construction:	Description:


Photos

Upstream:



Downstream:



Survey Data Sheet - Bridges, Weirs and Outlet Structures			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/20/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	321704.764		5265732.814
Structure ID:	KGB-B06	U/S Underside Elevation (m): 113.909	
Span (m)	9.839	D/S Underside Elevation (m): 113.916	
Size (m):	1.837	Top Deck Elevation (m): 114.248	
Material:	Timber	Water Level (m):	
Structure Type:	Bridge	Watercourse: Kitty Gaul Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Slow flowing water observed beneath bridge.
Photos			
Upstream:			
			
Downstream:			

Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	12/15/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321511.4	5264799.719	
Structure ID:	KGB-B07	U/S Underside Elevation (m):	81.677
Span (m)	9.584	D/S Underside Elevation (m):	81.703
Height (m):	1.33	Top Deck Elevation (m):	82.089
Material:	Steel	Water Level (m):	80.759
Structure Type:	Bridge	Watercourse:	Kitty Gaul Brook

Comments:	Condition:	Date of Construction:	Description:
	Poor		Missing Decking

Photos

Upstream:



Downstream:







Survey Data Sheet - Bridges, Weirs and Outlet Structures

Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's	Survey Date:	11/11/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321459.075	5264861.816	
Structure ID:	KGB-B06	U/S Underside Elevation (m):	85.937
Span (m)	13.991	D/S Underside Elevation (m):	85.941
Height (m):	1.793	Top Deck Elevation (m):	86.391
Material:	Steel	Water Level (m):	84.598
Structure Type:	Bridge	Watercourse:	Kitty Gaul Brook

Comments:	Condition:	Date of Construction:	Description:
	Good		Vegetation observed in riverbed



Photos








Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/09/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321106.024	5266829.981	
Culvert ID:	KGB-C01	U/S Invert Elevation (m):	200.728
Size (m):	0.500	D/S Invert Elevation (m):	200.005
Shape:	Circular	Culvert Slope (m/m):	0.071933141
Material:	HDPE	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	N/A	Length (m):	10.051
Wingwall Angle(°):	N/A	Watercourse:	Kitty Gaul Brook
Comments:	Condition:	Date of Construction:	Description:
	Poor		Water Observed flowing over the downstream invert. Lots of rock and debris surrounding upstream invert.
Photos			
Upstream:			
			
Downstream:			
			






Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/11/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)		Northing (m)
	321907.838		5266694.431
Culvert ID:	KGB-C03	U/S Invert Elevation (m): 153.248	
Size (m):	1.500	D/S Invert Elevation (m): 151.978	
Shape:	Circular	Culvert Slope (m/m): 0.025852417	
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	
Headwall Material:	Concrete	Length (m): 49.125	
Wingwall Angle(°):	30	Watercourse: Kitty Gaul Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Low lying vegetation observed at inlet and outlet




Photos	
Upstream:	
	
Downstream:	
	

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 11/09/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321908.527	5266697.265	
Culvert ID:	KGB-C02	U/S Invert Elevation (m): 153.477	
Size (m):	1.525	D/S Invert Elevation (m): 152.145	
Shape:	Circular	Culvert Slope (m/m): 0.027086934	
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	
Headwall Material:	Concrete	Length (m): 49.175	
Wingwall Angle(°):	30	Watercourse: Kitty Gaul Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Low lying vegetation observed at invert and outvert.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 12/14/23
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	321430.939	5265303.103	
Culvert ID:	KGB-C09	U/S Invert Elevation (m):	103.934
Size (m):	2.100	D/S Invert Elevation (m):	103.931
Shape:	Circular	Culvert Slope (m/m):	7.17034E-05
Material:	Concrete	Road Top Elevation (m):	
No. of Barrels:	2	Water Level (m):	103.708
Headwall Material:	Concrete	Length (m):	41.839
Wingwall Angle(°):	0	Watercourse:	Kitty Gaul Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Double barrel culvert. Grass growing at invert and outvert.
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/10/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	319066.995	5261827.23	
Culvert ID:	SB-C02	U/S Invert Elevation (m):	152.336
Size (m):	2.900	D/S Invert Elevation (m):	151.396
Shape:	Arch	Culvert Slope (m/m):	0.026074173
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	36.051
Wingwall Angle(°):	35	Watercourse:	South Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Clear of debris
Photos			
Upstream:			
			
Downstream:			
			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/10/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	318163.332	5261770.7	
Culvert ID:	SB-C01	U/S Invert Elevation (m):	170.555
Size (m):	2.100	D/S Invert Elevation (m):	170.194
Shape:	Arch	Culvert Slope (m/m):	0.011346136
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Concrete	Length (m):	31.817
Wingwall Angle(°):	60	Watercourse:	South Brook
Comments:	Condition:	Date of Construction:	Description:
	Good		Clear of excess debris.
Photos Upstream: <div>    </div>			
Downstream: <div>   </div>			

Survey Data Sheet - Culverts			
Project:	2023-2024 Climate Change Flood Risk Mapping Study for the City of St. John's		Survey Date: 01/10/24
NAD83 MTM Zone 1 Coordinates:	Easting (m)	Northing (m)	
	318905.891	5261825.574	
Culvert ID:	SB-C02	U/S Invert Elevation (m): 153.842	
Size (m):	2.450	D/S Invert Elevation (m): 153.674	
Shape:	Arch	Culvert Slope (m/m): 0.008412619	
Material:	CMP	Road Top Elevation (m):	
No. of Barrels:	1	Water Level (m):	
Headwall Material:	Rock	Length (m): 19.97	
Wingwall Angle(°):	70	Watercourse: South Brook	
Comments:	Condition:	Date of Construction:	Description:
	Good		Clear of debirs
Photos			
Upstream:			
			
Downstream:			
			

Appendix F – Federal Airborne LiDAR Data Acquisition Guideline V3.1, 2022





Federal Airborne LiDAR Data Acquisition Guideline

Version 3.1

2022

Natural Resources Canada

General Information Product 117e

Natural Resources Canada

Public Safety Canada

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ACKNOWLEDGEMENTS

The *Federal Flood Mapping Guidelines Series* has been developed under the leadership of the Flood Mapping Committee, a partnership between Natural Resources Canada, Public Safety Canada, and member federal departments and agencies with an interest in flood mapping.

Contributions to the development of this guideline include members of the Technical Working Group on Flood Mapping, a group of key stakeholders from federal, provincial, territorial and municipal jurisdictions, Indigenous representatives, the private sector, and academia. Valuable input from volunteer working groups with subject matter expertise, and contract reports and studies were crucial in the development of this guideline.

Additionally, provincial and territorial government representatives provided essential feedback for this publication.

NOTICE

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Additional Information

For more information about this document, please contact the Canada Centre for Mapping and Earth Observation of Natural Resources Canada: NRCan.Geoinfo.RNCan@Canada.ca.

CONTEXT

A community achieves an elevated level of resilience when its risks are proactively managed, it is adequately prepared for known and potential disaster events, and it demonstrates an ability to recover after such events have taken place. To become resilient, a community's mitigation planners must first understand risks and ensure their capacity to manage those risks.

Floods are commonly occurring natural hazards in Canada and account for the largest portion of disaster recovery costs on an annual basis. Mitigating flood risks is therefore key to increasing the resilience of affected communities. By proactively investing in flood mitigation activities, a community secures its future growth and prosperity, reducing the risk of significant disaster recovery costs, productivity losses, economic losses, destruction of non-monetary cultural assets, environmental damage, injuries, and deaths.

Flooding is the temporary inundation by water of normally dry land and can occur on marine and lake coasts, along rivers, and in low-lying areas. Flooding is caused by extreme rainfall, rapid snow/ice/glacier melt, strong winds (storm surge and waves), stream blockages from ice jams or debris, failure of engineering works including dams, poor drainage characteristics, high groundwater levels, and other sources. Flood mapping that accurately depicts flood hazards, including those impacted by future conditions due to anticipated development or projected changes in climate, serves as the precondition for mitigation activities and is therefore the first step to increasing community resilience regarding flooding. Establishing a national approach to flood mapping will facilitate a common national best practice and increase the sharing and use of flood hazard information, thereby improving the foundation from which further flood risk mitigation efforts can be initiated.

FLOOD MAPPING FRAMEWORK

The Flood Mapping Framework consists of all the components of the flood mitigation process, from flood hazard identification to the implementation of flood mitigation efforts. Figure 1 illustrates the relationship between these different components.



Figure 1: Flood Mapping Framework

FEDERAL FLOOD MAPPING GUIDELINES SERIES

The following documents are intended to inform any individual or organization involved with flood management in Canada:

1. Federal Flood Mapping Framework
2. Flood Hazard Identification and Priority Setting
3. **Federal Airborne LiDAR Data Acquisition Guideline**
4. Case Studies on Climate Change in Floodplain Mapping
5. Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation
6. Federal Geomatics Guidelines for Flood Mapping

7. Flood Risk Assessment Procedures
8. Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure
9. Federal Land Use Guide for Flood Risk Areas
10. Bibliography of Best Practices and References for Flood Mitigation

GUIDELINE SUMMARIES

1. Federal Flood Mapping Framework

This document provides background and context on flood mapping in Canada, describes a vision and principles for flood guidance, and introduces the *Federal Flood Mapping Guidelines Series*. It provides a summary of each of the documents in the Series and explains how each document fits into the overall framework, including its role in the flood mapping cycle.

2. Flood Hazard Identification and Priority Setting

This document outlines methods for determining where to conduct flood mapping and how to prioritize flood mapping projects.

3. Federal Airborne LiDAR Data Acquisition Guideline

This document is a resource for the acquisition of base elevation data from airborne LiDAR data undertaken across Canada. This guideline provides technical specifications to federal, provincial and territorial departments, as well as individuals and organizations in Canada requiring information to understand and plan for airborne LiDAR data acquisition.

4. Case Studies on Climate Change in Floodplain Mapping

This collection of documents describes projects from across Canada where climate change was incorporated into the floodplain mapping process. It provides examples for practitioners to draw upon and learn from others' experiences and compliments the climate change-related information and resources included in the "Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation" document.

5. Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation

This document provides guidance to responsible agencies contracting or conducting hydrologic and hydraulic procedures necessary for preparing flood hazard maps in a Canadian jurisdiction, including standard of care, different types of flooding, procedures for hydraulic and hydrologic analyses, and incorporation of non-stationary processes such as climate change and varying land use.

6. Federal Geomatics Guidelines for Flood Mapping

This document contains information on the different types of flood maps and outlines technical specifications to consider when acquiring, managing and disseminating these maps and their associated geospatial data.

7. Federal Flood Risk Assessment Procedures

This document provides technical guidance on conducting flood risk assessments in Canada.

8. Federal Flood Damage Estimation Guidelines for Buildings and Infrastructure

This document provides guidance on how to evaluate potential economic losses, with a focus on buildings and infrastructure, incurred as a result of flooding.

9. Federal Land Use Guide for Flood Risk Areas

This document provides guidance to communities in using risk-based methodologies for the purpose of land-use planning with attention to flood prone areas.

10. Bibliography of Best Practices and References for Flood Mitigation

This document contains lists of Canadian and international references and case studies pertaining to hydrology and hydraulics, climate change, risk assessment and flood mapping. The purpose of this document is to provide a consolidated list of reference materials intended as further resources for practitioners involved in flood mapping.

LIST OF ABBREVIATIONS AND ACRONYMS

ANPD	Aggregate Nominal Pulse Density
ANPS	Aggregate Nominal Pulse Spacing
AOI	Area of Interest
ASPRS	American Society of Photogrammetry and Remote Sensing
CHA	Calculated Horizontal Accuracy
CCMEO	Canada Centre for Mapping and Earth Observation
CGG2013	Canadian Geoid 2013
CGVD	Canadian Geodetic Vertical Datum
CORS	Continuously Operating Reference Stations
CQL	Canadian Quality Level
CSRS	Canadian Spatial Reference System
DCAOI	Data collection Area of Interest
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
EPSG	European Petroleum Survey Group
ESRI	Environmental Systems Research Institute
GLONASS	Globalnaya Navigazionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Position System
GRS80	Geodetic Reference System 1980
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
ISO	International Standard Organization
LAS	LASer file format exchange
LAZ	LASzip
LiDAR	Light Detection and Ranging
NIR	Near Infrared
NPD	Nominal Pulse Density
NPS	Nominal Pulse Spacing
NRCan	Natural Resources Canada

NTS	National Topographic System
NVA	Non-Vegetation Vertical Assessment
OGC	Open Geospatial Consortium
PDOP	Position Dilution of Precision
PLS	Pulse(s)
PPP	Precise Point Positioning
RMSE _x	Horizontal Root Mean Square Error in the x direction (easting)
RMSE _y	Horizontal Root Mean Square Error in the y direction (northing)
RMSE _R	Horizontal Root Mean Square Error in the radial direction (includes both x and y directions)
RMSE _z	Vertical Root Mean Square Error in the z direction (elevation)
RMSD _z	Vertical Root Mean Square Difference in the z direction (elevation)
RTK	Real Time Kinematic
SBET	Smooth Best Estimate Trajectory
TIN	Triangular Irregular Network
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VVA	Vegetation Vertical Assessment
WKT	Well Known Text
XML	eXtensible Markup Language

1.0 INTRODUCTION AND PURPOSE

Development of this document has been coordinated by the Canada Centre for Mapping and Earth Observation (CCMEO) within Natural Resources Canada (NRCan) in response to the needs of the geospatial community and the government for a national guideline for acquisition of airborne LiDAR data. A key strategy of the CCMEO is to improve the national elevation data set through consistent application of airborne LiDAR technology. LiDAR has extensively been adopted across Canada by municipalities, provinces, territories and federal government departments as the main technology for acquiring high precision elevation data. The intention of this document is to provide the specifications to lead towards consistency in airborne LiDAR data acquisition across all levels of government in Canada, as well as to improve international cooperation with the United States along areas of cross-border data collection.

The process for developing the guideline has involved consultation with government, industry and academia, as well as a review of international best practices to provide a broad perspective for establishing the guideline. The federal guideline addresses many complex considerations including data acquisition, processing, validation, and deliverables, with the focus on developing accurate elevation data. The emphasis of the guideline is on data quality and accuracy requirements, while allowing for innovation and future technological advancements. It is the aim of the guideline to accommodate project-specific requirements, and there are cases where the suggested LiDAR acquisition specifications may be relaxed or modified due to factors such as project data requirements and financial considerations. The intent of this guideline is to set quality levels and good practices to achieve the various federal government needs. The guideline also contains supplemental recommendations for LiDAR acquisition in specific application areas, including forestry, flood mapping, mapping of high relief areas, and urban infrastructure.

LiDAR acquisition is an industry heavily reliant on cutting edge technology and is therefore seeing constant improvements in the technological components used in surveys, as well as software and methods used in LiDAR analysis. This document is reflective of the best practices in LiDAR acquisition at the time of the document release. NRCan intends to update this document periodically as the industry develops.

2.0 NOTE ON TERMINOLOGY

This guideline contains numerous references to industry specific terms that may vary in other application areas or differ from other guidelines or specifications. For example, in the LiDAR community, bare earth DEM is commonly used to represent ground surface terrain. In this guideline, DTM is used in alignment with the [High Resolution Digital Elevation Model \(HRDEM\) – CanElevation Series -Product Specification](#). DTM is considered equivalent to bare earth DEM. In addition, the term ‘pulse’ is used to represent the transmitted and received laser electromagnetic energy, while ‘point data’ represents pulse data that has been post processed and classified into point cloud. A glossary included in this document provides term definitions in the context of the present guideline.

3.0 TARGET AUDIENCE

This document is part of the Federal Flood Mapping Guidelines Series and is to be used as a resource for the acquisition of base elevation data from airborne LiDAR data undertaken across Canada. This guideline aims to provide advice to federal, provincial and territorial departments, whose responsibility is to provide technical guidance to their implementing bodies, as well as individuals and organizations in Canada that need to understand and plan for airborne LiDAR data acquisition. Users of this guideline may include department managers, project coordinators, geomatics experts, water resource engineers, and planners both within and outside of government. The document assumes that users have basic understanding of LiDAR technology and data, including terminology and data structure.

Some provinces and territories have already developed their own guidelines and specifications for airborne LiDAR data acquisition. Hence, this guideline is intended as a basis to further harmonize requirements for acquiring LiDAR data across Canada.

4.0 GUIDELINE STRUCTURE

The guideline has been organized based on a workflow structure involving planning, collection, processing, data validation and expected deliverables of airborne LiDAR data in the context of a Canadian landscape. Information on forest, urban infrastructure, flood and high relief mapping applications has been provided in the appendices section of the guideline. Appendices represent current best practice for collection of airborne LiDAR data. Recommended data and collection parameters are provided. In addition, an annex is also included for addressing contract related items for project data collections. The structure of the guideline is referenced by categories as listed below.

1. Planning
2. Acquisition
3. Data Processing
4. Validation
5. Deliverables

5.0 SUMMARY REQUIREMENTS

Requirements for the acquisition of airborne LiDAR data are summarized in Table 1 and presented in the form of generic formulas. "Canadian Quality Level 1" (CQL1) is the minimum requirement for airborne LiDAR data acquisition in Canada, as well as to support the Government of Canada's National Elevation Data Strategy. This strategy aims to provide Canadians with a detailed three-dimensional representation of the territory and to offer standardized products that allow consistent analyses across the country.

Some areas of application require more accurate and/or denser LiDAR data than CQL1. For these LiDAR acquisitions, the generic formulas presented in Table 1 can be used to establish the requirements. Examples of values to be used in the formula (replacing the terms ANPD,

RMSE_Z and RMSE_R) are provided in the appendixes of this document for various areas of application.

Section 6 provides further details on project planning, data validation and deliverables. There are also recommendations, assumptions and considerations. In the same way as for Section 5, the tables in Section 6 contain generic formulas and values for CQL1. Users are encouraged to read this entire document to learn more about the requirements.

Requirements	Generic specifications	Example for the Canadian Quality Level 1 (CQL1)	Category
Aggregate Nominal Pulse Density (ANPD)	$\geq \text{ANPD}$	$\geq 2 \text{ pulses/m}^2$	Acquisition
Aggregate Nominal Pulse Spacing (ANPS)	$\leq \frac{1}{\sqrt{\text{ANPD}}}$	$\leq \frac{1}{\sqrt{2}} \rightarrow 0.71 \text{ m}$	Acquisition
Non-vegetated Vertical Accuracy (NVA)			
Vertical Root Mean Square Error (RMSE _Z)	$\leq \text{RMSE}_Z$	$\leq 10.0 \text{ cm}$	Acquisition
Vertical Accuracy – 95% confidence level	$\leq 1.96 \times \text{RMSE}_Z$	$\leq 1.96 \times 10 \rightarrow 19.6 \text{ cm}$	Acquisition
Vegetated Vertical Accuracy (VVA) – 95 th percentile	$\leq 3 \times \text{RMSE}_Z$	$\leq 3 \times 10 \rightarrow 30 \text{ cm}$	Acquisition
Fundamental Horizontal Accuracy (FHA)			
Horizontal Root Mean Square Error (RMSE _R)	$\leq \text{RMSE}_R$	$\leq 35.1 \text{ cm}$	Acquisition
Horizontal Accuracy – 95% confidence level	$\leq 1.7308 \times \text{RMSE}_R$	$\leq 1.7308 \times 35.1 \rightarrow 60.0 \text{ cm}$	Acquisition
Calculated Horizontal Accuracy (CHA)	$\leq \text{RMSE}_R$	$\leq 35.1 \text{ cm}$	Acquisition
Relative Vertical Accuracy			
Intraswath (smooth surface repeatability) - RMSD _Z	$\leq 0.6 \times \text{RMSE}_Z$	$\leq 0.6 \times 10 \rightarrow 6 \text{ cm}$	Validation
Interswath (swath overlap difference) – RMSD _Z	$\leq 0.8 \times \text{RMSE}_Z$	$\leq 0.8 \times 10 \rightarrow 8 \text{ cm}$	Validation
Interswath (swath overlap difference) – Maximum difference	$\leq 1.6 \times \text{RMSE}_Z$	$\leq 1.6 \times 10 \rightarrow 16 \text{ cm}$	Validation
Horizontal Datum	Variable	NAD83 CSRS epoch 2010	Acquisition
Vertical Datum	Variable	CGVD2013	Acquisition
Geoid Model	Variable	CGG2013	Acquisition
Map Projection	Variable	Universal Transverse Mercator	Acquisition
Minimum Swath Overlap	15 %	15 %	Acquisition

Pulse Returns	Minimum 2 returns (First and Last). Intermediate is optional.	Minimum 2 returns (First and Last). Intermediate is optional.	Acquisition
Classification	Variable	1 – Processed but unclassified 2 – Ground 7 – Low points (noise) 9 – Water 17 – Bridge decks 18 – High noise	Processing

Table 1: Requirements summary

6.0 GUIDELINE

6.1 Project planning

Prior to airborne LiDAR data collection, vendors will undertake activities to design an acquisition plan and establish a processing approach to meet the specification as outlined in this document. Key planning tasks are identified in the following sections and will form part of the project deliverables. The following sections outline the type of information that will be assembled into a Project Report.

6.1.1 Project method

Description

The vendor is required to provide details on the methodology selected meets the technical requirements of the specifications. The project methodology must be described in a project planning report to be submitted in advance of the data collection.

Requirements

Name	Description	Category
Flight Planning	Details on flight coverage, flight line location, overlap, calibration flights, tie lines, including visual references such as maps and images. A detail work flow with quality control measures and survey work will be provided.	Planning
Survey Control	Proposed surveying control to support airborne GNSS and any ground validation will be identified with details including base stations (active or passive) to be used, along with the reference information on the position control.	Planning
Ground Truthing	Details on planned ground validation and in-situ measurements, including location, and propose method for collecting ground survey data.	Planning

Data Processing	Details on the planned data processing including software, methods, filtering, any ancillary data to be used in data processing. A schematic work flow diagram showing the data processing steps and the quality control procedures incorporated in the processing will be included.	Planning
Quality Control	Data validation method, check for classification, accuracy verification, data voids, and other data checks. Information should include frequency and quantity sampled	Planning
Schedule	Planned schedule for airborne collection and ground truthing activities.	Planning

Table 2: Project method requirements.

Considerations, Limitations and Assumptions

- Any deviation from the project methodology will be provided to the contracting authority in advance of the data collection for review and approval.

6.1.2 Instrumentation

Description

A document is required that provides details on the airborne and ground survey equipment proposed for the project. The document should include specifications (including manufacturer, model and year) of the LiDAR sensor, the GNSS system used in the aircraft, the IMU sensor, and the ground survey instrumentation. The document should also include details regarding the calibration of the sensors including date of the last calibration. The document should be provided as part of the project deliverables.

Requirements

Name	Description	Category
Sensor Instrument	Details of the specific LiDAR sensor will be provided including manufacturer, year, model, ownership, most current calibration with date. A copy of the most current manufacturer's calibration for the complete system including laser, IMU, and GNSS system used maybe requested and upon request must be provided. Any sensor changes, failure or replacement prior or during the data collecting is required to be reported.	Planning
GNSS	The type of position sensors used in the acquisition (ground and airborne) is documented. Details to be provided include the manufacturer, year, and model. Any reference network information (active or passive) including number, location monuments, reference statement and published coordinates must be provided.	Planning
IMU	Provide details on the proposed IMU for the data collection including manufacturer, year, and model.	Planning

Table 3: Instrumentation requirements.

Considerations, Limitations and Assumptions

- Any deviations from the proposed instrumentation must be communicated to the contracting authority for approval in advance of the data collection. The alternative instrumentation must be equal or better than planned sensors. The contracting authority may accept or reject proposed changes.

6.1.3 Data Collection Planning

Description

The minimum requirements for planning a collection of airborne LiDAR data are provided below.

Requirements

Name	Description	Category
Area of Interest (AOI)	A project area of interest is defined in the form of enclosed geographic boundaries using the coordinate system as identified in this guideline.	Planning
Data Collection Area of Interest (DCAOI)	A buffer of 100 metres is uniformly applied to the AOI and represents the actual data collection coverage. Data collected in the buffer area is to be submitted as part of the deliverables and must be collected to the same requirements as the data within the AOI.	Planning
Discrete Returns	The system used in the collection must be capable of collecting multiple discrete returns per pulse. At minimum, first and last returns are required. Intermediate returns are optional. Waveform data is optional.	Planning
Intensity	The intensity for each discrete return will be recorded and stored and as a 16-bit normalized value. A linear scaling will be applied as defined in ASPRS LAS 1.4 R15.	Planning
Swath Overlap	A minimum of 15% swath overlap is required for a CQL1 acquisition. However, the swath overlap requested by the contracting authority in the acquisition contract can be higher.	Planning

Table 4: Data collection planning requirements.

Considerations, Limitations and Assumptions

Airborne LiDAR data acquisition is dependent on using a reference control data source to precisely position the LiDAR pulses returns from the land surface. The reference control data for mapping the position of the pulse return use a range of global navigation satellite systems (GNSS). These systems include different constellations such as GPS, GLONASS, QZSS, Galileo or BeiDOU. However, the application of GNSS for positioning is affected by satellite geometry and solar flare which creates instability in the ionosphere. Therefore, it is recommended that a Position Dilution of Precision (PDOP) be less than 3, that a minimum of 7

satellites be in view, and that solar weather be checked prior and during data collection. A Single Ground base station for correcting GNSS signals should typically be within 25-35 km of field collection. Depending on the size and configuration of the DCAOI, two or more ground base control stations is recommended with baselines longer than 35km. Active control GNSS correction for RTK that use Continuous Operating Reference Stations (CORS) for real time correction or post processing such as Canadian Geodetic Survey PPP is permissible. The use of satellite-derived PPP corrections is also permissible. The vendor must provide information on the positional method and ensure that the proposed solution meets the accuracy requirements of this guideline. Further information may be found in the *Guidelines for RTK/RTN GNSS Surveying in Canada* (2013).

- Cross-tie lines are flight lines acquired perpendicular to the planned data acquisition flight lines. Cross-tie lines provide data to support accuracy validation and can be used to support adjustment of data such as in periods of unexpected poor PDOP. It is strongly recommended that cross-tie lines be collected to support data quality assessment and validation.
- The requirement for swath overlap is a minimum of 15% for a CQL1 acquisition to support quality assessment between adjacent swaths and to minimize potential data gaps. Actual overlapping swath used in the collection is at the discretion of the data collector to ensure the absence of data gaps in the useable portion of the swath (typically centre 95% of the swath width) and that the required data density is met.
- The scan angle used for airborne LiDAR data collection typically ranges from ± 15 to ± 30 degrees. Higher scan angles are discouraged as they result in increased footprint size thereby reducing pulse energy at the edges, increasing positional errors and scattering off the sides of vertical structures. In addition, when collection over undulating and/or high relief terrains, higher scan angles should also be discouraged. Best practice typical angles are between ± 20 to ± 25 degrees. The selection of a scan angle should consider vertical and horizontal accuracy requirements across the swath as well as per the project objective.

6.2 Data Collection

This section provides details on how to meet airborne LiDAR data acquisition requirements.

6.2.1 Conditions

Description

LiDAR data collection is affected by surface and atmospheric conditions which impact the quality and quantity of LiDAR pulse returns. This section describes the minimum requirements for airborne LiDAR acquisition with respect to the atmospheric, surface and other conditions.

Requirements

Name	Description	Category
Atmospheric	Collection should not take place during rain, snowfall, smoke or fog. No haze or clouds should be present between the aircraft and the ground.	Acquisition
Surface	Surface should be free from extensive flooding or inundation, snow cover and ice buildup on shoreline or land areas. Dry land surface condition is required. Frost is acceptable.	Acquisition
Tides	Areas affected by tides should be collected within 2 hours of the low tide. Low tide is time when the tide will be at its lowest point for given place and time the collection will take place.	Acquisition
Survey	Monitoring and recording of Global Navigation Satellite System conditions for Positional Dilution of Precision and solar activities during acquisition is required.	Acquisition
Temporal	Aside from the low tide requirement, there is no restriction on the time of day for LiDAR acquisition. Data may be acquired during day or night, provided data collection is compliant within any regulatory or legal conditions, and safety requirements are given paramount attention.	Acquisition

Table 5: Data collection conditions requirements.

Considerations, Limitations and Assumptions

- The collection of LiDAR data is encouraged during river low flow (baseflow) conditions to maximize coverage of river banks and floodplains.
- At the discretion of the contract authority, the snow-free surface requirement may be waived for areas where there are permanent snowfields or glaciers.
- Except for specialized data collection projects focusing on vegetation (for example, forest biomass studies), leaf-off is a preferred vegetation condition, since it increases penetration to the ground and results in higher quality bare-earth surface (see Annex A). Leaf-on collection may be acceptable if the vendor collection method can demonstrate sufficient ground penetration to achieve accurate and reliable bare-earth surface that meet accuracy requirements. The contract authority will work with the vendor to determine acceptable vegetation conditions for LiDAR acquisition in the DCAOI.
- Very light non-drifting snow cover (less than 1cm) may be permissible at the discretion of the contracting authority.

6.2.2 Collection Pulse Density

Description

LiDAR pulse density and spacing for DCAOI is defined in this guideline as an aggregate nominal pulse density (ANPD) and aggregate nominal pulse spacing (ANPS). The aggregate pulse density/spacing is referred to as an overall pulse density/spacing whereby a swath may overlap other swaths completely, partially, or not at all. An overlapping swaths condition is achieved when a portion of the swath is covered with an adjacent flight line, flown on top of an existing swath with a single sensor, or acquired by two independent sensors using separate IMU's, with separate boresights on the same aircraft. A dual channel system using single Inertial Navigation System (INS) and boresight is considered to be acquiring single swath data. In swaths where a portion of the swath has no overlap then ANPD/ANPS is equivalent to Nominal Pulse Density and Nominal Pulse Spacing (NPD/NPS). See glossary for further definitions.

Requirements

Name	Description	Category
Aggregate Nominal Pulse Density (ANPD)	\geq ANPD (pls/m ²) evaluated with first pulse returns across DCAOI	Acquisition
Aggregate Nominal Pulse Spacing (ANPS)	$\leq \frac{1}{\sqrt{ANPD}}$	Acquisition
Laser Returns	Pulse data collection is based on laser pulse echo returns measured at the receiving sensor. At a minimum, first and last returns are required and intermediate returns are optional.	Acquisition

Table 6: Pulse density requirements

Note: For the CQL1, replace ANPD by 2. For areas of application requiring denser LiDAR data than CQL1, use the suggested ANPD values in the appendixes of the present Guideline.

Considerations, Limitations and Assumptions

- ANPD and ANPS in this Guideline document refers to the net overall pulse density and pulse spacing from multiple independent sensors or multiple overlapping swaths. For single swath, ANPD and ANPS equal, respectively, to NPD and NPS.
- An intermediate pulse can provide addition information for applications involving forest/trees, transmission/distribution wires and buildings.

6.2.3 Data Collection Accuracy

Description

This section covers requirements for absolute and relative vertical and horizontal accuracy of LiDAR acquisition.

Requirements

Name	Description	Category
Non-vegetated Vertical Accuracy (NVA)		
Vertical Root Mean Square Error (RMSE _Z)	$\leq \text{RMSE}_Z$	Acquisition
Vertical Accuracy – 95% confidence level ($1.96 \times \text{RMSE}_Z$)	$\leq 1.96 \times \text{RMSE}_Z$	Acquisition
Vegetated Vertical Accuracy (VVA) - 95 th percentile	$\leq 3 \times \text{RMSE}_Z$	Acquisition
Fundamental Horizontal Accuracy (FHA)		
Horizontal Root Mean Square Error (RMSE _R)	$\leq \text{RMSE}_R$	Acquisition
Horizontal Accuracy – 95% confidence level	$\leq 1.7308 \times \text{RMSE}_R$	Acquisition
Calculated Horizontal Accuracy (CHA)	$\leq \text{RMSE}_R$	Acquisition
Relative Vertical Accuracy		
Intraswath (smooth hard surface repeatability) - RMSD _Z	$\leq 0.6 \times \text{RMSE}_Z$	Acquisition
Interswath (swath overlap difference – RMSD _Z)	$\leq 0.8 \times \text{RMSE}_Z$	Acquisition
Interswath (swath overlap difference) – Maximum difference	$\leq 1.6 \times \text{RMSE}_Z$	Acquisition

Table 7: Data collection accuracy requirements

Note: for the CQL1, replace RMSE_Z by 10 cm and RMSE_R by 35.1 cm. For areas of application requiring more accurate LiDAR data than CQL1, use the suggested RMSE_Z and RMSE_R values in the appendixes of the present Guideline.

The Calculated Horizontal Accuracy (CHA) - Horizontal accuracy is influenced by GNSS positional errors, the angular errors arising from the IMU used and the flight altitude. A calculated horizontal accuracy will be derived using LiDAR Horizontal Error (RMSE_r) in *ASPRS 2014 Positional Accuracy Standards for Digital Geospatial Data* in Section 7.5. The formula is as follows:

$$\text{LiDAR Horizontal Error (RMSE}_r) = \sqrt{(\text{GNSS positional error})^2 + (\tan(\text{IMU error})/0.55894170 \times \text{flying altitude})^2}$$

More details on the usage of the formula are given here:

<https://doi.org/10.14358/PERS.81.7.531>

Considerations, Limitations and Assumptions

- The accuracy assessment should be conducted within the geometrically usable portion of the swath (typically the centre 95% of the swath width). The horizontal and vertical accuracy

of the ground check points must be three times more accurate than the LiDAR and always better than 5 cm (95%). See section 6.4.1 for more details.

- The relative vertical accuracy is used to examine geometric stability across all portions of the swath for data consistency. The overlap area can be considered as a measure of geometric alignment of two overlapping swaths with respect to positional shifts and vertical alignment. In addition, relative accuracy is a measure within the swath to detect any anomalous pulse data potentially due to laser issues and sensor related anomalies. The assessment is to be done at multiple locations throughout the DCAOI. See Data Validation section for more details.

6.3 Data Processing and Management

6.3.1 Data File Format

Description

Collected LiDAR point cloud data should be stored in the ASPRS LASer File Exchange format (LAS). For bulk storage of data, LAS files can be compressed into the lossless LAZ (LAS zip) format.

Requirements

Name	Description	Category
Standard	ASPRS LAS 1.4 – R15 will be used for storing LiDAR point cloud data. LAS 1.4 moves to 64-bit file structure.	Data Processing
Content	The Public Header information is to be completed.	Data Processing
Pulse Data Record	Record Formats 6, 7, 8, 9, or 10 are to be used for discrete pulse data. The format values depend if colour information is added and or wave packets are added to the LAS record structure.	Data Processing
Overlap and Overage	Overage pulses in the swath overlap region (i.e. points not part of the tenderloin) shall be identified as using overlap bit 3 flag as described in Table 16 in LAS 1.4 – R15 specification for Record Format 6. Applying a point classification field in any way for overage/overlap is not permissible. See definition of overage in glossary.	Data Processing
Withheld Pulses	Withheld pulses due to noise, erroneous data points, and geometrically unreliable points should be retained using classification bit 2 as per Table 16 in LAS 1.4 – R15 specification.	Data Processing
Swath identification	A unique file identifier (File ID) for individual flight swaths must be applied prior to data processing and available to identify each swath to source as identified in LAS 1.4 specification. Each point within the swath must also be assigned a point source identifier (Point Source ID) that equals the unique file identifier.	Data Processing

	The unique file and point identifier must be persistent and preserved through the data processing steps.	
Georeference	A correct and properly formatted geo-reference must be present in all LAS file headers. Open Geospatial Consortium (OGC)'s Well-Known Text (WKT) is used for the required Coordinate Reference System (CRS).	Data Processing
Open Access	Only open LAS format is to be used and no proprietary formats are acceptable.	Data Processing
Compression	Compression of LAS form using an open source product is acceptable for data management. The compression must be lossless and converted seamlessly from and to LAS format, retaining all the information. LAZ format is the recommended compression format. The contracting authority will specify the file format required as the deliverable.	Data Processing
GPS Time	Each Global Navigation Satellite System (GNSS) aircraft positional measurement must be time stamped using Adjusted Global Positioning System (GPS) Time, at a precision sufficient to allow a unique timestamp for each LiDAR pulse. Adjusted GPS time is the satellite GPS time minus 1×10^9 . The encoding tag in the LAS header shall be properly set.	Data Processing
Measurement Units	Measurements are in metres (m), and must be specified to a minimum of 3 decimal places.	Data Processing

Table 8: Data file format requirements.

Considerations, Limitations and Assumptions

- Georeferencing specifications is currently based OGC 2001 WKT standard which has since been deprecated. In 2015 OGC adopted the ISO WKT standards. However, ASPRS LAS standards is still based OGC 2001 WKT text. Change in georeferencing specification may be required in the future.
- Waveform data is considered optional and may be requested at the discretion of the contracting authority.
- All data collected within DCAOI shall be processed and provided as deliverables. No pulse data will be deleted from swath LAS files.

6.3.2 Pulse Classification

Description

All LiDAR pulse data, except pulses identified as Withheld, will undergo processing to be classified. All above ground level features (vegetation, buildings and other objects) shall be filtered to produce a "bare-earth" ground point data. The software, processing and use of ancillary data to achieve the classification accuracy threshold are at the discretion of the vendor. The classification schema will be based on LAS 1.4 – R15 specification for Point Data Record Format 6 – 10, Table 17. All pulses not identified as Withheld must be processed for

classification. No points in LAS point cloud are to remain assigned to class 0 (created but not processed for classification), unless these points are flagged as Withheld.

CQL1 requirements

Given that the classification requirements may vary based on the needs, only the minimum required class designation for CQL1 is identified below. It is advisable to require this minimum classification.

Name	Description	Category
Classification	1 – Processed but unclassified 2 – Ground 7 – Low points (noise) 9 – Water 17 – Bridge decks 18 – High noise	Data Processing

Table 9: Pulse classification requirements for CQL1 (LAS 1.4-R15 required classes).

Considerations, Limitations and Assumptions

- If breaklines are requested, it is recommended to include class 20 – Ignored ground (near a breakline). Note: ASPRS LAS Class 10 which has been used in the past for ignored ground points, is assigned to rail points.
- Point(s) created from techniques independent of LiDAR collection such as digitize from photogrammetric stereo model are considered Synthetic point(s). Synthetic points are discouraged and if used must be classified using bit field encoding set to 0. Details are to be provided as part of the project reporting. See Table 16 ASPRS LAS 1.4 R15 specification for Synthetic point(s).

6.3.3 Coordinate Reference System

Description

The deliverable coordinate system of LiDAR data will be based on the current version of the Canadian Spatial Reference System (CSRS). Data will be represented in orthometric height and projected as listed below.

CQL1 requirements

Given that the reference system requirement may vary based on the needs, only the CQL1 designation is identified below.

Name	Description	Category
Horizontal Datum	NAD83 CSRS, 2010 epoch	Data Processing
Vertical Datum	CGVD 2013	Data Processing
Geoid Model	CGG2013a	Data Processing
Map Projection	Universal Transverse Mercator (UTM)	Data Processing

Table 10: Coordinate Reference System requirements for CQL1.

Considerations, Limitations and Assumptions

- The processing of LiDAR pulse data should be conducted using a single UTM zone, except in locations where DCAOI extends into multiple zones and would result in unacceptable distortions to the data set. The data will then be split into subareas with appropriate UTM zones. Full tiles, with complete data coverage, should be maintained when data is split between UTM zones. One tile overlap into each zone should be maintained. Each subarea will be processed and provided as a separate subproject deliverable. The requirements applied to a project shall also apply to each subproject area.
- NAD83(CSRS) is a 3-dimensional geometric reference system whose realization is the current adopted national referencing standard in most federal and provincial agencies in Canada. It uses GRS80 as the reference ellipsoid and the current geoid model (presently CGG2013a) to convert from ellipsoidal heights to orthometric heights in the CGVD2013 vertical datum. NAD83(CSRS) coordinates can be expressed as geographical (latitude, longitude and ellipsoidal height) or UTM (easting, northing and height) coordinates and can be transformed to and from using geodetic transformation software from other reference system such as WGS84. GNSS receivers use WGS84 as the default coordinate reference system for ellipsoid heights. The Canadian Geodetic Survey (CGS) has a number of services and applications available to transform coordinates. The GPS-H software application provides the ability to transform GNSS derived data from ellipsoidal heights in either the ITRF coordinate reference systems (compatible with WGS84 which is currently aligned with ITRF08), or NAD83(CSRS) epoch's to orthometric heights in the CGVD28 or CGVD2013 vertical datum. The TRX software application provides the ability to transform coordinates between NAD83(CSRS) and various realization ITRF. It also includes the ability to convert between geographic, Cartesian and local coordinate systems. NAD83(CSRS) coordinates at the current epoch can also be directly obtained through post processing of raw static or kinematic GNSS data using Canada Active Control System (CACS) data and/or the online Precise Point Positioning (CSRS-PPP) service. The CSRS-PPP service uses the best available ephemerides and ionospheric corrections. The so-called "Ultra Rapid" products are used within approximately 90 minutes of data collection providing ± 15 cm accuracy. The "Rapid" products are used within a day providing ± 5 cm accuracy, and final products are used after 13 days to provide higher accuracy positions for raw observation data at ± 2 cm. It is left for data collectors to determine if CSRS-PPP solution would adequately meet CQL1 standards for location and time of data collection.
- EPSG codes are effective standards and efficient means of assigning coordinate reference system. There are currently 52 different EPSG codes for the different projected coordinate system and one for the NAD83(CSRS) (EPGS: 6140). However, EPSG code 6140 treats the

different realization and epochs of NAD83(CSRS) as the same and does not recognize the subtle differences. In Canada each province have adopted different realization and epoch of NAD83CSRS. These are currently not recognized at the time of this publication but is expected to be updated in EPSG registry. In future, the use of EPSG codes as coordinate reference system is worth considering for adoption.

- Virtual Reference Systems (VRS) are based on a network of GNSS receivers that are spaced apart at a separation distance on the order of about 40-60km. The GNSS receivers act as Continuously Operating Reference Stations (CORS). The information collected by GNSS receivers actively broadcast the localized correction to the network. The corrections are uploaded for real-time monitoring and correction of static and RTK GNSS receivers. When using VRS control, it is recommended to implement appropriate calibrations and checks for verification and validation of the data and results. VRS receivers provide another potential source for control of GNSS airborne and ground receivers. The use of these networks is permissible at the discretion of the vendor and contracting authority to ensure accuracy requirements are met.

6.3.4 Point Families

Description

A transmitted LiDAR pulse can have one to many returns. The complete set of multiple returns reflected from a single LiDAR pulse is considered a point family.

Requirements

Point families (multiple return “children” of a single “parent” pulse) will be maintained throughout all processing before tiling. Multiple returns from a given pulse will be stored in sequential (collected) order.

Considerations, Limitations and Assumptions

- Systems with multiple channel lasers or multiple points in air will maintain pulse families for each single pulse.

6.3.5 Tiling Scheme

Description

The processing of LIDAR data will include preparing and delivering the data using a tiling scheme.

Requirements

Name	Description	Category
Size	1 km x 1 km	Data Processing
Condition	Edge-match seamlessly, no gaps or overlap	Data Processing
Naming	Each tile will be named following a name standard identified below.	Data Processing
Georeferencing	Coordinate Reference System and units of the data will be used.	Data Processing
Type	Pulse, point and raster data will use the same tiling scheme.	Data Processing
Format	Data tiles will be produced in LAS or LAZ format as determined by the contracting authority.	Data Processing
Index file	A digital index file as ESRI shapefile must be provided with the data, with file naming convention in the attribute table, including separate fields for index reference, project name, collection date.	Data Processing

Table 11: Tiling scheme requirements.

Tiles will be created with a unique naming convention using the following principles:

- The structure should be designed in a manner that is readily programmable.
- Each tile must be uniquely defined in the data sets both in time and position, so there is no duplication.
- File names should be easy to interpret and clearly identify the file's content.
- Naming should be consistent with standards such as using address codes for provinces and territories.

In Table 12, a recommended file naming convention for LiDAR data is summarized.

Name	Description	Example
Province/Territory	Abbreviate names using postal addressing standards.	ON, BC, YK etc.
Project Name or ID	Short project name (max 20 characters) typically a geographic reference such as city, town, watershed, region	Kitmat, BanffPark, LongPoint, 2698A
Project Collection Date	Year and month date field (YYYYMMDD) of Acquisition end date	20170511
Coordinate Reference System	A reference to coordinate reference system or map projection	NAD83CSRS_UTMZ9
Tile Size	The square kilometre tile size	1km
Tile Corner Coordinate	Using the southwest corner of the tile, assign the UTM easting and northing. Use 4 digits for easting and 5 for northing - EXXXX_NYYYYY	E5237_N59906

Quality Level	Use the value for the quality level of the data product field.	CQL1
Product	A short field name for LiDAR products produced such as classified point data, data merged with orthophotos or derivative products such as DSM.	CLASS – Point Cloud Classification CLASSRGB DTMR – Bare Earth DTM Raster BEP – Bare Earth – Ground Point Data DSMR – Digital Surface Model Raster UNCLASS – Unclassified Point Cloud INT – Intensity Image HS – Hillshade CHM – Canopy Height Model Etc.
File Extension	Standard file extensions used	LAS, LAZ, TIF, shp

Table 12: File naming conventions for LiDAR data.

Format would consist of the following:

P/T_ProjectNameorID_ProjectCollectionDate(YYYYMMDD)_CoordinateReferenceSystem_Tile
Size_TileCorner(SW)EXXXX_NYYYYY_QualityLevel_Product.extension

Example:

BC_Kitmat_20170511_NAD83CSRS_UTMZ9_1km_E5237_N59906_CQL1_CLASS.LAS

Considerations, Limitations and Assumptions

- For LiDAR data with higher density or accuracy specifications than CQL1, no quality level should be indicated in the name.

6.3.6 Derivative Products

Derivative products, with the exception of pulse classifications, have been considered outside the scope of this guideline. However, some products such as gridded and raster DTM, intensity and hillshade images may be generated to support the quality assessment. For more information on derivative products see [High Resolution Digital Elevation Model \(HRDEM\) – CanElevation Series -Product Specification](#).

6.4 Data Validation

The quality assurance of LiDAR data with respect to this guideline involves implementing and conducting data validation procedures to provide confidence that the quality requirements are fulfilled. In this guideline, several quality control procedures have been specified as independent quality checks to assess if the LiDAR data requirements are being satisfied. The quality check includes the following:

- Positional Accuracy
- Spatial Distribution and Regularity

- Pulse Density
- Pulse Classification
- Data Voids
- Relative Accuracy

The contracting authority is responsible for selecting a party to conduct all or part of the independent quality checks. The party may be a single or multiple independent organizations, an in-house resource or data collection vendor.

6.4.1 Positional Accuracy

Description

The verification of LiDAR positional accuracy both horizontal and vertical should be conducted using independent check points. Check points should be divided into non-vegetated and vegetated areas. Check points may be acquired by a vendor collecting the LiDAR data, by the contracting authority, or by an independent third party at the discretion of the contracting authority. The check point collection process involves selecting a sampling areas size, sampling area land cover types, number of sampling areas and number of check points to be collected. The check point validation process should follow, at a minimum, the ASPRS guidelines for Positional Accuracy Standards for Digital Geospatial Data 2014 (ASPRS 2014). The ASPRS guidelines provide the recommended number of check points for horizontal and vertical accuracy assessment of elevation data as a function of AOI area (Table C.1). The check points will be conducted for Non-Vegetated Vertical Accuracy (NVA), Vegetated Vertical Accuracy (VVA), and Fundamental Horizontal Accuracy (FHA) assessments as described below.

Requirements

Name	Description	Category
Non-Vegetated Vertical Accuracy (NVA)	<p>The check points for NVA assessment areas will be surveyed in clear open areas devoid of vertical features (such as vegetation, vehicles, pipes, wires, etc.) where LiDAR pulses have single returns. Survey area must have a minimum size of $(ANPS \times 5)^2$ and should use flat ground with slope less than 10 degrees. Acceptable land cover type includes open areas of low grass, such as lawns and golf courses, bare earth and urban paved areas. Distribute the sampling areas where the surface has been altered such as plowed fields are not acceptable. The survey should be adequately distributed to cover the whole AOI and all varieties of land cover types within it.</p> <p>The NVA must meet the requirements outlined in Section 6.2.3 (Table 7).</p>	Validation

Vegetated Vertical Accuracy (VVA)	<p>The assessment of VVA will be conducted in vegetated areas, such as tall grass, crops, brush land, short trees and forests. The survey area must have a minimum size of $(ANPS \times 5)^2$ and flat ground (slope less than 10 degrees).</p> <p>The VVA must meet the requirements outlined in Section 6.2.3 (Table 7).</p>	Validation
Fundamental Horizontal Accuracy (FHA)	<p>The check points for assessment of Fundamental Horizontal Accuracy should be acquired over well-defined linear features with distinct breaks in elevation or intensity, such as road markings, buildings, walls, railway tracks and road pavement edges. Areas must be flat (slope less than 10 degrees) with hard or compacted surfaces.</p> <p>The FHA must meet the requirements outlined in Section 6.2.3 (Table 7).</p>	Validation

Table 13: Check point requirements.

The absolute vertical and horizontal accuracy will be evaluated against NVA and VVA check points. The vertical accuracy check is also conducted for the final DTM for NVA and VVA. The DTM check requirements will be provided by the contracting authority.

- The accuracy assessment assumes the errors are normally distributed and therefore metrics such as RMSE are statistically valid. An alternative numerical method would be required if the errors were not normally distributed.
- The number of checkpoint sampling areas for conducting combined accuracy assessment is based on ASPRS. The designated checkpoint sampling area is a homogeneous flat area equivalent to $(ANPS \times 5)^2$. For projects with an AOI less than 500 km² a minimum number of check points sampling areas is determine by the contracting authority. For projects that are greater than 500 km² and less than 2,500 km² the number of check points will be a linear expansion of the ASPRS 2014 Table C.1 as a minimum sampling area amount which is approximately ~ 1 checkpoint per 25 km². The contracting authority may request additional check points be conducted by the vendor or independently to verify the accuracy of the data. This may include selecting areas of diverse ground cover and topography. For vertical assessment of areas >2,500 km², add five additional vertical checkpoints for each additional 500 km² area. Each additional set of five vertical checkpoints for 500 km² would include three checkpoints for NVA and two for VVA. The recommended number and distribution of NVA and VVA checkpoints may vary depending on the importance of different land cover categories and Contracting Authority requirements. For horizontal testing of areas >2500 km², Contracting Authority should determine the number of additional horizontal checkpoints, if any, based on criteria such as resolution of imagery and extent of urbanization.

- The Fundamental Horizontal Accuracy (FHA) assessment will involve sampling over surfaces with clear linear features or easily identifiable features on ground, seen using interpolated intensity images.
- In general, the minimum number of check points to be collected shall be no less than 20 points, and preferably 30 points evenly distributed across the project AOI and proportional distributed for NVA and VVA as recommend in ASPRS Positional Accuracy Standards for Digital Geospatial Data version 1 November 2014. Checkpoints may be distributed more densely in the vicinity of important features and more sparsely in areas that are of little or no interest. The contracting authority may adjust the number of check points collected in locations of concern or due to challenging areas for NVA, VVA and FHA.
- Check points will not be surveyed in areas of extremely high NIR absorption (fresh asphalt, wet soil, or building roofs with asphalt surface), or in areas that are near abrupt changes in NIR reflectivity (white beach sand adjacent to water) because such abrupt changes usually cause unnatural vertical shifts in LiDAR elevation measurements.
- In land covers other than forested and high-density urban, the check points should have no obstructions above 15 degrees over the horizon (to improve GNSS reception and maximize LiDAR pulse collection).
- Check points shall be an independent set of points used for the sole purpose of assessing the vertical and/or horizontal accuracy of the data collection and cannot have been used in calibration or integrated into the data acquisition.
- Survey of check points with each assessment type (NVA, VVA and FHA where possible) will be well-distributed across the entire AOI.
- The altimetric and planimetric check points shall be at least three times more accurate than the required accuracy of the LiDAR data to be acquired, and always better than 5 cm (95%). The contracting authority may specify a higher degree of accuracy with survey check points. In addition to newly acquired survey check points, historical points may be used, provided they were acquired within the last 3 years and not used in calibration or data acquisition of the current project. Historical points must meet all the check point requirements and surface conditions at the check point location must be temporally invariant and verifiably undisturbed. The contracting authority must be advised in advance if historical points will be used and reserves the right to reject any or all points.
- Vertical accuracy testing of point data will use a TIN model to conduct the comparison between point data and check points. First and only pulse data will be used to create a TIN. The TIN will be used to extract an interpolated value at the location of the ground sample check points were collected for the comparison.

Considerations, Limitations and Assumptions

- All required check points are to be collected within the AOI. However, at the discretion of the Contracting Authority supplementary checkpoints may be collected with 100m buffer areas.
- In some DCAOI, access restrictions, safety, difficult terrain, and transportation constraints may prevent the desired spatial distribution of checkpoints across land cover types; Where it is not geometrically or practically applicable to meet the recommended checkpoint collection targets, data vendors in conjugation with the Contracting Authority, should use their best professional judgment to apply the spirit of that method outlined in ASPRS Positional Accuracy Standards for Digital Geospatial Data version 1 November 2014 in selecting locations for checkpoints.

6.4.2 Spatial Distribution and Regularity

Description

The spatial distribution of pulses within the geometrically usable portion of the swath (typically 95% of the centre portion of the swath width) will be collected with a uniform distribution to represent a regular lattice distribution. Although LiDAR sensors do not collect in regular distributed pattern, the collection shall be designed and carried out to produce an aggregate first return point cloud that approach a regular lattice of pulses as defined in the requirements below.

Requirements

Name	Description	Category
Spatial Distribution and Regularity	<p>Uniformity of the spatial distribution and regularity of pulses distribution is assessed through a distribution grid covering the entire project with the first return pulses within the geometrically usable centre part of each swath and excluding acceptable data voids.</p> <p>The resolution of the distribution grid should be twice the design ANPS (Ex for the CQL1: $2 \times 0.71 \text{ m} = 1.42 \text{ m}$). The uniformity requirement is to have at least 1 pulse per distribution grid cell for at least 90% of the grid cells.</p>	Validation

Table 14: Spatial distribution and regularity check requirements.

Considerations, Limitations and Assumptions

- The approach used to count LiDAR pulses within the distribution grid will be dependent on the software tool used. Some software tools use a count based on pulses that fall within the grid cell and others use a search radius to count pulses that fall within a grid. For software tools that use a search radius approach for determining counts within a grid cell, the search radius shall be equal to the design ANPS.

- The assessment excludes acceptable data voids as identified in Section 6.4.4.
- This analysis is only related to regular and uniform point distribution. The assessment is not for assessing ANPD or NPD across the DCAOI (see Section 6.4.3).
- The concession of this threshold in difficult areas such as high relief may be waived at the discretion of the contracting authority.

6.4.3 Pulse Density Check

Description

A data check is conducted to verify that ANPD has been achieved across the DCAOI. A pulse density grid is used to assess whether the pulse density has achieved for the specified CQL. The specific requirement is identified in the table below:

Requirements

Name	Description	Category
Pulse Density Grid	Pulse density verification will be conducted using a 20m x 20m cell pulse density grid covering all DCAOI.	Validation
Evaluation	ANPD must be satisfied at least 90% of time within the pulse density grid cells for DCAOI based on first returns. A visual grid output with red cells showing below ANPD and green for cells meeting ANPD requirement. A histogram distribution will be used to quantify the pulse density distribution.	Validation

Table 15: Pulse density check requirements.

Considerations, Limitations and Assumptions

The assessment excludes acceptable data voids as identified in Section 6.4.4.

- Insufficient pulse density may result in the requirement to reacquire data in deficient areas at the discretion of the contracting authority.

6.4.4 Data Voids

Description

Gaps in LiDAR point cloud data can occur as a result of surface absorption or refraction in the near-infrared, sensor issues, processing anomalies, and improper data collection. Data voids arising from errors in collection and processing must be identified and corrected. Data voids are not permitted in the DCAOI as outlined in the requirements.

Requirements

Name	Description	Category
Data voids	A data void is any area greater than or equal to $(4 \times \text{ANPS})^2$ which is measured using first returns. Data voids within a single swath are not acceptable, except where caused by water bodies or low near infrared reflectivity areas, or where voids have been appropriately filled in by data from another swath. Overlapping swath used for fill in must meet all requirements as specified in this guideline.	Validation

Table 16: Data void check requirements.

Considerations, Limitations and Assumptions

- Data voids larger than the threshold may result in vendor requiring to re-fly at the discretion of the contracting authority

6.4.5 Pulse Classification Accuracy

Description

The classification of pulse data is an iterative process involving software tools and ancillary information to convert the pulse data into land cover type classes. The process can involve automated and semi-automated software routines with ancillary data to produce point cloud classified data. An accuracy assessment is applied to evaluate if the required quality is achieved. The specific classification accuracy assessment is identified below.

Requirements

Name	Description	Category
Test Area	Using a 20m x 20m cell grid	Validation
Accuracy	No more than 2% of non-withheld points can have a demonstrable classification error within AOI. As an alternative for large projects, the error percentage can be calculated based on the number of cells in error rather than the number of points. A cell is identified in error when one or more classification errors are found within it. A maximum of 2% of the cells may have a demonstrable classification error within the AOI.	Validation
Assessment	The assessment of the classification should be tested by comparing known ground control points and/or using ancillary information including high resolution ortho	Validation

	imagery or other relevant geospatial data sets. Sampling should be well distributed across the AOI. A minimum of 5 grid cells per sq. km will be sampled. The contracting authority may increase the sampling requirements.	
Other error types	<p>In addition to the evaluation of erroneous points or cells, certain anomalies in the classification of the dataset may result in the rejection of the data by the contracting authority :</p> <ul style="list-style-type: none"> - Point classification is not consistent across the entire project. There are variations in the character, texture, or quality of the classification between tiles, swaths, flights, or other unnatural divisions. - There are areas showing inconsistency in ground points due to uneven terrain. - There are duplicate points (2 points with the same XYZ coordinates) or artificial points. 	Validation

Table 17: Classification accuracy requirements.

Considerations, Limitations and Assumptions

- Classification may be relaxed by the contracting authority for challenging areas.

6.4.6 Relative Accuracy Check

Description

The accuracy of pulse returns should be consistent across the useable portion of a single swath and in the overlap areas of swaths. The relative vertical accuracy checks are used to validate the geometric stability of the data collection.

Requirements

Name	Description	Category
Relative Vertical Accuracy – Intrawath (smooth hard surface repeatability) – (RMSD_z)	Intrawath assessment will use a single swath with only single returns in a non-vegetated area. The assessment will be conducted on smooth hard surfaces to determine vertical elevation discrepancy not to exceed the threshold outlined at Section 6.2.3 (Table 7). This is calculated using Root Mean Square Difference (RMSD _z) between the minimum and maximum. The assessment will use a gridded signed difference raster with cell size equal to 2 x ANPS rounded up to closes integer. The sampling area will be approximately 50 m ² and will be conducted	Acquisition

	for multiple locations both across the swath and along the swath within the usable portion of the swath. A minimum of three sample area per swath for all swaths in AOI. The contracting authority may request or conduct additional sampling. The sampling area will be evaluated with a signed difference raster between the maximum and minimum elevation for each grid cell. The raster difference must not exceed the table value for intraswath relative accuracy.	
Relative Vertical Accuracy – Interswath (swath overlap difference) – (RMSD_z and maximum differences)	The assessment of two swaths for interswath consistency is achieved by generating a gridded raster from single returns in non-vegetated area. The comparison will use gridded signed difference raster with a cell size equal to 2 x ANPS rounded up to the closest integer for each swath. The assessment is conducted by subtracting the difference between the grid surfaces. Root Mean Square Difference (RMSD _z) and maximum differences between minimum and maximum calculated for the points in the raster surface should not exceed the thresholds outlined at section 6.2.3 (Table 7).	Acquisition

Table 18: Relative accuracy requirements.

Considerations, Limitations and Assumptions

- Hillshade raster images are useful for identifying anomalies in the data processing stream.

6.5 Project Deliverables

A comprehensive Project Report must be provided that includes assembly of all content including documentation, images, notes and data created from the project.

6.5.1 Deliverable Items*Project Reporting*

Item	Description	Format
Project Planning	Content includes the following: <ul style="list-style-type: none"> • Project method details (Section 6.1.1) • Instrumentation details (Section 6.1.2) • Data collection (Section 6.1.3) 	Microsoft Word or PDF
Progress Reports	During the acquisition, progress reports shall be provided at frequency stipulated by the contract authority. <ul style="list-style-type: none"> • On/off schedule • Status of collection % completion and where • Any changes to the collection plan including people or instrumentation 	Microsoft Word or PDF

	<ul style="list-style-type: none"> Any current issues causing delay Any anticipate issues that affect data collection, budget, or the schedule 	
Project Deliverables	<p>Project deliverable reporting items will include the following:</p> <ul style="list-style-type: none"> Field notes for surveying, flight logs The Data Quality Assurance report with detail of data validation for vertical and horizontal accuracy, check points collection, classification accuracy check, regularity and pulse density check, all calculation and results The Deliverable Report contains an assembly of information related to all deliverables provided and processing, data list, and metadata. It should contain sufficient detail to demonstrate the specifications have been met for each pulse data collected. 	Microsoft Word or PDF
Data Inventory List	A data inventory and dictionary describing all the data and documentation collected in the project will be provided in a structured table list. It will include file name, creation date, description and a contact responsible for the items.	Microsoft Excel or PDF

Table 19: Report deliverables

Field Data

Item	Description	Recommended Format
Survey Control	<ul style="list-style-type: none"> Active or passive station data including location and any monument station, date time stamp, GNSS data collected should be included Control points used to calibrate and process the pulse data Photos of survey control and a map of the base station locations 	RINEX, PDF
Flight	<ul style="list-style-type: none"> Flight trajectory – SBET files – including any tie lines or calibration flights. A shapefile with all the trajectory, orientation, time, date information should be retained. Flights should be separated by lifts and by logical separation such as flight blocks. 	Shapefile
In-situ Validation	<ul style="list-style-type: none"> Check point measurements All GNSS field and control data including parameters for collection Photographs of site of measurement areas - both ground and site views 	Excel RINEX/MS Word-PDF TIFF/JPG PDF/JPG

	<ul style="list-style-type: none"> Map of the locations of the check point areas and the classification checks 	
Metadata	Metadata will be provided for the field data. The structure of the metadata will use XML format using ISO 19115:2003 standard.	XML

Table 20: Field data deliverables

LiDAR Data

Item	Description	Format
Point Cloud Data	Classified point cloud data in tiles using naming conventions	LAS/LAZ
Index File	Index file of point cloud data with date, naming convention, project name, location	shapefile
Raw data	Not required for delivery, except if desired by the contracting authority or when final point cloud data is not delivered. Vendor must retain a master copy of the raw data for a period of 6 month from the date of delivery.	
Metadata	Metadata on the data delivery in XML format using ISO 19115:2003 standard North American Profile and supplemental information on the LiDAR acquisition	XML (Metadata) Excel (Supplemental information on the LiDAR acquisition)

Table 21: LiDAR data deliverables.

Supplemental information on the LiDAR acquisition

The *Supplemental information on the LiDAR acquisition* shall be included in an Excel file to complement the Metadata ISO 19115:2003 standard North American Profile.

- | | |
|--------------------------|---|
| • classification_code | LAS Class used |
| • ldr_sensor | LiDAR Sensor Used |
| • ldr_max_number_return | Maximum number of returns per pulse |
| • ldr_theoretical_APND | Theoretical or planned ANPD |
| • ldr_flight_height | Flight Height (m) |
| • ldr_flight_speed | Flight speed (knts and km/hr) |
| • ldr_scan_angle | Scan Angle (degrees) |
| • ldr_scan_frequency | Scan Frequency (Hz) |
| • ldr_pulse_rate | Pulse Repetition Frequency (kHz) |
| • ldr_pulse_width | LiDAR pulse footprint size (m) |
| • ldr_wave_length | Sensor wavelength (nm) |
| • ldr_multi_pulse_in_air | Whether the sensor was operated with Multiple Pulses In The Air, 0=No; 1=Yes. |
| • ldr_beam_divergence | Beam Divergence (mrad) |
| • ldr_swath_width | Swath width (m) |
| • ldr_swath_overlap | Swath overlap (%) |
| • las_version | LAS version used (e.g. v1.4) |

- las_overlap Points classified in areas overlap
- las_withheld Detail description on points removed as noise, low points, or anomalous points.
- las_intensity_resolution Intensity bit resolution

Data Validation

Item	Description	Recommended Format
Spatial Distribution and Regularity	Results from checking the distribution pulse data	Excel and PDF
Relative Accuracy	Calculation of relative accuracy including all data used for: <ul style="list-style-type: none"> • Intrawath comparison • Interswath comparison 	Excel, GeoTiff, PDF
Pulse Density	Visual grid and histogram - calculated result from applying the pulse density grid	GeoTiff
Data Voids	Results from conducting a data void check.	Excel, GeoTiff, and PDF
Pulse Classification	Summary of classification results	Excel, GeoTiff and PDF
Positional Accuracy	The results of positional accuracy including all data used for check point location for vertical and horizontal – NVA, VVA, FHA and CHA will be provided.	Excel, GeoTiff and PDF

Table 22: Data Validation Deliverables

6.5.2 Raw LiDAR Data

- Raw project source data, such as native format LiDAR files, are not required for delivery. However, the Vendor must hold a copy of all relevant raw project data, for a minimum time as specified in Table 21 or an agreed upon time between the contracting authority and vendor beyond the final delivery of the project deliverables. This period is considered a review period to ensure all deliverables are met. During this period, additional quality control and assurance testing may be conducted as needed and determined by the contracting authority. If any deficiencies are found in the deliverables, content, and data (i.e: not meeting the specifications guideline), the contractor authority may reject the data, requiring completion of the deliverables or reprocessing or re-flying of deficient areas at a timeline specified by contracting authority.

6.6 Data Ownership and Copyright

It is recommended that the vendor must deliver all the data with unrestricted copyright, and the ability for the contract authority to place the data within the public domain or distribute as the contracting authority sees fit. The specific arrangement is to be determined by the contracting authority and the vendor. This recommendation is strongly encouraged for any data acquired through federal funds.

7.0 GLOSSARY

95% Confidence Level: Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product. Where errors follow a normal error distribution, vertical accuracy is defined at the 95% confidence level, and horizontal accuracy at the 95% confidence level (NDEP 2004).

95th Percentile: Accuracy reported at the 95th percentile indicates that 95% of the vertical errors will be of equal or lesser value of the specified accuracy and 5% of the vertical errors will be of larger value. This term is used when vertical errors may not follow a normal error distribution, e.g., in forested areas where the classification of ground elevations may have a positive bias.

Accuracy: The degree of conformity of a measured or calculated value compared to the actual value. Accuracy relates to the quality of a result and is distinguished from precision, which relates to the quality of the operation by which the result is obtained (ASPRS Guidelines for Procurement).

- **Absolute Accuracy:** A measure that accounts for all systematic and random errors in a dataset. Absolute accuracy is stated with respect to a defined datum or reference system.
- **Relative Accuracy:** A measure of variation in point-to-point accuracy in a data set. In LiDAR, this term may also specifically mean the positional agreement between points within a swath, adjacent swaths within a lift, adjacent lifts within a project, or between adjacent projects.

Aggregate Nominal Pulse Density (ANPD): A variant of nominal pulse density that expresses the total expected or actual density of pulses occurring in a specified unit area resulting from multiple passes of the light detection and ranging (LiDAR) instrument, or a single pass of a platform with multiple LiDAR instruments, over the same target area. In all other respects, ANPD is identical to nominal pulse density (NPD). In single coverage collection, ANPD and NPD will be equal. Note:

$$NPD = 1/NPS^2$$

Aggregate Nominal Pulse Spacing (ANPS): A variant of nominal pulse spacing that expresses the typical or average lateral distance between pulses in a LiDAR dataset resulting from multiple passes of the LiDAR instrument, or a single pass of a platform with multiple LiDAR instruments, over the same target area. In all other respects, ANPS is identical to nominal pulse spacing (NPS). In single coverage collections, ANPS and NPS will be equal. Note:

$$NPS = \frac{1}{\sqrt{NPD}}$$

Attitude: The position of a body defined by the angles between the axes of the coordinate system of the body and the axes of an external coordinate system. In photogrammetry, the

attitude is the angular orientation of a camera (roll, pitch, yaw), or of the photograph taken with that camera, with respect to some external reference system. With LiDAR, the attitude is normally defined as the roll, pitch and heading of the instrument at the instant an active pulse is emitted from the sensor.

Bare Earth (Bare-earth): This refers to the digital elevation data of the terrain, free from vegetation, buildings and other man-made structures (elevations of the ground)

Boresight: Calibration of a LiDAR sensor system equipped with an Inertial Measurement Unit (IMU) and Global Positioning System (GPS) to determine or establish the accurate:

- Position of the instrument (x, y, z) with respect to the GPS antenna
- Orientation (roll, pitch, heading) of the LiDAR instrument with respect to straight and level flight.

Breakline: This is a linear feature demarking a change in the smoothness or continuity of a surface such as abrupt elevation changes or a stream line.

Calibration: This refers to the process of identifying and correcting for systematic errors in hardware, software, or procedures. Calibration can also be defined as determining the systematic errors in a measuring device by comparing it's measurements with the markings or measurements of a device that is considered correct. Airborne sensors can be calibrated geometrically and radiometrically.

Check Point: A check point is a surveyed point used to estimate the positional accuracy of a geospatial dataset against an independent source of greater accuracy. Check points are independent from, and may never be used as control points on the same project.

Classification: This refers to the classification of LiDAR point cloud returns in accordance with a classification scheme to identify the type of target from which each LiDAR return is reflected. The process allows future differentiation between bare-earth terrain points, water, noise, vegetation, buildings, other man-made features and objects of interest.

Control Point: A control point is a surveyed point used to geometrically adjust a LiDAR dataset to establish its positional accuracy relative to the real world. Control points are independent from, and may never be used as check points on the same project.

Data Void: In LiDAR, a data void is a gap in the point cloud coverage, caused by surface non-reflectance of the LiDAR pulse, instrument or processing anomalies or failure, obstruction of the LiDAR pulse, or improper collection flight planning. Any area greater than or equal to four times the aggregate nominal pulse spacing (ANPS) squared, measured using first returns only, is considered to be a data void.

Datum: A datum consists of a set of reference points on the Earth's surface against which position measurements are made, and (often) an associated model of the shape of the earth (reference ellipsoid) to define a geographic coordinate system. Horizontal datum (for example, the North American Datum of 1983 Canadian Spatial Reference System (NAD83 (CSRS))) are used for describing a point on the earth's surface, in latitude and longitude or another coordinate

system. A vertical datum, for example the Canadian Geodetic Vertical Datum 2013, measures elevations or depths. In engineering and drafting, a datum is a reference point, surface, or axis on an object against which measurements are made.

Digital Elevation Model (DEM): A DEM is a digital representation of relief composed of an array of elevation values referenced to a common vertical datum and corresponding to a regular grid of points on the earth's surface. These elevations can be either ground or reflective surface elevations.

Digital Terrain Model (DTM): A DTM is a representation of the bare ground surface without any objects such as vegetation and buildings.

Digital Surface Model (DSM): A DSM is a representation of the earth's surface including vegetation and man-made structures. The Digital Surface Model (DSM) provides the height of the vegetation, canopies and structures above the vertical datum.

Discrete Return: This is a LiDAR system or data in which important peaks in the waveform are captured and stored. Each peak represents a return from a different target, discernible in vertical or horizontal domains. Most modern LiDAR systems are capable of capturing multiple discrete returns from each emitted laser pulse.

Field of View (FOV): This is the angular extent of the portion of object space surveyed by a LiDAR sensor, measured in degrees. To avoid confusion, a typical airborne LiDAR sensor with a field of view of 30 degrees is commonly depicted as ± 15 degrees scan angle on either side of nadir.

First Return: This is the first important measurable part of a returned LiDAR pulse. First returns also include single returns.

Fundamental Horizontal Accuracy: Horizontal accuracy compares horizontal positions of precisely known and easily discernible ground/check points to LiDAR ground point positions reported as RMSE or error at 95% confidence level (ASPRS 2014). Horizontal accuracy is defined as a radius of a circle of uncertainty and assumes a normal distribution. At 95% confidence, radial horizontal accuracy is defined as:

$$\text{Horizontal Accuracy} = 1.7308 \times \text{RMSE}_r$$

Where

$$\text{RMSE}_x \text{ or } \text{RMSE}_y = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_{i(\text{LiDAR})} - x_{i(\text{Survey})})^2}$$

$$\text{RMSE}_r = \sqrt{\text{RMSE}_x^2 + \text{RMSE}_y^2}$$

Note that $x_{i(LiDAR)}$ are set of LiDAR points being evaluated and $x_{i(Survey)}$ are the corresponding survey check points used to compare the LiDAR horizontal (r) points at that geographic location. n is the number of check points.

Grid: A grid is a geographic data model that represents information as an array of equally sized square cells. Each grid cell is referenced by its geographic or x/y orthogonal coordinates.

Intensity: For discrete return LiDAR instruments, intensity is the recorded amplitude of the reflected LiDAR pulse at the moment the reflection is captured as a return by the LiDAR instrument. LiDAR intensity values can be affected by many factors, such as the instantaneous setting of the instrument's automatic gain control and angle of incidence and cannot be equated to a true measure of energy. In full-waveform systems, the entire reflection is sampled and recorded, and true energy measurements can be made for each return or overall reflection. Intensity values for discrete returns derived from a full-waveform system may or may not be calibrated to represent true energy.

Inertial Navigation System (INS): INS is a navigation aid that uses a computer control system, Inertial Measurement Unit (motion sensors (accelerometers) and rotation sensors (gyroscopes)) coupled with a Global Navigation Sensor System such as Global Position System to continuously calculate via dead reckoning the position, orientation, and velocity (direction and speed of movement) of the aircraft.

LAS: This is a public file format for the interchange of 3D point cloud data between data users. The file extension is .las.

Lattice: A lattice is a 3D vector representation method created by a rectangular array of points spaced at a constant sampling interval in x and y directions relative to a common origin. A lattice differs from a grid in that it represents the value of the surface only at the lattice mesh points rather than the elevation of the cell area surrounding the centroid of a grid cell.

Last Return: This is the last important measurable part of a return LiDAR pulse.

LiDAR: LiDAR stands for Light Detection and Ranging and is an instrument that measures distance to a reflecting object by emitting timed pulses of light and measuring the time difference between the emission of a laser pulse and the reception of the pulse's reflection(s). The measured time interval for each reflection is converted to distance, which when combined with position and attitude information from GPS, IMU, and the instrument itself, allows the derivation of the 3D-point location of the reflecting target's location.

Lift: A lift is a single takeoff and landing cycle for a collection platform (fixed or rotary wing) within an aerial data collection project, often LiDAR.

Metadata: Metadata is any information that is descriptive or supportive of a geospatial dataset, including formally structured and formatted metadata files, reports, and other supporting data.

Multi-channel LiDAR: Multiple channels of data from a single instrument are regarded as a single swath. In this sense, a single instrument is regarded as one in which each channels meet the following criteria:

- They share fundamental hardware components of the system, such as global positioning system (GPS), Inertial Measurement Unit (IMU), laser, mirror or prism, and detector assembly,
- They share a common calibration or boresighting procedure and solution, and
- They are designed and intended to operate as a single-sensor unit.

Nadir: This is the point or line directly beneath the collection platform, corrected for attitude variations. In LiDAR, this would correspond to the centerline of a collected swath.

Overlap: This is the percent of overlap associated with two adjacent flight lines that happens as a result of the plane flying back and forth through the project area to achieve desired uniform data density and optimal ground cover under canopy

Overage: Overage corresponds to those parts of a swath that are not necessary to form a complete single, non-overlapped, gap-free coverage with respect to the adjacent swaths. They are the non-tenderloin parts of a swath. In collections designed using multiple coverage, overage are the parts of the swath that are not necessary to form a complete non-overlapped coverage at the planned depth of coverage. In the LAS Specification version 1.4 (American Society for Photogrammetry and Remote Sensing, 2011), these points are identified by using the incorrectly named “overlap” bit flag. See overlap, tenderloin.

Point Cloud: Often referred to as the “raw point cloud”, this is the primary data product of a LiDAR instrument. In its crudest form, a LiDAR raw point cloud is a collection of range measurements and sensor orientation parameters. After initial processing, the range and orientation associated with each laser pulse is converted to a position in a three-dimensional frame of reference and this spatially coherent cloud of points is the base for further processing and analysis. The raw point cloud typically includes first, last, and intermediate returns for each emitted laser pulse. In addition to spatial information, LiDAR intensity returns provide texture or color information.

Point: A point is defined in the guideline as LiDAR pulse that has been collected, validated and classified.

Pulse: A laser pulse is the transmission of electromagnetic energy from a coherent light source using a laser at a specific wavelength.

Pulse footprint: This is the area of ground intersected by the laser pulse. It is a function of range, angle of incidence, slope of the ground and beam divergence. Pulse footprint energy distribution is define by a Gaussian distribution as $1/e$ or $1/e^2$ depending on sensor used.

Pulse Repetition Frequency (PRF): PRF is the frequency of transmitted laser pulses. High PRF enables dense point-spacing on the ground providing higher-resolution descriptions of the landscape. However, since PRF is inversely related to pulse energy, high PRF might reduce the probability of foliage penetration in densely vegetated areas.

Raster: is a matrix of rows and columns of pixels that contain a value and can represent a surface. See Grid

Spatial distribution: In LiDAR, spatial distribution is the regularity or consistency of the point density within the collection. The theoretical ideal spatial distribution for a LiDAR collection is a perfect regular lattice of points with equal spacing on X and Y axes.

Swath: A swath is the data resulting from a single flight line of collection representing the coverage width area across the flight path of the LiDAR sensor.

Tenderloin: This is the central part of the swath that, when combined with adjacent swath tenderloins, forms a complete, single, non-overlapped, gap-free coverage. In collections designed using multiple coverage, tenderloins are the parts of the swath necessary to form a complete non-overlapped, gap-free coverage at the planned depth of coverage.

Triangulated Irregular Network (TIN): A TIN is a vector data structure that partitions geographic space into contiguous, non-overlapping triangles. In LiDAR, the vertices of each triangle are LiDAR points with x, y, and z values. In most geographic applications, TINs are based on Delaunay triangulation algorithms in which no point in any given triangle lies within the circumcircle of any other triangle.

Vertical Accuracy: Vertical accuracy is the measure of the positional accuracy of a data set with respect to a specified vertical datum, at a specified confidence level or percentile. At 95% confidence, vertical accuracy is defined as:

Vertical Accuracy at 95% = 1.96 x RMSE_z

$$RMSE_z = \sqrt{\frac{1}{n} \sum_{i=1}^n (x_{i(LiDAR)} - x_{i(Survey)})^2}$$

Note that $x_{i(LiDAR)}$ are a set of LiDAR points being evaluated and $x_{i(Survey)}$ are the corresponding survey check points used to compare the LiDAR elevation (z) points at that geographic location. n is the number of check points.

- **Vegetated Vertical Accuracy (VVA):** VVA replaces supplemental vertical accuracy (SVA) and consolidated vertical accuracy (CVA). It is an estimate of the vertical accuracy, based on the 95th percentile, in vegetated terrain where errors do not necessarily approximate a normal distribution.
- **Non-vegetated Vertical Accuracy (NVA):** NVA replaces fundamental vertical accuracy (FVA). It is the vertical accuracy at the 95-percent confidence level in non-vegetated open terrain, where errors should approximate a normal distribution.

Vertical Error: This is the displacement of a feature's recorded elevation in a dataset from its true or more accurate elevation, usually recorded as Delta (Z_D) value.

Waveform Data (Full-waveform): This is a LiDAR system or data in which the entire reflection of the laser pulse is fully digitized, captured, and stored. Discrete return point clouds can be extracted from the waveform data during post processing.

Well-distributed: For a dataset covering a rectangular area that has uniform positional accuracy, check points should be distributed so that points are spaced at intervals of at least 10 percent of the diagonal distance across the dataset and at least 20 percent of the points are located in each quadrant of the dataset (adapted from the NSSDA of the Federal Geographic Data Committee, 1998). As related to this specification, these guidelines are applicable to each land cover class for which check points are being collected.

Withheld Points: A withheld points is marked by a single bit flag indicating that the associated LiDAR point is geometrically anomalous or unreliable and should be ignored for all normal processes. These points are retained because of their value in specialized analysis. Withheld points typically are identified and tagged during preprocessing or through the use of automatic classification routines.

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9.0 REVISION HISTORY

Version 3.1

1. Extensive update of Appendix 1 – Forestry.
2. Fixed various typographical errors.
3. Included bookmarks for quick navigation inside the document.

Version 3.0

1. Addition of Appendix 5 regarding topo-bathymetric LiDAR acquisition.
2. In Appendices 1, 2 and 4, accuracy and density recommendations that were less demanding than the Canadian Quality Level (CQL1) have been modified to meet them.
3. In Appendices 1, 2 and 4, explanations for using the recommended accuracy and density values in the generic formulas in the guide have been added.
4. All references to first and only returns have been changed to first returns.
5. Modification of the formula for vegetated vertical accuracy (95th percentile) and consequently, adjustment of the recommended value for the CQL1.
6. Addition of the statement that acceptable data voids should be excluded from the density assessment.
7. Modification of the grid resolution for assessment of regularity (removal of the requirement to round up).
8. Correction of an error in the decimal values of the horizontal accuracy formula.
9. Correction of an error in the example used for horizontal accuracy (95%) of the CQL1 in Table 1.
10. Modification of the calculated horizontal accuracy value (CHA) to be equivalent to the Horizontal Root Mean Square error (RMSE_R) and corresponding adjustment of the recommended value for CQL1.
11. Addition of indication that the use of satellite-derived PPP corrections is permitted.
12. Rewording of the accuracy requirement for check points.
13. Addition of an alternative not based on the number of error points for the evaluation of the classification for large projects.
14. Addition of new types of classification errors that can lead to data rejection.
15. Addition of indication that only withheld points can be assigned to class 0 in the final point cloud dataset.
16. For the naming convention of LiDAR files, addition of the mention indicating not to insert a quality level if the acquisition is denser or more precise than CQL1.
17. Updating of versions/edits of reference documents.

Version 2.0

1. Addition of generic formulas to determine accuracy and density requirements for LiDAR acquisitions. The CQL1 remains the minimum standard in Canada and is used as an example for the use of generic formulas. The addition of generic formulas allows greater flexibility to establish denser and/or more precise acquisition specifications.

APPENDIX 1 – Forestry

Introduction

Airborne light detection and ranging (LiDAR; also commonly referred to as airborne laser scanning or ALS), has become an important technology to provide simultaneously three-dimensional information on both the vertical structure of forest ecosystems and terrain morphology. LiDAR data are used for a range of natural resource applications related to fibre and non-fibre goods and services (e.g., wildlife habitat, clean water, recreation). The data are useful for estimating biophysical parameters (e.g., height, volume, aboveground biomass, vegetation density), as well as indicators of biological diversity (e.g., forest area coverage, structural assemblage, riparian habitat characterization), and indicators of ecosystem condition and productivity (e.g., post disturbance structure, canopy gaps, growth and yield forecasting). Forest inventory applications of LiDAR are typically either area-based or at the individual tree level. While the area-based approach (ABA; Næsset, 2002) is currently considered operational in a forest inventory context, individual tree approaches (ITA; e.g., Hyyppä & Inkinen. 1999) continue to be developed due to the inherent complexities in successfully delineating individual tree crowns. LiDAR can further be used for accurate and precise mapping of the terrain surface beneath the forest canopy. The derived bare-earth Digital Terrain Model (DTM) has utility for a broad range of applications (e.g. forest engineering, hydrological modelling, soil mapping).

The information provided in this appendix represents current recommended minimum specifications regarding airborne LiDAR acquisitions in support of forest applications. There are complex interactions between acquisition parameters, as well as between the laser pulses, the targeted forest environment, and complexity in topography, which require specifications to be assessed holistically, and tailored to suit project-specific information needs. Furthermore, these guidelines are not intended to be prescriptive, as sensor technology evolves rapidly and project-specific information needs vary and must also be considered.

Note: Currently, discrete return linear mode, discretized full waveform and more recently, single photon or photon-counting LiDAR data are being used in forest applications. The recommendations outlined in this appendix pertain solely to linear-mode and discretized full waveform LiDAR data, as recommended flight specifications and preprocessed point cloud data are similar. For details pertaining to single-photon LiDAR data, White et al. (2021a) and White et al. (2021b) evaluate in detail the use of these data for terrain characterization and operational implementation of enhanced forest inventory (EFI) using an ABA, respectively. For a model development and applications guide for generating an EFI using LiDAR and an ABA, see White et al. (2013 and 2017).

Data Considerations

The LiDAR data must be acquired consistently across the entire dataset to produce robust derivatives (i.e., metrics, predictions, surface models). The spatial distribution of useable points (LiDAR returns) must therefore be uniform and free from clustering, with consistent pulse densities throughout the project area. Ultimately, the uniformity in the sampling distribution across the target area is an important component of the data quality and helps assess its suitability for use. Multiple factors affect the distribution of pulse returns in a LiDAR dataset

(e.g., instrument characteristics and parameterization, terrain, turbulence, environmental conditions, vegetation structure). Table A1 provides some guidelines regarding minimum pulse density ranges for different Canadian forest types. Below are the main data considerations:

- A mixture of sensors and sensor generations on a single project should be avoided as the optimal acquisition specifications will inevitably vary (beam divergence, wavelength, return digitization capability, etc.) causing non-uniformity in the resulting merged dataset, and consequently impacting any subsequent use of these data. It is advisable that sensors with similar characteristics and parameterization be used with coincident flight parameters for data acquisitions in support of a given project.
- LiDAR systems using a conical, rotating, or nutating mirror system yield uniform sampling patterns throughout the sampled swath, and hence minimize uneven spacing in sampling, namely at the swath's edge. Uneven spacing in sampling can be greatly reduced using a 50% overlap with oscillating mirror systems. Additionally, certain oscillating mirror systems are equipped with technology that offers a dynamic field of view. The technology maintains fixed-width swaths, despite variations in terrain height, while sustaining regular point distributions.
- Opposing adjacent flight lines can increase the configurations from which the forest is sampled, although are not a requirement when using conical scan systems due to the two ground perspectives achieved in a single flight line.
- The targeted forest environments' structure can be used to guide the scan angle limit. For example, the use of greater scan angles has been demonstrated to be inconsequential on the estimation of forest attributes for open canopies, or canopies composed of spike-like crowns on relatively uniform terrain, providing sufficient overlap (i.e., min. 20%) is maintained between flight lines (e.g., $\pm 30^\circ$ for balsam fir dominated stands; van Lier et al., 2021). Greater scan angles produces a wider swath width, however the probability of obtaining ground returns decreases at the swath's edge, notably for dense and complex forest environments. In open terrain and sparse forest environments, a wider scan angle has less effect on the nominal point spacing (NPS) of ground returns.
- Requirements should consider the type of terrain, the complexity of the forest structure being sampled, the desired derived information products and their scale.
- The pulse density must be sufficient to reliably characterize the environment of interest throughout the project area. Greater pulse densities increase sampling of the forest canopy, increase the likelihood of obtaining ground returns, and increase confidence in identifying ground returns in forested areas, especially in complex environments. The majority of sensors made within recent years will achieve, and most often exceed, the recommended minimum of 2 pulses per square meter, even at the highest operating altitudes. As a general rule, the required pulse density will increase as the complexity of the forest environment sampled and/or associated terrain increase.

- Fall or early spring LiDAR acquisitions during leaf-off conditions in areas of significant deciduous tree cover, and where understory and other vegetation cover are in a dormant state, will decrease the NPS of ground returns, producing a more accurate terrain characterization and consequently a higher quality DTM. By contrast, acquiring data during leaf-on conditions may enable improved characterization of forest structure, although the requirement for a leaf-on or leaf-off data acquisition is ultimately dependent on the forest type and the information needs. White et al. (2015) provide a summary of literature that explore the use of leaf-on and leaf-off data using an area-based approach. Note that a mixture of leaf-on and leaf-off acquisitions on a single project should be avoided as the change in forest structure may necessitate additional sampling and modelling efforts to produce coherent products.
- A DTM grid with a spatial resolution of 2 m or less is suitable for height normalization of the point cloud. A finer resolution may be required for extremely steep terrain.

Forest Region ¹	Characteristics	ABA Minimum Pulse Density ²	ITA Minimum Pulse Density
Boreal; Acadian	Primarily conifer forests with areas mixed with deciduous trees, particularly in riparian zones. Sparse and open canopies with diminishing tree sizes and low relief are found in Northern forests, while dense and open to closed canopies with undulating to hilly topography is characteristic of southern forests.	2 - 4 pls/m ²	6 - 8 pls/m ²
Deciduous; Great Lakes – St. Lawrence	Primarily deciduous forests and areas mixed with conifer trees comprised of dense and closed canopies with rolling topography and low relief.	2 - 4 pls/m ²	4 - 8 pls/m ²
Montane; Coast; Columbia; Subalpine	Sparse and open canopies in higher elevations, closed and dense canopies in lower elevations. Predominantly mountainous topography with high relief.	6 – 12 pls/m ²	6 – 12 pls/m ²

Table A1: Guidelines for minimum range of aggregate pulse densities depending on forest inventory application and forest region. **Note:** required pulse densities increase with increases in either forest environment and/or terrain complexities.

Acquisition Parameter Specifications and Considerations

LiDAR sensors can be configured in a manner to be optimized for forest applications. Again, the parameters selected for forest applications are dependent on the intended project objectives and associated information needs. Table A2 provides a summary of recommended acquisition

¹ Rowe (1972)

² Although minimum pulse densities of 1 pls/m² have been recommended to support the ABA (e.g., White et al., 2013), the density ranges presented here have been adjusted for coherence with Canadian minimum standards presented within this federal guideline.

parameters based on current scientific knowledge and available sensors. No single parameter can be assessed on its own as many are dependant on one another (e.g., increasing pulse repetition frequency will increase pulse density; increasing flight altitude will decrease pulse density). Detailed recommendations regarding LiDAR data suitable for the ABA are similarly further discussed in White et al. (2013).

The recommendations below should be viewed as absolute minimum requirements. Seeking expert opinion from service providers on appropriate parameters for specific forest conditions and project needs should always be undertaken. In general, end users should be particularly concerned with sufficient pulse density, swath overlap, scan angle, and acquisition timing (i.e. leaf-on versus leaf-off data).

Acquisition Parameter	Recommendation	Considerations
Laser beam divergence	Between 0.1 - 0.6 mrad	The angular spread of the laser pulse and flight altitude influence the footprint size of the laser pulse on the ground (e.g., altitude of 1000 m with a beam divergence of 0.5 mrad will yield a footprint ~50 cm in diameter).
Scan angle	$\leq 20^\circ$ off-nadir is recommended; up to $\leq 25^\circ$ off-nadir.	Narrower scan angles increase penetration through the canopy, support smaller footprints, and increase incident pulse energy.
Swath overlap	50% overlap is recommended; 20% is the minimum.	Double coverage at planned aircraft height above ground is obtained with a swath overlap of 50%, ensures the target is double sampled when using oscillating, rotating or nutating mirror scanners, and further reduces the potential of data gaps. Although gyro-stabilized mounts mitigate the risk of gaps between flight lines, a minimum swath overlap of 20% is recommended to ensure no data gaps occur between the useable portions of the swaths. When overlap is less than 20%, the potential for data gaps to occur between swaths increases.
Pulse repetition frequency	50 kHz or more (current systems offer > 400 kHz)	Higher pulse repetition rates allow for faster flying while maintaining similar point densities.
Returns per pulse	4 or more potential returns	Five returns are well within the capacity of current LiDAR sensors.
Environmental conditions	Clear sky Snow free	Atmospheric conditions should be cloud, fog, haze and smoke free between the aircraft and ground. The ground must be free of snow and of extended flooding. See the Section 6.2.1 Conditions of the Federal Airborne LiDAR Data Acquisition Guideline for additional details on the acquisition conditions considerations.

Swath-to-swath vertical accuracy	± 0.08 m (RMSD _z)	± 0.05 to 0.25 m difference in z between swaths is acceptable, depending on survey objectives.
Vertical accuracy	± 0.1 m (RMSE _z)	The vegetated vertical accuracy (VVA) under the canopy is impacted by the interaction between the laser and the canopy. Therefore, up to ± 0.50 m relative error in z is acceptable, depending on survey objectives.
Horizontal accuracy	± 0.35 m (RMSE _R)	± 0.5 to 1 m relative error in (x,y) , depending on survey objectives. Can be difficult to quantify, often measured according to manufacturer's documentation.

Table A2: Summary of minimum recommended LiDAR survey design specifications and associated considerations for forest applications (adapted from Laes et al., 2008 and White et al., 2013).

- To establish all the specifications related to the density of a LiDAR data acquisition project, a value within the pulse density range associated to the appropriate application and forest type may be used as an Aggregate Nominal Pulse Density (ANPD) in the generic formulas in Sections 5 and 6 of the Federal Airborne LiDAR Data Acquisition Guideline.
- To establish all the specifications related to the accuracy of a LiDAR data acquisition project, the vertical (RMSE_z) and horizontal (RMSE_R) accuracies recommended in the table above can be used in the generic formulas in Sections 5 and 6 of the Federal Airborne LiDAR Data Acquisition Guideline. A documented quality check and verification process should be included with the data delivery.
- Current LiDAR sensors have high repetition rates sufficient for providing adequate pulse densities. Sensor configuration of repetition rate should be largely determined by flight parameters, designed ANPD, scan angle, swath overlap for no gaps and sufficient pulse energy to avoid drop outs.
- LiDAR surveys should be designed and conducted with the objective of having no data voids, except in areas where low near infrared surface reflectance features are present, such as waterbodies. The spatial distribution of geometrically usable points should be uniform and regular except for data void areas. A specified minimum pulse density, as recommended in Table A1 or defined by the project objectives, should be present in 90% of cells of a uniform density grid within usable portion of a swath. See the Section 6.1.1 Project Method of the Federal Airborne LiDAR Data Acquisition Guideline for additional details on the acquisition planning considerations.
- A recommended minimum LiDAR point cloud classification will be conducted for forest applications compliant with ASPRS LAS 1.4 – R15 format and specification. Classification should be consistent across the entire project, void of noticeable variation in character, texture or quality of the classification between tiles, swaths, lifts or other non-natural division. Classification accuracy should be in compliance with the Federal Airborne LiDAR Data Acquisition Guideline in Section 4. Calibrated unclassified LiDAR returns (Class 0; Created, never classified) will be classified and assigned to Class 2 for bare earth ground returns, Class 7 for low noise, and Class 18 for high noise. Outliers, geometrically unstable pulse data, and blunders will be identified using the Withheld Flag

and not be used in the classification process. The remaining points will be placed into Class 1 for processed but unclassified. Additional classification requirements will be based on project-specific requirements, which may include Class 3 for low vegetation, Class 4 for medium vegetation, Class 5 for high vegetation and Class 9 for water.

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APPENDIX 2 – Flood Mapping

Introduction

LiDAR data is considered to be the primary source of Digital Elevation Model (DEM) data for various flood mapping applications, including specialized technical products such as inundation, flood hazard or flood risk maps, as well as public information maps. The primary goal of LiDAR applications in flood mapping is to obtain accurate elevation data, which are required for both the hydraulic modelling (deriving water elevations and extents for floods of various magnitudes) and the cartographic components of flood mapping projects. The elevation datasets include:

- Ground elevation data, which is built from last LiDAR returns, contains only topography, and is usually referred to as the Digital Terrain model (DTM).
- First return elevation data, which is built from first returns and includes structures (e.g. buildings and bridges) and tree canopy, and is usually called the Digital Surface Model (DSM).

Another use of LiDAR data is to facilitate flood zone area characterization, i.e. extraction of planimetric or basemap features useful for guiding hydraulic modelling and for creating flood maps, such as roads and pavement areas, stream banks, bridges, ditches, etc. Flood zone area characterization is best accomplished using LiDAR in combination with orthophotos. The level of detail in flood zone area characterization should be appropriate for the scale of the intended flood mapping (e.g. higher detail will be required for 1:2,000 scale maps compared to 1:5,000).

Data Acquisition Considerations

Low Flow Conditions

In addition to the environmental conditions typically recommended for LiDAR data collection (no snow or ice on the ground, shorelines and water courses free from significant ice buildup, no unusual flooding or inundation), LiDAR collection for flood mapping should take place during base flow (dry) conditions to maximize the area of water courses exposed; thus, maximizing the utility of the collected data for hydraulic modelling.

Stable Flows and Levels

Flow and levels in the water courses and water bodies should remain stable, i.e. free of significant fluctuations throughout the data collection period to maximize consistency of collected data. This is important in situations where water flows/levels are prone to rapid changes, e.g. rivers with flashy response or regulated rivers. When data collection spans a significant length of time (usually due to a large size of data collection area, which could potentially require data acquisition during several seasons), preference should be given to data collection during similar flow/level conditions.

Leaf-off Conditions

Leaf-off conditions are recommended to maximize canopy penetration thus maximizing ground point density and the quality of the resulting DTM. However, leaf-off acquisition is not required as long as the point density and vertical accuracy of non-canopy returns are sufficient to meet DTM and DSM accuracy requirements. In some cases leaf-on acquisition may be preferred or necessary to map and characterize vegetation types, for example for hydrological or detailed hydraulic (e.g. estimation of Manning's n) modelling.

Acquisition Parameters

Table B1 summarizes the minimum required and recommended LiDAR acquisition parameters for flood mapping applications. Higher swath overlap is recommended for areas of high relief terrain.

Acquisition Parameter	Minimum	Recommended
Swath overlap – overlap between geometrically usable portions of swaths (typically 95% of swath width)	20%	50%
Field of view (FOV)	± 25 degrees from nadir	± 20 degrees from nadir
Number of returns	≥ 2	>3
Intensity	Yes	Yes

Table B1: Minimum required and recommended LiDAR acquisition parameters for flood mapping applications.

Orthophoto Acquisition

Aerial images, particularly orthophotos, are extremely useful for flood mapping, providing valuable information for hydrologic, hydraulic and risk analyses, as well as a very useful basemap dataset for all types of flood maps. Orthophotos are also invaluable for hydro-enforcement of DTM, which is a recommended practice for post-processing LiDAR-derived DEMs (see below). If sufficiently high-quality and up-to-date orthophotos are unavailable for the planned LiDAR data collection area, consideration should be given to acquisition of orthophoto data within the same time frame as LiDAR to maximize data usability for flood mapping.

Data Quality Considerations

Data Density and Accuracy

Floods can have a variety of land cover types from open to low vegetation, brushland, forested or urban. Acquisition of LiDAR data in the flood zone area is therefore subject to a variety of conditions and should ultimately be guided by the need to collect sufficient ground returns for all cover types present in the flood zone area. For example, if a portion of the data collection area is covered in dense riparian vegetation, higher overall data collection density may be required in order to achieve sufficient ground point density in the riparian area.

The level of data collection effort (point density, vertical and horizontal accuracy) should generally reflect the requirements of the intended flood mapping application, which typically

depend on the level of flood risk and the regulatory framework in place. Table B2 lists the recommended approximate LiDAR data accuracy and density specifications for flood mapping applications. These specifications meet the minimum requirement for airborne LiDAR data acquisition in Canada (CQL1) and are established according to the flood risk category, based on the review of existing provincial and territorial guidelines (Alberta Environment, 2011; Kerr Wood Leidal, 2011; Spatial Energistics Group, 2012; Elevation Coordination and Consultation Committee, Government of Ontario, 2016) and the National Floodplain Mapping Assessment report by MMM Group Limited (2014). The flood risk categories are defined following the MMM report, and are similar to the vertical accuracy classes adopted in the Ontario guidelines:

- High Flood Risk Category: All urban areas and rural areas that are protected by diking;
- Medium Flood Risk Category: All other rural areas that include settlements and agricultural lands;
- Low Flood Risk Category: Sparsely populated areas.

	Flood Risk Category		
	High	Medium	Low
Vertical Accuracy (open, level, hard surfaces)			
Non-vegetated Vertical Accuracy (NVA) – Vertical Root Mean Square Error (RMSE _z)	5.0-7.5 cm	7.5-10.0 cm	10.0 cm
Non-vegetated Vertical Accuracy (NVA) – 95% confidence level ($\approx 1.96 * RMSE_z$)	10-15 cm	15-19.6 cm	19.6 cm
Horizontal Accuracy (open, level, hard surfaces)			
Horizontal Root Mean Square Error (RMSE _r)	11-15 cm	30-35.1 cm	35.1 cm
Horizontal Accuracy – 95% confidence level ($\approx 1.7308 * RMSE_r$)	20-25 cm	50-60 cm	60 cm
Data Density			
Aggregate nominal pulse density (ANPD)	4-10 pls/m ²	2-4 pls/m ²	2 pls/m ²

Table B2: Recommended approximate LiDAR data accuracy and density for flood mapping applications.

The accuracy and density specifications to be used depend on the flood risk category. To determine the risk category, refer to the definitions above. Once the category has been identified, values within the ranges of vertical (RMSE_z) and horizontal (RMSE_r) accuracies and density (DNGL) in the table above can be used in the generic formulas in sections 5 and 6 of the Federal Airborne LiDAR Data Acquisition Guideline.

Classification

The minimum required classes include ground, non-ground, bridge decks and water, which are necessary for creating a hydro-conditioned DTM. Buildings and other man-made structures class(es) will also typically be required to create a DSM, as well as to facilitate the removal of the building/structures returns from the DTM. It is recommended that the DTM should have at least 90-95% of buildings and structures removed. In addition, vegetation classes may be necessary in some cases for hydrotechnical modelling and base mapping.

Hydro-flattening

Hydro-flattening is a post-processing method applied to LiDAR-derived DEMs to ensure that water surfaces are flat in the bank-to-bank (perpendicular to the apparent direction of flow) direction, and non-increasing in the downstream direction. In some cases, further hydrological enforcement may be required for drainage features and flat river area with islands/channels where 2D flows may occur. Hydro-flattening is a recommended flood mapping application, the specific guidelines and specifications would be defined by the contracting authority

Other Considerations

Topo-bathymetric LiDAR

Consideration may be given to utilizing topo-bathymetric LiDAR systems for simultaneous and seamless collection of topographic and bathymetric data. Traditional methods for collecting bathymetric data (underwater portion of the river channel geometry), which involve echo sounding devices on boats or manual surveying, are expensive, time consuming and potentially hazardous. Topo-bathymetric systems include a green laser for penetrating the water and measuring the bathymetry and are able to generate a seamless above/below water elevation data. Details on using topo-bathymetric LiDAR are included in Appendix 5.

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APPENDIX 3 – High Relief Terrain

Introduction

Conducting topographic mapping and/or forest inventory in high-relief terrain areas using airborne LiDAR data requires an adjusted approach to data collection. High relief areas are typically mountainous areas where steep slopes occur e.g. > 35 degree and there is significant altitude change that results in implications to LiDAR collection e.g. surface conditions due altitude temperature difference or impacts on flying parameters due to terrain characteristics. High relief areas complicate typical data collection due to a mix of undulating terrain, steep slopes, remote access, and environmental conditions. The intent of this section is to provide recommendations and considerations when collecting airborne LiDAR data in high-relief areas.

Parameter	Condition	Description
Scan Angle	Select narrow scan angles $\leq \pm 15^\circ$	The rapid surface slope changes in mountainous terrain can elongate laser pulses footprints and have a more pronounce effect on vertical features such as trees. The steep slope also increases positional uncertainty at swath edges. Narrow scan angels minimize this effect and provide improved mapping of trees in mountainous areas.
Overlap	50% recommended	Changing terrain increases the potential for data gaps. Higher overlap between flights lines minimizes gaps in the data and increases ground penetration in high relief terrain.
Pulse Repetition Frequency (PRF)	Lower to increase pulse return energy and less drop out.	Steep slope and uneven terrain increases LiDAR pulse scattering away from the receiving sensors resulting shot drop out. Lower PRF increases transmitted pulse energy, potentially lowering pulse drop out. In addition, aircraft can fly higher, increasing safety margin.
Collection Conditions	At altitude, surface snow persist longer and terrain can create higher wind turbulence	Snow on the ground at higher altitudes remains longer than at lower elevation. The window of data collection is narrower and planning should consider the impact of extended surface snow period at altitude. Also, terrain characteristics may increase air turbulence in the data collection area. This will impact the quality of the data including increase potential of data gaps due to aircraft rolling to compensate for windy conditions.

Positioning	GNSS signal loss	Aircraft and in-situ check point measurements using GNSS receivers may be impacted by terrain blockage. Terrain may impact the PDOP value reducing the number of visible satellites and the determination of position. Ground base station baseline distance is recommended at 25-30km
Flight Lines	Adjust flight block size and orientation	Flight planning should consider terrain characteristics including orientation and sizes of flight blocks for creating even swath areas and pulse density distribution. Smaller block sizes are recommended.
Remote Access	Difficulty collecting Checkpoints	High-relief areas present challenges for in-situ checkpoint collection. Access can be difficult and may limit the number of checkpoints.

Table C1: Recommended collection parameters.

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APPENDIX 4 – Urban Infrastructure Mapping

Introduction

The advancements in airborne LiDAR technology provide a multidimensional data source for 3D mapping at finer precision for urban environments. LiDAR applications for cities include mapping building features, urban forestry, defining floodplain areas, utility feature extraction, land cover classification and corridor assessment to name a few. Adjustments to LiDAR data collection and processing are needed to accommodate the variation in the urban landscape. This guideline aims to provide general guidance for LiDAR data collection for different types of urban applications.

Data Collection Considerations

Table D1 is general data collection consideration and recommendations for collecting in urban environments.

Items	Description
Conditions	The collection of LiDAR data for urban infrastructure is desirable to be acquired under leaf-off conditions except for the applications of urban forestry. This increases exposure to ground, building rooftops and distribution wires. Other collection conditions as specified in Section 4 would be recommended.
Swath Overlap	This should be no less than 50% of the swath overlap to minimize voids, building shadowing or surface areas with little to no near infrared reflectivity such as asphalt.
Scan Angle	Narrow scan angles ≤ 40 degrees Field of View (+/- 20 degrees from the nadir) to minimize occluded areas.
Accuracy Requirements	Typical urban applications of LiDAR technology would desire pulse data vertical accuracy within open areas 7.5 cm (RMSE _z) and horizontal accuracy 25 cm (RMSE _R).
Pulse Footprint	Small footprints are preferred for detecting edges of objects.
Return	Multiple discrete returns are usually required, at least first and last returns. Intermediate pulses are beneficial for tree/forestry applications, multiple wires and building edges.
Flight Orientation	Depending on the orientation of roadway, flight lines perpendicular to road orientation for cities dominated by rectilinear grid roads would be preferred. Furthermore to minimize occluded areas, flights could be orientated for both parallel and perpendicular lines. However, this would require additional cost due to increase flying requirements.

Table D1: Collection considerations.

Data Processing Considerations

The LiDAR data acquisition process should include intensity image, point cloud classification and digital surface models. Digital surface models for cities include Digital Elevation Models with appropriate breaklines and hydro-flattening, Digital Surface Model and Canopy Height Model. Additional point cloud classification of pulse data based on LAS 1.4 – R15 classification would depend on project specific requirements but may include features such as rails, road surface, wires, and vegetation. Additional classes that could be assigned to class 64-255 for urban environments includes, light poles, road markings, street car tracks, electrical distribution poles, sidewalks, parking lots, and trails.

Pulse Density for Feature Extraction

The table below represents recommended LiDAR pulse density ranges (ANPD) for various urban applications for feature extraction. General recommendation for urban mapping is for a pulse density ≥ 10 pls/m², however depending on project specific objectives, the pulse density may range to accommodate the type of feature extraction.

Application	Data Collection	Data processing
Building Footprint Extraction	8 - 15 pls/m ²	Building footprint extraction depends on the desired level of detail of the structure and the physical spacing between the buildings and roof features. In developed urban environments, higher pulse density is preferred with small pulse footprints to accurately define building edges, gaps between buildings and roof characteristics. Intermediate pulses may be beneficial for refining building edges.
Land Cover	5 - 10 pls/m ²	General urban land cover classification using LiDAR data requires sufficient pulse density to separate different land cover features. In cities, land cover types change rapidly and detecting small land cover types requires higher pulse densities.
Terrain	4– 15 pls/m ²	Mapping urban topography requires sufficient spatially distributed pulse density to extract ground features. The pulse density is dependent on the complexity of the terrain and accuracy required.
Utility and Corridor Mapping	10 – 25 pls/m ²	The mapping of utility wires, light poles, road marks and signs requires

		high pulse density with narrow footprints at regular short pulse spacing; whereas, intermediate pulse return may be desirable for mapping poles with multiple wires.
Individual Trees	4 - 12 pls/m ²	Tree modeling requires a higher pulse density than forest area mapping and requires a smaller footprint size.
Forest Area	2 – 4 pls/m ²	This is adequate for canopy height modeling and bare earth returns.
City 3D Model	6 – 20 pls/m ²	The pulse density for generating DSM, DEM, Classified point clouds depends on the application of the model.

Table D2: Pulse Density Ranges for Feature Extraction.

Considerations, Limitations and Assumptions

- A value within the pulse density range associated to the appropriate application may be used as an ANPD in the generic formulas in Sections 5 and 6 of the Federal Airborne LiDAR Data Acquisition Guideline.
- Acquisition of airborne LiDAR data in urban areas may be performed during day or night and may be restricted due to air traffic control limitations. Planning for data collection should consider impacts to scheduling due to limitations in collecting the data near airports.
- In urban areas, certain building heights and structures can contribute significantly to LiDAR shadows and occlusions, which can cause a large number of data gaps in the LiDAR point cloud. From this perspective, multiple angles or narrow FOV of LiDAR systems may be necessary for urban applications. The decision should provide a balance between the building density, height and road network orientation in conjunction with financial considerations.
- In mapping buildings and the distribution of power lines, these may be obscured by trees; therefore, they may not be fully extracted from LiDAR data. Leaf off conditions can improve the detection of these features.
- Some building roofs and walls are made of glass which may be transparent or semitransparent. Consequently, there is a significant number of unexpected LiDAR points reflected from objects inside the building and under the rooftop. Many of these points may be considered as noise; thus, classified point clouds should take noise class into account.

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APPENDIX 5 – Airborne topo-bathymetric LiDAR

Introduction

Airborne topo-bathymetric LiDAR (TBL) systems typically utilize two lasers: a near infrared (NIR) laser for topographic data collection and a green laser for bathymetric data collection. These systems allow for the generation of high-resolution seamless digital terrain models (DTMs) that include land and submarine elevation. TBL works equally well in fresh or saltwater, however the water clarity is typically the limiting factor. Although shallow water (TBL) sensors are relatively new, the deeper water airborne laser bathymetry sensors were referred in the literature to ABL systems – airborne bathymetric LiDAR. For the rest of this Appendix, all systems will be referred to as TBL systems. The technology for TBL systems has been around since the late 80's and early 90's. A recent text entitled "Airborne Laser Hydrography II" provides a detailed history of the technology and a review of the current systems and application of TBL and is free to download (Philpot, 2019).

The intent of this Appendix is to concentrate on the bathymetric LiDAR component of TBL systems for specifications and guidelines. A focus is made on TBL for flood risks applications. For information related to the topographic component of TBL surveys, one should refer to section 6 of the current guideline and the appendix 2 on flood mapping. The topographic component of TBL surveys for flood risks applications must at least meet requirements presented in appendix 2.

Topo-bathymetric LiDAR general principles

TBL works by emitting a near-infrared (NIR) and a green laser from an aircraft, typically in an elliptical or circular scan pattern, and measuring the travel time of the laser pulses to and from the land, water surface, and seabed (Figure A1 A, B). The NIR laser pulse reflects off the land or water, while some of the green laser pulse is reflected at the air-water interface, the rest is refracted and attenuated as it passes through the water column and is reflected from the seabed to return to the detector (Figure A1-C, D). The travel path of the green laser is complex. As it passes from air to water, the speed of the light slows down by approximately 25% and thus is refracted. Once in the water column, the green light is scattered and loses its energy exponentially with depth until it reflects off the sea-river bed and returns to the detector. In order to compensate for the refraction angle and change in the speed of light from air to water, the system must be able to detect the water surface. The NIR laser returns and the green laser returns are used to detect the water surface in order to compensate for these optical effects of the green laser changing media from air to water and the return path back to the detector. The beam divergence of the NIR laser is typical of that of topographic LiDAR on the order of 0.5 mrad, whereas the green laser will have a larger beam divergence on many TBL sensors.

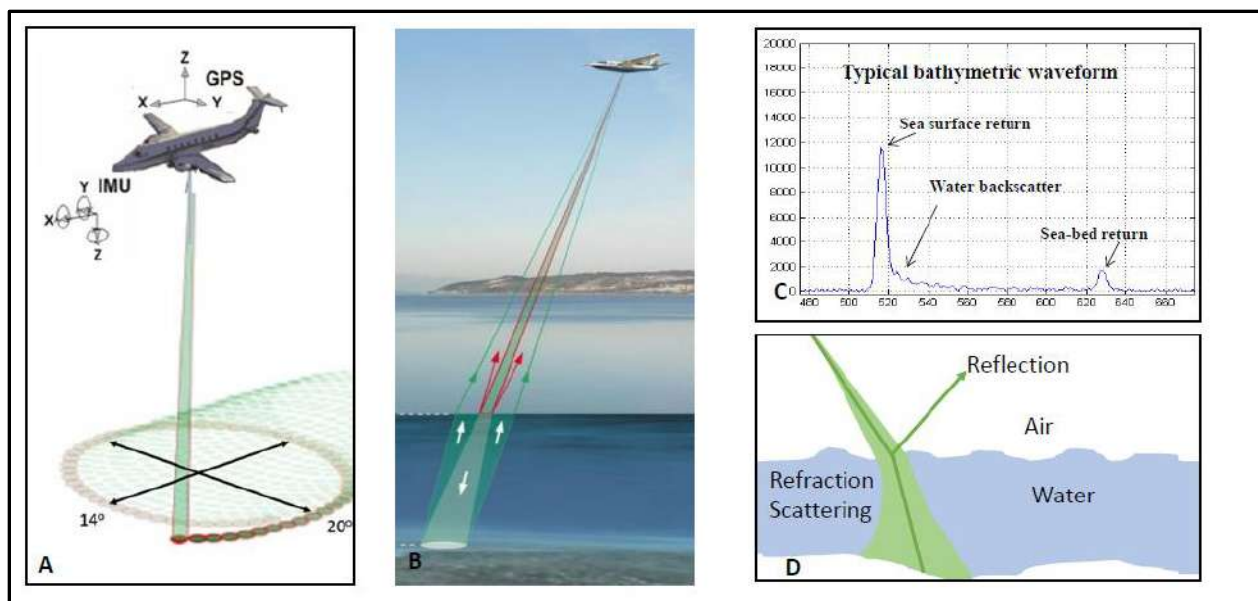


Figure A1. Topo-bathymetric LiDAR (TBL) principles. A - Typical elliptical scan pattern for TBL with navigation system GPS+IMU. Image taken and adapted from Leica Geosystems. B- Most TBL system have a NIR and green laser. C – Typical waveform captured from the green laser. D – Interaction of the green laser light when travelling between air and water, refraction and scattering take place.

The main limiting factor affecting depth of penetration of TBL is water clarity. Thus, turbidity management is required for a successful survey. The main sources that can adversely affect the green laser from penetrating the water column come from suspended sediment, although algae blooms may also have negative impacts, as well as dissolved organic matter which can be common in some lakes and streams that originate in bogs. The water clarity fluctuations of a study site should be considered when planning a survey (See section 'Guidelines for a Topo-Bathymetric LiDAR project'). Moreover, the green laser of the TBL does not penetrate air bubbles (white caps, surf zone, etc.) as a result of the scattering. This has implications along coastlines with heavy surf that may need to be flown twice at different tide levels.

Flights operations, GNSS base stations set up and sensor calibration principles are similar to those of typical topographic LiDAR and thus are not presented here.

The processing of TBL data after a mission is like topographic data as the first step is to process the trajectory of the aircraft using a ground base station and the GNSS and inertial measurement unit in the sensor. During a TBL survey, the waveforms of the NIR and green laser are recorded and are related to the trajectory by GNSS time. Once related to the trajectory, the waveforms are then post processed into discrete points. During the processing of the green laser waveforms, the water surface is detected and modelled for the green laser pulse path to be refracted at the water surface and the range adjusted by the change of the speed of light in water. The typical recorded waveform from the green laser consists of a large amplitude return from the water surface followed by the volume backscatter of the laser pulse through the water column and then a peak representing reflection off the seabed or riverbed (Figure A1-C).

One distinct advantage of surveying hydrography with TBL when compared to echo sounding is that the speed of the light in water is only marginally affected by changes in salinity and temperature compared to how these properties effects on the speed of sound in water. This

property makes TBL ideal for surveying in estuarine environments where fresh and saltwater mix in a sometimes-complex fashion.

Benefits of Topo-Bathymetric LiDAR for flood risk mapping

Most recent flood inundation maps were based on topographic LiDAR alone with no details of the bathymetry. Although the methods used to produce inundation maps from topographic LiDAR have been found to be reasonably accurate, these approaches do not calculate the speed of the flood water or the time and duration of inundation. In order to calculate these variables, one must utilize a hydrodynamic modelling software. One of the main parameters that controls the movement of water in a hydrodynamic model is the bathymetry. Other parameters also effect the movement of water including bed roughness, sometimes defined as Manning's Roughness Coefficient, which effects the drag between the water and the bed. The results of TBL survey can provide information of topography and bed material (with LiDAR intensity) and have been used to construct benthic cover maps or habitat maps (Webster et al., 2016), which can be used to estimate bed roughness for hydrodynamic models.

Coastal flood risk is associated with elevated sea-levels associated with storm surges. In addition to elevated total water levels (tide+surge), waves and wave-runup can also cause additional flooding and erosion. In order to model the hydrodynamics of a storm surge event and possible wave set-up and run-up, a seamless DTM is required. In order to calculate wave set-up and wave run-up, near shore bathymetry is required (Olabarrieta and Warner, 2016). Nearshore bathymetry has been a challenge to map prior to TBL. Most techniques for mapping land elevation do not work in the coastal zone (e.g. photogrammetry, topographic LiDAR) and techniques to map the deep water such as boat-based echo sounding are dangerous and inefficient in shallow water. The ability of TBL to acquire seamless DTMs across the coastal zone into the near shore has enabled detailed hydrodynamic models to be constructed.

In the case of fluvial or inland flood risk mapping, many studies have used topographic LiDAR to map the exposed floodplain and estimate the river channel topography. Many fluvial models are based on 1-Dimensional hydrodynamic models, or 1-D models where cross-sections are extracted from the floodplain and river channel and used to calculate the momentum and mass of water moving through the section. Measuring riverbed cross-sections manually (e.g. Using GNSS, or boat-based echo sounding) is expensive and time consuming and in some cases dangerous to the operators. As a result, the channel topography is only measured in a few cross-sections and the remaining areas are estimated by interpolation or using an empirical relationship based on the exposed channel geomorphology. The discharge or flow (cubic meters per second) of a river is controlled by the channel bathymetry and gradient. The ability of TBL to acquire seamless elevation data of the floodplain and the river channel offers a great deal of potential to improve the accuracy of the cross-sections that are used in flood models.

Accuracy standards

The International Hydrographic Organization (IHO) specifies different Orders standard for bathymetric data in terms of total vertical or horizontal accuracy, at 95% confidence interval (IHO, 2008). The Order 1 standard applies for areas shallower than 100 m and Special Order is typically recommended for areas or applications requiring the highest accuracy of survey. The

Total Vertical Uncertainty (TVU) varies with depth and is defined in the equation below, where ‘a’ represents the portion of uncertainty that does not vary with depth (e.g. airport position uncertainty from the trajectory processing), ‘b’ represents the coefficient of the portion of the uncertainty that varies with depth ‘d’. All TBL system currently on the market can exceed the Order 1 requirements set out by IHO for depths less than 100 m (Saylam et al., 2018).

$$TVU = (a^2 + [b \times d]^2)^{1/2}$$

The following table describes the different IHO Orders and the horizontal and vertical accuracy expected.

ORDER		Exclusive	Special	1a	1b	2	3 (Imprecise)
Examples of Typical Areas		Shallow water in Harbours, berthing areas, and associated critical channels with minimum under-keel clearances or engineering surveys	Harbours, berthing areas, and associated critical channels with minimum under-keel clearances	Areas shallower than 100 metres where under-keel clearance is less critical but <i>features</i> of concern to surface shipping may exist.	Areas shallower than 100 metres where under-keel clearance is not considered to be an issue for the type of surface shipping expected to transit the area.	Areas generally deeper than 100 metres where a general description of the sea floor is considered adequate.	All areas where the accuracies do not meet the requirements of the previous orders
H	Horizontal Accuracy (95% Confidence Level)	1m	2m	5m + 5% of depth	5m + 5% of depth	20m + 10% of depth	> 20m + 10% of depth
V	Depth Accuracy for Reduced Depths (95% Confidence Level) ⁽¹⁾	a = 0.15m b = 0.0075	a = 0.25m b = 0.0075	a = 0.5m b = 0.013	a = 0.5m b = 0.013	a = 1.0m b = 0.023	Same as order 2

Table E1: IHO Orders and horizontal and vertical accuracies at 95% confidence interval (IHO, 2008).

In order to better appreciate how the TVU varies with depth for these different IHO orders, the TVU has been calculated at typical depths achieved by shallow water LiDAR sensors (15 m) and deep-water sensors (20 m and greater) (Table E).

IHO Order	a	b	TVU (m) d=5m	TVU (m) d=10m	TVU (m) d=15m	TVU (m) d=20m
Exclusive Order	0.15	0.0075	0.15	0.17	0.19	0.21
Special Order	0.25	0.0075	0.25	0.26	0.27	0.29
Order 1a	0.5	0.013	0.50	0.52	0.54	0.56
Order 1b	0.5	0.013	0.50	0.52	0.54	0.56

Table E2: Example of IHO orders and vertical accuracies (95% confidence) for depths 5, 10, 15, and 20 m.

Other bathymetric quality levels exist, such as the ones developed more recently through the “US’ National Coastal Mapping Strategy 1.0: Coastal Lidar Elevation for a 3-D Nation” (NSTC, 2016), but are not detailed in this appendix. Note that some of those quality levels are equivalent to the IHO Orders.

Acquisition Parameters Considerations

For TBL acquisitions for flood mapping and flood risks purposes, Table E3 provides summary of recommended acquisition parameters based on current scientific knowledge and available sensors.

Parameters	Recommendation
Bathymetric point density	≥ 2 pts/m ² (applicable for areas submerged at the time of survey).
Accuracy	Vertical and horizontal accuracies equivalent to IHO Special Order are recommended.
Swath overlap	20% minimum, but 50% is recommended
Flight altitude	400 m is recommended
Inland part	A minimum of 400 m inland horizontally, from the mean low water.
Depth of penetration of the LiDAR survey	Minimum 1.5 times the Secchi depth. The expected average penetration depth is 4 to 9 m in coastal areas, depending on water clarity. This value could be lower in some shallow rivers.
Maximum Scan angle	± 20 degrees is recommended (40 degrees field of view)
Time of acquisition	For areas affected by tides, acquisition should be made around low tide as much as possible (i.e. between two hours prior and two hours after low tide).

Table E3: Recommended LiDAR acquisition parameters for flood-related TBL acquisition.

- It is usually accepted that shallow water TBL are the sensors appropriate for flood risk studies and flood mapping. In cases where 2-3 Secchi depths need to be achieved at a lower point density for bathymetric coverage to support flood risk mapping, a combination of shallow and deep-water sensors may be suitable. Also, systems do exist that combine shallow and deep-water capabilities. Otherwise, the shallow water sensors provide the point density and penetration required to support most flood risk studies and can be supplemented with echo sounding data.
- For TBL acquisitions related to hydrographic charting, the Canadian Hydrographic Service specifies that the spatial accuracy of the bathymetric portion of the TBL must meet the IHO Order 1b standards. They also specify deep-water TBL sensors capable of 2-3 Secchi depth of penetration in optimal conditions.

Guidelines for a Topo-Bathymetric LiDAR project

This section aims to provide some general guidance for a TBL project. The details and methods were inspired from the Canadian Hydrographic Services specifications, the NOAA specifications and the existing literature (e.g. Webster et al., 2016; Saylam et al., 2018).

A) Project planning and collection

During the mission planning phase and execution of the survey, the contractor must account for, demonstrate and implement strategies to mitigate the impact of the following parameters:

- Topography of the survey area and surrounding area, such as mountainous terrain that could prevent or hinder flight operations.
- Weather, including but not limited to water clarity and turbidity management. See the sub-section 'Water clarity considerations' below for more details.
- Native phenomenon, such as kelp growth and algae blooms.
- Maximum data acquisition around low tide. This is described as two hours prior and two hours after.
- Include all bays, inlets, islands, peninsulas, inter tidal zones, flood plains, river deltas and land areas that are within the survey blocks.

The required point density is also important as it can influence how many flight lines are required and the level of overlap between survey lines. In general, if the desired point density can be achieved with a single flight line, then 20% overlap is sufficient to ensure there are no gaps during the collection process. A 50% overlap is recommended for flood-related TBL acquisitions to reduce data gaps and to ensure a more uniform distribution of points. It is understood that the requested density may not be met due to certain environmental conditions that cannot be controlled. Table E3 provides the recommended acquisition parameters for TBL acquisitions for flood-related applications.

The flight lines must be flown in alternate directions. They must also be planned to maximum expected depths, with the intention of collecting data to the point of extinction, not necessarily to the full extent of the survey blocks. Cross lines must be run across all planned LiDAR survey lines at angles ranging from 45 to 90 degrees more than the original survey line. Cross lines must be acquired and processed to the same accuracy and data quality standards as the main survey lines and may be included in the final product of the survey.

For shoreline mapping and modeling uses, it is particularly important to have good bathymetric data in the very shallow (0-4 m) areas. For this reason, the LiDAR systems, software, and processing procedures shall enable measurement of bathymetry in this very shallow region. The sensor used for this mapping shall have an operational measurement depth range equal to or greater than a 1.5 Secchi depth.

The time of acquisition must also be considered when conducting a TBL project. One challenge to TBL river surveys during full leaf-on conditions is the problem of overhanging vegetation obscuring the riverbed below. To overcome this, one could survey in the spring or fall during leaf-off conditions. The benefits of the leaf-off condition would have to be weighed against typical increased water levels and perhaps poorer water clarity conditions at that time of year.

Although not required, it is often desirable to have a field team on the water during the survey. The field team can collect Secchi depth readings to confirm the water clarity conditions (See the sub-section 'Water clarity considerations' for more details), and depending on the end application of the data, collect bottom samples and photographs to determine the benthic cover

material. The field team would also collect check points both of hard surfaces on land and directly on the seabed to validate LiDAR data accuracy (see section 'Data Validation' below).

If coastal surveys are being conducted and any islands need to be surveyed, a twin-engine aircraft must be used in order to be able to safely make a landing if there is an engine failure. In addition to this safety requirement, most TBL surveys require a larger aircraft because of the increased power requirements for the green laser.

Water clarity considerations

For coastal and riverine TBL surveys, the weather preceding a survey can greatly influence the conditions and probability of success. For example, in coastal areas, an onshore wind can cause waves which cause sediment to become suspended and thus high turbidity conditions where the particles in the water cause the light to scatter and not penetrate to the seabed. In the case of riverine environments, heavy rain can cause sediment and other organic materials to be transported into the river, thus degrading the water clarity. Turbidity management involves understanding the environmental conditions that cause high turbidity (e.g. wind and rain) and the length of time for the water to clear before it is suitable for a survey (Webster et al., 2016). A secondary factor affecting the depth of penetration of the green laser is the brightness of the seabed or riverbed. Darker objects have tendency to absorb the green light, while light objects, such as sand, reflect more of the green light and thus allow the signals to reflect back to the sensor at greater depths.

A Secchi disk is commonly divided into black and white quadrants in order to maximize contrast, and the depth at which the black and white disk disappears from view is called the "Secchi depth". Clear waters will have a larger Secchi depth than more turbid waters, and the size of the Secchi disk may need to be adjusted for different water clarity conditions (Philpot, 2019). TBL shallow water sensors typically have a depth rating of 1.5 times the Secchi depth, and deep water sensors have a rating of 2-3 times the Secchi depth.

Ideally when conducting TBL coastal surveys, there are multiple survey sites within the region that have different shoreline orientations such that not all sites will be turbid as a result of a regional wind event. It can be challenging to obtain Secchi depths leading up to a TBL survey and thus ensure the conditions are suitable. There are numerous terrestrial weather stations available on-line that can provide insights into the past and current wind and rain conditions; however it still can be challenging to predict the turbidity conditions, especially after a wind event when the water needs time to clear. This has led to the investigation of using real-time turbidity sensors that can be deployed in bays with different shoreline orientations or different geological and sedimentary conditions. These real-time turbidity buoys are equipped with a turbidity sensor and a communication package (e.g. cellular modem) that can transfer the readings to the internet to be checked remotely. This allows for a time-series of turbidity conditions to be measured and monitored prior to committing to a TBL flight.

Another approach to measure the water clarity is by using the Diffuse Attenuation Coefficient (K_d). The rate of change of the irradiance energy, E , is a function of the depth (Ed) and is a measure of water clarity that is similar in concept to the Secchi depth in that the rate of change will be faster in turbid waters than in clear waters. The rate of change of Ed , or logarithmic derivative of Ed , is the diffuse attenuation coefficient, K_d (Philpot, 2019).

$$K_d = -\frac{d \ln E_d(z, \lambda)}{dz} = -\frac{1}{E_d(z, \lambda)} \frac{dE_d(z, \lambda)}{dz} \quad (m^{-1})$$

Figure A2: Diffuse Attenuation Coefficient K_d , $E(\lambda)$ radiance distribution over a hemisphere at a certain wavelength of energy (λ) at depth z (Philpot, 2019).

K_d values can change rapidly for a body of water, however the typical values of K_d range from 0.05 for clear water to 0.11 for turbid water for wavelengths used in TBL. For coastal areas, some medium resolution satellites, such as MODIS, can help estimate K_d or *Secchi depth* for certain wavelengths which can aid to determine if a TBL survey is feasible for an area or the best season to attempt a survey.

B) Data processing and management

Once the waveform data have been processed into discrete points (see section ‘Topo-bathymetric LiDAR general principles’ for more details), the classification is then typically performed. The points located in the bathymetric area must be classified according to the classes detailed in Table E4. We recommend that the points onshore be classified at least with the classes specified at section 5 of the current Guideline. Automatic and manual refinement of the classification are typically required using many of the standard tools that are used for topographic LiDAR processing. Most TBL system are equipped with a RGB or multispectral camera system that can be used to colorize the LiDAR point cloud and generate orthophotos. The coincident orthophotos can be very useful in assisting with the interpretation of some of the LiDAR returns.

Classification Value	Meaning
40	Bathymetric point (e.g., seafloor or riverbed; also known as submerged topography)
41	Water surface (sea/river/lake surface from bathymetric or topographic-bathymetric lidar; distinct from Point Class 9, which is used in topographic-only lidar and only designates “water,” not “water surface”)
42	Derived water surface (synthetic water surface location used in computing refraction at water surface)
43	Submerged object, not otherwise specified (e.g., wreck, rock, submerged piling)
44	International Hydrographic Organization (IHO) S-57 object, not otherwise specified
45	No-bottom-found-at (bathymetric lidar point for which no detectable bottom return was received)

Table E4: Classification codes used for bathymetric features for the LAS 1.4 data (Excerpt from the topo-bathy LiDAR domain profile, July 2013)

During data processing, all blunders and artifacts (boats, fisheries, weeds, etc.) must be assigned to class 1.

The delivered point cloud data and/or derived DEMs must be a seamless product (i.e. topographic and bathymetric LiDAR data joined), referenced to common horizontal and vertical coordinate

reference systems. For flood risk studies, we recommend using the same coordinate reference systems than those recommended for topographic LiDAR data in the current Guideline (See section 6.3.3).

For hydrographic charting, it may be required that the bathymetric data be referenced to the Chart Datum. In some case, a separation model between the Chart Datum and ellipsoidal heights can be provided by the technical authority to perform vertical transformation. If no such file is provided, the vendor is encouraged to use the Canadian Continuous Vertical Datum for Canadian Waters (CVDCW) process and the applicable Hydrographic Vertical Separation Surfaces (HySEP or SEP) for the survey area. The HySEP/SEP provides the separation between Chart Datum and the GRS80 (NAD83(CSRS)) ellipsoid.

The delivered point cloud data must be classified and in a LAS 1.4 point cloud format. Intensity values must be required for each multiple discrete return. The values recorded in the LAS files shall be normalized to 16 bit, as described in the LAS Specification.

C) Data validation

Wherever possible, it is always recommended that independent check points of a high precision be collected to compare to both the topographic and bathymetric LiDAR points. The standard approach is to utilize RTK GNSS to collect check points in the floodplain and across the river channel. For more information on the validation methods for topographic LiDAR data, see section 6.4 from the current Guideline.

For the bathymetric portion of a TBL survey, horizontal and vertical accuracy requirements are defined using the IHO Orders as stated earlier (Section 'Accuracy standard'). However, there are no set guidelines in terms of the number of check points required or their distribution for TBL surveys. As with all validation techniques, the check points used to validate the LiDAR points or surface models must be at least 3 times more accurate than the expected accuracy of the LiDAR.

It is recommended that for river TBL surveys, cross-sections be taken using survey grade GNSS positioning directly of the riverbed and where that is not possible using echo sounding techniques. These check points should be distributed to include examples of variable depths and conditions in the river.

In the case of coastal TBL surveys, direct measurements of the seabed elevation are possible using a GNSS antenna connected to an extendable pole, on the order of 4 m. This ensures direct measurements of the seabed for check points in shallow water. These check points must be taken near the time of the TBL survey, unless the seabed is comprised of exposed bedrock and is not expected to change over time. In deeper areas, echo sounding techniques can be used if the vertical accuracy of the data is suitable. As with topographic LiDAR, the expected vertical accuracy of TBL surveys will be influenced by the conditions of the seabed and will vary based on the presence, density and height of submerged aquatic vegetation (SAV). The TBL systems utilize green light which will not penetrate a dense canopy of SAVs, similar to topographic LiDAR and dense vegetation on land. Thus, when collecting check points on the seabed, it is also desirable to measure the presence and height of SAV.

D) Deliverables

Prior to the acquisition period, it is recommended that the contractor provide the technical authority with a project planning report containing details on team mobilization, GNSS and base stations data, water clarity monitoring approach, calibration reports and methods, as well as a detailed project schedule. The project planning could be subject to acceptance by the technical authority.

During the acquisition period, it is recommended that the contractor provide the technical authority with progress reports at regular intervals or following acquisition days.

Typical final deliverables for a TBL project may include the following items:

- Seamless topo-bathymetric classified LiDAR files. In some cases, the combination of topographic and bathymetric point cloud may not be required. The raw point cloud could also be required in certain cases.
- Seamless topo-bathymetric digital elevation models. Note that for some projects, the combination of topographic and bathymetric digital elevation models may not be required.
- Final project report, including but not limited to data acquisition, data processing and quality assurance details, position techniques and ground control. This report should contain sufficient detail to demonstrate that the specifications have been met for each pulse data collected.
- Final index showing coverage of the data with complete explanation of possible data gaps (e.g. depth extinction, water clarity, etc.).
- Orthophotos taken simultaneously to the acquisition.
- Metadata compliant with the ISO 19115:2003 standard.
- Flight lines trajectory
- Check points with horizontal and vertical accuracy estimates.
- Depending on the variable uses of the data, flight line normalized LiDAR intensity model (NIR returns on land and green laser returns of the river-seabed).

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APPENDIX 6 – Contract

The guideline reflects specifications for collecting airborne LiDAR data and contracts identify specific requirements, enhancements or changes to the guidelines. Key contract items included are listed below.

Definitions

Include a reference list of terms used in contract with definition.

Vendor Information

Provide information about the vendor including legal name, operational centre, and contact information.

Scope

Project specific requirements would be specified in this section. They would include data requests such waveform data, increase quality assurance where the vendor requires more sampling, and higher pulse density. A schedule and detailed deliverables would be clearly listed.

Some specific project scope contract items to be consider by the contracting authority are as follows:

DCAOI

Pulse density required

Review of methodology

Deviation from instrumentation

Vertical and horizontal accuracy

Request for intermediate or waveform pulse data

Data collection period

Check points consideration including the number and who will conduct this

Data ownership and usage

Contingency plan

Time period for data validation and verification on project deliverables

Raw data requirements

Additional post classification fields

Any derivative products i.e. DEM, contours, hydro-flattening

Tile sizes, file format and naming convention

Waivers or adjustment for high relief areas, snow and vegetation conditions

Accepting compress LAZ files

Use of Virtual Reference Systems

Number of classification check

Conditions for rejecting the data e.g. data voids or density

Insurance

Insurance coverage for aircraft and automobile is required. This would include Commercial General Liability and Errors and Omission. Specific liability amount would be identified. The contract authority would be identified as rider on the insurance.

Confirm Insurance coverage and requested certificate
Confirm Workplace Safety Insurance Coverage

Safety

Workplace safety plan would be provided to ensure the safety in data collection particularly in remote locations. This would include identification of hazards, risk assessment, mitigation plan and required safety gears. Safety consideration must follow all federal and provincial government regulations. Examples include: vehicle roadside safety, hours of data collection and wildlife hazards.

Request vendor health and safety plan

Termination Clause

Identify the conditions where a vendor fails to perform duties or breaches contract. A termination clause would be included in the contract identifying conditions for termination.

Dispute Resolution

Should a dispute in the terms and condition of the requirements and contract occur, this section would cover a detailed process for dispute resolution including notification by vendor or contracting authority, mediation and actions that can be taken.

Wavier

Any exceptions or adjustments by the contracting authority with the terms and conditions of the contract and data collection requirements are to be put into writing to be valid.

Deliverable Review Period

The vendor will provide as part of its deliverable early in the project a plan with methodology for meeting the guideline with respect to data collection, processing and deliverables. A time period is required for the review of the processing and to inspect and accept the deliverables. Terms would be included and a completion certificate for accepted work would be submitted by the vendor.

Payment Terms

Financial payments for the project would consider the upfront costs for airborne operations and the deliverables. Milestone payment and percentage of payment would be structured in the contract. Any withholding would be identified.

Subsuppliers and Subcontractors

Any additional changes of subsuppliers and subcontractors would require written consent by the contract authority for any changes. Workplace safety and all insurance requirements must be enforced with subsuppliers and subcontractors.

Force Majeure

A description outlining a breach of contract due to events such as war, riot, fire, sabotage, national security and other events or circumstances which are not reasonably foreseen and which have not been caused by an act, omission or negligence and is beyond the control of the vendor or contracting authority is included and what conditions and notification would transpire.

Entire Agreement

The contract is to contain all conditions, requirements and specifications. No other terms, agreements or conditions shall be binding.

Performance of Services

A clause indicating time of essence and agreement to perform the required task with the agreed schedule. The contracting authority may terminate the contract upon a default of agreed upon conditions.

Permits

A clause identifying any permits for flying, ground access or other requirements to provide the service and products is required by the Vendor at its own cost.

Compliance with Law

A clause is placed to bind the vendor and any subcontractors, agents, contractors to comply to all applicable laws and regulations at all levels of government. Vendor also indemnify the contract authority from any negligence occurring on behalf of the Vendor, its agents, contractors and subcontractors.

Expediting

A clause may be placed to expedite work and delivery of product should it become apparent that the schedule will not be met.

Warranty

Any warranty with the deliverables shall be provided. Warranty will cover compliance with specifications, quantity and quality. The warranty shall have a period of time and period in which non-conformity would be rectified. The warranty clause may contain any potential liability arising from defected product.

Governing Laws

The laws in which the contract applies can be provincial, federal and/or international laws.

Indemnity

The contract would contain clauses with respect to indemnification arising from not performing the service or delivering the product or negligence in the operation of collecting the data or any other breach of contract.

Confidentiality

Information provided to the vendor by the contracting authority identified as confidential information shall protect the information from unauthorized use, disclosure and duplication of content.

Successors and Assignments

A clause would restrict a vendor from transferring the contract to another party without the consent of the contracting authority. The clause would stipulate the contracting authority's rights to accept or deny the request.

Data Ownership

This designates the assignment of rights and ownership of the data to the contracting authority. The data ownership model determined between the contracting authority and vendor is on a project by project basis.

Appendix B Hyetographs



Appendix B

Table B-1: Hyetographs – 6-hour Storm

Time (H:M)	Cumulative Volume (mm)			
	1:20-current	1:20-cc	1:100-current	1:100-cc
0:00	0.0	0.0	0.0	0.0
0:30	4.9	6.8	6.2	8.8
1:00	12.4	17.1	15.6	22.0
1:30	21.9	30.2	27.5	38.9
2:00	34.5	47.5	43.3	61.2
2:30	49.4	68.0	62.0	87.7
3:00	60.9	83.8	76.4	108.1
3:30	64.8	89.2	81.3	115.0
4:00	67.7	93.2	84.9	120.1
4:30	70.1	96.5	88.0	124.4
5:00	71.7	98.7	90.0	127.3
5:30	72.6	99.9	91.1	128.8
6:00	73.0	100.5	91.6	129.5



Appendix B

Table B-2: Hyetographs – 12-hour Storm

Time (H:M)	Cumulative Volume (mm)			
	1:20-current	1:20-cc	1:100-current	1:100-cc
0:00	0.0	0.0	0.0	0.0
1:00	1.0	1.4	1.2	1.8
2:00	1.9	2.7	2.4	3.5
3:00	6.6	9.4	8.3	12.2
4:00	16.7	23.9	21.0	31.1
5:00	35.4	50.6	44.6	65.7
6:00	58.7	83.9	73.9	109.0
7:00	75.5	107.9	95.0	140.3
8:00	84.9	121.3	106.8	157.6
9:00	89.5	127.9	112.6	166.2
10:00	91.3	130.5	114.9	169.6
11:00	92.3	131.9	116.2	171.4
12:00	93.2	133.2	117.3	173.1



Appendix B

Table B-3: Hyetographs – 24-hour Storm

Time (H:M)	Cumulative Volume (mm)			
	1:20-current	1:20-cc	1:100-current	1:100-cc
0:00	0.0	0.0	0.0	0.0
2:00	7.2	10.6	8.9	14.0
4:00	18.1	26.7	22.4	35.1
6:00	32.0	47.3	39.7	62.3
8:00	50.3	74.3	62.3	97.9
10:00	72.0	106.3	89.1	140.1
12:00	88.8	131.1	109.9	172.7
14:00	94.4	139.4	116.9	183.7
16:00	98.8	145.8	122.2	192.1
18:00	102.3	151.0	126.6	198.9
20:00	104.7	154.5	129.5	203.6
22:00	105.8	156.2	131.0	205.8
24:00	106.5	157.2	131.8	207.0



Table B-3: Calibration Event Hyetograph

Date & Time	Cumulative Volume (mm)
1-Nov-23 19:40	0.0
1-Nov-23 21:40	2.4
1-Nov-23 23:40	6.1
2-Nov-23 01:40	10.8
2-Nov-23 03:40	16.9
2-Nov-23 05:40	24.2
2-Nov-23 07:40	29.9
2-Nov-23 09:40	31.8
2-Nov-23 11:40	33.2
2-Nov-23 13:40	34.4
2-Nov-23 15:40	35.2
2-Nov-23 17:40	35.6
2-Nov-23 19:40	35.8



Appendix C Assessment of Hydraulic Structure Capacities



Appendix C

Table C-1: Outer Cove Brook Hydraulic Structure Capacity Assessment (Red Indicates Overtopping)

Structure Location/Name	Structure ID	Structure Geometry	Road/ Bridge Deck Elevation (m)	Max Upstream Elevation (m)			
				Current Climate		Climate Change	
				20 Year	100 Year	20 Year	100 Year
Autumn Drive	OCB-C01	600 mm CMP	158.15	157.72	158.11	158.21	158.27
Airport Heights Drive	OCB-C02	1500 mm Concrete	159.52	157.23	157.03	157.07	157.23
Savannah Park Drive	OCB_C03	900 mm HDPE	156.44	156.06	156.25	156.33	156.56
Savannah Park Drive	OCB-C04	900 mm HDPE	156.15	155.96	156.06	156.06	156.25
Savannah Park Drive (Driveway)	OCB-C04A	900 mm HDPE	156.00	155.62	155.78	155.8	155.85
Savannah Park Drive	OCB-C05	900 mm HDPE	153.66	152.85	153.03	153.13	153.72
Piper Street	OCB-C06	2.2x1.6m CMP Arch	149.46	147.37	147.49	147.54	147.72
Navajo Place	OCB-C08	2.2x1.6m CMP Arch	148.04	144.8	145.28	145.45	145.93
Virginia River Trail	OCB-C08	1,400 mm CMP	145.80	144.61	145.24	145.51	145.85
Portugal Cove Road	OCB-C09	2 x 800mm CMP	145.30	144.57	145.19	145.45	145.71
Navigator Avenue	OCB-C10	3 X 0.8m CMP Arch	141.60	140	140.13	140.19	140.44
Airport Service Road (Barrel 1)	OCB-C12	1,500 mm CMP	137.57	136.3	136.4	136.45	136.56
Airport Service Road (Barrel 2)	OCB-C12	1,000 mm CMP	137.57	136.3	136.4	136.45	136.56
Airport Service Road (Barrel 3)	OCB-C12	900 mm CMP	137.57	136.3	136.4	136.45	136.56
Airfield Building Access 1	OCB-C12	3.26 x 2 m Rectangular Concrete	138.63	134.84	134.94	134.99	135.16
Airfield Building Access 2	OCB-C13	1.85 x 2.1 m Rect. Concrete	137.54	133.75	133.99	134.1	134.48
Airfield Taxiway	OCB-C14	2.79 x 2.0 m Rect. Concrete	135.65	133.14	133.29	133.36	133.8
Airfield Taxiway/Runway	OCB-C15	2,000 mm CMP	133.36	130.84	131.05	131.15	131.58
Airport Service Road 2 (Barrel 1)	OCB-C16	1,100 mm CMP	116.70	115.56	115.93	116.07	116.53
Airport Service Road 2 (Barrel 2)	OCB-C16	1,100 mm CMP	116.70	115.56	115.93	116.07	116.53
Airport Service Road 2 (Barrel 3)	OCB-C16	1,100 mm CMP	116.70	115.56	115.93	116.07	116.53
Sea Rose Avenue	OCB-C17	6.1x 2.5 m Rectangular Concrete	110.05	107.29	107.38	107.44	107.58
Torbay Road	OCB-C18	4.4 x 3.7 m CMP Arch	100.25	97.12	97.37	97.57	97.92
Golf Course Road	OCB-C19	2 x 1.2m X 1m CMP Arch	90.15	89.99	90.13	90.19	90.22



Appendix C

Table C-2: Holes in Marsh Brook Hydraulic Structure Capacity Assessment (Red Indicates Overtopping)

Structure Location/Name	Structure ID	Structure Geometry	Road/ Bridge Deck Elevation (m)	Max Upstream Elevation (m)			
				Current Climate		Climate Change	
				20 Year	100 Year	20 Year	100 Year
Kelsey Drive	HMB-C01	2 m x 1.3 m Concrete Weir	126.36	124.19	124.27	124.31	124.44
Team Gushue Higy On-Ramp	HMB-C02	2,000 mm CMP Culvert	121.11	119.45	119.51	119.53	119.6
Team Gushue Highway	HMB-C03	2,000 mm CMP Culvert	123.11	117.01	117.06	117.09	117.15
Team Gushue Highway Off-Ramp	HMB-C04	2,000 mm CMP Culvert	116.05	113.41	113.46	113.49	113.55
Duffy Place	HMB-C05	2,000 mm CMP Culvert	105.44	102.81	102.9	102.94	103.05
Mews Place	HMB-C06	1,450mm CMP Culvert	100.57	99.29	99.47	99.54	99.74
Pippy Place	HMB-C07	2.7m x 1.4mm CMP Ellipse	97.70	95.28	95.36	95.39	95.5
Hallett Crescent Inlet Structure	HMB-C08	1,650 mm CMP Culvert	94.69	93.45	93.65	93.94	94.88

Appendix C

Table C-3: Barrows Road Stream Hydraulic Structure Capacity Assessment (Red Indicates Overtopping)

Structure Location/Name	Structure ID	Structure Geometry	Notes	Road/ Bridge Deck Elevation (m)	Max Upstream Elevation (m)			
					Current Climate		Climate Change	
					20 Year	100 Year	20 Year	100 Year
Backyard Culvert (Civic #40)	BRS-C01	450 mm CMP Culvert		30.84	30.1	30.18	30.32	30.88
Regiment Road (Storm Sewer outlet)	BRS-C02	450 mm CMP Storm Pipe	Storm sewer outlet. HGL taken at downstream node	22.09	20.8	20.82	20.82	20.84
Pedestrian Bridge in Open Space Area	BRS-B01	5.890m x 0.084m Timber Bridge	Timber bridge. HGL taken at upstream side of bridge deck	2.04	1.95	1.97	1.98	2.01
Cuckholds Cove Road	BRS-C03	450 mm CMP Culvert		30.16	29.13	29.39	29.82	30.20
Barrows Road	BRS-C04	450 mm CMP Culvert		1.50	1.94	1.96	1.97	2.00

Appendix C

Table C-4: Virginia River Hydraulic Structure Capacity Assessment (Red Indicates Overtopping)

River/Tributary	Structure Location/Name	Structure ID	Structure Geometry	Road/ Bridge Deck Elevation (m)	Max Upstream Elevation (m)			
					Current Climate		Climate Change	
					20 Year	100 Year	20 Year	100 Year
Main Branch	Pedestrian Bridge Upstream of Dumbarton Place	VR-B01	Wooden Deck on Concrete Foundation	160.13	158.5	158.57	158.61	158.71
	Durness Street	VR-C01	1,600 mm CMP Arch	152.50	151.01	151.19	151.31	151.63
	McNiven Place	VR-C02	4.357 m x 1.5 m Concrete Box Culvert	147.65	145.81	145.98	146.1	146.44
	Airport Heights Drive 1 (RHODERA ST)	VR-C04	3.426m x 1.7 m CMP Arch	146.27	144.26	144.54	144.68	145.01
	Pedestrian Bridge Near Airport Heights Drive	VR-B02	Timber Bridge	145.57	144.44	144.63	144.74	145.04
	Airport Heights Drive 2 (MCNIVEN PL)	VR-C03	4.357x m 1.5 m CMP Arch	146.50	144.94	145.16	145.3	145.65
	Portugal Cove Road	VR-C05	2.21m x 1.6 m CMP Arch	145.19	141.36	141.81	142.34	143.21
	Transmission Line Access Road	VR-C06	4.089 m x 2.565 m Concrete Arch	130.77	129.31	129.65	129.83	130.04
	Boardwalk Upstream of Trans-Canada Highway	VR-B03	Timber Bridge	123.38	122.97	123.03	123.05	123.11
	Trans-Canada Highway	VR-C07	2,800 mm CMP Culvert	126.44	122.66	122.84	122.92	123.06
	Tributary Crossing the Trans-Canada Highway	VR-C08	1,400 mm CMP Culvert	123.79	120.42	120.49	120.53	120.63
	Pedestrian Bridge	VR-B04	Timber Bridge	113.32	112.74	112.83	112.88	112.95
	Penny Crescent	VR-C10	6.1 m x 4.2 m Concrete Deck	106.40	103.45	103.67	103.78	103.98
	Torbay Road	VR-C11	7.481 m x 2 m Concrete Box Culvert	92.88	91.17	91.34	91.44	91.62

Appendix C

Highland Drive Tributary	Tributary Crossing Aspen Place	VR-C27	750 mm HDPE Culvert	106.27	104.86	104.87	104.89	104.92
	Tributary Crossing Oakridge Drive	VR-C28	750 mm CMP Culvert	99.38	95.93	95.96	95.99	96.06
	Tributary Storm Sewer Inlet at Highland Drive	N/A	750 mm Culvert	94.00	92.87	92.90	92.93	92.99
Main Branch	Fall River Plaza Access 1	VR-C12	7.973 m x 2 m Rectangular Concrete	91.56	89.88	90.11	90.24	90.46
	Fall River Plaza Access 2	VR-C13	7.973 m x 2 m Rectangular Concrete	88.20	87.11	87.31	87.41	87.61
	Lawton's Parking Lot	VR-C14	7.973 m x 2 m Rectangular Concrete	83.40	82.77	83.02	83.12	83.33
	Gleneyre Street	VR-C15	3.6 m x 3 m Rectangular Concrete	82.97	81.89	82.14	82.23	82.43
	Pedestrian Bridge Downstream of Gleneyre Street 1	VR-B05	Timber Bridge	82.46	80.01	80.15	80.23	80.32
	Pedestrian Bridge Downstream of Gleneyre Street 2	VR-C16	Timber Bridge	79.08	77.53	77.66	77.7	77.8
	Pedestrian Bridge Near Paul Reynold's Centre	VR-B06	Timber Bridge	77.23	75.53	75.74	75.94	76.09
	Carrick Drive	VR-C17	2.87 m x 1.829 m CMP Arch	75.64	75.22	75.61	75.87	76.01
	Pedestrian Bridge Downstream of Carrick Drive	VR-B07	Timber Bridge	75.76	74.18	74.3	74.36	74.48
	Pedestrian Bridge Near Labrador Place Playground	VR-B08	Timber Bridge	69.58	67.95	68.19	68.34	68.59
	Newfoundland Drive	VR-C19	5.993 m x 1.5 m Rectangular Concrete	62.94	60.98	61.35	61.63	62.61
Hunts Lane/ Johnson Crescent Tributary	Johson Crescent Storm Sewer Inlet	N/A	1,050 mm Culvert	106.77	105.56	105.93	106.23	106.85
	Outer Ring Road Culvert 1	N/A	1,000 mm Culvert	143.43	142.99	143.07	143.12	143.21
	Outer Ring Road Culvert 2	N/A	1,000 mm Culvert	147.09	145.23	145.29	145.33	145.41

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	Hunts Lane Culvert 1	N/A	1,000 mm Culvert	128.32	128.5	128.64	128.71	128.85
	Hunts Lane Culvert 2	N/A	900 mm Culvert	124.16	122.53	122.86	122.97	123.63
	Padre Nangle Place Culvert	N/A	4.5 m x 1.2 m Rectangular Concrete	124.91	123.16	123.34	123.4	123.89
	Hunts Lane Storm Sewer Inlet	N/A	900 mm Storm Sewer	124.12	122.5	122.73	122.93	123.57
Lawlers Brook Tributary	Lawlers Brook Storm Sewer Outlet Upstream of Guzzwell Drive	VR-C20	**Storm sewer outlet. HGL downstream of pipe	61.40	59.77	59.86	59.92	59.95
	Guzzwell Drive	VR-C21	9.5 m x 2.1 m Rectangular Concrete	59.83	58.21	58.4	58.6	59.26
	Pedestrian Bridge Downstream of Guzzwell Drive	VR-B09	Timber Bridge	58.97	57.89	58.23	58.56	59.1
Main Branch	Logy Bay Road	VR-C22	5.75 m x 2 m Rectangular	59.20	57.71	58.12	58.48	59.11
	Charter Avenue	VR-C23	6.3 m x 2 m Rectangular	27.73	24.79	25.26	25.84	27.27
	Churchill Avenue	VR-C24	9.5 m x 2 m Rectangular	21.30	16.84	17.21	17.6	17.93
	The Boulevard	VR-C25	5 m x 2 m Rectangular	12.80	12.21	12.57	12.83	12.99
	Pedestrian Bridge Near Quidi Vidi Lake	VR-B10	Timber Bridge	12.37	10.72	10.83	10.92	11.02

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Table C-5: Mundy Pond Brook Hydraulic Structure Capacity Assessment (Red Indicates Overtopping)

Structure Location/Name	Structure ID	Structure Geometry	Road/ Bridge Deck Elevation (m)	Max Upstream Elevation (m)			
				Current Climate		Climate Change	
				20 Year	100 Year	20 Year	100 Year
Empire Ave	MPB-C02	1,000 mm Culvert	135.2	135.33	135.38	135.40	135.43
Jensen Camp Rd	MPB-C03	Start: 1,800 mm CMP; End: 1.8 m x 1.1 m CMP Arch	131.6	131.26	131.50	131.60	131.72
Coefield St	MPB-C04	4.0 x 1.9 m Rectangular Concrete	110.6	109.28	109.46	109.55	109.81
Pedestrian Bridge Near Columbus Dr	MPB-B01	Span: 16.87 m; Height: 1.77 m	104.3	103.28	103.32	103.33	103.37
Columbus Dr	MPB-C05- 01	Start: 2 x 1,500 mm Culvert	103.6	101.93	101.98	102.01	102.08
Columbus Dr	MPB-C05- 02	Start: 1,800 mm Culvert End (downstream of Mundy Pond Road): 1.8 x 1.2 m Rectangular Concrete	103.6	101.77	101.78	101.79	101.80
Driveway Crossing - 212 Mundy Pond Rd	MPB-B02	Span: 1.90 m; Height: 0.65 m	99.7	99.22	99.29	99.32	99.42
Driveway Crossing - 208 Mundy Pond Rd	MPB-B03	Span: 4.47 m; Height: 1.15 m	98.7	97.84	97.90	97.92	97.99
Driveway Crossing - 204 Mundy Pond Rd	MPB-B04	Span: 3.14 m; Height: 1.00 m	97.0	96.44	96.51	96.53	96.61
Driveway Crossing - 198 Mundy Pond Rd	MPB-B05	Span: 3.10 m; Height: 0.84 m	95.5	94.85	94.96	94.99	95.11
Driveway Crossing - 194 Mundy Pond Rd	MPB-B06	Span: 4.46 m; Height: 0.74 m	95.1	94.45	94.51	94.57	94.61
Driveway Crossing - 190 Mundy Pond Rd	MPB-B07	Span: 4.60 m; Height: 0.80 m	94.3	93.54	93.60	93.63	93.70

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Mundy Pond Rd	MPB-C06	1,200 mm Culvert (with fish baffle)	93.1	93.15	93.19	93.20	93.25
Pedestrian Bridge Downstream of Mundy Pond Road	MPB-B09	Span: 7.21 m; Height: 0.76 m	88.4	87.86	87.96	88.01	88.17
Mundy Pond Outlet	MPB-C07	1.35 m CMP	87.7	87.07	87.32	87.44	87.75

Table C-6: Kitty Gaul Brook Hydraulic Structure Capacity Assessment (Red Indicates Overtopping)

Structure Location/Name	Structure ID	Structure Geometry	Road/ Bridge Deck Elevation (m)	Max Upstream Elevation (m)			
				Current Climate		Climate Change	
				20 Year	100 Year	20 Year	100 Year
Redmond's Road	KGB-C01	400 mm HDPE and 500 mm Concrete	201.4	201.47	201.49	201.51	201.54
Team Gushue Highway North	KGB-C02; KGB-C03	2 x 1,500 mm Concrete	156.8	154.27	154.51	154.65	155.06
Blackmarsh Road	KGB-C04; KGB-C05	1,600 mm CMP; 850 mm HDPE	139.86	139.04	139.4	139.66	139.90
Pedestrian Bridge Between Blackmarsh Road and Cherrington Street (1)	KGB-B01	Span: 9.31 m; Height: 2.28 m	131.1	129.47	129.59	129.66	129.84
Pedestrian Bridge Between Blackmarsh Road and Cherrington Street (2)	KGB-B02	Span: 8.75 m; Height: 1.24 m	127.7	126.57	126.66	126.71	126.82
Pedestrian Bridge Between Blackmarsh Road and Cherrington Street (3)	KGB-B03	Span: 8.75 m; Height: 1.61 m	127.2	126.12	126.22	126.29	126.49
Cherrington Street	KGB-C06	3.80 m x 1.18 m Rectangular Concrete	126.0	124.67	124.82	124.91	125.12
Pedestrian Bridge Between Cherrington Street and Frecker Drive (1)	KGB-B04	Span: 10.02 m; Height: 2.07 m	125.4	123.75	123.89	123.97	124.16
Pedestrian Bridge Between Cherrington Street and Frecker Drive (2)	KGB-B05	Span: 10.00 m; Height: 2.83 m	124.8	122.14	122.19	122.23	122.37
Frecker Drive	KGB-C07	3.74 m x 1.38 m Rectangular Concrete	116.8	114.59	114.82	114.96	115.40

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Pedestrian Bridge Near Cowan Heights Duck Pond	KGB-B06	Span: 9.84 m; Height: 1.82 m	114.3	112.85	112.97	113.05	113.30
Canada Drive	KGB-C08	3.65 m x 1.92 m Rectangular Concrete	110.6	109.50	109.75	109.92	110.31
Team Gushue Highway South	KGB-C09	2 x 2,100 mm Concrete	107.5	105.03	105.37	105.51	105.88
Mount Pearl Square	KGB-C10	Start: 2 x 1,400 mm Concrete; End: 3.00 m x 1.09 m Rectangular Concrete	95.3	94.65	94.84	95.07	95.47
Pedestrian Bridge Near Greenwood Crescent	KGB-B07	Span: 13.99 m; Height: 1.57 m	86.4	85.20	85.30	85.37	85.58
Pedestrian Bridge Near Dunn's Road	KGB-B08	Span: 9.58 m; Height: 1.06 m	82.1	81.36	81.42	81.46	81.59

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Table C-7: South Brook Hydraulic Structure Capacity Assessment

Structure Location/Name	Structure ID	Structure Geometry	Road/ Bridge Deck Elevation (m)	Max Upstream Elevation (m)			
				Current Climate		Climate Change	
				20 Year	100 Year	20 Year	100 Year
Southlands Boulevard (Upper Crossing)	SB-C01	4.2 m x 2.6 m CMP Arch	171.4	169.89	170.17	170.34	170.94
Tree Top Drive	SB-C02	6.2 m x 3.0 m CMP Arch	154.8	152.95	153.23	153.41	153.95
Southlands Boulevard (Lower Crossing)	SB-C03	6.0 m x 3.9 m CMP Arch	152.6	149.59	149.76	149.86	150.11

Appendix D Sensitivity Analyses – Detailed Results



Table D-2: Saturated Hydraulic Conductivity Sensitivity Analysis Results

River	Location	Storm Duration (hrs)	Max. Flow (m³/s)						
			100 Year Current Climate						
			Calibrated Model Flow	Plus 10%	Plus 20%	Plus 30%	Minus 10%	Minus 20%	Minus 30%
Holes in Marsh Brook	Holes in Marsh Brook at Kelsey Drive	6	2.62	2.60	2.61	2.59	2.62	2.65	2.65
	Holes in Marsh Brook at Pippy Place	6	5.56	5.55	5.53	5.52	5.57	5.58	5.60
	Total Runoff	6	7.25	7.24	7.23	7.22	7.27	7.28	7.30
Outer Cove Brook	Outer Cove Brook at Virginia River Trail	6	4.31	4.28	4.24	4.19	4.32	4.35	4.39
	Outer Cove Brook at Torbay Road	6	20.53	21.27	21.13	21.00	21.58	21.74	21.92
	Total Runoff	6	24.09	23.90	23.73	23.56	24.28	24.49	24.71
Barrows Road Stream	Barrows Road Stream at Barrows Road	6	0.33	0.33	0.33	0.33	0.33	0.33	0.34
	Barrows Road Stream at Cuckhold's Cove Road	6	0.38	0.38	0.38	0.38	0.38	0.38	0.40
	Total Runoff	6	1.21	1.21	1.20	1.20	1.22	1.22	1.23
Virginia River	Virginia River at Penny Crescent	12	12.54	12.18	11.86	11.51	12.92	13.31	13.72
	Virginia River Tributary at Guzzwell Drive	12	10.30	10.56	10.48	10.40	10.64	10.62	11.02
	Virginia River at Virginia Lake Outlet	12	10.9	10.39	10.07	9.80	11.50	12.17	12.91
	Virginia River at Logy Bay Road	12	20.69	20.31	19.63	19.53	21.49	22.40	23.48
	Total Runoff	12	32.39	30.85	30.60	28.76	32.51	33.28	34.73
Mundy Pond Brook	Mundy Pond Brook at Coefield Street	6	5.57	5.55	5.53	5.51	5.59	5.62	5.64
	Mundy Pond Outlet Structure	6	3.90	3.90	3.90	3.90	3.92	3.90	3.90
	Total Runoff	6	17.99	17.88	17.77	17.67	18.11	18.23	18.36
Kitty Gaul Brook	Kitty Gaul Brook at Blackmarsh Road	6	5.47	5.43	5.40	5.37	5.51	5.55	5.59
	Kitty Gaul Brook at Greenwood Crescent	6	13.58	13.56	13.53	13.48	13.57	13.68	13.79
	Total Runoff	6	14.84	14.78	14.72	14.67	14.90	14.96	15.03
South Brook	South Brook at Southlands Boulevard (Upper)	12	9.83	9.78	9.74	9.70	9.90	9.97	9.99
	South Brook at Tree Top Drive	12	13.59	13.47	13.36	13.24	13.72	13.85	14.00
	Total Runoff	12	19.50	19.34	19.19	19.03	19.67	19.86	20.05

Table D-3: Suction Head Sensitivity Analysis Results

River	Location	Storm Duration (hrs)	Max. Flow (m³/s)						
			100 Year Current Climate						
			Calibrated Model Flow	Plus 10%	Plus 20%	Plus 30%	Minus 10%	Minus 20%	Minus 30%
Holes in Marsh Brook	Holes in Marsh Brook at Kelsey Drive	6	2.62	2.61	2.60	2.59	2.62	2.64	2.64
	Holes in Marsh Brook at Pippy Place	6	5.56	5.55	5.54	5.53	5.57	5.58	5.59
	Total Runoff	6	7.25	7.24	7.24	7.23	7.26	7.27	7.28
Outer Cove Brook	Outer Cove Brook at Virginia River Trail	6	4.31	4.25	4.24	4.25	4.34	4.35	4.37
	Outer Cove Brook at Torbay Road	6	20.53	21.30	21.20	21.09	21.54	21.66	21.80
	Total Runoff	6	24.09	23.94	23.79	23.65	24.25	24.43	24.71
Barrows Road Stream	Barrows Road Stream at Barrows Road	6	0.33	0.33	0.33	0.33	0.33	0.34	0.34
	Barrows Road Stream at Cuckhold's Cove Road	6	0.38	0.38	0.38	0.38	0.38	0.38	0.39
	Total Runoff	6	1.21	1.21	1.20	1.20	1.22	1.22	1.22
Virginia River	Virginia River at Penny Crescent	12	12.54	12.26	12.01	11.78	12.84	13.17	13.52
	Virginia River Tributary at Guzzwell Drive	12	10.33	10.36	10.46	10.58	10.49	10.60	10.45
	Virginia River at Virginia Lake Outlet	12	10.86	10.46	10.21	10.00	11.38	11.96	12.61
	Virginia River at Logy Bay Road	12	20.69	20.53	19.98	19.57	21.51	22.15	23.12
	Total Runoff	12	32.39	31.52	30.66	30.26	33.10	32.67	34.15
Mundy Pond Brook	Mundy Pond Brook at Coefield Street	6	5.57	5.56	5.54	5.53	5.58	5.60	5.62
	Mundy Pond Outlet Structure	6	3.90	3.90	3.89	3.89	3.90	3.90	3.90
	Total Runoff	6	17.99	17.91	17.84	17.76	18.07	18.15	18.24
Kitty Gaul Brook	Kitty Gaul Brook at Blackmarsh Road	6	5.47	5.45	5.43	5.41	5.49	5.51	5.53
	Kitty Gaul Brook at Greenwood Crescent	6	13.58	13.57	13.56	13.55	13.57	13.57	13.63
	Total Runoff	6	14.84	14.81	14.78	14.75	14.87	14.90	14.93
South Brook	South Brook at Southlands Boulevard (Upper)	12	9.83	9.82	9.79	9.78	9.85	9.89	9.93
	South Brook at Tree Top Drive	12	13.59	13.53	13.46	13.40	13.66	13.73	13.81
	Total Runoff	12	19.50	19.41	19.32	19.23	19.60	19.70	19.81

Appendix D

Table D-4: Roughness Sensitivity Analysis Results

River	Location	Storm Duration (hrs)	Max. Water Elevation (m)						
			100 Year Current Climate						
			Calibrated Model Elevation	Plus 10%	Plus 20%	Plus 30%	Minus 10%	Minus 20%	Minus 30%
Holes in Marsh Brook	Holes in Marsh Brook at Kelsey Drive	6	124.04	124.05	124.06	124.06	124.02	123.99	123.98
	Holes in Marsh Brook at Pippy Place	6	83.82	83.82	83.82	83.82	83.82	83.82	83.82
	Downstream	6	88.93	88.94	88.93	88.94	88.94	88.93	88.93
Outer Cove Brook	Outer Cove Brook at Virginia River Trail	6	143.99	143.99	143.98	143.98	143.99	144.00	144.00
	Outer Cove Brook at Torbay Road	6	96.81	96.79	96.78	96.78	96.79	96.79	96.80
	Downstream	6	86.07	86.03	86.03	86.06	86.04	86.02	86.03
Barrows Road Stream	Barrows Road Stream at Barrows Road	6	0.71	0.71	0.71	0.72	0.71	0.70	0.70
	Barrows Road Stream at Cuckhold's Cove Road	6	29.18	29.18	29.16	29.15	29.21	29.22	29.23
	Downstream	6	1.15	1.15	1.15	1.15	1.16	1.16	1.16
Virginia River	Virginia River at Penny Crescent	12	101.01	101.01	101.01	101.01	101.01	101.01	101.01
	Virginia River Tributary at Guzzwell Drive	12	59.54	59.54	59.54	59.54	59.54	59.55	59.54
	Virginia River at Virginia Lake Outlet	12	72.98	72.98	72.98	72.98	72.98	72.98	72.98
	Virginia River at Logy Bay Road	12	57.46	57.46	57.46	57.46	57.46	57.46	57.46
	Downstream	12	10.88	10.83	10.85	10.83	10.83	10.85	10.84
Mundy Pond Brook	Mundy Pond Brook at Coefield Street	6	109.54	109.55	109.57	109.58	109.52	109.51	109.51
	Mundy Pond Outlet Structure	6	87.32	87.32	87.32	87.32	87.32	87.32	87.32
	Downstream	6	87.32	87.32	87.32	87.32	87.32	87.32	87.32
Kitty Gaul Brook	Kitty Gaul Brook at Blackmarsh Road	6	129.59	129.62	129.65	129.67	129.55	129.52	129.48
	Kitty Gaul Brook at Greenwood Crescent	6	84.55	84.55	84.70	84.70	84.55	84.37	84.37
	Downstream *	6	78.03	78.04	78.08	78.08	78.03	77.98	77.97
South Brook	South Brook at Southlands Boulevard (Upper)	12	168.82	168.86	168.87	168.89	168.79	168.75	168.70
	South Brook at Tree Top Drive	12	153.89	153.90	153.93	153.93	153.89	153.84	153.83
	Downstream *	12	149.35	149.38	149.38	149.39	149.35	149.33	149.29
* Values reported are for the second last cross-section, as the downstream boundary conditions is a fixed water level.									

Appendix D

Table D-5: Peak Flow Sensitivity Analysis Results

River	Location	Storm Duration (hrs)	Max. Water Elevation (m)						
			100 Year Current Climate						
			Calibrated Model Elevation	Plus 10%	Plus 20%	Plus 30%	Minus 10%	Minus 20%	Minus 30%
Holes in Marsh Brook	Holes in Marsh Brook at Kelsey Drive	6	124.04	124.07	124.10	124.13	124.01	123.95	123.91
	Holes in Marsh Brook at Pippy Place	6	83.82	83.82	83.85	83.87	83.77	83.74	83.71
	Downstream	6	88.93	88.95	88.97	88.94	88.9	88.87	88.84
Outer Cove Brook	Outer Cove Brook at Virginia River Trail	6	143.99	144.20	144.33	144.39	143.75	143.52	143.32
	Outer Cove Brook at Torbay Road	6	96.81	96.91	96.94	96.95	96.76	96.76	96.75
	Downstream	6	86.07	86.07	86.07	86.24	86.03	86.02	86
Barrows Road Stream	Barrows Road Stream at Barrows Road	6	0.71	0.71	0.72	0.72	0.71	0.71	0.70
	Barrows Road Stream at Cuckhold's Cove Road	6	29.18	28.69	28.95	29.11	28.20	28.16	28.13
	Downstream	6	1.15	1.16	1.15	1.16	1.16	1.16	1.15
Virginia River	Virginia River at Penny Crescent	12	101.01	100.99	101.01	101.03	100.95	100.92	100.90
	Virginia River Tributary at Guzzwell Drive	12	59.54	59.57	59.59	59.61	59.51	59.48	59.45
	Virginia River at Virginia Lake Outlet	12	72.98	72.98	73.00	73.02	72.93	72.90	72.87
	Virginia River at Logy Bay Road	12	56.96	56.98	57.07	57.11	56.83	56.78	56.70
	Downstream	12	10.88	10.88	10.92	10.92	10.8	10.74	10.7
Mundy Pond Brook	Mundy Pond Brook at Coefield Street	6	109.54	109.60	109.65	109.71	109.49	109.42	109.35
	Mundy Pond Outlet Structure	6	87.32	87.42	87.51	87.59	87.22	87.12	87.03
	Downstream	6	87.32	87.42	87.51	87.59	87.22	87.12	87.03
Kitty Gaul Brook	Kitty Gaul Brook at Blackmarsh Road	6	129.59	129.63	129.66	129.70	129.55	129.50	129.46
	Kitty Gaul Brook at Greenwood Crescent	6	84.55	84.60	84.65	84.69	84.50	84.45	84.39
	Downstream *	6	78.03	78.05	78.07	78.09	78.01	77.99	77.97
South Brook	South Brook at Southlands Boulevard (Upper)	12	168.82	168.85	168.88	168.91	168.79	168.75	168.71
	South Brook at Tree Top Drive	12	153.89	153.91	153.92	153.94	153.87	153.85	153.83
	Downstream *	12	149.35	149.37	149.39	149.40	149.34	149.32	149.30
* Values reported are for the second last cross-section, as the downstream boundary conditions is a fixed water level.									