Photo source: NHC (March 8th, 2022).

Brooklyn Hydrologic Assessment

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DISCLAIMER

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1 INTRODUCTION

Brooklyn Creek habitat restoration work has been led by Brooklyn Creek Watershed Society and Current Environmental for over a decade. Brooklyn Creek has been impacted by human activities with sections subsequently restored by several stream restoration projects. Fisheries values have focused a large portion of previous work. The quality of stream habitat has been enhanced through various modifications to Brooklyn Creek, such as installing fishways at Balmoral Avenue and Dogwood Avenue, a high flow diversion and fish screen at Prichard Road (NHC, 2005), construction of a side channel for the collection of stormwater (NHC, 2016), and numerous City of Comox / Current Environmental projects.

As project complexity has increased over time, there is a need to gain a better understanding of flood flows and low flows in Brooklyn Creek. NHC was approached by Current Environmental on behalf of the Brooklyn Creek Watershed Society to assess discharge at five locations along Brooklyn Creek. The objective of this work is to provide updated flow estimates to inform future design of stream restoration projects for fish habitat in Brooklyn Creek. This work is funded by the Pacific Salmon Foundation.

2 SCOPE OF WORK

The following scope of work was completed by NHC:

1. Review of available data and background information.
2. Develop flood estimates for the 2, 5, 10, 50, and 100-year return intervals at the following locations:
    a. Guthrie Road
    b. Pritchard Road
    c. Dogwood Avenue
    d. Balmoral Avenue
    e. The estuary (tide water)
3. Develop 7-day low flow estimates for the above 5-study locations.
4. Complete a 1-day field assessment to measure channel dimensions at project locations to help verify the reasonableness of the discharge estimates
5. Summarize findings and recommendations.

3 STUDY AREA

The study area is located on the East Coast of Vancouver Island, in the seaside town of Comox, British Columbia (Figure 1). The watershed is oriented southeast towards the Strait of Georgia and flows into the Comox Harbour. Brooklyn Creek is a small, urban, and highly modified watershed. Historic peak discharges have occurred in January, while minimum mean monthly flows typically occur in August (Davies and Bryden, 1997). Several springs have been identified in the area, providing low but consistent flows (NHC, 2016). Supplementary flow is also provided by all-season stormwater inflows at the

Balmoral Ave site, as observed during site inspections. Peak flows have been reduced immediately upstream of the Pritchard Rd crossing via a flow diversion intake structure designed by NHC in 2005, which diverts flow directly to Comox Bay. The intake flow rate is based on construction design elevations and discharges up to a 100-yr discharge of 1.98 m^3/s. Design flows for the diversion have been applied to the results presented in this report.

We expect that urban development has impacted Brooklyn Creek flows during low and peak flow events. Analysis provided in this report were intended to quantify potential updates to flow estimates for each location along Brooklyn Creek. The location of each site and portions of the watershed boundary were verified during a field visit, which supported the selection of the Freshwater Atlas watershed delineation (GeoBC, n.d.). Significant stormwater inflows affect the Balmoral Road crossing year-round, including the supplementation of summer low flows (according to local knowledge). For this reason, the stormwater network for this portion of the watershed was included in the drainage area. The watershed delineation is shown in Figure 1.

BROOKLYN CREEK WATERSHED SOCIETY

nhc northwest hydraulic consultants

- Project sub-watersheds
- Mack Laing Bridge gauge
- Climate Station
- WSC 08HB075 Dove Creek, study proxy gauge
- Brooklyn Creek Watershed

SCALE - 1:63,360

0 1 2 KM

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Coordinate System: NAD 1983 UTM ZONE 10N
Units: METERS

Job: 3005595

Date: 03-AUG-2022

BROOKLYN CREEK WATERSHED AND STUDY LOCATIONS

FIGURE 1

ABC, C:\Users\rhay\OneDrive - NHC\Documents\ArcGIS\Project Folders\Brooklyn Hydrology\Study Area Map_R1.mxd

4 HYDROLOGIC ASSESSMENT

4.1 Study Approach

Flood flow and low flow estimates were calculated for five culvert stream crossings:

- Guthrie Road
- Pritchard Road
- Dogwood Road
- Balmoral Ave
- estuary/tidewater

It is accepted practice to provide several means of flow estimation to assess the range in results (NHC, 2021). Several regional hydrology approaches were used to estimate flood flows:

- flood frequency analysis using a suitable Water Survey of Canada (WSC) proxy gauge was adjusted to the study locations using area-based scaling.
- the rationale method.
- multiple regression model using precipitation and watershed area.

To verify the reasonableness of the estimated flood discharges, field data was assessed:

- discharge data from the Brooklyn Creek hydrometric gauge was compared to the Dove Creek WSC gauge to verify the scaling factor.

Low flow estimates for Brooklyn Creek were also developed based upon scaling of the Dove Creek WSC gauge.

The following sub-sections detail the methodology applied in each estimation.

4.2 Sub-watershed characteristics

A photograph of each sub-watershed cross-section are shown in Figure 2. Watershed characteristics were derived from the WSC Gauge Atlas (NHC, 2021), the Freshwater Atlas (GeoBC, n.d.), and ArcMap geospatial tools. Time of concentration describes the rain-runoff relationship of a watershed and is used in the Rational Method. Table 1 contains values utilized in this analysis. Additional photographs and cross-section plots for each sub-watershed are presented in Appendix A.

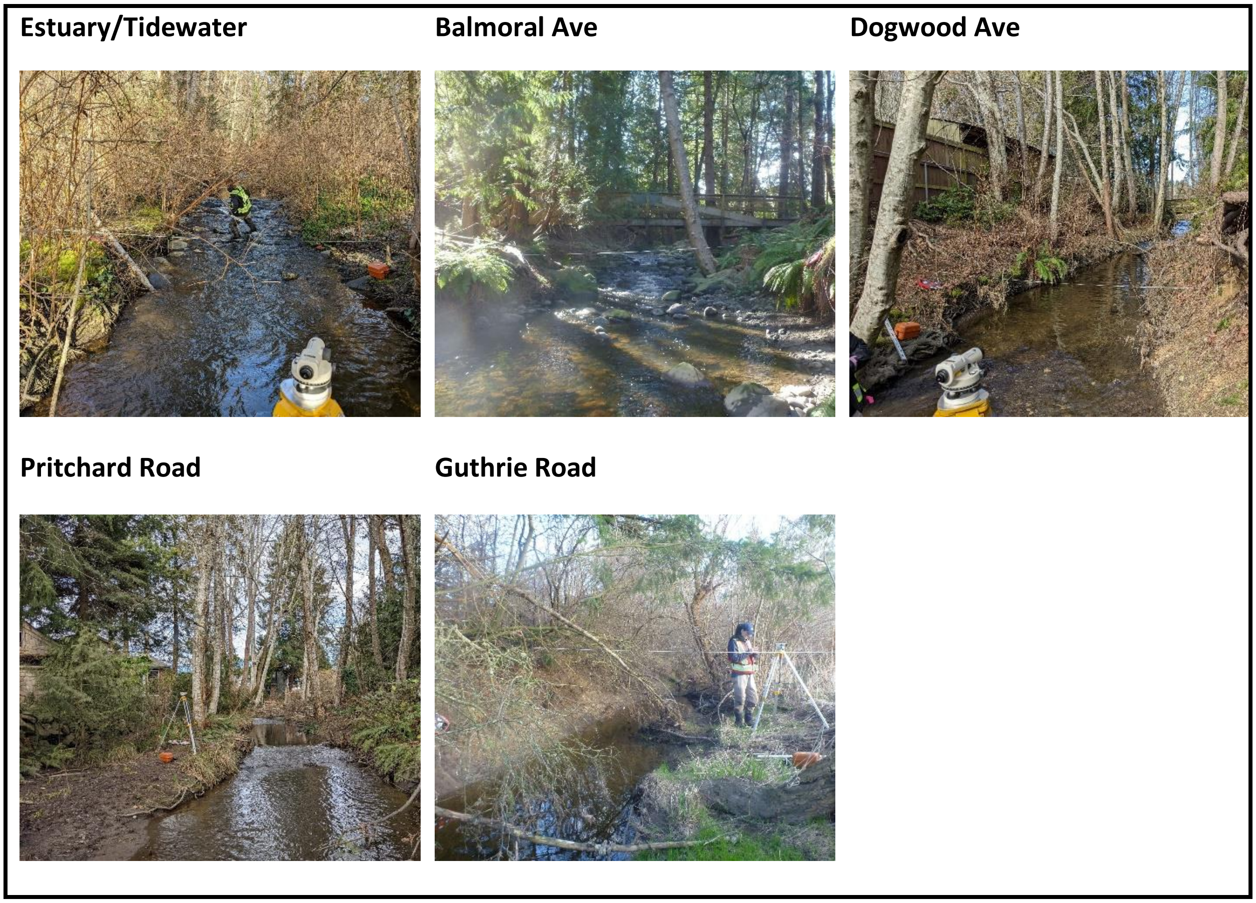

Figure 2. Cross-section locations for each sub-watershed site.

Table 1. Watershed characteristics by sub-watershed.

Sub-Watershed	Characteristics	Value
Guthrie Road	Watershed Area (km^2)	4.34
	Median elevation (m)	64.5
	Mean Slope %	6.2
	Stream length (m)	4038.2
	Time of concentration (hr)	4.7
Pritchard Road	Watershed Area (km^2)	5.15
	Median elevation (m)	57.9
	Mean Slope %	6.18
	Stream length (m)	4792.1
	Time of concentration (hr)	5.2
Dogwood Ave	Watershed Area (km^2)	5.59
	Median elevation (m)	59.7
	Mean Slope %	6.16
	Stream length (m)	5261.0
	Time of concentration (hr)	5.25

Sub-Watershed	Characteristics	Value
Balmoral Ave	Watershed Area (km^2)	6.51
	Median elevation (m)	55.3
	Mean Slope %	6.42
	Stream length (m)	6276.9
	Time of concentration (hr)	5.8
Estuary/Tidewater	Watershed Area (km^2)	6.75
	Median elevation (m)	50.3
	Mean Slope %	6.63
	Stream length (m)	7183.7
	Time of concentration (hr)	5.9

4.3 Flood frequency analysis and area-based scaling

Area-based scaling is a method used for ungauged catchments, by statistically relating a gauged (or "proxy") station and using this relationship to estimate discharge. To provide a robust relationship, a proxy gauge must have at least 10-years of data, be close geographically, have similar physiographic characteristics and a similar proportion of hydrologic features (such as lakes, glaciers, landcover and regulation). Three WSC gauges were considered as proxy gauges for this study as presented in Table 2**.** In this case, 08HB075 was selected as the most suitable proxy by process of elimination due to the unsuitability of 08HB011 (regulated) and 08HB025 (higher elevation). The 08HB075 Dove Creek gauge is suitable because it has a small watershed area; is unregulated; is partly urban; and, the gauge and watershed elevation are near sea-level. The proxy gauge is located 15 km northwest from the Brooklyn watershed.

Table 2. Key hydrologic characteristics of WSC proxy basins.

WSC Gauge No.	WSC Gauge Name	Watershed Area (km^2)	Gauge Elevation (m)	Median Basin Elevation (m)	Mean Annual Precip. (mm)	Length of Record (yrs)
08HB075	Dove Creek near the mouth	44.2	63	315	1980	33
08HB011	Tsolum River near Courtenay	251	7	214	1870	53
08HB025	Browns River near Courtenay	87.9	62	947	2673	33

Flood frequency analysis was derived for 08HB075 Dove Creek Near the Mouth based upon maximum annual instantaneous discharge observations. The LPIII, GEV, Gumbel and log-normal3 distributions were compared. The Gumbel distribution was adopted based upon the best visual fit (Figure 3).

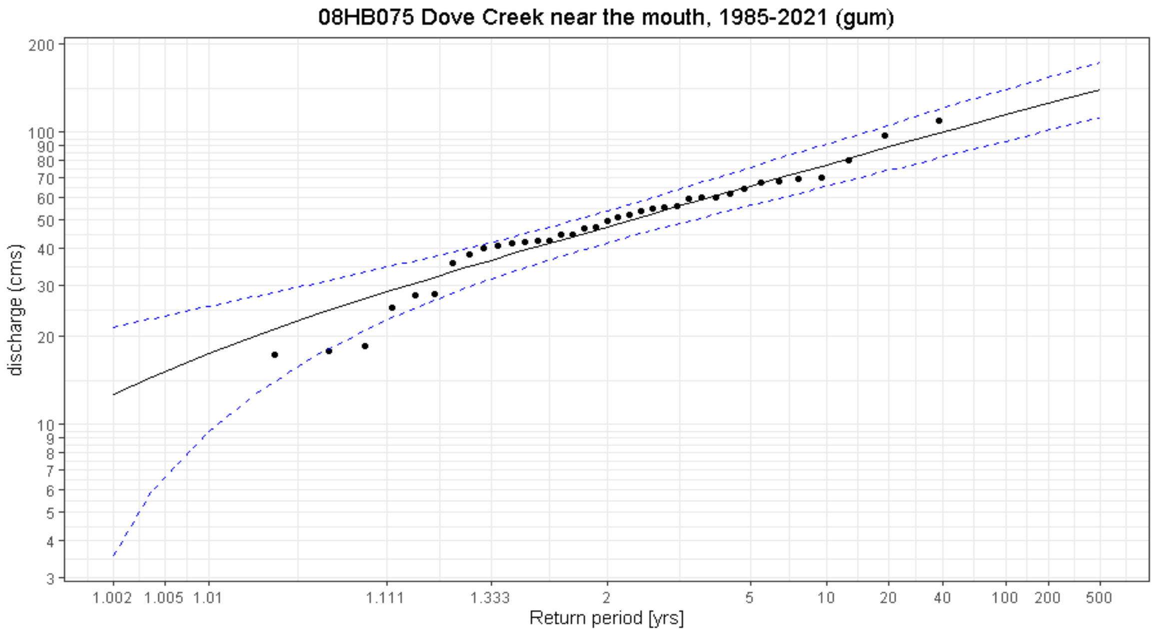

Figure 3. Gumble distribution for 08HB075 Dove Creek Near the Mouth discharge data.

The return period discharges for 08HB075 were then transposed to the Brooklyn Creek watershed study sites using area based scaling (NHC, 2021):

$$Q_{ungauged} = Q_{gauged} \times \left(\frac{Area_{ungauged}}{Area_{gauged}}\right)^{b} \qquad \text{Equation 1}$$

where Q_{gauged} is the discharge from a proxy gauge for a specific return period, and $Area_{gauged}$ and $Area_{ungauged}$ are watershed areas for proxy and ungauged basins. The scaling factor b is based on the Ecoprovince or Ecozone the watershed is located in, referenced from Figure 2-22, and Table 2-21 in NHC (2021). Brooklyn Creek watershed is located in Ecoprovince 13.1, and a scaling factor of 1.00 is recommended by NHC (2021). The relationship between daily discharge between Brooklyn Creek and Dove Creek was also compared to inform area-based scaling. Based on this analysis, an adjustment factor of 0.47 was also applied to the area scaling (see Section 4.6 for more information). Flood frequency estimates for the Brooklyn Creek study sites are presented in Table 3.

Table 3. Flood frequency estimates in cubic meters per second (m^3/s) for Brooklyn Creek study sites. Flood estimates are based on scaled results from Dove Creek WSC gauge. A scaling factor of 1.0 was adopted with an 0.47 adjustment factor. Discharge values do not include the subtraction of flow from the Pritchard diversion and do not include climate change.

Basin-Area Scaled (Ecoprovince Scaling Factor 1.0 with adjustment factor of 0.47)					
Return Period	Guthrie Rd	Pritchard Rd	Dogwood Ave	Balmoral Ave	Estuary/tidewater
2	2.19	2.60	2.83	3.29	3.41
5	3.02	3.59	3.90	4.54	4.70
10	3.57	4.24	4.60	5.36	5.56
50	4.79	5.68	6.16	7.18	7.44
100	5.30	6.29	6.82	7.95	8.24

4.4 Rational method

The rational method as described below was also used to estimate flood flows for Brooklyn Creek study sites. The rational method is an equation that relates rainfall intensity to runoff. This equation is applicable to small watersheds (<10 km^2 ; Equation 2):

$$Q_n = 0.0028 \times C \times I \times A \qquad \text{Equation 2}$$

where Q_n is the estimated peak discharge for n-year event (m^3/s), C is the runoff coefficient, and I is the rainfall intensity for the same n-year event and a duration equal to the time of concentration (mm/hr). A is the watershed area (hectares), and 0.0028 is an SI conversion factor. The runoff coefficient corresponds to surface conditions and physiography (Coulson, 1991).

The TAC Geometric Design Guide, 1000 Hydraulics Chapter (BC MoTI, 2021) is a key reference used to support using the Rational Method. The time of concentration (Tc) determines the rainfall intensity duration and is calculated via various methods depending on the suitability for the study watershed. The suitability of the Hathaway Formula, Water Management Method, and Kirpich Formula were tested. The Water Management Method (Figure 1020.B in BC MoTI, 2021; Table 4) was selected in this case, due to its suitability for small catchments and most plausible Tc estimate. Rainfall intensity data from the Environment Climate Change Canada (ECCC) station 1021830 Comox A was adopted for this analysis (ClimateData.ca, 2022). Comox A is located adjacent to the northeastern coast in Comox and is representative of the local climatology and rainfall intensity affecting the Brooklyn watershed.

Estimated peak flow values for the Brooklyn Creek study sites using the Rational Method are presented in Table 5.

Table 4. Time of Concentration (Tc) values based on the Water Management Method.

	Guthrie Rd	Pritchard Rd	Dogwood Ave	Balmoral Ave	Estuary/tidewater
Tc (hr)	4.70	5.20	5.25	5.80	5.90

Table 5. Rational Method estimated peak flow values in cubic meters per second (m^3/s) for the Brooklyn Creek study sites. Discharge values do not include the subtraction of flow from the Pritchard diversion and do not include climate change.

Return period	Guthrie Rd	Pritchard Rd	Dogwood Ave	Balmoral Ave	Estuary/tidewater
2	3.71	4.73	5.09	5.63	5.77
5	5.37	6.09	6.56	7.35	7.43
10	6.64	7.47	8.05	8.93	9.26
50	9.11	10.49	11.27	12.17	12.76
100	10.48	10.87	11.77	13.40	14.03

4.5 Multiple regression model estimate using mean annual precipitation

NHC (2021) developed a regression model for estimating the 10-year 100-year flows in various ecozones of BC (Equation 3):

$$Q = 10^{A} \times \mathrm{Area}^{B} \times \mathrm{MAP}^{C} \times \mathrm{MedianZ}^{D} \qquad \text{Equation 3}$$

where Area is basin area in km^2, MAP is mean annual precipitation (mm), MedianZ is the median basin elevation (m), and coefficients A, B, C, and D are regression coefficients that vary based upon ecozone and specified return period.

The above regression model was used to estimate the 10-yr and 100-yr flood flows for the Brooklyn Creek study sites. Regression coefficients from Table 2-18 and 2-19 in NHC (2021) were adopted.

The WSC Gauge Atlas contains watershed details for each WSC site, including mean annual precipitation (MAP) (NHC, 2021). The proxy gauge 08HB075 Dove Creek Near the Mouth MAP was selected because the topographic characteristics that influence rainfall were comparable between this site and Brooklyn. Median elevation was calculated in ArcMap. Estimated peak flow values for the Brooklyn Creek study sites using the NHC (2021) regression model are presented in Table 6.

Table 6. Estimated peak flow values in cubic meters per second (m^3/s) for the Brooklyn Creek study sites using the multiple regression model equation from NHC (2021). Discharge values do not include the subtraction of flow from the Pritchard diversion and do not include climate change.

Return period	Guthrie Rd	Pritchard Rd	Dogwood Ave	Balmoral Ave	Estuary/tidewater
10	5.19	6.06	6.50	7.47	7.75
100	7.62	8.78	9.42	7.47	11.01

4.6 Brooklyn hydrometric gauge

Current Environmental operated a hydrometric station on Brooklyn Creek at Mack Laing Bridge, upstream of the estuary/tidewater site, from April 2014 to January 2017. The station recorded stage and water temperature and was used to develop a rating curve relating stage to flow (Figure 4). The Mack

Laing Bridge derived discharge timeseries was compared to the WSC Dove Creek proxy gauge (Figure 5). Linear correlation was completed between the daily flows for both the summer and winter periods. The correlation was used to inform scaling for flood flows and low flows. An adjustment factor of 0.47 was applied to the area scaling of flood flows.

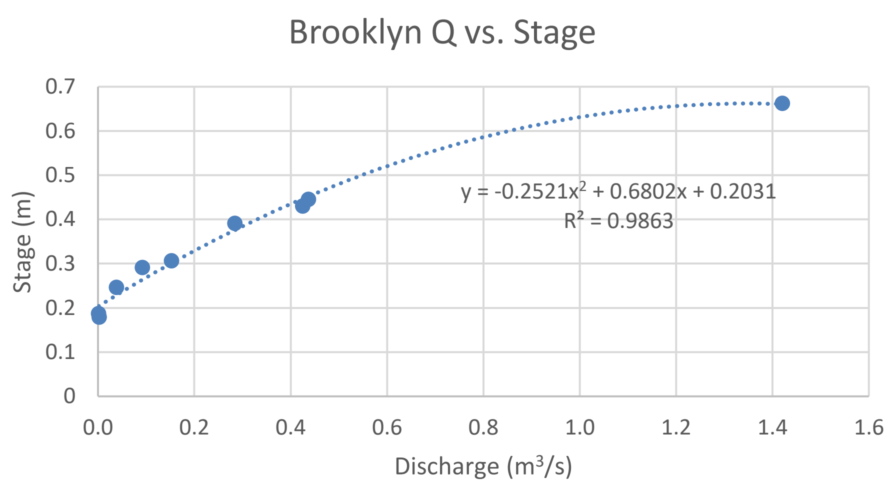

Figure 4. Brooklyn Creek Rating Curve, developed by Current Environmental.

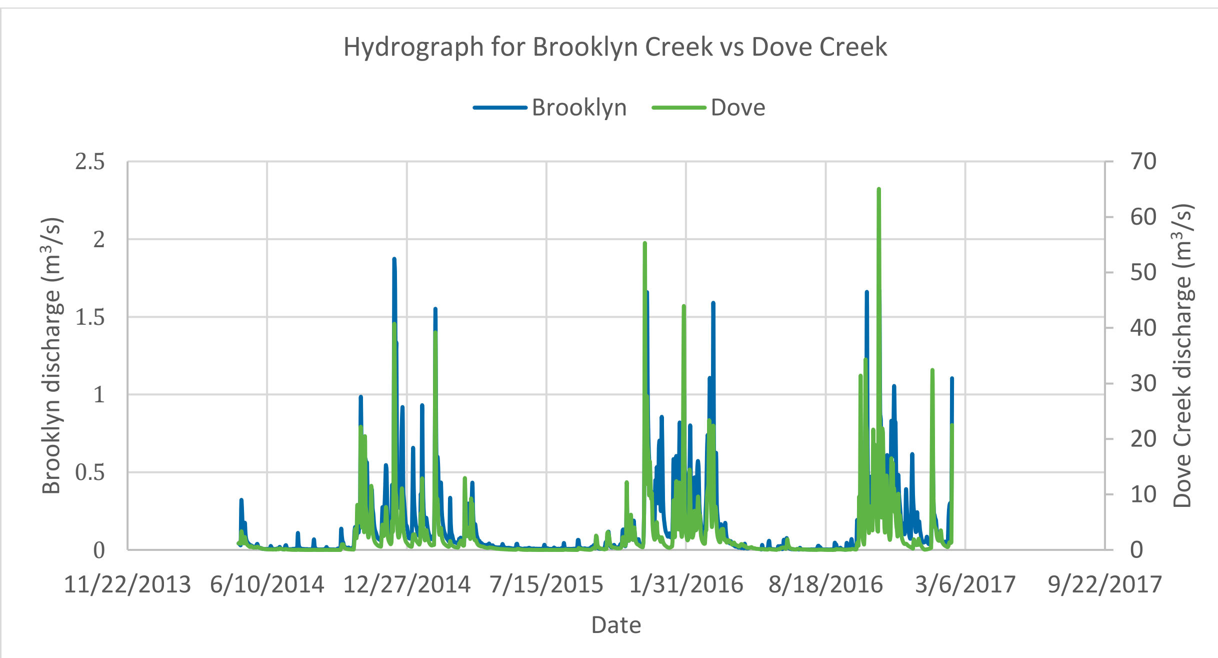

Figure 5. Brooklyn Creek and Dove Creek daily flow hydrographs.

4.7 Low Flows

The average annual 7-day low flow was calculated for the Dove Creek WSC gauge. Frequency analysis was then completed on the annual 7-day low flows at Dove Creek. The average annual and return period discharges for 7-day low flows at 08HB075 were then transposed to the Brooklyn Creek watershed study sites using area-based scaling. The recommended scaling factor of 1.0 as per NHC (2021) was verified when comparing daily summer flows from Brooklyn Creek to Dove Creek. Low flow estimates compare well with the minimum mean monthly discharge estimate for Brooklyn Creek (0.009 m^3/s) completed by Davies and Bryden (1997). Therefore, when transposing low flows to Brooklyn Creek a scaling factor of 1.0 was used. Personal communications with Wong (2022) noted that additional contributions to Brooklyn Creek occur during low flows, specifically upstream of the Balmoral culvert. Additional contributions from springs and stormwater would increase the low flow estimates for Brooklyn Creek provided in this report. Further analysis and monitoring are recommended to provide a more accurate understanding of low flows. The mean annual 7-day low flow along with return period 7-day low flows for the Brooklyn Creek study sites are presented in Table 7.

Table 7. Long-term average 7-day low flow estimates in cubic meters per second (m^3/s) for WSC proxy gauge 08HB075 and Brooklyn Creek Study sites. Discharge values do not include the subtraction of flow from the Pritchard diversion.

Return Period	Dove Creek Gauge 08HB075	Guthrie Rd. Subbasin	Pritchard Rd. Subbasin	Dogwood Ave. Subbasin	Balmoral Ave. Subbasin	Tidewater / Estuary Subbasin
100	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000
20	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0009	0.0000	0.0000	0.0000	0.0000	0.0001
5	0.0016	0.0000	0.0000	0.0000	0.0000	0.0002
2	0.0049	0.0000	0.0000	0.0000	0.0001	0.0007
mean (1985-2020)	0.0113	0.0000	0.0000	0.0000	0.0003	0.0017

4.8 Climate Change

Climate change impacts vary regionally and on different timescales. Based on different global emission scenarios, the atmosphere is predicted to warm by 0.9 to 5.4°C globally by 2090 (under RCP2.6 to RCP8.5; CMIP5, Taylor et al., 2012; World Climate Research Programme, no date). These increases in temperatures are expected to produce more frequent and severe drought conditions. These extreme droughts will decrease low flows and increase water temperatures. As air temperatures increase, the atmosphere can hold larger volumes of moisture. This increases the maximum rainfall potential, which therefore increases flood risk. Many parts of British Columbia are predicted to see increased flood risks as a result of climate change (EGBC, 2018; Warren et al., 2021).

The Mann-Kendall statistical test was used to test for changes in the WSC Dove Creek Near the Mouth gauge data. This test can be used to determine if the data set is increasing or decreasing over time. The Mann-Kendall statistical test indicated annual instantaneous peak flows at the WSC gauge Dove Creek Near the Mouth were increasing significantly over time (Table 8). This shift in the flood flows at Dove

Creek could be due to changes in climate or land use. It is assumed that a similar change has also occurred in the flows at Brooklyn Creek.

To account for this change in future planning, a 20% climate change factor was applied to peak discharge results as recommended by EGBC (2018).

Table 8. Mann-Kendall Test Summary for 08HB075 Dove Creek Near The Mouth Discharge.

Tau	2-sided p-value	p-value
0.279	0.015538	<0.05 there is a significant positive trend in the data

5 SUMMARY & RECOMMENDATIONS

5.1 Discharge

- Final discharges account for flows diverted away from the channel via the flow diversion structure at Pritchard Creek. If the diversion screens or pipe are blocked then the discharge in Brooklyn downstream of the diversion may be greater than those provided in this report. We are not aware of any diversion flow testing, thus the diversion flow rates are considered theoretical at this time.
- Our professional opinion is that flood frequency analysis based upon the Dove Creek WSC proxy gauge represents a reasonable flood estimate for Brooklyn Creek; however, it also produced the lowest flood discharges which may not be suitable for some projects, such as habitat restoration design.
- The relationship between Brooklyn Creek discharge and Dove Creek discharge was verified using approximately 2.5 years of data.
- Table 9 and Table 10 present a summary of peak discharge estimates based upon the Rational Method, the multiple regression model, and the regional proxy gauge approach.
- Climate change impacts were accounted for by adding a 20% increase to the flood discharges. The discharges with climate change are included in Table 10.
- The regression model flow estimates compare reasonably well with the proxy gauge frequency analysis.
- The Rational Method flow estimates produced the largest discharge estimates but were comparable to the multiple regression model outputs.
- All peak discharge estimates are intended for use in river restoration planning and design only. The final design flood selection should be based upon the scope of its application.
- 7-day low flow estimates are shown in Table 7. The Dove Creek proxy gauge produced 7-day low flows that do not include additional flow contributions observed by Wong (2022). Additional low flow measurements and analysis are recommended to refine these estimates.
- Discharge estimates from NHC (2005) are presented in Table 11.

Table 9. Summary of flood discharge estimates in cubic meters per second m^3/s for Brooklyn Creek study sites. Discharge values include the subtraction of flow from the Pritchard diversion but no climate change additions. Ration = Rational Method, Regres = Regression Method, Region = Regionalization method.

Return Period	Guthrie			Pritchard			Dogwood			Balmoral			Estuary-Tidewater		
	Ration	Regres	Region	Ration	Regr	Region	Ration	Regr	Region	Ration	Regr	Region	Ration	Regr	Region
2	1.7	-	2.2	2.8	-	2.6	3.1	-	2.8	3.6	-	1.3	3.8	-	1.4
5	3.4	-	1.0	4.1	-	1.6	4.6	-	1.9	5.4	-	2.6	5.5	-	2.7
10	4.7	3.2	1.6	5.5	4.1	2.3	6.1	4.5	2.6	7.0	5.5	3.4	7.3	5.8	3.6
50	7.1	-	2.8	8.5	-	3.7	9.3	-	4.2	10.2	-	5.2	10.8	-	5.5
100	8.5	5.6	3.3	8.9	6.8	4.3	9.8	7.4	4.8	11.4	8.7	6.0	12.1	9.0	6.3

Table 10. Summary of flood discharge estimates in cubic meters per second m^3/s for Brooklyn Creek study sites. Discharge values include the subtraction of flow from the Pritchard diversion and the addition of a 20% climate change factor. Ration = Rational Method, Regres = Regression Method, Region = Regionalization method.

Return Period	Guthrie			Pritchard			Dogwood			Balmoral			Estuary-Tidewater		
	Ration	Regr	Region	Ration	Regr	Region	Ration	Regr	Region	Ration	Regr	Region	Ration	Regr	Region
2	2.1	-	2.6	3.3	-	3.1	3.7	-	3.4	4.4	-	1.6	4.6	-	1.7
5	4.1	-	1.3	4.9	-	1.9	5.5	-	2.3	6.4	-	3.1	6.5	-	3.3
10	5.6	3.8	1.9	6.6	4.9	2.7	7.3	5.4	3.1	8.3	6.6	4.1	8.7	6.9	4.3
50	8.6	-	3.4	10.2	-	4.4	11.1	-	5.0	12.2	-	6.2	12.9	-	6.6
100	10.2	6.8	4.0	10.7	8.2	5.2	11.7	8.9	5.8	13.7	10.5	7.2	14.5	10.8	7.5

The estuary-tidewater location represents the bottom of the watershed and is comparable to a whole watershed estimate (i.e. Table 11). For each estimate, the discharge value from this report has increased when compared to NHC (2005). When comparing the 'regional' or proxy results, the 2-year discharge increased by 20%, 5-year by 15%, 10-year by 30%, and the 100-year by 50%. While the estimates provided in Table 10 appear high, adding a climate change factor has proven to be important given the peak flows are statistically significant at the WSC Dove Creek site. Future hydrologic studies should consider including a Stormwater Management Model (SWMM) model and the storm drain network from the City of Comox to better represent stormwater contributions.

Table 11. NHC discharge estimates (in cubic meters per second, m^3/s) from previous studies for comparison (NHC, 2005).

Return period	Brooklyn Creek/Estuary-Tidewater
2	2.55
5	3.20
10	3.62
100	5.33

6 UNCERTAINTY & ASSUMPTIONS

These analyses include, but are not limited to, the following uncertainties and assumptions:

- Runoff flow with a given return period of rainfall assumes that rainfall of a given frequency produces streamflow of the same frequency.
- Assumed antecedent moisture conditions.
- Considerable uncertainty in precipitation intensity data.
- The suitability of a proxy gauge in area-based scaling is uncertain.
    - The urbanized percentage of the 08HB075 Dove Creek Near the Mouth watershed is substantially lower than Brooklyn Creek.
    - It is assumed that the mean annual precipitation received by both watersheds is comparable.
    - Assume important hydrologic features or events are known.
- Stormwater and groundwater contributions are ungauged and unknown.
- Uncertainty in low flow contributions from springs and groundwater during periods of drought.
- Considerable uncertainty related to climate change impacts on events of all magnitudes.
- It should be noted that the uncertainty in hydrologic estimates used in this study was high due to stream alterations and significant urban development.

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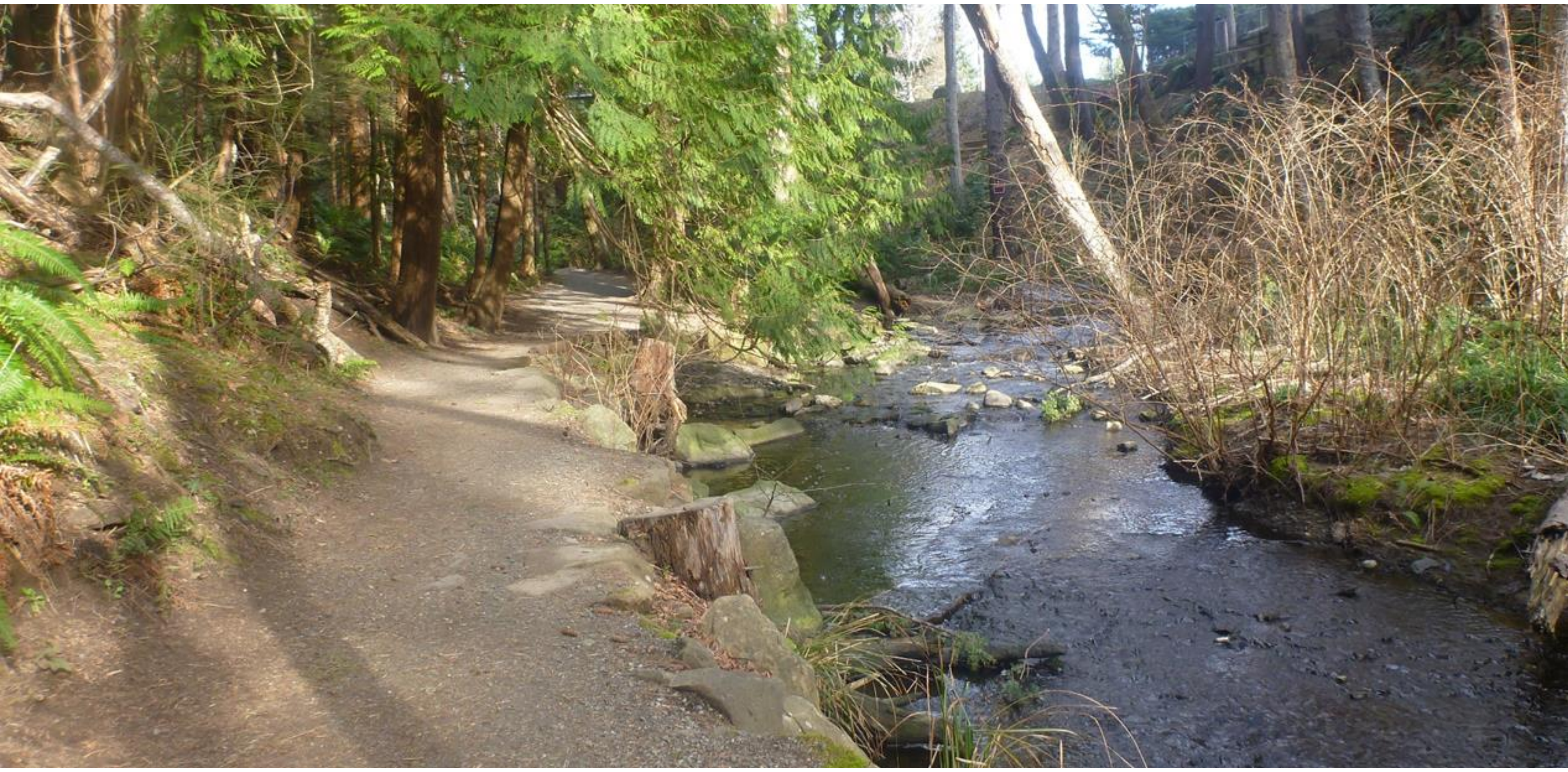

Photo source: NHC (March 8th, 2022).

Brooklyn Hydrologic Assessment
Appendix A: Hydrology

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Appendix A: Hydrology

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Prepared for:

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APPENDIX A
HYDROLOGY

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1 FIELD MEASUREMENTS

NHC staff completed a site assessment of the Brooklyn Creek study sites on the 8th of March 2022. Tasks completed at each site were to take measurements of channel cross-sections (Figure 1-Figure 5); verify the study site location; collect particle size measurements; and, identify any major stormwater inflows and/or stream modifications. Stormwater inflows are discussed in Section 3 of the report.

At each study site, cross section measurements were taken from the top and bottom of bank on each side. Top of banks were defined based upon morphological features and past debris flow marks, and the depth of water was assumed to be the full bank height. Bankfull flood flows are typically associated with the mean annual flood or a flood with a 1- to 2-year return period. Most drainages on Eastern Vancouver Island experienced flood flows during the record-breaking November 15, 2021 flooding. Evidence of recent debris lines were observed at some study sites. The Pritchard Road cross-section includes two top of bank width measurements, due to evidence of flood debris beyond the expected top of bank. The Dove Creek WSC proxy gauge did not experience a significant flow event on November 15, 2021. It did however experience a high flow event on October 25, 2021 (69 m^3/s, approximately 6-year return period). There is high uncertainty estimating the return period associated with the top of bank cross section measurements at the Brooklyn Creek study sites. Table 1 presents results from field measurements.

Table 1. Field measurements for each study site. Two channel widths were used at Pritchard based on observations in the field.

Value	Guthrie	Pritchard		Dogwood	Balmoral	Estuary-Tidewater
		Width1	Width2			
Area (m^2)	9.69	3.62	7.23	1.99	5.69	4.74
Wetted perimeter (m)	6.47	7.20	7.15	4.70	7.37	6.17
Slope (m/m)	0.008	0.012		<0.000	0.007	0.043
d50 (mm)	12.5	23.5		17	18.5	13

Note - Width1 is 3.3m; Width2 is 10.2m. Both widths were used in analysis due to the discovery of flood debris beyond the expected top of left bank.

The Pritchard Rd cross-section was difficult to define on the left bank, as evidence of high water marks were found beyond the first potential top of bank location. Two channel widths (3.3m and 10.2m) were used to provide an estimate for both bank measurements. A cross-section image and plot are shown in Figure 2. Figure 1-Figure 5 present each cross-section measured in Brooklyn Creek. Slope measurements were collected from a differential elevation survey in the channel. The cross-sectional area was calculated from field measurements using stakes and a long tape measure. The median (d50) particle size was assessed from a scaled photograph.

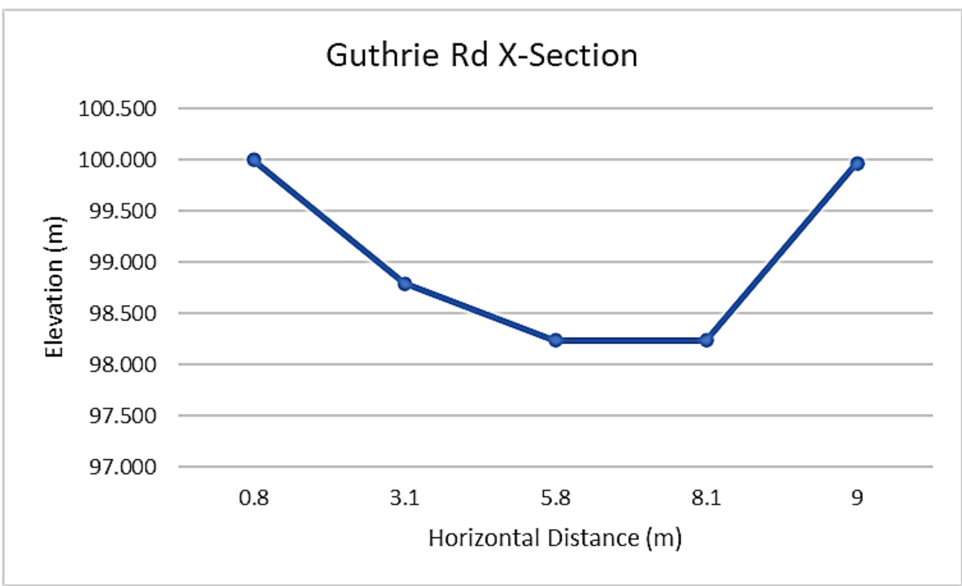

Figure 1. Guthrie Rd cross-section.

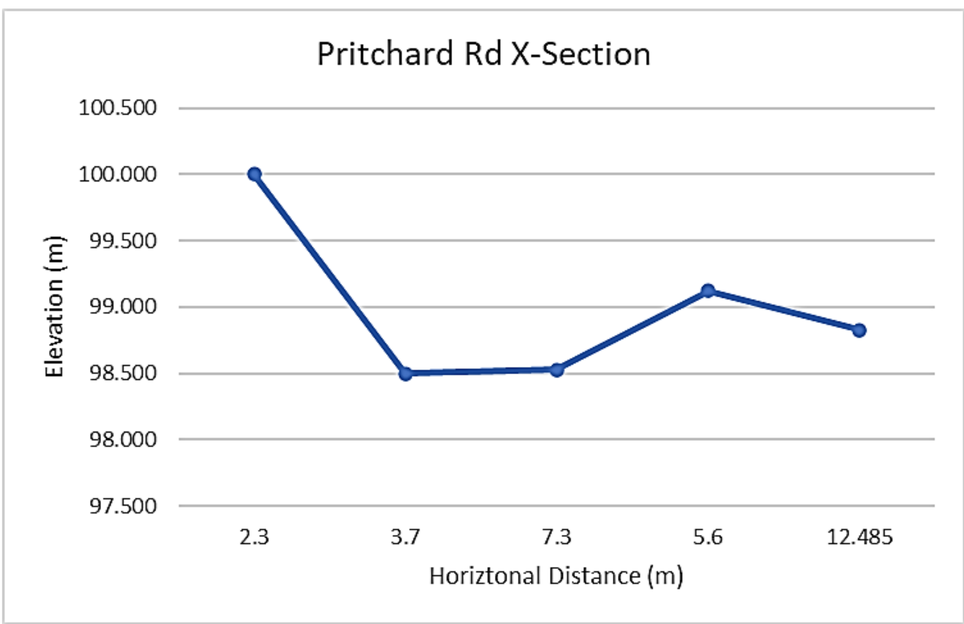

Figure 2. Pritchard Rd cross-section. Width1 is 3.3m; Width2 is 10.2 m.

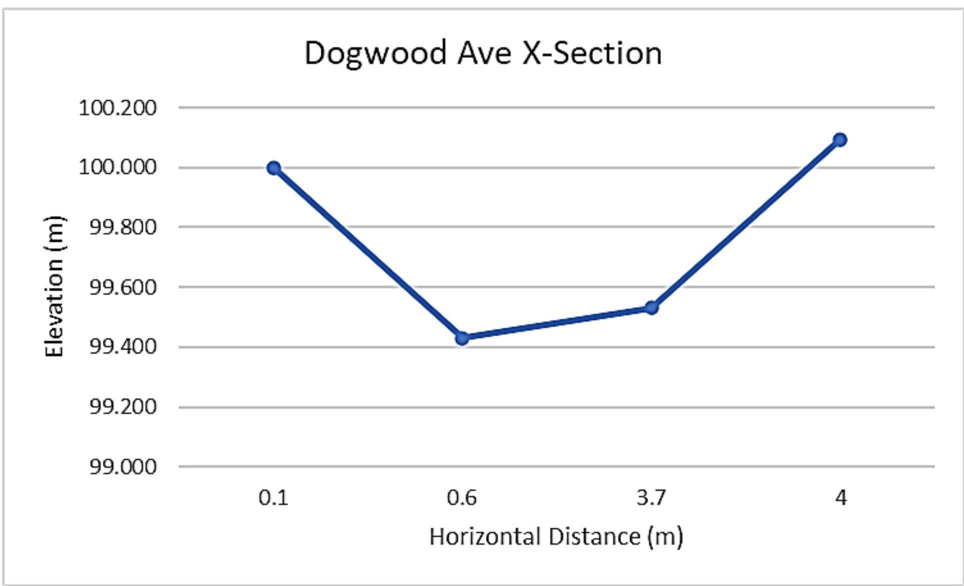

Figure 3. Dogwood Ave cross-section.

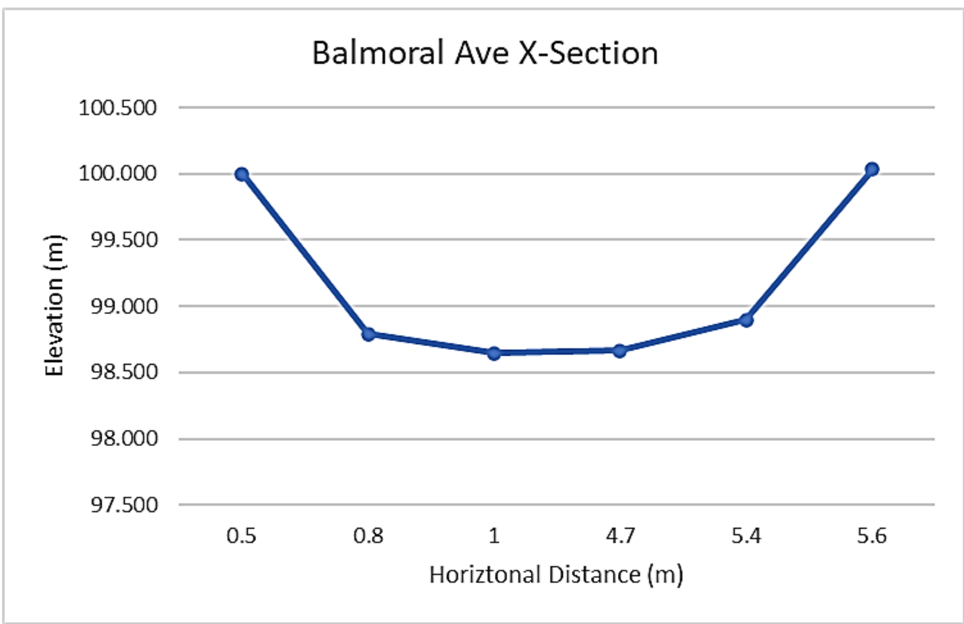

Figure 4. Balmoral Ave cross-section.

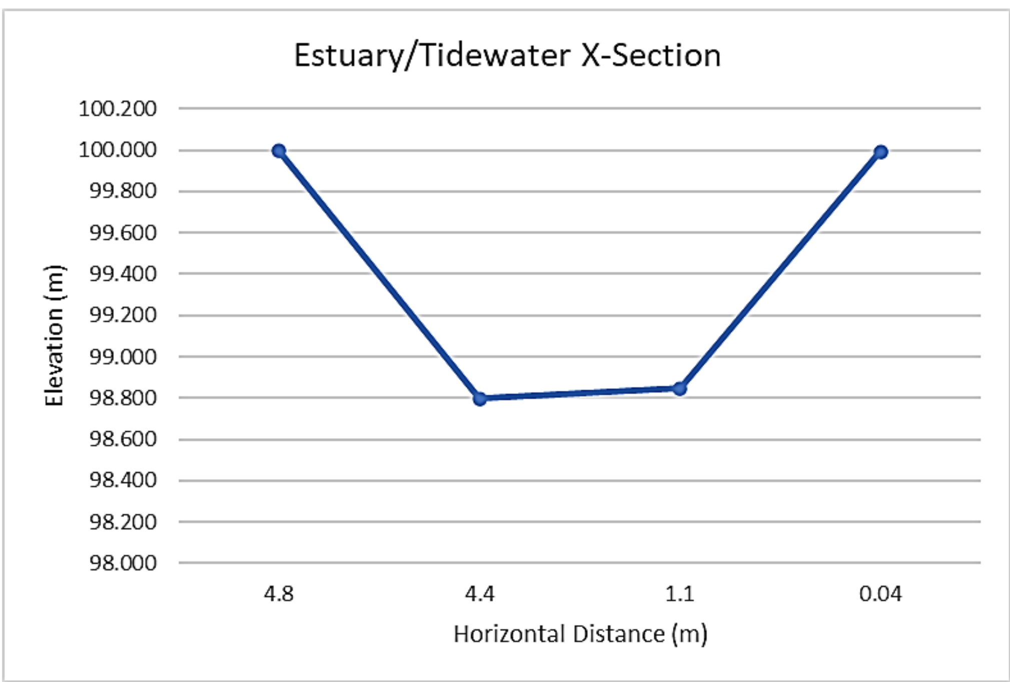

Figure 5. Estuary-tidewater cross-section.

2 VELOCITY ESTIMATES

Average velocity can be estimated using the average 5-year discharge from Table 9 and Table 10 and the cross-sectional area from each study site (Table 1). The 5-year discharge is selected because it is assumed that the cross-sectional area measurements approximately represent a flow of this magnitude (see F). This method uses Manning's Equation. Manning's can be defined as an empirical, dimensional equation for the flow of water in open channels and determines a relationship between flow and velocity.

$$Q = V \times A \qquad \text{Equation 1}$$

where Q is discharge (m^3/s), V is the average velocity (m/s), and A is the flow area of the channel (m^2).

The average velocity is provided for both current climate and future climate change conditions (Table 2), based on the flow values from Section 5.1 in the report. It should be noted that there is a large degree of uncertainty in these velocity values, which vary over time and in different channel conditions.

Table 2. Average velocity calculated from the average of all peak flow estimates for a 5-yr return period, and cross-sectional area.

Average Velocity (m/s)	Guthrie	Pritchard	Dogwood	Balmoral	Estuary-Tidewater
5-yr (no climate change)	0.23	0.39	1.64	0.70	0.87
5-yr (with climate change)	0.28	0.47	1.96	0.84	1.03