3 PHASE 2: TECHNICAL ASSESSMENTS AND INFRASTRUCTURE RISK ASSESSMENT

Following the successful completion of Phase 1, the **Phase 2** process started, comprising of a series of multi-disciplinary technical assessments, to characterize existing conditions within the Newtonbrook Creek study area. Upon completion of these technical studies, risk sites were formally established for each area where there were erosion risks to City owned sanitary, storm sewer, and watermain infrastructure. For each of these risk sites, as part of **Phase 2**, a geomorphic risk assessment was completed, ultimately identifying the twenty-four (x24) highest priority sites to be further addressed as part of the NCGSMP.

3.1 Technical Assessments

A series of multi-disciplinary technical assessments intended to provide insight into the integrated relationship between dynamic environmental processes and the long-term integrity of municipal and private infrastructure within the watershed were completed. These technical studies included fluvial geomorphic, terrestrial ecology, aquatic ecology, utility conflict, hydrologic and hydraulic, and climate change assessments, as outlined in the following sub-sections.

3.1.1 Fluvial Geomorphic Assessments

3.1.1.1 Reach Delineation

Geomorphic stream reaches are relatively uniform lengths of channel in terms of surface geology, hydrology, channel slope, boundary materials, and vegetation that control dominant geomorphic processes and sediment transport dynamics. In other words, the physical channel processes and resulting river morphology are relatively consistent over the length of the reach as compared to the differences between adjacent reaches. While in practice this requires that reaches be discretely divided by “reach breaks”, in reality, reach changes may be abrupt or may transition gradually depending on changes in the controlling variables. For example, contact with bedrock may abruptly confine the channel vertically or horizontally modifying channel processes and thus can represent a distinct reach break. In contrast, a gradual change in the boundary materials (e.g., increasing or decreasing sand supply) would result in a gradual change in channel processes and the mapped reach break would only approximate the location of this transition.

Newtonbrook Creek and Blue Ridge Creek have been previously delineated as single reaches that are tributaries to the Don River. In this study these tributaries are divided into reach segments based on landuse, divisions defined by large road crossings and creek infrastructure, and geomorphic parameters. In Newtonbrook Creek, four (4) distinct reaches were identified and assessed. Similarly, Blue Ridge Creek was divided into a further four (4) distinct reaches and assessed. These reach delineations are summarized in **Table 3-1** with a description of their upstream and downstream extents. Reach names beginning with “N” represent reaches within Newtonbrook Creek, whereas reach names beginning with “Br” represent reaches within Blue Ridge Creek.

Table 3-1: Summary of Reach Delineations in Newtonbrook Creek (N) and Blue Ridge Creek (Br)

Reach Name	Reach Limits
N1	Confluence with the Don River to Forest Grove Drive
N2	Forest Grove Drive to Bayview and Finch Avenue
N3	Bayview and Finch Avenue to Maxome Avenue
N4	Maxome Avenue to Willowdale Avenue
Br1	Confluence with the Don River to east of Citation Drive
Br2	Eastern end of Citation Drive to Burbank Drive
Br3	Confluence west of Clarinda Drive to Bayview Avenue
Br4	Confluence west of Clarinda Drive to Blue Ridge Road

3.1.1.1.1 Newtonbrook Creek Reach Delineation

Newtonbrook Creek was walked the 4,328 metres from the Don River to its most upstream channelized extent at Willowdale Avenue and Silverview Drive. The Newtonbrook Creek watershed covers over 8.21 km^2, and the average gradient of Newtonbrook Creek is 1.14%.

3.1.1.1.1.1 Reach N1

The most downstream reach in Newtonbrook Creek begins at the confluence of the Don River and extends upstream for 1,125 metres to Forest Grove Drive. The average channel gradient is 1.13%. At bankfull flow conditions, the local backwater from the Don River would propagate upstream for over 100 metres. This moderately sinuous reach has a sinuosity index of 1.20.

Between successive meanders, the channel has been straightened and lined with gabion baskets on the banks and channel substrate. The channel takes on a trapezoidal geometry in the lower part of the reach (**Figure 3-1)** with a trail running along the top of slope. Bankfull channel depths average 1.07 metres, with an average bankfull width of 5.61 metres. In the upper reach, the channel substrate is no longer gabion baskets, rather cobble sized gabion stone and coarse gravel. The channel banks that lack erosion control are composed of erodible medium sand (**Figure 3-2**). Erosion control throughout this reach is predominantly gabion baskets and mats in conditions ranging from fair to very poor and failed. Larger, boulder-sized blocks of repurposed concrete are also used as bank material in some of the mid-reach segments. Key geomorphic parameters for Reach N1 are summarized in **Table 3-2**.

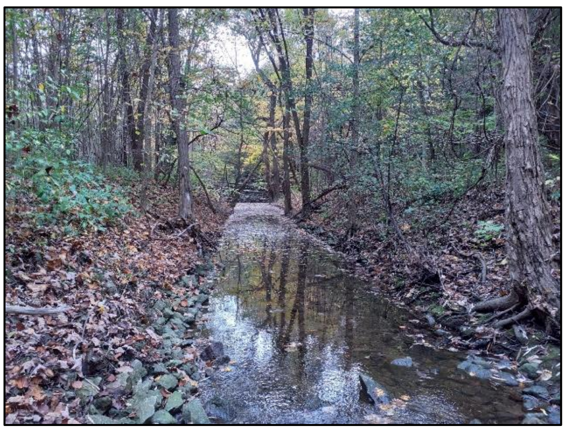

Figure 3-1: Gabion Lined Channel in Reach N1

Figure 3-2: Gravel and Cobble Substrate with Sandy Banks in Reach N1

Table 3-2: Relevant Fluvial Geomorphic Parameters for Reach N1

Length, L_r (m)	Width, B_w (m)	Depth, H_{bf} (m)	Gradient, S (%)	Sinuosity Index, *S.I.*	Substrate Material	Critical Bed Shear, $\tau_{cr(bed)}$ (N/m^2)	Bank Material	Critical Bank Shear, $\tau_{cr(bank)}$ (N/m^2)
1,125	5.61	1.07	1.14	1.20	Gravel/Cobble	11.9	Med Sand	0.19

3.1.1.1.1.2 Reach N2

Reach N2 begins at the Forest Grove Drive crossing at the downstream extent and extends 1,362 metres upstream to the intersection at Bayview Avenue and Finch Avenue in Newtonbrook Creek. The channel gradient is an average of 1.04%. Bankfull flow depth is typically 1.17 metres, and bankfull width spans 7.98 metres through most natural riffles.

This sinuous reach has a sinuosity index of 1.31. The many tight meander bends exhibit the erodible nature of the bank material. Point bar accretion dominates most of this reach as the material is highly mobile in this system (**Figure 3-3**). Armourstone erosion protection is frequently outflanked in this reach due to the limited span of the works, the erodible nature of the banks, and the high rates of erosion. Much of this reach has been previously realigned. This may suggest why the bank material lacks cohesive strength due to a mud deficient matrix in the aggregate used. The more stable boulder toe protection that is present is not embedded into the bank (**Figure 3-4**) and is easily outflanked as the channel meanders into the bank. Key geomorphic parameters for Reach N2 are summarized in **Table 3-3**.

Figure 3-3: Mature Point Bar Development Through Reach N2

Figure 3-4: Washed-Out Angular Stone and Boulder Treatments in Reach N2

Table 3-3: Relevant Fluvial Geomorphic Parameters for Reach N2

Length, L_r (m)	Width, B_w (m)	Depth, H_{bf} (m)	Gradient, *S* (%)	Sinuosity Index, *S.I.*	Substrate Material	Critical Bed Shear, $t_{cr(bed)}$ (N/m²)	Bank Material	Critical Bank Shear, $t_{cr(bank)}$ (N/m²)
1,362	7.98	1.17	1.04	1.31	Coarse Gravel	11.9	Clay /Sand	0.19

3.1.1.1.1.3 Reach N3

Reach N3 extends from the Finch Avenue and Bayview Avenue intersection in Newtonbrook Creek, 966 metres upstream to Maxome Avenue. The channel gradient through this reach is 1.15%. Average bankfull flow depth is 1.07 metres through a typical riffle, and bankfull width is 7.50 metres on average. This reach is highly sinuous, with a sinuosity index of 1.41 and includes a 100-metre-long outfall channel from Gustav Crescent.

Nearly all of this channel has been realigned from the original drainage predating 1954 aerial imagery. The segment of this reach immediately upstream of Bayview Avenue is a trapezoidal channel that is completely gabion basket lined. Upstream of St. Luke's Church, the exposed banks are composed of well compacted silty sand overlying a clay layer. Depositional sedimentary structures suggest that this represents the original bank material from glacial deposition (**Figure 3-5**). Bank material throughout the majority of the reach is composed of sand and gravel from the original sanitary sewer construction in 1960. Substrate material is predominantly coarse gravel throughout the reach with frequent angular stone erosion control bed treatments. Bank treatments such as armourstone and gabion baskets through this reach range in condition from good to very poor as the sandy bank material is easily eroded. Many erosion controls have failed as a result (**Figure 3-6**). While most of erosion control measures themselves are still intact or in place, the lack of adequate embedding or a sufficient tie-in length has either outflanked these works or translated the erosion intensity downstream of the protection. Key geomorphic parameters for Reach N3 are summarized in **Table 3-4**.

Figure 3-5: Clay and Silt Rich Sand and Gravel in Exposed Banks in Reach N3

Figure 3-6 Failed Gabion Baskets Through Reach N3

Table 3-4: Relevant Fluvial Geomorphic Parameters for Reach N3

Length, L_r (m)	Width, B_w (m)	Depth, H_{bf} (m)	Gradient, *S* (%)	Sinuosity Index, *S.I.*	Substrate Material	Critical Bed Shear, $t_{cr(bed)}$ (N/m^2)	Bank Material	Critical Bank Shear, $t_{cr(bank)}$ (N/m^2)
966	7.50	1.07	1.15	1.41	Gravel/Cobble	11.9	Silt/Sand	1.20

3.1.1.1.1.4 Reach N4

Reach N4 extends from Maxome Avenue in Newtonbrook Creek, 875 metres upstream to Willowdale Avenue where Newtonbrook Creek ends and is fed by a storm water collection network spanning another 5.5 km^2. The average channel gradient through the reach is 0.87%, more gently sloping than the downstream N1, N2 and N3 reaches. With a bankfull depth of 0.83 metres, and a bankfull width of 7.63 metres; it is a moderately sinuous reach with a sinuosity index of 1.27.

The lower reach is confined in a narrow valley setting (**Figure 3-7**). The banks and valley slopes are composed of well graded, medium sand material. Angular and cobble material protect the toe of both slope and banks, while the substrate material is mainly coarse gravel with some smaller cobble material, likely sourced from upstream gabion baskets. The gabion baskets in the upstream part of this reach include grouted baskets used as drop structures, emptied gabion baskets used to protect maintenance holes, and partially emptied baskets lining both sides of the channel through Newtonbrook Park (**Figure 3-8**). While Reach N4 maintains the same bankfull width as other downstream reaches, evidence of scour and overall channel depth is far less. This is likely due to the floodplain access provided by Newtonbrook Park during high discharge events. As a result, outflanked structures are not observed in this reach, a significant distinction from the rest of the creek. Key geomorphic parameters for Reach N4 are summarized in **Table 3-5**.

Figure 3-7: Confined Lower Segment Upstream of Maxome Avenue in Reach N4

Figure 3-8: Partially Emptied Gabion Baskets Line the Upper Portion of Reach N4

Table 3-5: Relevant Fluvial Geomorphic Parameters for Reach N4

Length, L_r (m)	Width, B_w (m)	Depth, H_{bf} (m)	Gradient, S (%)	Sinuosity Index, *S.I.*	Substrate Material	Critical Bed Shear, $t_{cr(bed)}$ (N/m^2)	Bank Material	Critical Bank Shear, $t_{cr(bank)}$ (N/m^2)
875	7.63	0.83	0.87	1.27	Gravel/Cobble	11.9	Sand	0.19

3.1.1.1.2 Blue Ridge Creek Reach Delineation

Blue Ridge Creek was walked 2,029 metres from the Don River to its most upstream channelized extent at Bayview Avenue, and included two (2) valley-confined tributaries. The Blue Ridge watershed covers over 1.63 km^2. The main trunk of Blue Ridge has a high knickpoint that separates Reach Br1 from Br3 and a high average gradient of 2.53%. The tributaries have gradients of approximately 5%.

3.1.1.1.2.1 Reach Br1

The lowest reach in Blue Ridge Creek begins at the confluence of the Don River and extends upstream for 530 metres to a tributary confluence and knickpoint at the end of Sifton Court. The average channel gradient is 2.51% and is in a steep valley that shows signs of active downcutting. At bankfull flow conditions, the local backwater from the Don River would propagate upstream for just over 40 metres. This moderately sinuous reach has a sinuosity index of 1.28.

Bankfull width in this reach is 2.74 metres, while average bankfull depth is 1.04 metres upstream of the Don River backwater. The channel is actively downcutting, shown from the exposure of buried infrastructure (**Figure 3-9**). The steep gradient and resulting erosion potential causes the valley to both widen and deepen. This presents the added challenge of slope stability as mature trees are undercut in the steep valley setting (**Figure 3-10**). The banks and slope material are silt and sand rich gravel material that erodes easily. The existing armourstone bank protection throughout this reach was designed to protect maintenance hole and sewer infrastructure, however erosion continues in the segments where this armouring is absent. Boulder channel treatments in this reach are still intact, while most angular stone channel treatments are washed out, exposing the glacial clay channel base. This clay layer contacts the sandy gravel material at the slope toe and acts as a flow horizon for groundwater, increasing its susceptibility to erosion. Key geomorphic parameters for Reach Br1 are summarized in **Table 3-6**.

Figure 3-9: Incised Channel Near the Don Confluence Exposing Buried Pipes and Bank Erosion.

Figure 3-10: Steep Valley Confined Upstream Segment in Reach Br1

Table 3-6: Relevant Fluvial Geomorphic Parameters for Reach Br1

Length, L_r (m)	Width, B_w (m)	Depth, H_{bf} (m)	Gradient, *S* (%)	Sinuosity Index, *S.I.*	Substrate Material	Critical Bed Shear, $t_{cr(bed)}$ (N/m^2)	Bank Material	Critical Bank Shear, $t_{cr(bank)}$ (N/m^2)
530	2.74	1.04	2.51	1.28	Gravel/Cobble	11.9	Sand	7.6

3.1.1.1.2.2 Reach Br 2

Reach Br2 is a tributary of Blue Ridge Creek that extents from Citation Drive and Reach Br1 341 metres up-slope to Burbank Drive. This high gradient reach has a slope of 5.79% and is an essentially straight channel with a sinuosity index of 1.04. At the time of field investigation, the channel was dry and likely remains so until a rain event. Very little erosion was observed as the dense leaf litter and tree debris had obscured any potential observations (**Figure 3-11**).

As a rough estimate, based on similar sized channels, bankfull width would be less than 2 metres with a bankfull depth less than 1 meter, even during a regional event. Theoretical limits on the maximum depth of a 2 metres wide channel with this gradient would likely approximate 0.2 – 0.3 metres. Slope and bed material is composed of sandy gravel. This material is likely prone to undermining once heavy rainfall or snowmelt is subject to the slope around mature trees. Many of the cut trees in this valley were ash (**Figure 3-12**), however other uprooted trees were not. Key geomorphic parameters for Reach Br2 are summarized in (**Table 3-7**).

Figure 3-11: Steep Valley Confined Tributary Channel in Reach Br2

Figure 3-12: Debris from Fallen and Cut Trees in Reach Br2

Table 3-7: Relevant Fluvial Geomorphic Parameters for Reach Br2

Length, L_r (m)	Width, B_w (m)	Depth, H_{bf} (m)	Gradient, S (%)	Sinuosity Index, *S.I.*	Substrate Material	Critical Bed Shear, $\tau_{cr(bed)}$ (N/m^2)	Bank Material	Critical Bank Shear, $\tau_{cr(bank)}$ (N/m^2)
341	2.00	1.00	5.79	1.04	Silt/Sand	1.4	Sand	0

3.1.1.1.2.3 Reach Br3

Reach Br3 is the main trunk channel of the Blue Ridge Valley, upstream of the knickpoint at Sifton Court. It extends 1,352 metres upstream to Bayview Avenue at Bayview Village Park. The average channel gradient through the reach is 2.16%. With a bankfull depth of 1.2 metres, and a bankfull width of 3.35 metres; it is a straight reach with a sinuosity index of 1.09.

Exposed banks are gently sloping and composed of sandy gravel material. Most of the reach however has been realigned and hardened with either boulder or armourstone bank treatments (**Figure 3-13**). Similarly, cable concrete and armourstone was widely used throughout the reach to harden the bed from eroding (**Figure 3-14**). These measures have since deteriorated in the downstream section where access to floodplain is limited. Key geomorphic parameters for Reach Br3 are summarized in **Table 3-8**.

Figure 3-13: Armourstone and Concrete Lined Channel Upstream of the Confluence with Br1

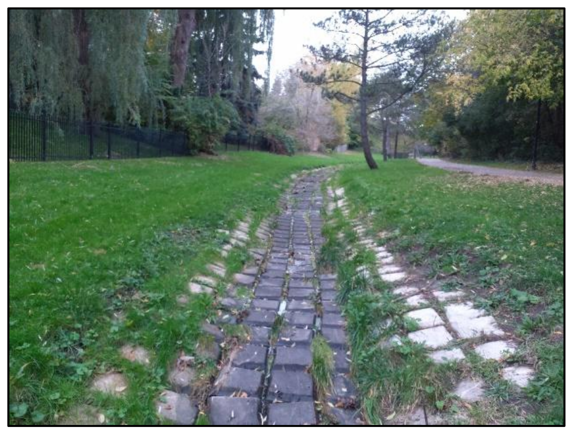

Figure 3-14: Cablecrete and Armourstone Through Bayview Village Park

Table 3-8: Relevant Fluvial Geomorphic Parameters for Reach Br3

Length, L_r (m)	Width, B_w (m)	Depth, H_{bf} (m)	Gradient, S (%)	Sinuosity Index, *S.I.*	Substrate Material	Critical Bed Shear, $\tau_{cr(bed)}$ (N/m^2)	Bank Material	Critical Bank Shear, $\tau_{cr(bank)}$ (N/m^2)
1,352	3.35	1.20	2.16	1.09	Cable Concrete	145	Sand	7.6

3.1.1.1.2.4 Reach Br 4

Reach Br4 is a tributary of Blue Ridge Creek that extents from Sifton Court and Reach Br1 197 metres up-slope to Blue Ridge Road. This high gradient reach has a slope of 4.72% and is a low sinuosity channel with a sinuosity index of 1.22. The channel is completely valley confined and has no access to floodplain. Approximate bankfull width is just over 3 metres with a bankfull depth just over 1 metre during a high discharge event. Theoretical limits on the maximum depth of a 3 metres wide channel with this gradient would likely approximate 0.4 – 0.6 metres.

Slope material is composed of sandy gravel material and is actively eroding, undermining mature trees, and causing slope hazards to adjacent private property (**Figure 3-15**). Erosion control measures in the reach include gabion basket slope stability works and angular stone bed treatments. Gabion baskets have slumped to the point of failure in some sections and angular stone has washed downstream or had been displaced completely in some sections (**Figure 3-16**). The dominant erosion hazard in this reach is the oversteepened valley slope stability driven by channel scour. Key geomorphic parameters for Reach Br4 are summarized in **Table 3-9**.

Figure 3-15 Steep Valley Confined Tributary Channel in Reach Br4

Figure 3-16: Failed Gabion Baskets and Channel Angular Stone in Reach Br4

Table 3-9: Relevant Fluvial Geomorphic Parameters for Reach Br4

Length, L_r (m)	Width, B_w (m)	Depth, H_{bf} (m)	Gradient, *S* (%)	Sinuosity Index, *S.I.*	Substrate Material	Critical Bed Shear, $t_{cr(bed)}$ (N/m^2)	Bank Material	Critical Bank Shear, $t_{cr(bank)}$ (N/m^2)
197	3.20	1.20	4.72	1.22	Gravel/Cobble	11.9	Sand	7.6

3.1.1.2 Geomorphic Stability

The Rapid Geomorphic Assessment (RGA) (MOE, 2003) tool was used during field walks to assess the fluvial conditions of the watercourses. The RGA protocol uses visual indicators to determine whether a given stream is stable or in adjustment. Stability of the channel is determined by adjustments in slope; the bed elevation may be increasing due to sediment deposition (aggradation) or decreasing due to bed erosion (degradation). Consideration of increases in bank-to-bank width (widening) and indicators suggesting a change in the planform regime (planimetric form adjustment) are also part of the assessment. Based on the results of the RGAs, reaches were classified as “stable”, “transitional”, or “in adjustment” depending on the stability index value as described in (**Table 3-10**).

Table 3-10: Rapid Geomorphic Assessment (RGA) Descriptions Based on Index Value

Stability Index (SI) Value	Stability Class	Description
SI ≤ 0.2	In Regime	Channel morphology is within the expected range of variance for stable channels of similar type. Channels are in good condition with minor adjustments that do not impact the function of the watercourse.
0.21 ≤ SI ≤ 0.4	Transitional	Channel morphology is within the expected range of variance but with evidence of stress. Significant channel adjustments have occurred and additional adjustment may occur.
SI > 0.4	In Adjustment	Metrics are outside of the expected range of variance for channels of similar type. Significant channel adjustments have occurred and are expected to continue.

3.1.1.2.1 Geomorphic Evaluation Results

The existing geomorphic conditions of Newtonbrook Creek and Blue Ridge Creek were documented during the field assessments. RGA stability classifications for all reaches assessed are listed in **Table 3-11** and the results of individual reaches are shown by location in **Figure 3-17**.

As noted previously, the RGA score does not provide a measure of the risk to property, infrastructure, and public safety. Thus, alone, the RGA score is not a means of prioritizing channel restoration works. Rather, as a measure of channel stability, RGA scores can be used as both a predictor and a proxy for locations where erosion-related risks occur. In general, reaches with high geomorphic instability are more likely to exhibit erosion sites, and the results of the geomorphic assessment are valuable in providing an understanding of the channel adjustments at work in the reach. The information gathered during the geomorphic assessment can be used further in the development of restoration approaches for priority erosion sites.

Table 3-11: RGA Stability Classification for All Reaches in the Study

Reach #	RGA Score	Dominant Process	Stability Regime
N1	0.63	Widening	In Adjustment
N2	0.53	Widening, Degradation	In Adjustment
N3	0.34	Widening	In Transition
N4	0.00	(Engineered channel)	RGA does not apply
Br1	0.37	Widening	In Transition
Br2	0.27	Degradation	In Transition
Br3	0.14	Widening	In Regime
Br4	0.38	Degradation	In Transition

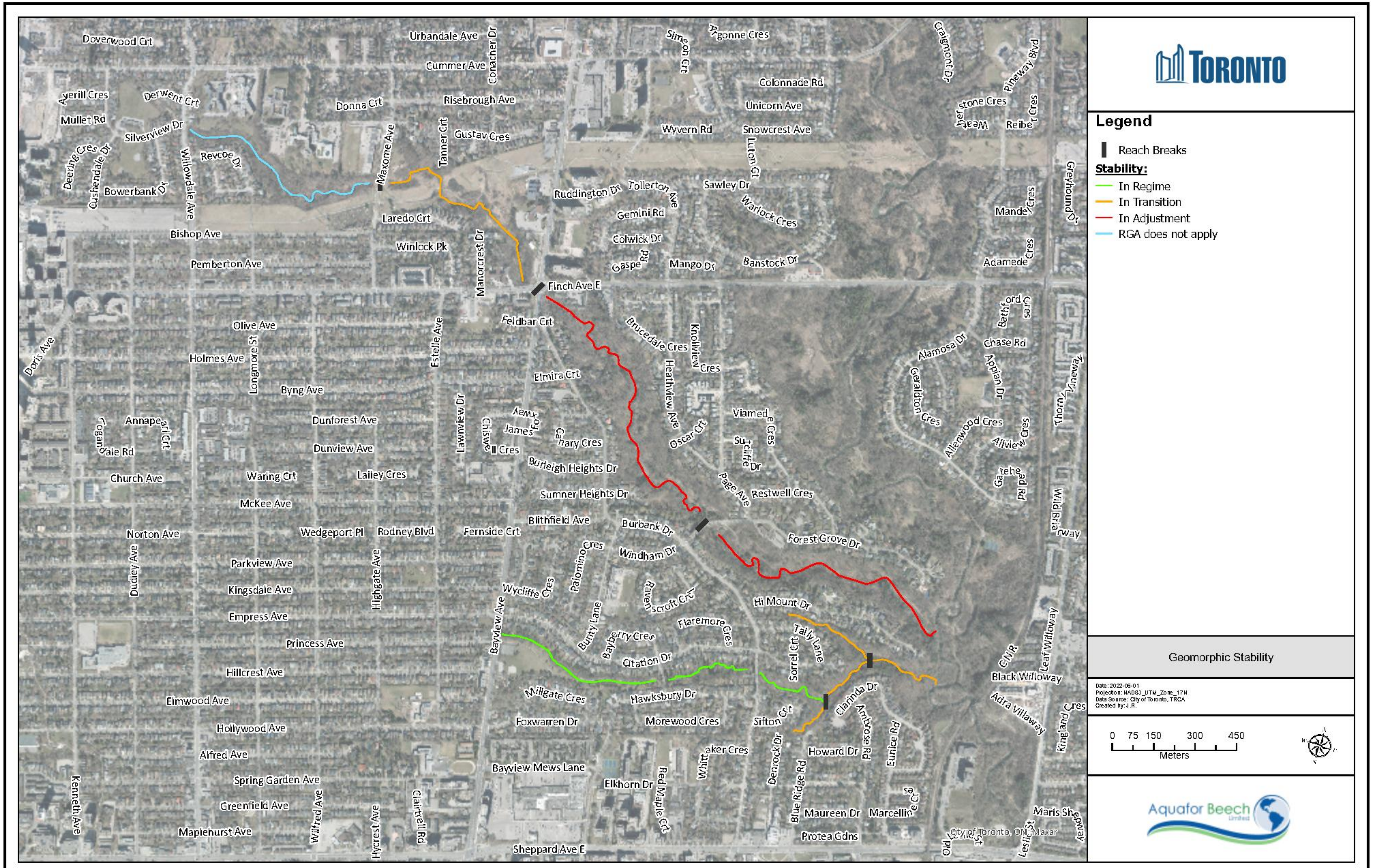

Figure 3-17: Stability Regime of Creek Reaches from RGA Results

3.1.1.3 Rates of Erosion

The high gradients observed in both Newtonbrook Creek and Blue Ridge Creek present significant potential for both lateral bank erosion and channel bed scour. These high rates of erosion are evident from the presence of exposed sanitary sewer crossings, and lateral exposures of maintenance holes, sewer lines, storm outfalls and natural gas pipelines. For the purposes of evaluation, these rates have been calculated in terms of their horizontal (lateral risk hazard) and vertical (scour potential) components. Higher gradients promote higher velocity flows that increase the shear stress applied to the bed and banks. The materials that make up the bed and banks have specific shear stress thresholds that, once exceeded, will be subject to processes of erosion. To determine these specific vertical and horizontal rates, historical imagery and as-built drawings provided by the City of Toronto were compared against historic erosion rates to similar systems.

3.1.1.4 Historic Assessment of Newtonbrook Creek and Blue Ridge Creek

An assessment of historic aerial imagery was completed to gain an understanding of past watershed conditions and to estimate lateral rates of channel migration; particularly how the channel has been modified and altered to accommodate surrounding urbanization. This analysis is also used to provide insight into historic channel patterns and processes, which can then be used to estimate future erosion and planform development. Historical aerial imagery was provided by the City of Toronto, including orthorectified (1954, 1965, 1978, 1999, 2011, 2012, 2015, and 2016) years of imagery.

Prior to 1960, the Newtonbrook Creek drainage was a natural tributary drainage within the Don Valley watershed. The only road crossing was Bayview Avenue which essentially separated a semiconfined channel through agricultural land on the upstream side from a forested valley confined drainage downstream of Bayview. With the 1960 construction of the adjacent sewer trunk, was expansion to the roads at Bayview and Finch Avenue and new road culverts at Maxome Avenue and Forest Grove Drive. With these constructed reach breaks, came channel hardening and realignment to a straitened channel in Reach N3 and N4.

Later straightening and lining of Reach N1 was completed between 1965 and 1978. By 1999, the downstream segment of Reach N3 at the intersection of Bayview Avenue and Finch Avenue was also hardened. Much of this erosion control was in response to the high migration potential of Newtonbrook Creek due to its sandy material, high gradient and increasing discharge rates as continual development reduced infiltration ability in the watershed.

Due to tree cover and the resolution of older aerial imagery, only minor changes in bank migration were observed in Blue Ridge Creek from recent satellite imagery and the 2015 Lidar Dataset from the province of Ontario.

3.1.1.5 Scour Hazard Limit

Ontario’s Ministry of Transportation (MTO) defines scour as follows:

“Scour is the lowering and/or widening of the streambed due to the erosive forces exerted by flowing water. Channel scour is an important consideration in the design of water crossings as it may undermine the foundations of the structure, possibly leading to its failure. There have been documented failures of structures as a result of scour.”

Vertical scour risks are particularly critical for urban watercourses where sewer infrastructure crosses under the channel. In such cases, channels (such as Newtonbrook Creek, and Blue Ridge Creek) have cut vertically down to expose previously buried sewer pipes and other utilities. This process of vertical incision (or scour) can be particularly severe in urbanized watercourses that have been impacted by historical changes to the hydrological regime, whereby agricultural land cover and urban land use changes in the watershed have significantly increased runoff to watercourses. This runoff impact (sometimes referred to as hydromodification) tends to result in channel enlargement due to the higher flows and greater sediment entrainment and transport capacities. Such post-urban channel adjustments often include accelerated vertical and/or lateral erosion rates; however, in some cases where the channel banks have been engineered for horizontal bank stability, much of the excess flow energy works to erode the bed vertically. Evidence of the vertical scour processes described above have been observed throughout the Newtonbrook and Blue Ridge Creek system in order to determine the scour hazard limit on a reach-by-reach basis. The Scour Hazard Limit, as defined within Credit Valley Conservation's Fluvial Geomorphic Guidelines, is visually illustrated in **(Figure 3-18**).

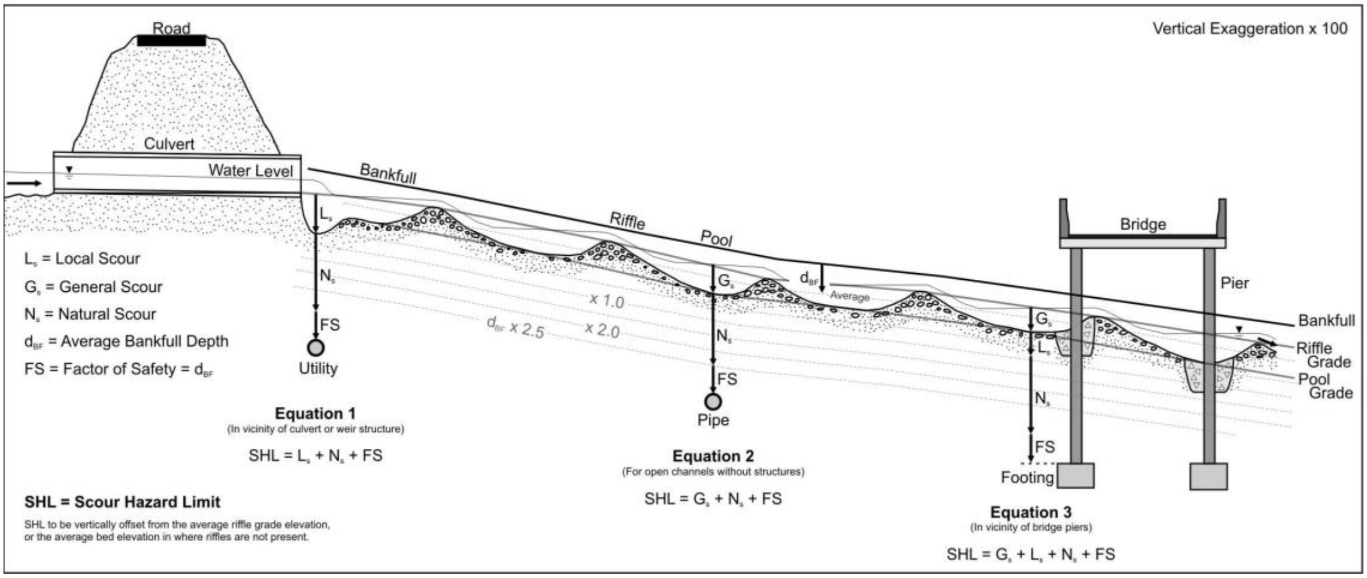

Figure 3-18: Graphical Definition of the Scour Hazard Limit for Three Cases, Including Culverts, Buried Pipes, and Bridges (CVC, 2019)

Historical records were referenced to estimate the potential for future scour hazards in the Newtonbrook and Blue Ridge systems, including scour rates from nearby urban creek systems around the Greater Toronto Area. Cooksville Creek, Highland Creek, Taylor Massey Creek and Mimico Creek were combined to provide context for these scour rates (**Figure 3-19**).

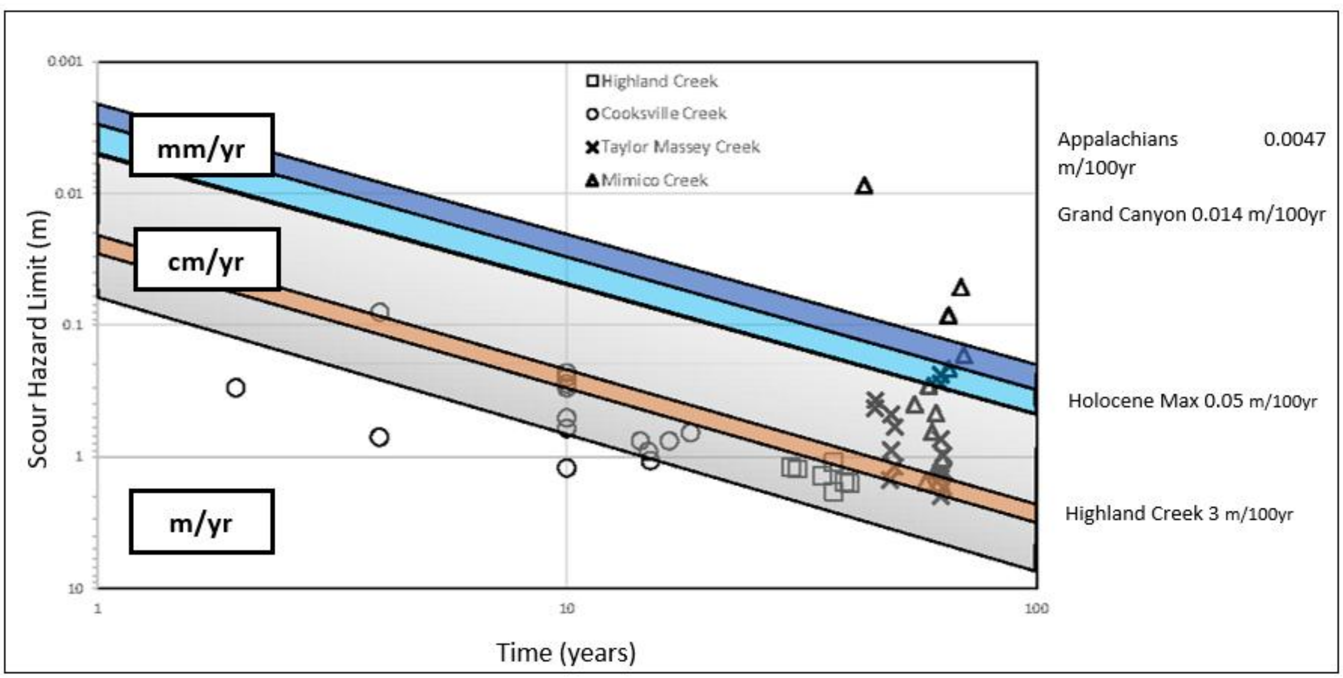

Figure 3-19: Historical Scour Depths within Urban Creek Systems in Toronto

To evaluate the historical scour depths for this study, 2021 topographic surveys of the channel over the sewer crossings were overlaid on as-built profile drawings for the sewers from dates ranging from 1960 to 1984. A total of nine (x9) utility crossing locations were analyzed based on the available as-built data as presented in **Figure 3-20**. The calculated scour depths range from 0.36 metres to 1.47 metres based on the difference between the average historical bed elevation from the as-built drawings and the minimum bed elevation from the 2021 surveys (**Figure 3-20**). The historical period between the as-built drawings and 2021 ranged from about 37 to 61 years.

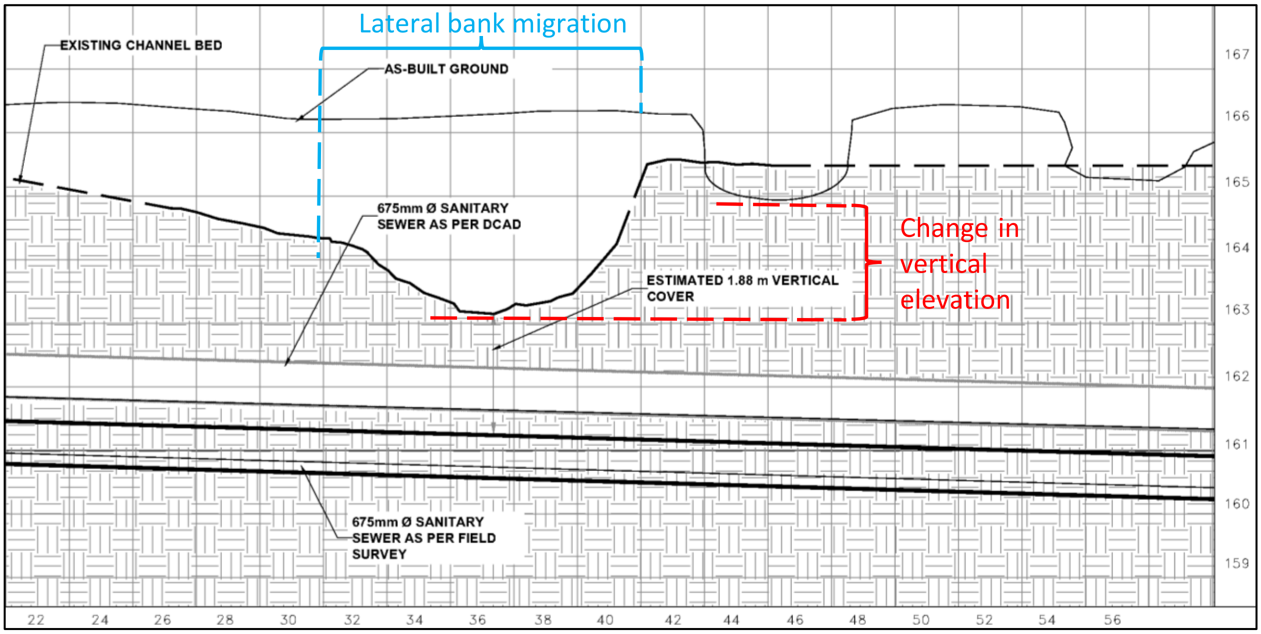

Figure 3-20: Examples of Vertical Scour Depth and Lateral Bank Migration Offset Between the Time of the As-Built Condition to the 2021 Survey.

The calculated scour hazard depths (m/100 yr) were plotted against the channel gradient (%) for each reach to consider the scaling of the scour hazard with slope on Newtonbrook Creek and Blue Ridge Creek (**Figure 3-21 A**). Similarly, the associated scour hazard depths were plotted against bankfull channel depth (m) as a comparative basis for channel size (**Figure 3-21 B**).

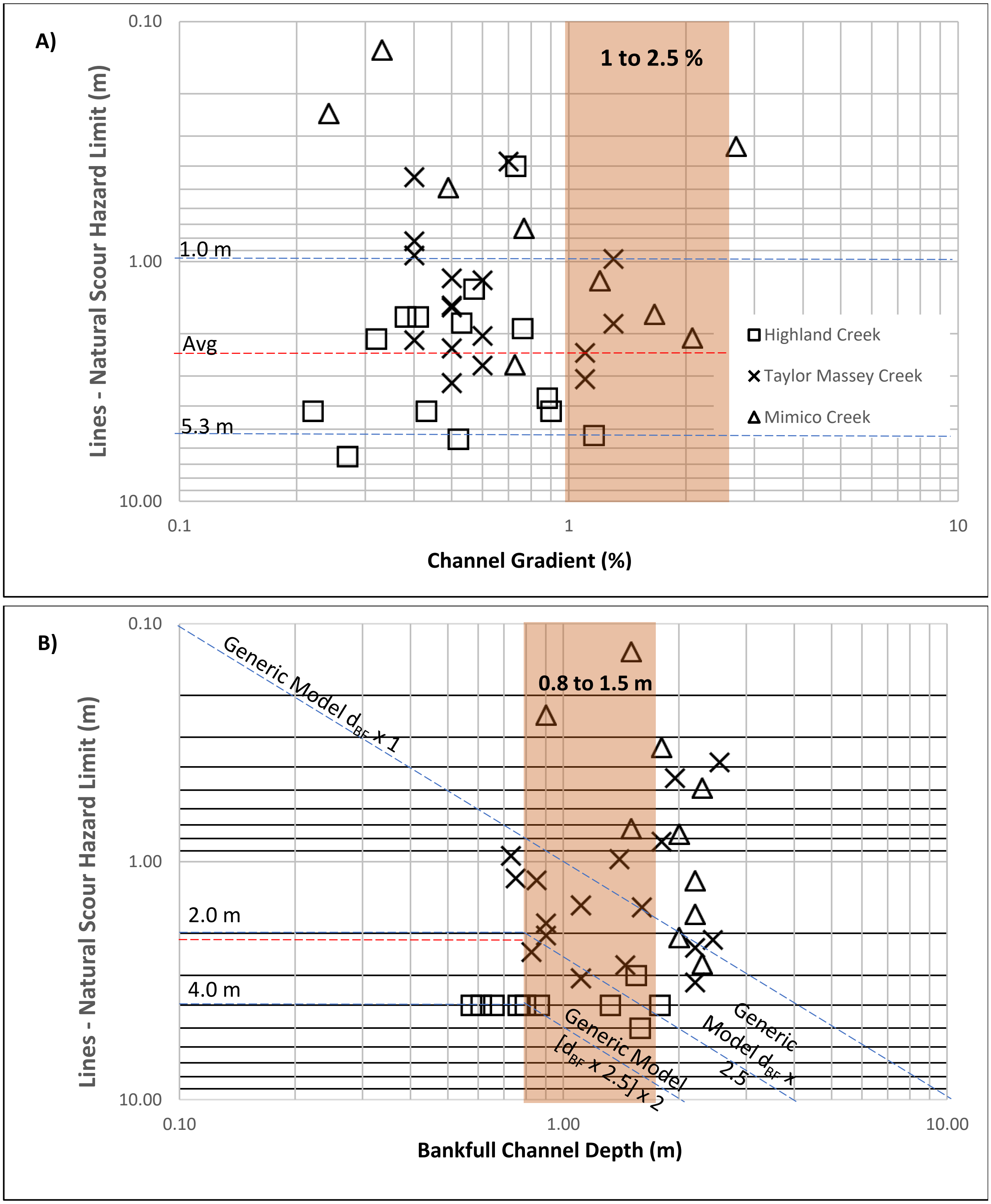

Figure 3-21: Generic models for the Scour Hazard Limit based on A) channel gradient and B) bankfull depth, including the SHL x 2 for Factor of Safety (modified from: CVC, 2020)

In reaches where no as-built drawings exist to compare channel scour, adjacent reaches with similar gradient and depth parameters were used to estimate scour potential. In high gradient reaches such as Reach Br2 and Br4 tributaries, geometric relationships were estimated, assuming a maximum scour in the downstream reach, and no scour in the upstream extent, and calculated a maximum potential scour to the theoretical surface of channel equilibrium (**Figure 3-22**). In these cases, it was assumed these scour limits were underestimates and that they should be considered minimum values.

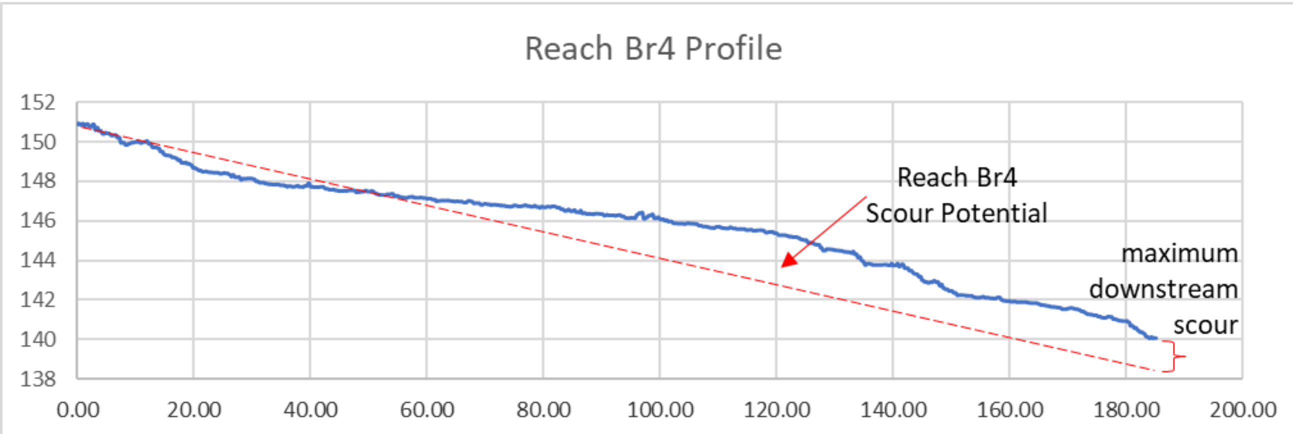

Figure 3-22: Theoretical Scour Potential Estimates

Based on this analysis, the recommended average 100-year scour hazard for Newtonbrook Creek and Blue Ridge Creek ranges from 1.10 to 2.38 metres (**Table 3-12**). These first-order results align with the bankfull depth and channel gradient generic models, whereby the scour limit estimates are within the expected range, and reasonable to estimate the Time to Contact. While the presented model provides a constrained future prediction of the scour hazard with a high degree of uncertainty, the primary purpose of this analysis is for the vertical risk assessment of the sites identified in in the following sections of the report.

Table 3-12: Reach averaged scour rates and their associated 100-yr Scour Hazard Limit

Reach #	Crossings	Exposed Sanitary Sewer Crossings	Degradation Rate (m/yr)	100-yr Scour Hazard Limit
N1	1-4	2	0.0238	2.38 m
N2	5-8	4	0.0175	1.75 m
N3	9-14	1	0.0222	2.22 m
N4	15-17	0	0.0110	1.10 m
Br1	None	0	0.0115	1.15 m
Br2	18	0	0.0115*	1.15 m
Br3	19	1	0.0130	1.30 m
Br4	none	0	0.0160	1.60 m

*The erosion rate in Br2 applies to the crossing location only and not the reach as a whole.

3.1.1.6 Lateral Erosion Hazard Limit

For nine of the utility crossings (sewer, water, gas) that were surveyed as a part of this study, as-built drawings provided by the City of Toronto were georeferenced and overlain onto as-built cover profiles to delineate both the bank location at the time of the 2021 topographic survey as well as the historic bank location at the time of construction relative to the adjacent maintenance hole. The lateral migration, corrected for the obliquity of the angle of the sewer (or watermain) crossing by multiplying by the sine of the angle of intersection, represents the value of net lateral migration. The concept of overlaying an as-built drawing onto a recently surveyed profile is illustrated in **Figure 3-20**, which also defines the concept of lateral bank migration. Where possible, multiple values were averaged from crossings within the same reach. In reaches where there were no crossings, or where as-built references were not available, historic imagery comparison was used.

The use of historic imagery presents several challenges. Data capture methods transitioned from aerial photography to satellite imagery sometime after 2000. The aerial imagery is inconsistent throughout the years 1954 to 1999. After the change to satellite imagery, the air photos have been archived to the satellite format comparing inconsistent elevation heights, look angles and times of day. The georeferenced images therefore lack absolute reference to fixed known points. Where possible, bank positions have been measured relative to buildings and other "fixed" locations for confidence estimates, however; the trend seems to be that the older the imagery, the less accurate the bank position.

To address this disparity in image reliability, all photos were compared to the most recent image possible (typically 2015, as foliage obscured less of the creek) or the 2015 Ontario Lidar dataset (ODTM, 2015). In segments where channels have been realigned, pre- and post-realignment values were recorded to determine the erosion rates of the un-protected banks. These values of bank migration rates were calculated by determining the distance of migration divided by the time between the compared imagery. Once values had been calculated, a weighted average was determined using an inverse distance weighting (IDW) method that made the reach-scale averages less sensitive to the older, less accurate data. In this IDW method, a survey comparison would be weighted 1, a recent satellite comparison from 2011-2015 would be weighted 0.25, or (1/(2015-2011), and an older pre-realignment comparison from 1965 to 1978 would be weighted 0.02, or (1/2015-1965). This IDW method ensures that survey data is prioritized in the average value.

Table 3-13 shows the rates of lateral migration for each reach. The predicted lateral erosion rate based on provincial standards (MNR 2002) is shown for each reach based on the dominant bank material. It should be noted that for some reaches, the 100-year erosion limit is not simply 100 times the lateral migration rate as this system is valley confined. In other words, at the reach-scale, the creek can only migrate so far before it hits the valley slope and will then migrate in another direction, or slow down.

Table 3-13: Reach averaged lateral erosion rates and their associated 100-yr Erosion Hazard Limit.

Reach #	Lateral Risk Sites	Lateral Migration Rate (m/yr)	100-yr Erosion Hazard Limit (m)**	MOE 2002 Erosion Hazard Rate (m/yr)
N1	1-4	0.0243	21.00	0.15
N2	5-11	0.0256	25.62	0.15
N3	None	0.0215	21.50	0.15
N4	12-16	0.0231	23.06	0.15
Br1	17-22	0.0298	21.50	0.15
Br2	none	0.08	8.00	0.08
Br3	none	0.0160	15.98	0.15
Br4	none	0.08	8.00	0.08

**The 100-yr Erosion Hazard considers the annual lateral migration rate and the maximum lateral migration potential in the valley setting

3.1.1.7 Meander Belt Assessment

It is recognized that sustainable long-term management strategies for watercourses should allow for natural fluvial processes to occur within an erodible corridor—a geomorphic hazard zone (Piégay et al., 2005). Also proposed as 'Freedom Space', there are long-term ecological, economic, and social benefits to allowing rivers and streams enough space to adjust within a natural corridor (Biron et al., 2014; Buffin-Bélanger et al., 2015). Geomorphic erosion hazards for unconfined, single-channel, perennial streams and rivers are typically evaluated as the corridor width of the “meander belt” plus a century-scale erosion allowance (TRCA, 2004). The degree to which a channel will meander—through fluvial processes of lateral migration and avulsion—depends upon the channel’s hydrological flow regime and environment controls such as geology and vegetation.

A meander belt can be a useful conceptual tool for planning around watercourses, but the concept has fundamental limitations for representing geomorphic erosion hazards around headwaters and low-order streams (e.g., 1st and 2nd order) and is also an oversimplified concept for confined systems. The concept also has severe limitations if applied within urbanized watercourses—such as Newtonbrook and Blue Ridge Creek—where there is a history of channel realignments, engineering, and erosion control structures intended to stabilize the channel indefinitely. For historically straightened and engineered channels, the ultimate lateral “migration” zone might in theory be re-attained if given enough time to recover (i.e., natural channels are rarely straight), but given the constraints imposed by urban sewers and other infrastructure within the valley, the erosion controls are likely to be maintained to some effect well into the future.

To identify the location and occurrence of lateral risk sites, as no change in hydraulic regime is expected; a meander belt analysis was completed for the study area where the final meander belt width was defined as follows:

Where the meander belt and bankfull channel width >50 metres:

$$Final\ Meander\ Belt\ Hazard\ Width\ (m) \\ = \\ Meander\ Belt\ Width\ (m) + Bankfull\ Channel\ Width\ (m) + TRCA\ Factor\ of\ Safety\ (m)$$

Where the meander belt and bankfull channel width <50 metres:

$$Final\ Meander\ Belt\ Hazard\ Width\ (m) \\ = \\ Lateral\ 100\ Year\ Erosion\ Hazard\ (m) + Meander\ Belt\ Width\ (m) + Bankfull\ Channel\ Width\ (m)$$

The lateral 100-year erosion hazard was defined on a reach-by-reach basis using the annual rates of lateral migration listed in **Table 3-13.** The Meander belt width was calculated using aerial imagery and a lidar derived digital elevation model assuming a non-engineered channel, and TRCA factor of safety was then evaluated as 10% of the meander belt width where applicable.

Considering the incised nature of Newtonbrook and Blue Ridge Creeks, alternative meander belt delineation was required as the creeks are unable to meander freely when in contact with the valley walls in which it is confined. The total meander belt hazard width was determined to be the lesser of the final meander belt hazard width or the 100-year erosion hazard limit of the existing valley slope. The resulting meander belt limit therefore lacks the smooth sides of an unconfined meander belt, as it is dominantly controlled by the valley margin and not the meander belt axis. **Figure 3-14** defines the final meander belt hazard width in meters for all reaches assessed as though this were an unconfined system, and the lateral offset from the toe of the valley slope, delineated to be coincident with the top of the channel bank or higher.

Table 3-14: Summary of Meander Belt Widths by Reach

Reach #	Preliminary Meander Belt Width (m)	Bankfull Channel Width (m)	Existing Meander Belt Width (m)	Lateral Migration Rate (m/yr)	Lateral 100-Year erosion Hazard (m)	TRCA Factor of Safety	Final Meander Belt Hazard Width (m)	Toe of Slope Erosion Hazard Limit (m)
N1	44.5	5.6	50.1	0.0243	21.00	1.1	55.1	8
N2	42.1	8.0	50.1	0.0256	25.62	1.1	55.1	8
N3	22.5	7.5	30.0	0.0215	21.50	1	73.0	8
N4	20.4	7.6	28.0	0.0231	23.06	1	74.0	8
Br1	13.3	2.7	16.0	0.0298	21.50	1	75.6	8
Br2	8.0	2.0	10.0	0.08	8.00	1	40.0	8
Br3	10.7	3.4	14.0	0.0160	15.98	1	46.0	8
Br4	6.8	3.2	10.0	0.08	8.00	1	40.0	8

An example of the meander belt extent completed for Reach N1 is provided in **Figure 3-23**, with the total meander belt hazard limits for the entire study area presented in **Appendix E**.

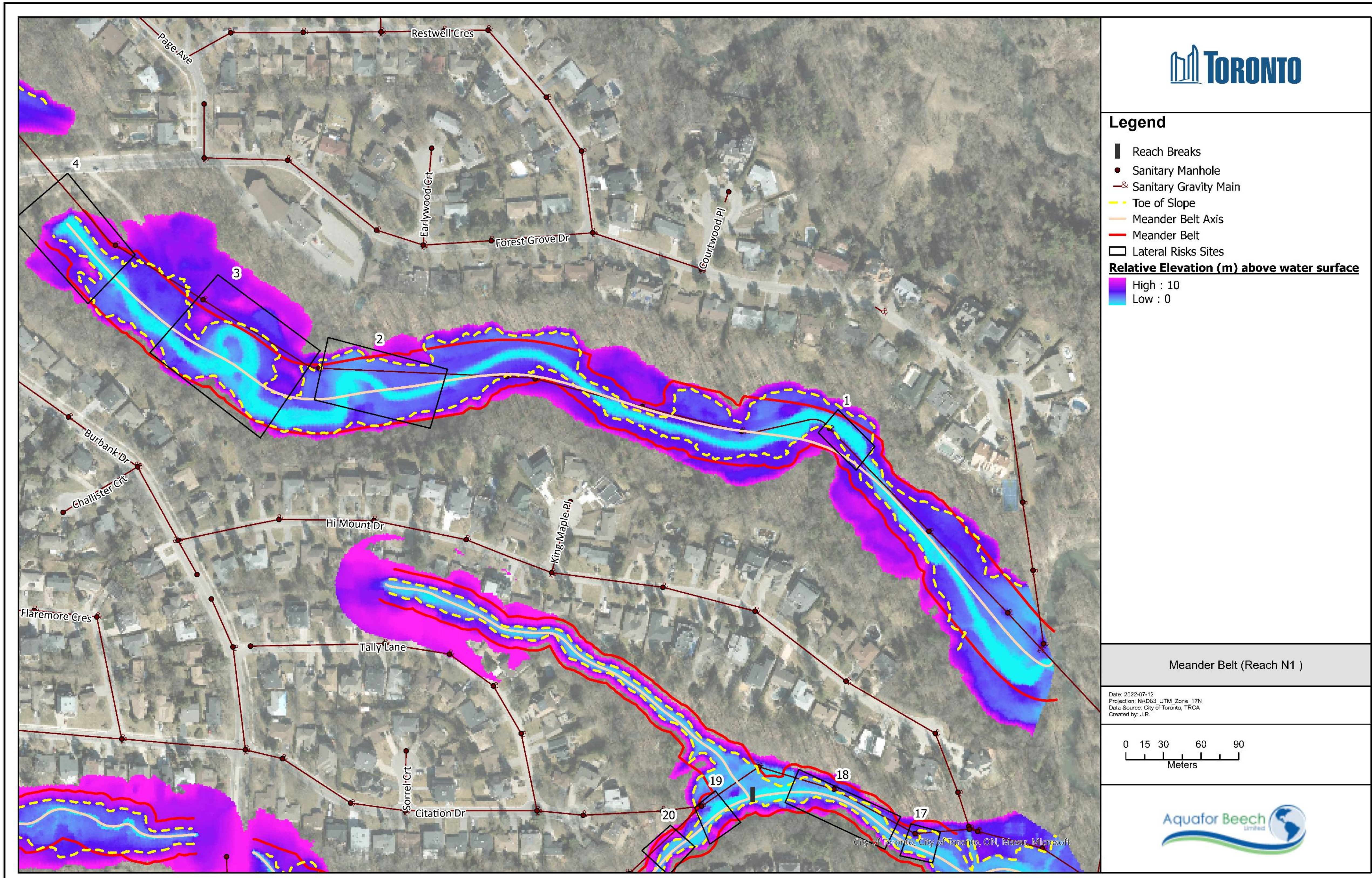

Figure 3-23: Meander Belt Mapping for Reach N1

3.1.2 Terrestrial Ecology

The riparian corridors surrounding Newtonbrook Creek and Blue Ridge Creek are tightly constrained by the surrounding developments. Newtonbrook Creek is associated with a wooded corridor (fairly consistently ~150 metres wide downstream of Finch Avenue, narrower and more variable upstream), while Blue Ridge Creek has a much narrower vegetated riparian area and is frequently overlapped with the rear yards of residential lots. Both corridors are expected to experience the types of anthropogenic influences (e.g., vegetation disturbance, debris/litter, trail incursions, non-native species, etc.) typical of urban creek corridors adjacent to development. According to the Don River Watershed Plan, the riparian corridor habitat condition for both Newtonbrook Creek and the lower reaches of Blue Ridge Creek is poor quality (**Figure 3-24)**; the upstream portion of Blue Ridge Creek did not have information available for it in that study.

Mapping provided by TRCA identifies the East Don Valley Swamp Environmentally Significant Area (ESA) in the lower reaches of Newtonbrook and Blue Ridge Creeks and along their confluence with the Lower East Don River. This ESA is described as containing “mature deciduous forest and valley floodplain with lowland deciduous forest and swamp along the Don River” (North-South Environmental, Dougan & Associates, and Beacon Environmental, 2012). Current wetland mapping maintained by the Ontario government identifies the East Don Valley Wetland Complex, a Provincially Significant Wetland (PSW), associated with the East Don River corridor to the east but not occurring within either the Newtonbrook or Blue Ridge Creek corridors (**Figure 3-25**).

TRCA’s vegetation community mapping for the East Don Valley Swamp ESA indicates that the Newtonbrook Creek corridor downstream of Forest Grove Drive contains Fresh-Moist Hemlock-Hardwood Mixed Forest (FOM6-2) and Dry-Fresh Sugar Maple-Beech Deciduous Forest (FOD 5-2) community types. The Blue Ridge Creek corridor downstream of Burbank Drive includes Dry-Fresh Sugar Maple Deciduous Forest (FOD5-1) and Dry-Fresh Sugar Maple-Hemlock Mixed Forest (FOM3-2) communities. Around their confluence with the East Don River, both creek corridors were characterized as Fresh-Moist Willow Lowland Deciduous Forest (FOD7-3).

TRCA’s flora and fauna records, as well as observations reviewed from community science websites eBird.org and iNaturalist.org, indicate the presence of many common plants and animals in the study area, as well as some that are considered locally rare in TRCA’s jurisdiction. A preliminary review of Species at Risk (SAR) records in the vicinity of the study area identified numerous records of potential species including Butternut (Endangered), Queensnake (Endangered), Snapping Turtle (Special Concern), Eastern Wood-pewee (Special Concern), Monarch (Special Concern), Ontario’s four Endangered bat species, and Black Ash.

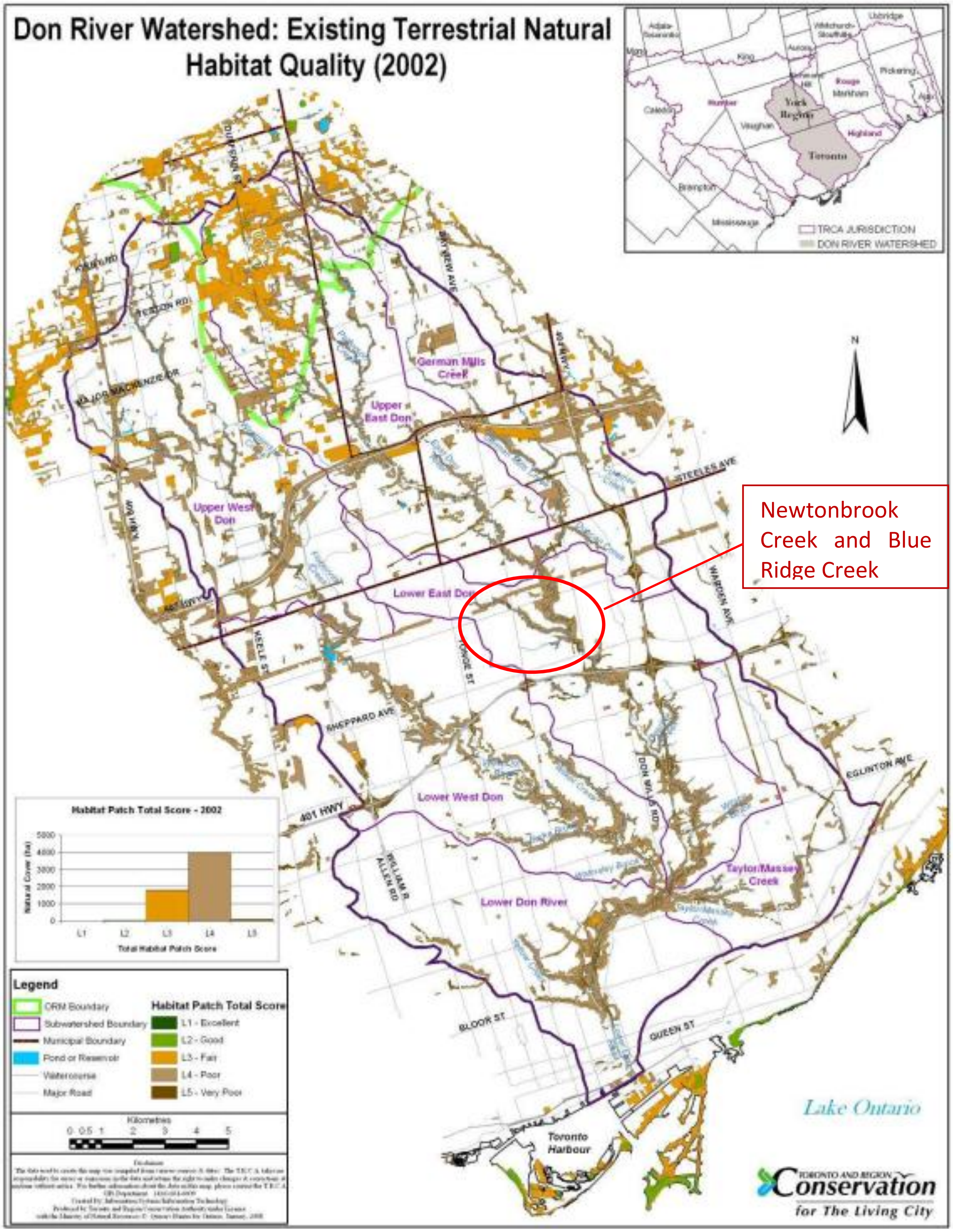

Figure 3-24: Existing Terrestrial Natural Habitat Quality (source: Don River Watershed Plan: Terrestrial Natural Heritage, TRCA 2009)

Figure 3-25: Provincially Significant Wetlands in Study Area (source: Queens Printer for Ontario, 2019)

3.1.3 Aquatic Ecology

Fish community and aquatic habitat within the Newtonbrook Creek and Blue Ridge Creek study area was initially reported on in the Don River Watershed Plan (TRCA, 2009) and in the Wet Weather Flow Management Master Plan (Marshall Macklin Monaghan, 2003). Site conditions through each watercourse were confirmed through a desktop exercise. The aquatic components of the study area are described in the following subsections.

3.1.3.1 Aquatic Habitat

According to the Don River Watershed Plan, Newtonbrook Creek and Blue Ridge are classified as having cool-water thermal regimes (TRCA, 2009), although TRCA targets for the Don River Reach 11 note that the fish community represents that of the “Type 4 Fish Community” or “tolerant warmwater” fish species (Marshall Macklin Monaghan, 2003). These species typically represent urban adapted communities that can handle the long-term effects of urbanization and landuse changes, along with the representative pressures placed on the creek. This is supported by the same targets outlining that currently, less than 20% of banks are contributed by woody vegetation and that less than 7% is represented by forest (Marshall Macklin Monaghan, 2003). Moreover, the Don River Watershed Plan shows that this study area is represented by greater than 25% of impervious cover. Thus, although site specific aquatic habitat or community species for the study area(s) were not available, these sources suggest that the aquatic ecology of the of Newtonbrook Creek and Blue Ridge Creek watersheds is highly altered. Pollutants such as road salt, phosphorus from fertilizer run-off, chemical contaminants, heavy metals, and fecal coliforms were all found in the East Don River Watershed, which contains Newtonbrook Creek and Blue Ridge Creek. In addition to pollutants, unbalanced creeks may have too much sediment, affecting the physical form of fish habitat.

According to TRCA (TRCA, 2009), there are three potential in-stream barriers to fish passage in Newtonbrook Creek and three barriers in Blue Ridge Creek, which also likely contribute to low aquatic habitat value and lower species richness among the available habitat. The rough locations can be seen in **Figure 3-26**.

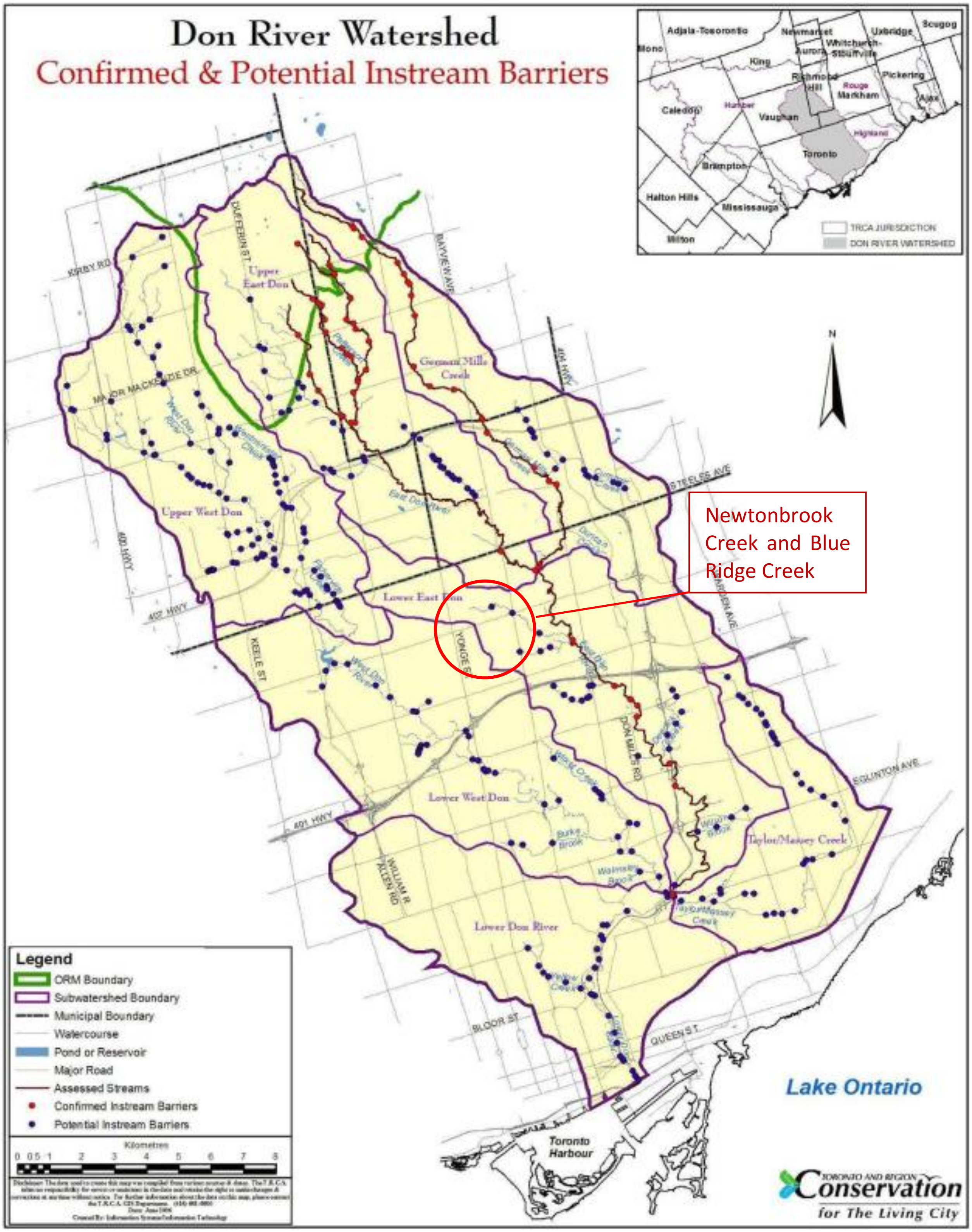

Figure 3-26: Fish Barriers Along Newtonbrook Creek and Blue Ridge Creek (TRCA, 2009)

3.1.3.2 Fish Community Assessment

MNRF records show that fish species found in Newtonbrook Creek are that of Blacknose Dace, Creek Chub, Fathead Minnow and Longnose Dace, of which represent species of high to intermediate tolerance of disturbance. According to the Don River Watershed Plan, few sensitive species were found in the subwatersheds between 2002 and 2005 during active sampling (TRCA, 2009). This is likely due not only to the alteration of the geomorphology of the creek but also the pollution that accompanies urbanization.

TRCA mapping details that there is no fish index of biotic integrity (IBI) score for the study area nor benthic invertebrate community data representative of the study area. As noted above, TRCA targets for the Don River Reach 11 note that the fish community represents that of the "Type 4 Fish Community" or "tolerant warmwater" fish species (Marshall Macklin Monaghan, 2003), supporting the fish species documented by the MNRF.

Evidence provided by MNRF and TRCA suggest that Newtonbrook Creek and Blue Ridge Creek and the study areas within them provides habitat to a variety of fish species, despite the multiple fish barriers discussed by TRCA.

3.1.3.3 DFO Self-Assessment

The federal *Fisheries Act* requires that projects avoid causing the death of fish and the harmful alteration, disruption or destruction of fish habitat unless authorized by the Minister of Fisheries and Oceans Canada (DFO). This applies to work being conducted in or near waterbodies that support fish at any time during any given year or are connected to waterbodies that support fish at any time during any given year. As noted above, the study area does contain fish at any time during any given year. Therefore, the *Fisheries Act* applies to works conducted in or near water with Newtonbrook and Blue Ridge Creeks.

Upon completion of the detailed design for the channel works at the study site, the works should be cross-referenced with the DFO "Projects Near Water" online service to determine if a request for regulatory review under the federal Fisheries Act is required. Based on field investigations and background information provided by TRCA, the study area does contain fish at any time during any given year. It is therefore the opinion of Aquafor Beech Limited that a request for regulatory review by Fisheries and Oceans Canada will be required. It is recommended that the proponent exercise the measures listed by Fisheries and Oceans Canada to avoid contravention with the Federal *Fisheries Act* and exercise due diligence by further mitigating accidental death of fish and the harmful alteration, disruption or destruction of fish habitat.

3.1.4 Utility Conflicts

Located within a highly urbanized watershed, the study area contains several types of utilities besides City-owned linear infrastructure (i.e., storm & sanitary sewers) including, but not limited to, telephone and communication cables, natural gas pipelines, oil pipelines, and overhead and underground electrical cables. As part of the risk assessment process, Aquafor has submitted a planning level One Call request. The compiled results are summarized below:

- **Bell:** Some existing conduits cross Newtonbrook Creek at major road crossings such as Maxome Avenue and Bayview Avenue. Buried lines cross Blue Ridge Creek where Burbank Drive crosses the creek. Otherwise there does not appear to be any other additional Bell infrastructure in the creek corridor.
- **Rogers:** Some existing conduits and buried infrastructure cross Newtonbrook Creek at Bayview and Finch Avenue. In addition, an existing conduit runs approximately parallel to the creek at that location.
- **Telecommunication cables** run parallel to Blue Ridge Creek from Bayberry Cr. to Burbank Drive. This area is entirely private property and has not been assessed as part of Aquafor's field investigations.
- **Enbridge Gas Inc.:** A natural gas pipeline runs parallel to the hydro corridor along Finch Avenue, and crosses Newtonbrook Creek downstream of Maxome Avenue.
- **Trans-Northern:** A natural gas pipeline runs parallel to Finch Avenue, and crosses Newtonbrook Creek downstream of Maxome Avenue. This pipeline crosses Newtonbrook Creek between Sanitary Sewer Crossing #13 and #12. The pipe is exposed in the bed of the channel and As-Built Engineering drawings have been received.
- **Sun-Canadian:** An oil pipeline crosses Newtonbrook Creek downstream of Maxome Avenue. This pipeline crosses Newtonbrook Creek between Sanitary Sewer Crossing #13 and #12. This pipeline is exposed laterally in the bank.

- **Imperial Oil:** A Field Locate was completed. A pipe crosses Newtonbrook Creek downstream of Maxome Avenue, adjacent to the Trans-Northern Pipeline. This pipeline crosses Newtonbrook Creek between Sanitary Sewer Crossing #13 and #12.

For the most part, there are minimal conflicts with telecommunications infrastructure in the NCGSMP study area. However, there are four (4) oil and gas pipelines crossing Newtonbrook Creek downstream of Maxome Avenue and upstream of Bayview Avenue. There is one (1) pipeline exposure in the bank of Newtonbrook Creek (Sun-Canadian), in addition to an exposed pipeline crossing in the bed of the channel (Trans-Northern).

3.1.4.1 Privately Owned Watermain

In addition to the City owned Watermain at Laredo Crescent, there is a second privately-owned watermain crossing along Newtonbrook Creek. As part of the requirements for a large hospital, St. John's Hospital has installed their own private watermain. This watermain provides a second feed to the hospital. Over time, erosion down cut the channel bed at the watermain crossing while the creek also migrated laterally, exposing a section of the private watermain. A sanitary sewer maintenance hole downstream was exposed as well. The City and St. John's Hospital retained an engineering consultant to design channel works to protect these two exposed structures and reduce future risk. In the associated design report, it was estimated that the channel had historically down cut at least 2.4 metres and migrated laterally 2.5 metres at the project site.

The design solution involved a vegetation buttress along the banks of the creek, covering and protecting the exposed watermain and sanitary sewer maintenance hole. In addition, efforts were made to enhance aquatic habitat as part of the restoration works. Construction was successfully completed in 2008.

3.1.4.2 Additional Risks to Infrastructure and Private Property

The valley corridor within which Newtonbrook and Blue Ridge Creek flow is part of a multi-use trail and park system. There are instances where the informal trail edges have been eroded along the creek. Private dwellings border this valley, with single-family detached homes located at the top of slope for much of the NCGSMP study area. These properties adjoining the watercourse are private residential properties, especially along Blue Ridge Creek, all of which are at risk if any channel erosion continues unmitigated. In fact, between Burbank Drive and Bayberry Crescent Blue Ridge Creek flows entirely through private residential properties.

3.1.5 Hydrologic And Hydraulic Conditions

Newtonbrook Creek and Blue Ridge Creek are tributaries of the East Don River. The drainage areas associated with both watersheds are fully contained within North York, Toronto's north-central administrative division. Both subwatersheds are heavily urbanized with limited pockets of parkland and natural undeveloped areas. Newtonbrook creek has an approximate length of 4 kilometers of open channel, which is roughly twice as long as Blue Ridge Creek. Both tributaries are feed by major storm sewer outfalls at their headwaters, and have several other outfalls situated along their length. The heavily urbanized nature of these watersheds is conducive to a "flashy" rainfall runoff response, which coupled with the steep channel gradients along both creeks, has contributed to significant in-stream erosion.

3.1.5.1 Streamflow Assessment

For the purposes of this Geomorphic Systems Master Plan Study, the Don River Watershed HSP-F model used in the 2003 WWFMMP was updated to generate a synthetic hourly streamflow timeseries for each of the delineated reaches along Newtonbrook Creek and Blue Ridge Creek. A hydrograph illustrating the modelled streamflow timeseries for Reaches N1 and Br1, the most downstream reaches of Newtonbrook and Blue Ridge Creeks, is provided in **Figure 3-27** & **Figure 3-28** for the 2012-2016 time period. The magnitude of select design storm flows (based on the HSP-F modelling analysis results) are clearly demarcated on each hydrograph to provide context regarding the magnitude of the modelled flows. In addition, **Table 3-15** provides a summary of the maximum hourly flow, minimum hourly flow, average hourly flow and median hourly flow, on a reach-by-reach basis for the modelled 2012-2016 timeframe.

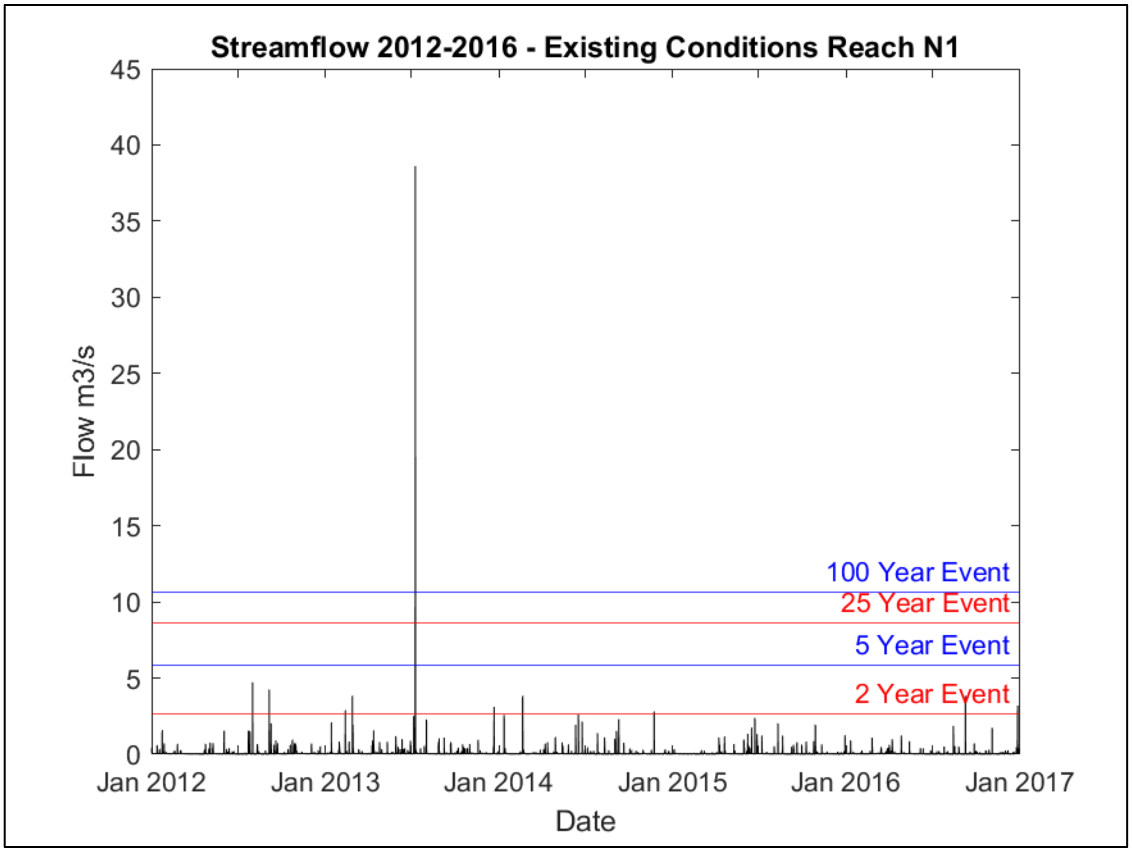

Figure 3-27: Hydrograph of Modelled Hourly Streamflow for Reach N1 from January 2012 – December 2016

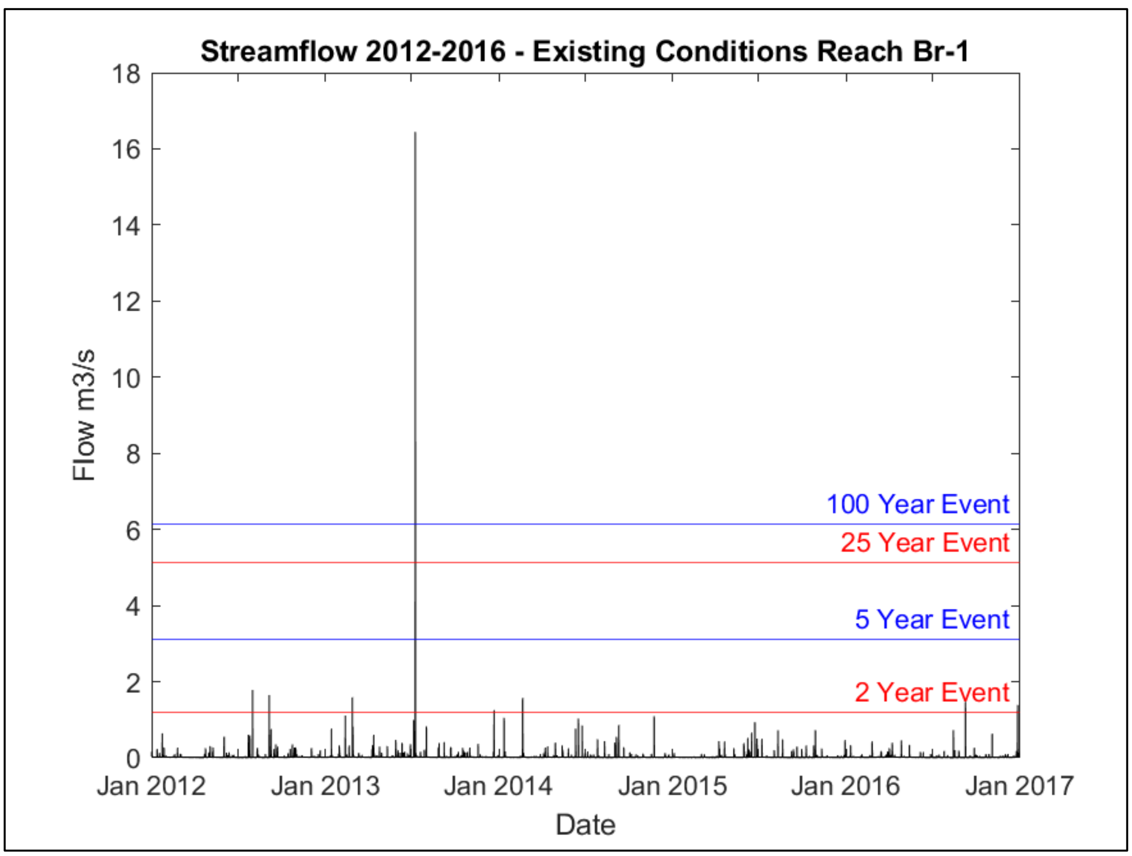

Figure 3-28: Hydrograph of Modelled Hourly Streamflow for Reach Br-1 from January 2012 – December 2016

Table 3-15: Reach by Reach Variability in Modelled Hourly Streamflow from 2012-2016

Reach	Max Flow (m^3/s)	Min Flow (m^3/s)	Average Flow (m^3/s)	Median Flow (m^3/s)
N1	38.611	0.005	0.052	0.026
N2	36.389	0.004	0.047	0.023
N3	23.028	0.003	0.030	0.014
N4	11.667	0.001	0.016	0.006
Br-1	16.444	0.002	0.021	0.011
Br-2	0.328	0.000	0.000	0.000
Br-3	11.583	0.001	0.012	0.006
Br-4	2.706	0.000	0.003	0.002

Figure 3-27 & **Figure 3-28**, along with the values reported in **Table 3-15**, illustrate that hourly flows within the Newtonbrook and Blue Ridge subwatersheds are typically less than 0.1 m^3/s but regularly exceed 2.0 m^3/s in Newtonbrook Creek and 1.0 m^3/s in Blue Ridge Creek when the watersheds are subjected to significant precipitation or runoff. This substantial variance between modelled low and high flow conditions is characteristic of a flashy-urban watershed. Over the course of the modelled five-year period (2012-2016) one (1) event exceeded the 5-year return period flow in both watersheds. This was the July 2013 flood which also exceeded the 100-year return period flow. Otherwise, the 2-year event was exceeded nine (9) additional times in the Newtonbrook Creek subwatershed and seven (7) additional times in the Blue Ridge Creek subwatershed, which is more frequent than expected. While the above hydrograph does show regular flooding in the spring period as a response to spring snowmelt, many of the largest floods occurred in the summer and fall seasons, indicating the rainfall-runoff response in the watershed is pluvial driven as opposed to spring-freshet dominant.

Further hydraulic analysis for this study area was carried out using the Don River HEC-RAS model developed by TRCA. A high-level summary of the flow regime for Newtonbrook and Blue Ridge Creeks is provided in **Table 3-16**, defining the peak flows associated with the 2–100-year design storms and the regional event. It should be noted that TRCA model does not include Reaches Br2 and Br4 of Blue Ridge Creek. Baseflow was also estimated on a reach-by-reach basis using the synthetic timeseries generated by the HSP-F model. Baseflow was determined by first isolating modelled flow measurements that did not experience significant fluctuations in magnitude for two (2) consecutive days before and after a given measurement. This process effectively removes higher magnitude flows that occur in response to a rainfall-runoff cycle. The average of the isolated points was then calculated to estimate baseflow on a reach-by-reach basis with values reported in **Table 3-17**. **Figure 3-29** & **Figure 3-30** provide a visualization of isolated baseflow values relative to the rest of the modelled hydrograph for reaches N1 and Br1, respectively.

Table 3-16: Newtonbrook and Blue Ridge Creeks Flow Regime Summary – Design Storm Events as Defined in TRCA Don River HEC-RAS Model

Reach	2-Year Flow (m^3/s)	5-Year Flow (m^3/s)	10-Year Flow (m^3/s)	25-Year Flow (m^3/s)	50-Year Flow (m^3/s)	100-Year Flow (m^3/s)	Regional Flow (m^3/s)
N1	7.00	13.74	17.03	20.20	22.63	24.80	126.20
N2	7.03	15.38	20.62	26.62	32.76	38.56	123.82
N3	7.38	15.25	19.77	25.38	31.37	36.99	112.72
N4	6.66	12.64	16.05	21.00	26.36	31.47	89.96
Br1	0.87	2.66	3.53	5.09	6.58	7.81	22.73
Br2*	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Br3	0.61	1.81	2.42	3.43	4.45	5.30	15.6
Br4*	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*TRCA Model does not include Reaches Br2 and Br4.

Table 3-17: Newtonbrook and Blue Ridge Creek Flow Regime Summary - Baseflow (m^3/s)

N1	N2	N3	N4	Br1	Br2	Br3	Br4
0.022	0.019	0.012	0.006	0.010	0.000	0.006	0.002

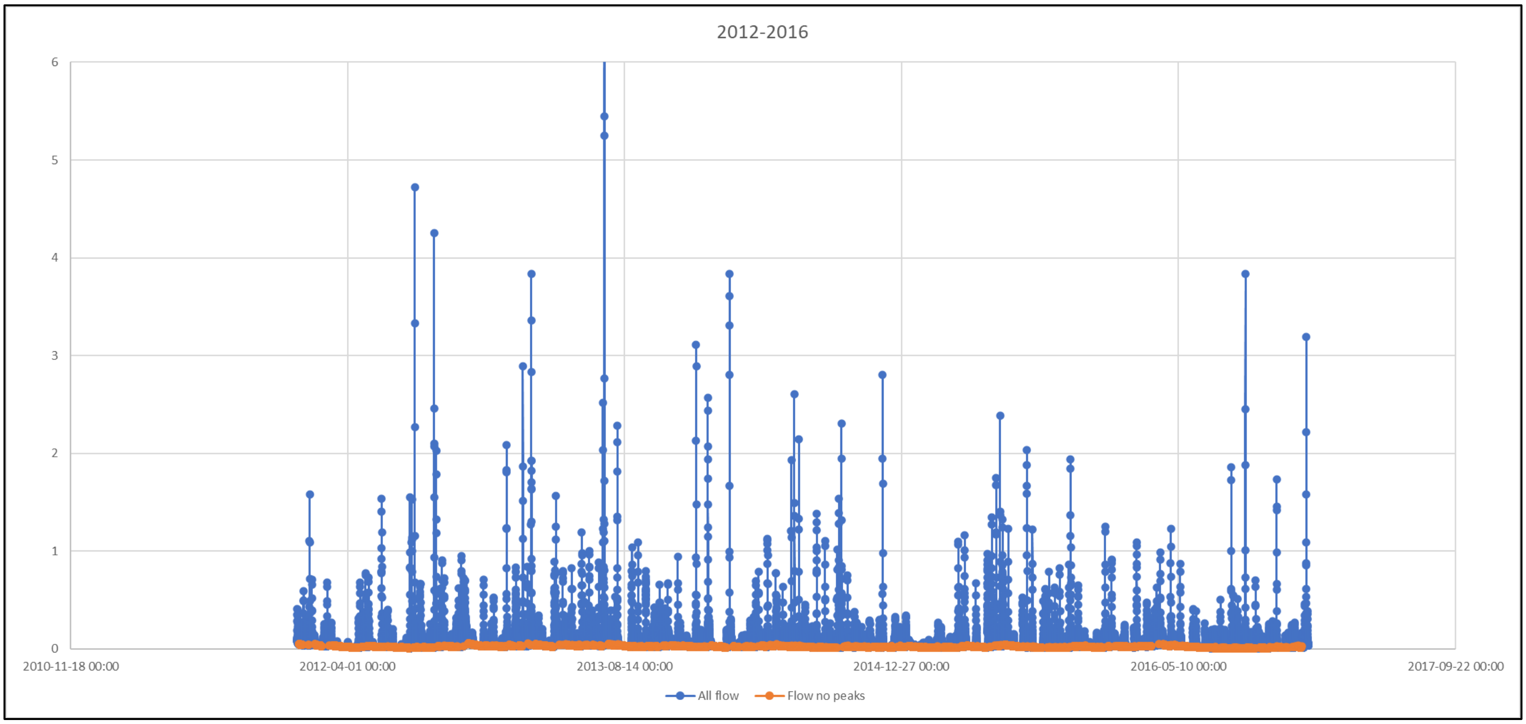

Figure 3-29: Isolated Baseflow Values Relative to the Rest of the Modelled Hydrograph for Reach N1

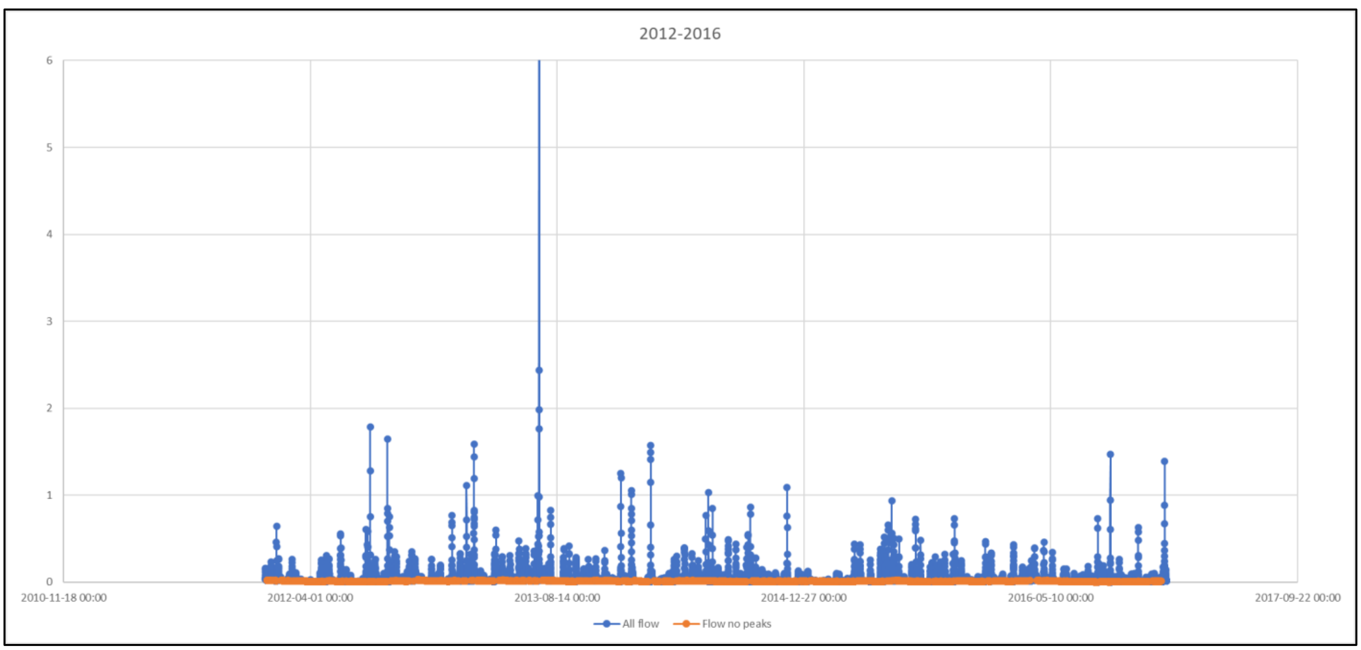

Figure 3-30: Isolated Baseflow Values Relative to the Rest of the Modelled Hydrograph for Reach Br1

3.1.5.2 Hydraulic Assessment

TRCA recently updated their HEC-RAS model for the Don River Watershed by adjusting channel geometry and model flow profiles. The project file associated with this model is “TRCAMar11Edits.prj”. Aquafor staff have reviewed TRCA model and determined that it covers the general extents of both Newtonbrook Creek and Blue Ridge Creek while also providing an accurate representation of current channel hydraulics. This model was used to assess the system response to seven (7) different flow scenarios, each of which is described in detail below.

Relevant HEC-RAS outputs are also summarized in tabular format within **Appendix F**. A summary of the model flows is provided above in **Table 3-16**.

2-Year Return Period Flow: The flow rate associated with a two-year return period event. An event of at least this magnitude has a 50% probability of occurring within a given year. Flow rates for the 2-year event were obtained directly from TRCA Don River HEC-RAS model. Analysis of the 2-year event provides insight into frequent flood flows and associated velocities / shear stresses that must be accounted for in the selection and sizing of bed and bank treatments at the conceptual design stage.

5-Year Return Period Flow: The flow rate associated with a five-year return period event. An event of at least this magnitude has a 20% probability of occurring within a given year. Flow rates for the 5-year event were obtained directly from TRCA Don River HEC-RAS model.

10-Year Return Period Flow: The flow rate associated with a ten-year return period event. An event of at least this magnitude has a 10% probability of occurring within a given year. Flow rates for the 10-year event were obtained directly from TRCA Don River HEC-RAS model.

25-Year Return Period Flow: The flow rate associated with a twenty-five-year return period event. An event of at least this magnitude has a 4% probability of occurring within a given year. Flow rates for the 25-year event were obtained directly from TRCA Don River HEC-RAS model.

50-Year Return Period Flow: The flow rate associated with a fifty-year return period event. An event of at least this magnitude has a 2% probability of occurring within a given year. Flow rates for the 50-year event were obtained directly from TRCA Don River HEC-RAS model.

100-Year Return Period Flow: The flow rate associated with a 100-year return period event. An event of at least this magnitude has a 1% probability of occurring within a given year. Flow rates for the 100-year event were obtained directly from TRCA Don River HEC-RAS model. Consideration of the 100-year design storm is of particular importance, and is often applied as the design threshold to which erosion control works are designed in creek restoration projects.

Regional Flow: The flow rate associated with the Regional storm. For the City of Toronto this is the flow rate associated with the 1954 Hurricane Hazel event. Flow rates for the Regional event were obtained directly from TRCA Don River HEC-RAS model. For the purposes of the NCGSMP, the regional flow was used to delineate regional flood lines under existing conditions. During the future detailed design phase, one of the design constraints will be to ensure any proposed works do not increase the Regional floodline extents and by extension flood risks to private property.

3.1.5.2.1 Regional Floodline Analysis

The regional floodline plot illustrating the regional floodline extents within the NCGSMP study area is provided in **Figure 3-31**. While the regional floodline is typically contained within the valley corridor, flooding of backyards adjoining Newtonbrook and Blue Ridge Creek were observed at several locations within the study area including properties along Forest Grove Drive, Burbank Drive, Farmingdale Road, Bayview Avenue, Finch Avenue East, Manorcrest Drive, Cummer Avenue, Harnish Crescent, Revcoe Drive, Hi Mount Drive, Citation Drive and Hawksbury Drive.

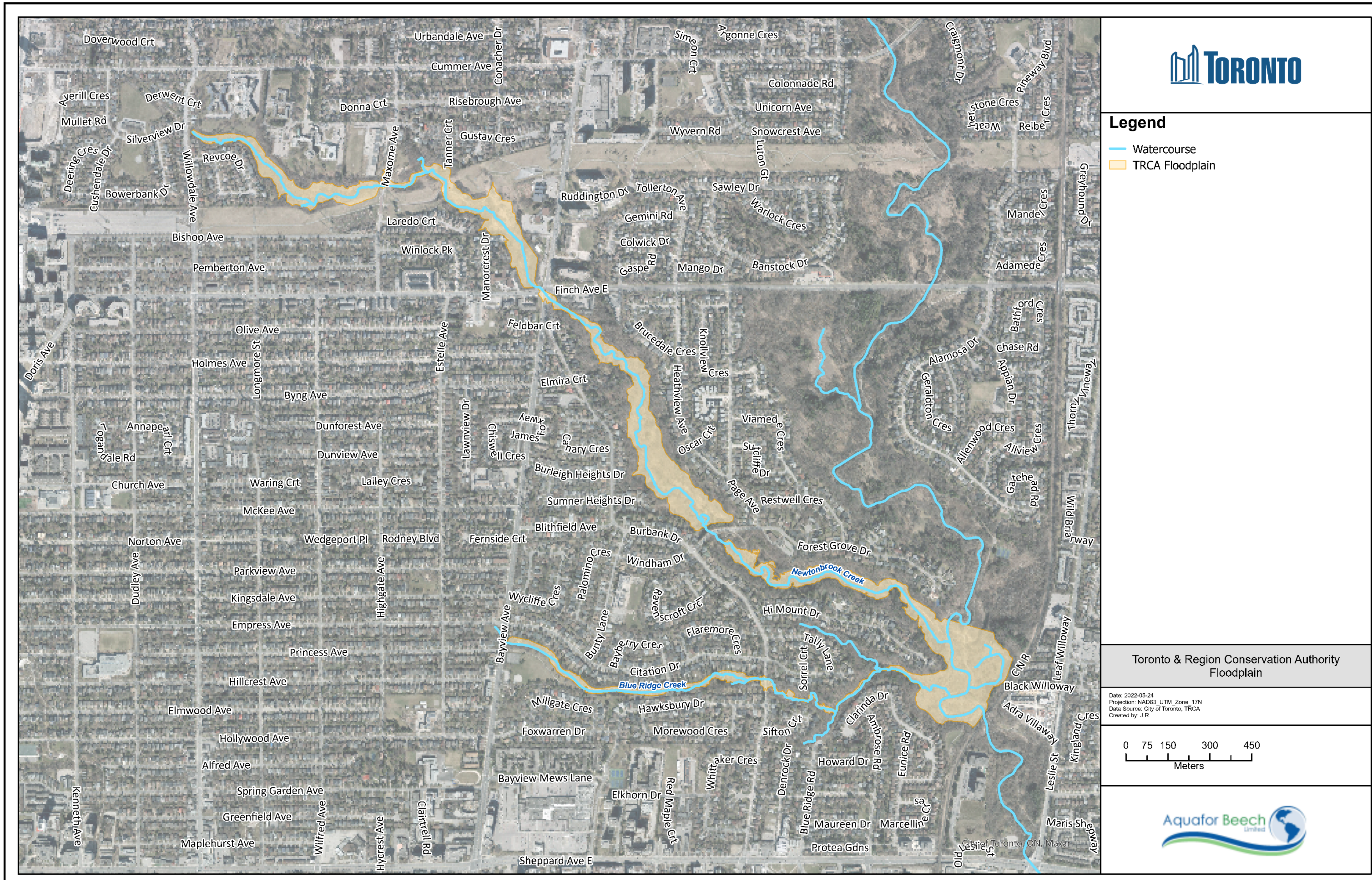

Figure 3-31: Regional Floodplain Mapping for NCGSMP Study Area

3.1.5.3 Analysis of Modelled Streamflow Velocities

In addition to having an understanding of floodline extents, careful consideration must be given to the expected velocities and shear stresses under the full range of modelled flows. In many instances the modelled velocities can be significant and are capable of causing large scale erosion and the failure of erosion control measures. **Figure 3-32** provides a visual summary of the range of velocities modelled along Newtonbrook Creek under the 2-100 year and regional flow events, while **Figure 3-33** does the same for Blue Ridge Creek.

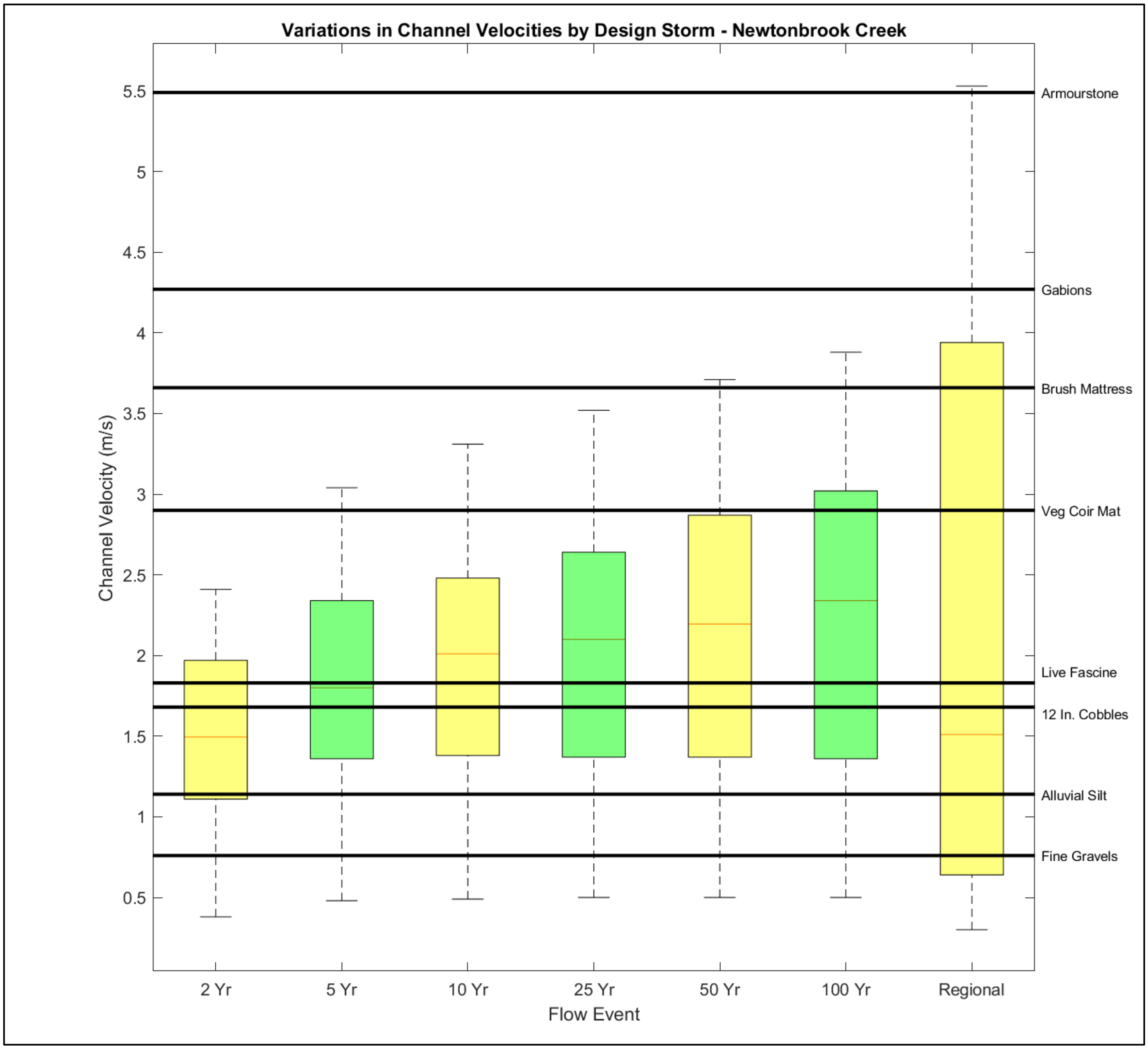

Figure 3-32: Box and Whisker Plot Illustrating Variations in Channel Velocities by Design Storm for Newtonbrook Creek. Permissible Minimum Velocities for Varying Materials as per Fischenich (2001) Shown on the Right.

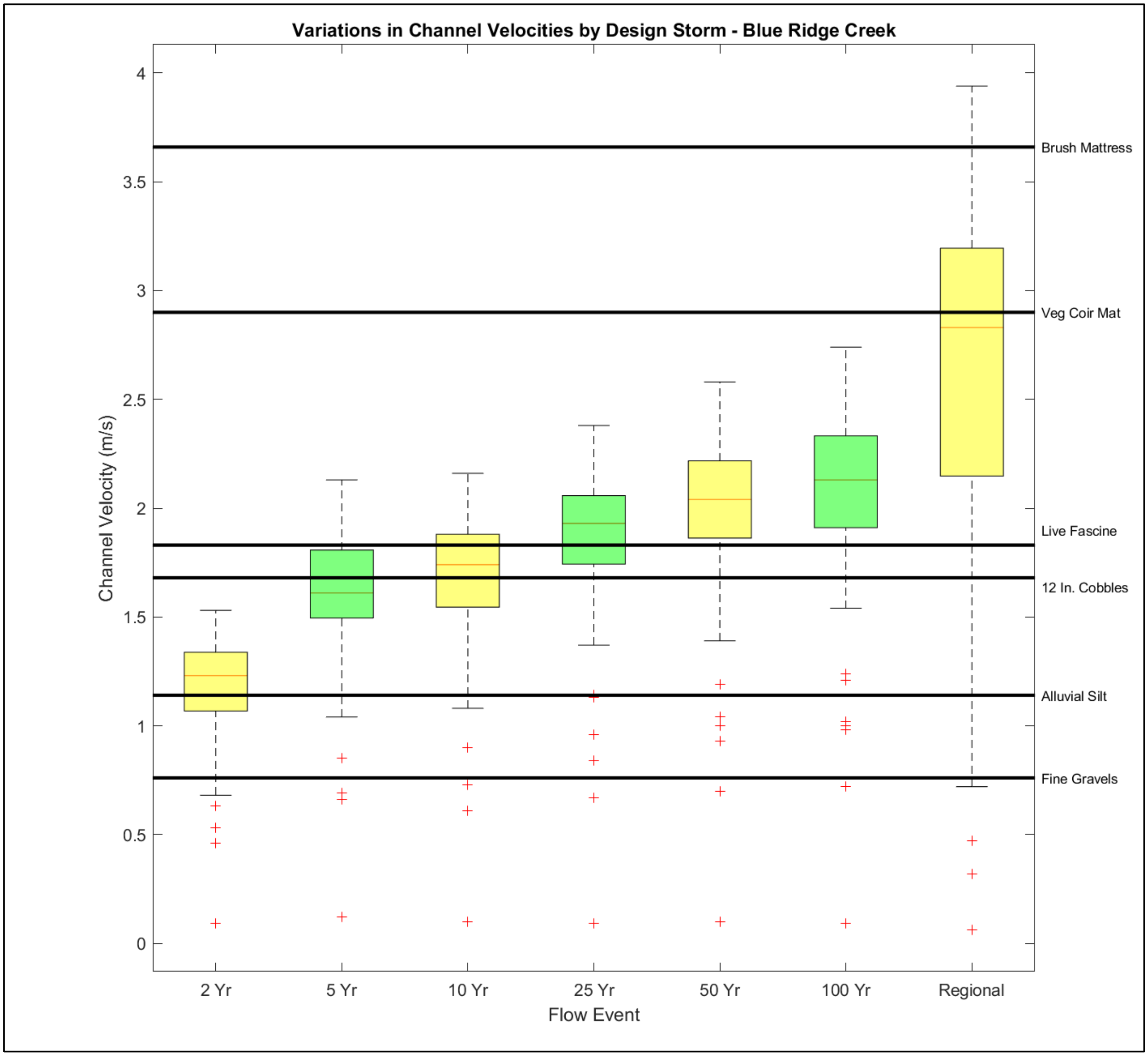

Figure 3-33: Box and Whisker Plot Illustrating Variations in Channel Velocities by Design Storm for Blue Ridge Creek. Permissible Minimum Velocities for Varying Materials as per Fischenich (2001) Shown on the Right.

As per **Figure 3-32** under the 2-year return period event, channel velocities within Newtonbrook Creek can exceed 2.0 m/s at select parts of the watercourse with the bulk of the modelled channel velocities for the 2-year event in the range of 1.0 – 2.0 m/s. Based on research conducted by Fischenich (2001) (**Table 3-18**), reasonable erosion control measures for velocities in this range include 12 inch cobbles, engineered rip-rap, live fascines and vegetated buttresses. Given that the 2-year event is likely to occur fairly frequently, it is recommended that a vegetated buttress, engineered riffle or equivalent method be considered as the primary materials for site restoration along Newtonbrook Creek, acknowledging that further analysis on a site-specific level is necessary to select and size erosion control measures for each priority site. With respect to Blue Ridge creek, as per **Figure 3-33** modelled velocities for the two-year return period event are lower, ranging from approximately 0.5 – 1.5 m/s. Live fascines or 12-inch cobbles/roundstone should be considered as candidates for the primary site restoration materials along Blue Ridge Creek.

Figure 3-32 also indicates that for Newtonbrook Creek under the 100-year event, velocities can exceed 3.75 m/s which is greater than the minimum permissible velocity defined by Fischenich for typical bioengineering measures like brush mattresses or vegetated buttresses. However, armourstone bank/bed treatments can provide sufficient protection for the range of modelled velocities associated with the 100-year return period event, as the minimum permissible velocity for armourstone is 5.49 m/s. Consequently, the use of localized armourstone treatments is recommended to protect critical infrastructure (i.e., a sewer crossing or vulnerable maintenance hole). It should be noted that under the Regional event, velocities within Newtonbrook Creek can exceed 5.5 m/s which is greater than the minimum permissible velocity for armourstone or concrete structures. The fact that a large enough wet weather flow event could reasonably prompt the failure of almost all engineered structures in the Newtonbrook Creek watershed provides support for ensuring adequate depth of cover is maintained, both vertically and laterally, between essential municipal infrastructure and the channel bed/bank.

As per **Figure 3-33** modelled velocities for Blue Ridge Creek associated with the 100-year event range from roughly 1.5 – 2.75 m/s, which can be effectively managed by select bioengineering treatments. However, modelled velocities for the regional event do exceed the minimum permissible velocities defined by Fischenich for bioengineering measures. As a result, the use of armourstone is recommended to protect the most critical infrastructure, particularly in instances were there are spatial constraints that require the construction of a vertical or near vertical retaining wall. As per the modelled velocities reported in **Figure 3-33**, well designed bed and bank treatments using a combination of armourstone and softer bioengineering measures should provide long-term protection of at-risk infrastructure along Blue Ridge Creek, provided all structures are properly constructed. Nevertheless, it is acknowledged that well designed and well constructed engineering structures can fail if they become undercut or outflanked. Therefore, re-establishing a minimum of 1.0 metres of cover over exposed or nearly exposed infrastructure is still recommended to provide additional protection where technically and financially feasible.

Table 3-18: Permissible Shear and Velocity Thresholds for Various Channel Lining Materials (Adapted from Fischenich, 2001)

Boundary Material	Permissible Shear Stress (N/m^2)	Permissible Velocity (m/s)
Soils		
Fine Gravels	3.6	0.76
Stiff Clay	12.4	0.91-1.37
Alluvial Silt	12.4	1.14
Graded Silt to Cobble	18.2	1.14
Shales and Hardpan	32.1	1.83
Non-Uniform Gravel / Cobble		
2 inch	32.1	0.91 - 1.83
6 inch	95.8	1.22 - 2.29
12 inch	191.5	1.68 - 3.66
Riprap		
6 - in. (150 mm) D_{50}	119.7	1.5 - 3
9 - in. (230 mm) D_{50}	181.9	2.1 - 3.4
12 - in. (305 mm) D_{50}	244.2	3 - 4
18 - in. (460 mm) D_{50}	363.9	3.7 - 4.9
24 - in. (610 mm) D_{50}	483.6	4.3 - 5.5
Channel Engineering Materials		
Gabions	478.8	4.27 - 5.79
Concrete / Armourstone	598.5	5.49
Soil Bioengineering		
Live fascine	59.8 - 148.4	1.83 - 2.44
Coir roll	143.6 - 239.4	2.4
Vegetated coir mat	191.5 - 383	2.9
Live brush mattress (initial)	19.2 - 196.3	1.22
Live brush mattress (grown)	186.7 - 392.6	3.66

3.1.6 Climate Change Assessment

The Summary for Policymakers included in the latest assessment reporting by the Intergovernmental Panel on Climate Change (IPCC), AR6 (IPCC, 2023) begins with the Current Status statement:

> *Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1^{o}C above 1850-1900 in 2011-2020.*

Global scale climate warming has been observed over the past several decades and will continue for the foreseeable future. This phenomenon is generally associated with a host of negative consequences across our biosphere. As the cause of recent accelerated global warming has been accredited to anthropogenic activities, the solutions must follow from human initiatives and changes in how things are done. Societies and nations must respond in two ways; firstly, by slowing and reversing the process of global warming (remediation) and secondly by adapting to the changing climate. Climate Change Assessment (CCA) is the first stage of the adaptation process.

This section documents the CCA conducted as part of the NCGSMP including the identification of issues, resources, approach, analysis and discussion. This assessment is hydrological in focus and modelling-based. The CCA identifies possible future climates and their hydrological consequences in Newtonbrook and Blue Ridge Creeks. This component is an integral part of the Risk Assessment portion of the NCGSMP.

In recognition of the reality of future climate warming, the NCGSMP requires a hydrologically based CCA in order to better understand the risks associated with environmental management of the watercourse and the watershed and the protection of essential infrastructure. Relevant climate sensitive environmental and risk management issues in the Newtonbrook and Blue Ridge Creeks catchments and watercourse include:

- Physical watercourse processes
- Erosion control & slope stability
- Aquatic and riparian habitat
- Flooding and floodplain management
- Public safety
- Infrastructure protection, and
- Recreational function

The purpose of the CCA is to examine and identify future climate warming in the watersheds of Newtonbrook and Blue Ridge Creeks in terms of degree of change and potential future impact to the hydrologic cycle. The urban stream is an ecological and societal asset that requires management and protection. Understanding that climate warming will affect the local hydrology and local environment in various ways informs the development of the Master Plan, especially in terms of the Risk Assessment and long-term management.

This CCA consists of two parts requiring different approaches. **Part 1** examines the potential hydrologic impacts of climate warming scenarios in terms of the resultant runoff and streamflow, including components of the hydrologic cycle in the local study area. These are the longer-term overarching changes in system hydrology. This part of the assessment examines climate change in terms of the prevailing conditions instream. It involves multi-year hydrological modelling runs as a way to understand the instream impacts to streamflow and the monthly, seasonal and annual nature of streamflow in the Creek. This part of the assessment focusses on issues that are relevant at longer timeframes (i.e., months, seasons, annually and longer) such as drought, habitat management, recreation and watercourse function.

Part 2 of the CCA examines the potential impacts of climate warming on the occurrence and intensity of major storms in the study area in the future and their impact upon instream flow. This part focusses on potentially damaging storm events that are likely to occur more frequently and thus, impact the streambed and underlying infrastructure. The non-stationarity of future climate, and by extension, local weather and hydrology necessitates a rational approach recognizing past practice and future change. The approach allows for consideration of change in instream erosion, channel stability, flooding, public safety and infrastructure protection and risk.

Each part is outlined in detail in the following subsections.

3.1.6.1 Climate Change Assessment Part 1: Monthly and Seasonal Assessment

3.1.6.1.1 Available Resources

This section identifies climate change information and tools used in this assessment.

Global Climate Models (GCMs) are coupled ocean-atmospheric models that attempt to simulate future climate under alternate greenhouse gas (GHG) forcing scenarios. GCMs are a primary tool in climate change assessment and have been applied to a wide variety of GHG scenarios over long simulation periods (i.e., 200-250 years). GCM simulations use a large-scale grid system with nodes spaced tens of kilometers apart covering hundreds of square kilometers per grid cell. At this scale these models cannot reflect smaller scale storms (i.e., thunderstorms) and thus, simulation results reflect regional weather patterns but not small-scale events.

Many GCMs have been produced around the world. These models have been rigorously calibrated and tested and are all considered valid. However, different models produce different results, highlighting the uncertainty of using models. Consequently, global modelling projects are conducted using many models applied to the same scenarios. The model's output is compared and ranked as a way to examine and quantify the uncertainty.

GCM output can represent climate, especially temperature, with good confidence. The same level of confidence with moisture simulation cannot be achieved, especially in terms of simulating storms and other short lived and localized events. GCM output cannot be used directly as input to hydrological models due to issues of spatial and temporal scale. GCM output is often downscaled using statistical methods or by using regional climate models.

Regional Climate Models (RCMs) use smaller grid sizes than GCMs (i.e., kilometers per side) and are nested within GCMs. RCMs take their boundary conditions from the GCMs that they are nested within and therefore remain consistent with the GCM in terms of energy and moisture. RCMs can downscale the GCM results by representing smaller areas with finer surface detail (i.e., local physiographic features including mountains and water bodies) at smaller time steps.

The Intergovernmental Panel on Climate Change is a United Nations scientific collaboration aimed at addressing the climate change challenge. Through joint ventures and information sharing, this collaboration of nations supports the release of a series of climate assessment reports (i.e., AR4, AR5, AR6, etc.) and supports the ongoing development and application of GCMs and modelling projects.

The **Canadian Climate Data Portal (CCDP)** and the **Ontario Climate Data Portal (OCDP)** provide internet sites for disseminating climate information, including the results of climate modelling, especially for the local study area. The websites provide supporting information and summary information for climate studies. Future climates used in this study were sourced from these sites.

The **HSPF** watershed scale hydrologic model of the Don River and its tributaries was developed as part of the Toronto Wet Weather Flow Management Master Plan (TWWFMMP) and is applied here. This model performs continuous long-term simulations of runoff and streamflow in urban and rural environments. It takes meteorological inputs and determines the movement and conditions of state of moisture through the surface and subsurface of the landscapes. The model also simulates the inflow of runoff to the Creeks and the instream flow rates throughout the system. A variety of urban stormwater management configurations, common across the watershed, are simulated under various climate scenarios.

3.1.6.1.2 Approach to Part 1 Climate Change Assessment

A modelling approach has been adopted for Parts 1 and 2 of the CCA. As mentioned above, the HSPF hydrologic model was used to simulate runoff in the watershed and streamflow in reaches under various climate conditions. For the NCGSMP, the model has been calibrated with 2011 to 2016 climate inputs and landuse (**Appendix Y**). Land use in the study area has not changed appreciably in the past two decades. The simulation timeframe includes some large storms including a significant storm in July 2013 and has provided for a more rigorous calibration of storm response than the earlier version of the model. Also, the updated model was calibrated for the full annual period, whereas the older model version was not evaluated for the cold weather/ frozen portion of the year.

For the NCGSMP select meteorological inputs have been altered to reflect the various future climate scenarios. The climate parameters that have been altered include air temperature, precipitation, dewpoint temperature and potential evapotranspiration. These are the parameters that have the greatest impact on local hydrology and streamflow. The unaltered climate inputs are wind speed and solar radiation.

Since the hydrologic model is considered calibrated and verified for 2011-2016, this period has been selected as the **reference period** for the assessment and serves as an example of existing conditions. That is, projected future climates and resultant hydrology are compared to the climate and hydrology of this period in order to estimate relative change. Annual, monthly and seasonal flow volumes and flow frequency statistics have been determined and documented for the reference and future periods.

Uncertainty is an ever-present aspect of a CCA. The various sources of uncertainty include the following:

- Estimating the pace of climate warming using GCMs is complicated by uncertainty around future emission rates of greenhouse gases (GHGs). The rate of climate warming is a function of the rate of release of GHGs. In turn, the rate of GHG releases is dependent upon human activity and societies' willingness and ability to remediate the situation. Because of the uncertainty around the future GHG emission rates several scenarios are required in the CCA to bracket some of the possibilities.
- The wide array of GCMs worldwide leads to an array of results. None is considered superior and therefore all are given equal stature. These models are fundamentally the same yet differ in details, process parameter values and calibration accuracy.
- Hydrologic model accuracy is a source of some uncertainty as it can introduce error. In this study the streamflow is not gauged in the local streams. It is necessary to take streamflow data from a nearby location in the Upper East Don River as a general indicator of flow in the study area. Rigorous calibration and reliable observational data (i.e., precipitation and streamflow) can minimize this error.
- The state-of-the-art in terms of projecting future major storms is in an early stage. Downscaling models (RCMs) that employ smaller sized discretization schemes improve the capability to model the smaller scale storm events (i.e., thunderstorms). Also, observational data collected over the past decades is enabling the use of statistical methods that can identify future changes and trends in storm occurrence and magnitude.

As a response to uncertainty around GCMs and GHG emission scenarios, six future climate conditions have been considered for this study. These involve three GHG emission scenarios applied at two future time periods (i.e., 2050 and 2080). This set should result in six future climates. GHG emission scenarios range from a more optimistic control scheme to less ambitious control schemes. GHG emission scenarios are referred to as 'representative concentration pathways' (RCPs). These RCPs refer to global radiative forcing functions and they relate to the degree of forcing change in the balance between incoming solar radiation and outgoing infrared radiation. The 3 RCPs examined in this assessment represent global radiative forcing values of 3.0, 4.5 and 8.5 W/m^2, respectively. These values are expected to bracket the wide range of possibilities for future emission management.

As mentioned, each of the RCPs has been modelled collaboratively using a wide set of GCMs. From the large set of GCM outcomes, individual model results are ranked in terms of their position within the larger group, and expressed as percentiles. That is, based upon results (i.e., average global temperature simulated) each model is ranked as to its position in the group in terms of its percentile (i.e., 10th percentile, 50th percentile, 90th percentile, etc.). We have chosen the 50th percentile model results for each RCP modelled in this study. In this way the selected model sets should be closest to the consensus results for any simulation. The use of model ensembles, RCMs and a range of RCPs in this study are attempts to minimize the effects of uncertainty. The future summarized climate model outputs were downloaded as monthly average values for the meteorological parameters mentioned at the future timeframes identified.

The reference climate (i.e., 2011 to 2016) and the climates of each of the 3 RCP scenarios were compared in terms of monthly average, maximum and minimum air temperature and precipitation volume for each future timeframe. The changes or 'delta' values for the future climates were determined by averaging the results for 20-year periods. So, for example, to characterize the results around the year 2050, the simulation results for 2040 through 2059 were averaged.

Climate input time series data used in hydrologic modelling was synthesized for each RCP scenario by factoring the reference period climate time series by the delta factors determined on a monthly basis. So, for example, to build a time series for air temperature reflecting a particular RCP in March of 2050., the delta temperature mean associated with that RCP in 2050 for March was added to all hourly values for air temperatures in the March time series. The process is repeated for each month of the year and meteorological parameter. Meteorological inputs were synthesized for air temperature, dewpoint temperature and precipitation in this manner.

Potential evapotranspiration (PEVT) is an important water balance element that is provided to the hydrologic model as a time series. It is generally not practical to measure this process and therefore it has been estimated. HSPF provides a utility for this purpose based upon the work of Jensen and Haise (1963). This utility calculates daily potential evapotranspiration based upon a monthly coefficient, daily minimum and maximum air temperatures and daily total solar radiation. PEVT was included in the group of four synthesized climate changed meteorological parameters by adjusting temperatures and calculating future PEVT for each scenario.

HSPF was run for the period 2010 to 2016 with 2010 treated as a spinup year for each climate scenario. Model output was summarized for 2011 to 2016 in terms of annual, monthly and seasonal runoff/streamflow. Streamflow time series were also compared directly to explain differences and impacts.

3.1.6.1.3 Projected Future Climates

3.1.6.1.3.1 GHG Emission Scenarios

The Ontario Climate Data Portal and the Canadian Climate Data Portal were created to disseminate climate projection information to the public. Available information is based upon climate modelling reported in the IPCC fifth Assessment Reports (AR5, IPCC, 2014). All scenarios available are based upon ensembles of model runs so that the variability across the spectrum of GCMs can be appreciated. In this study, scenarios selected satisfy the criteria of "highest plausible scenarios" in that the median or 50th percentile model results were used for each emission scenario and scenarios were selected which represent both a high impact worst case as well as a low impact favourable emission scheme. In all, three GHG scenarios and two future timeframes have been selected for this part of the CCA. The scenarios and timeframes are as follows:

1. **RCP2.6 2050** This **low emission** scenario (3.0 W/m^2 of global radiative forcing) results in rising global air temperatures to about the year 2050 followed by a period of temperature stabilization. This is the most favourable scenario assessed in IPCC modelling studies. This scenario/timeframe examines climate around the year 2050 when global warming would be limited to about 2 C^o.
2. **RCP4.5 2050** This is an **intermediate emission** rate scenario (4.5 W/m^2) that results in higher rates of temperature increase than RCP2.6. This emission scenario is expected to cause global warming of about 3 C^o after stabilizing in the latter part of this century. This scenario/timeframe examines climate around 2050.

3. **RCP8.5 2050** This is a **very high emission** rate scenario (8.0 W/m[2]), representing the worst case examined. This emission rate would cause warming greater than 4 C° beyond 2100 without stabilization. This scenario/timeframe represents the climate around 2050.
4. **RCP2.6 2080** This scenario/timeframe results in identical climate in 2080 as in 2050 due to stabilization of temperature beyond 2050. For this reason, results for RCP2.6 2080 are not unique and are not discussed further.
5. **RCP4.5 2080** This scenario/timeframe represents the RCP4.5 emission case around the year 2080 when climate stabilization is expected.
6. **RCP8.5 2080** This scenario represents the RCP8.5 emission case around the year 2080 as warming continues.

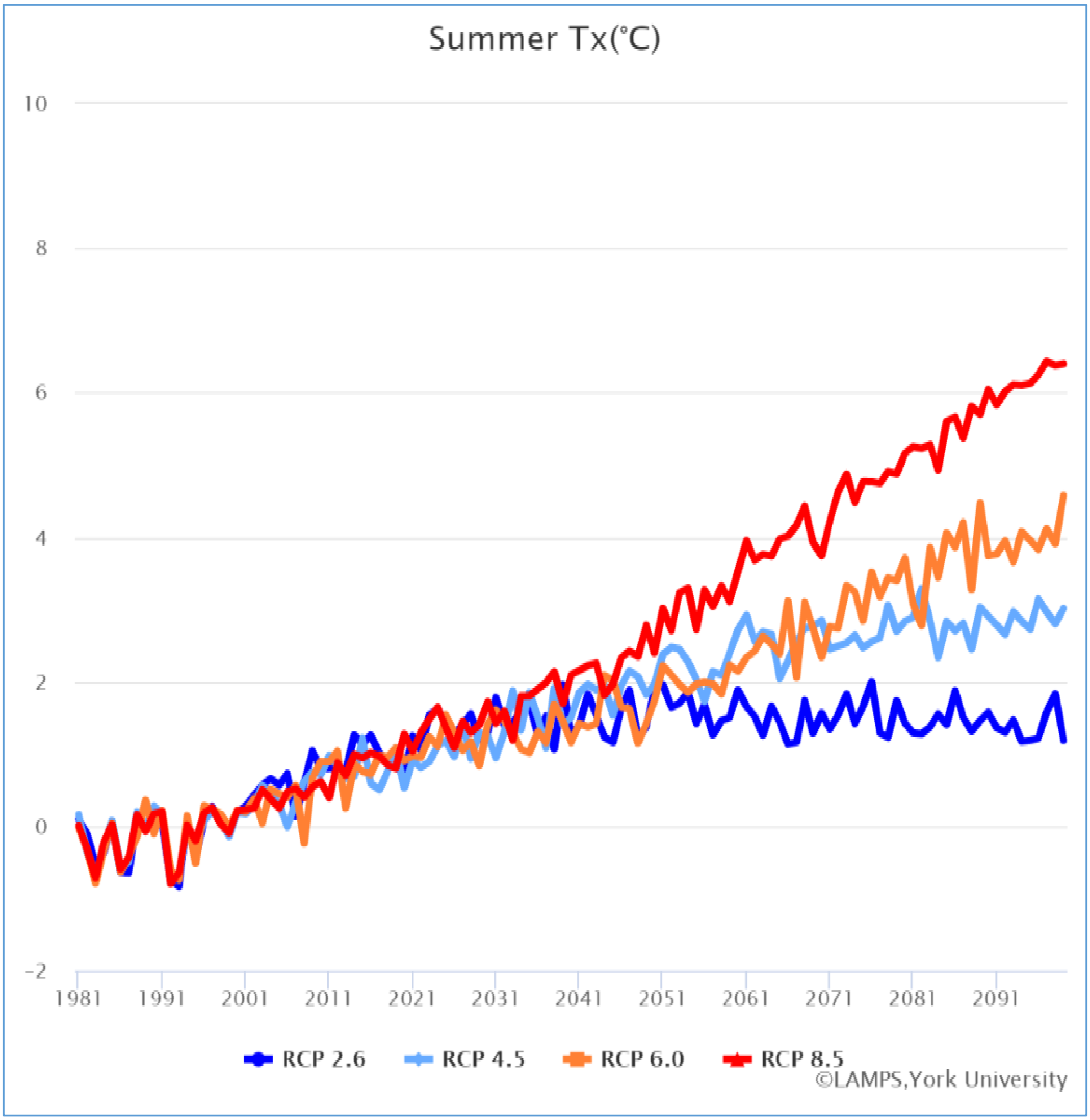

Figure 3-34: Ontario Summer Average Temperature Increases for Four RCPs from 1981 through 2100 (LAMPS, York University)

Figure 3-34 displays the average summertime daily temperature increase projected across Ontario with four alternative RCPs. RCP6.0 was not modelled as thoroughly as the other scenarios nor is it sufficiently different from RCP4.5 for the purpose of this assessment and is not included in this study. Note that these scenarios all show some degree of warming around the beginning of this century. The individual scenarios noticeably separate around the present time. The IPCC AR6 (IPCC, 2023) reported:

> *Global surface temperature was 1.09°C [0.95°C-1.20°C] higher in 2011-2020 than 1850-1900, with larger increases over land than water (1.59°C [1.34°C-1.83°C]) than over the ocean (0.88°C [0.68°C-1.01°C]).*

The GCM modelling results including monthly average values for the meteorological parameters of interest (i.e., mean, maximum and minimum daily temperatures and total monthly precipitation) were downloaded for the period 1950 to 2100. Representative values for each parameter were determined from these downloaded files for the period 2003 to 2022 (representing the reference period), 2040 to 2059 (representing the 2050 climate) and 2070 to 2089 (representing the 2080 climate).

3.1.6.1.3.2 Air Temperature

This section describes the nature of the climate scenarios applied in the CCA in terms of air temperature as modelled by the GCMs. The first set of five figures illustrate the current and future potential mean daily air temperatures in annual and monthly terms for the Newtonbrook and Blue Ridge Creeks catchments. **Figure 3-35** represents the present day GCM modelled monthly means and annual mean air temperature. The three scenarios are almost identical for the calibration time period since the climate models have been run with equal historical emissions to this time. For the purposes of the CCA this curve represents the reference period. The annual average temperature of 9.23 C° shown in **Figure 3-35** is about 1 C° above the 1980-2010 normal reported for this station.

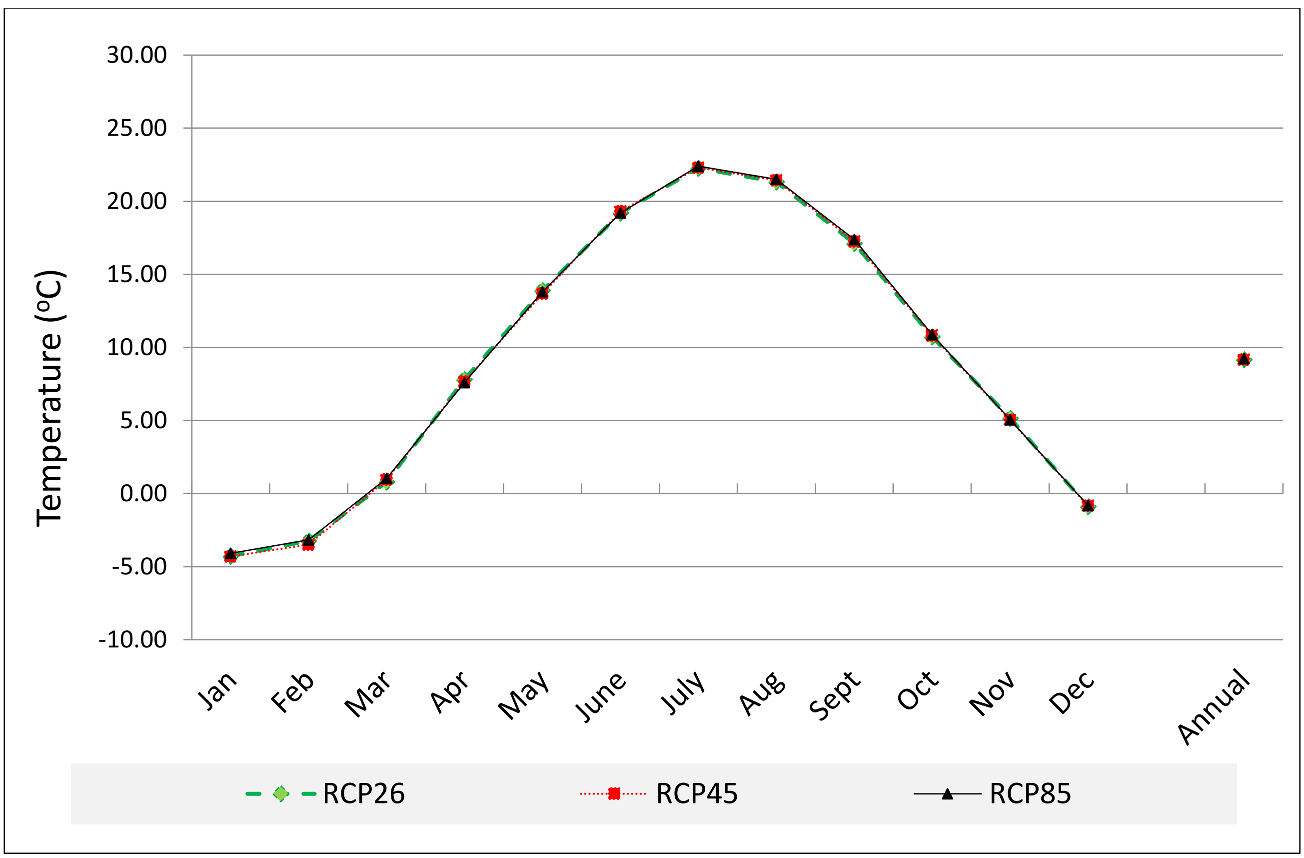

Figure 3-35: Hydrology Model Calibration Period (2011 to 2013) Average Monthly and Annual Temperatures

Figure 3-36 and **Figure 3-37** display the monthly and annual air temperature for all scenarios in 2050 and 2080 compared to the current condition, respectively. Clearly the three scenarios display higher temperatures in all months and both future time periods. Note that for RCP8.5, the average summer daily temperatures in July and August exceed 25° C by the 2080s, more than 4 C° higher than the present day.

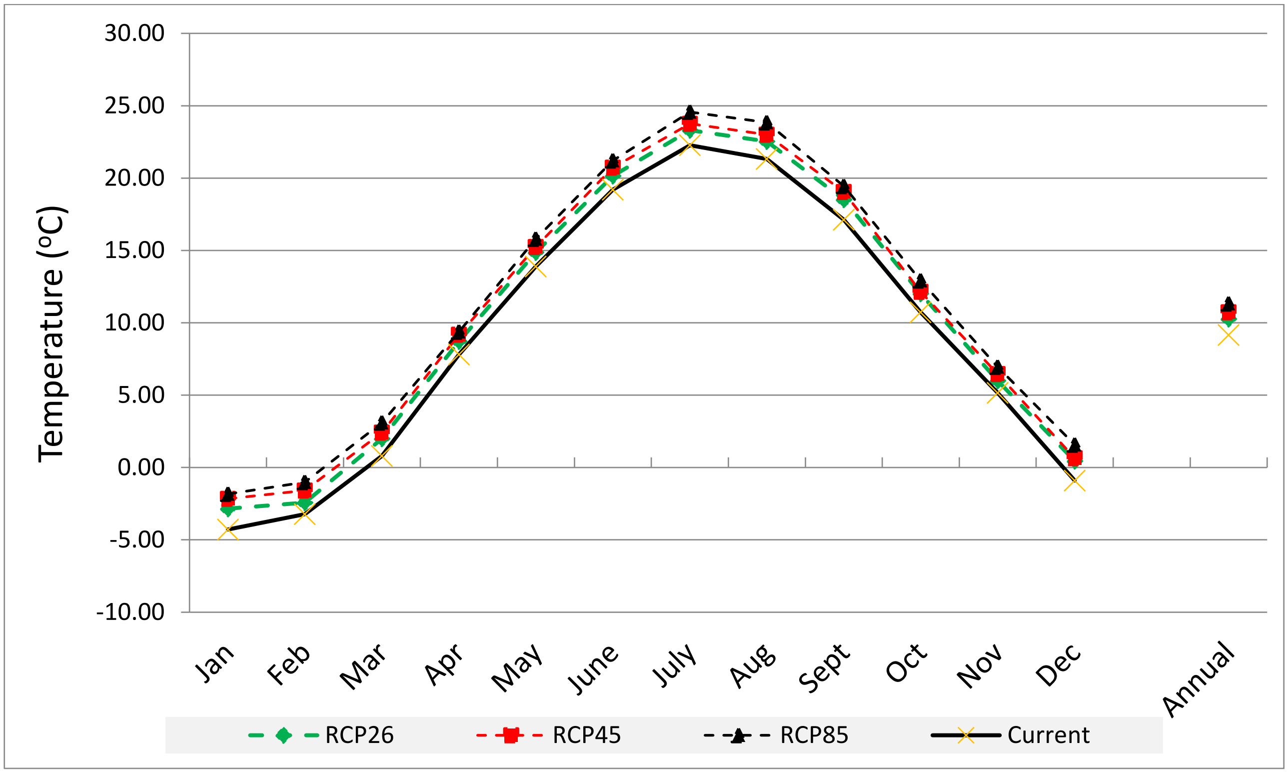

Figure 3-36: Annual and Monthly Average Temperatures for RCP2.6, RCP4.5 and RCP 8.5 in the 2050s Compared to Current Temperatures

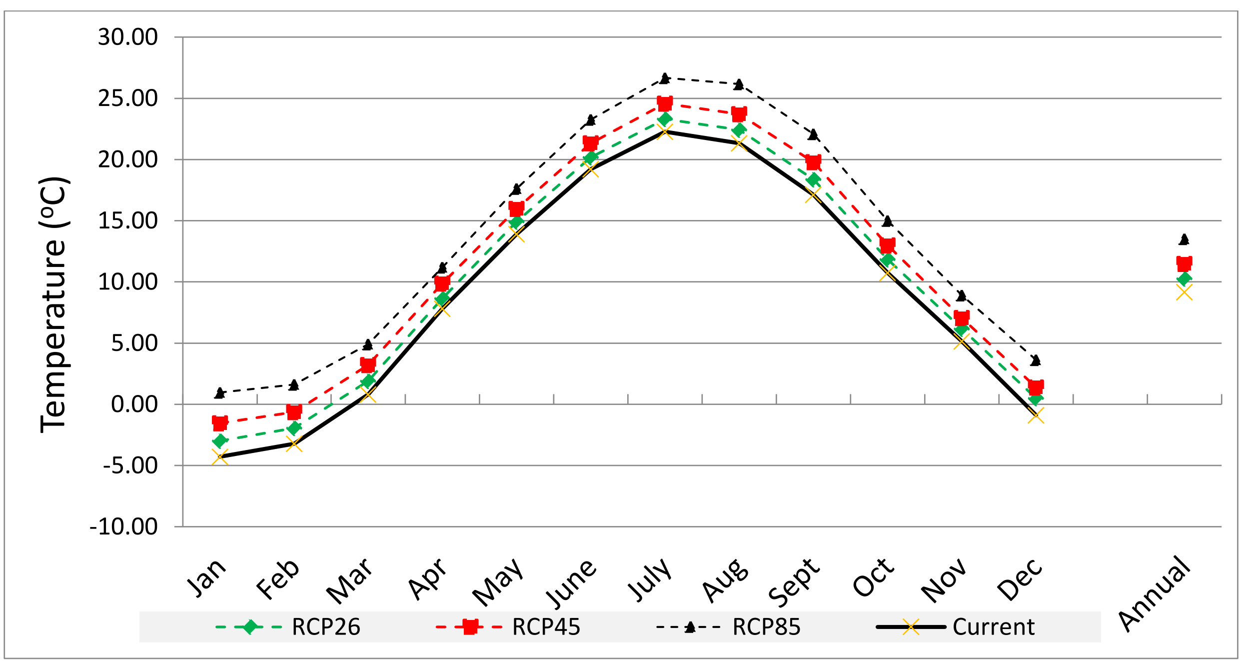

Figure 3-37: Annual and Monthly Average Temperatures for RCP2.6, RCP4.5 and RCP 8.5 in the 2080s Compared to Current Temperatures

Figure 3-38 and **Figure 3-39** represent the differences or, in this case, increases in temperature above present-day values for each scenario in 2050 and 2080, respectively. Annual temperature increases from the present day to the 2050s are 1.1 C° for RCP2.6, 1.6 C° for RCP4.5 and 2.1 C° for RCP8.5. So, the highest emission rate scenario is projected to cause an increase in air temperature that is about twice as large as the lowest emission scenario, over the next 30 years. By the 2080s the annual mean daily temperature increases for the three RCPs are 1.1, 2.3 and 4.3 C°. The RCP2.6 temperatures stabilize after 2050 with no further warming expected after this time.

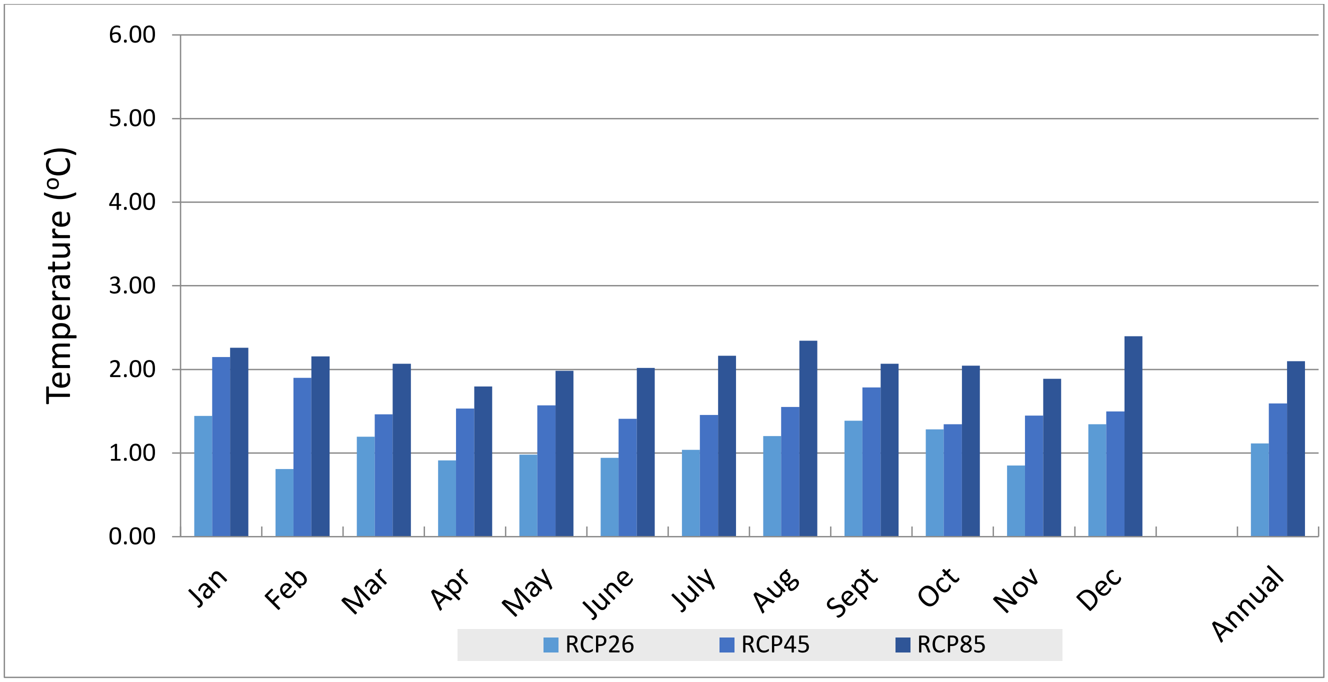

Figure 3-38: Annual and Monthly Average Temperature Increases for RCP2.6, RCP4.5 and RCP 8.5 from the Present to the 2050s

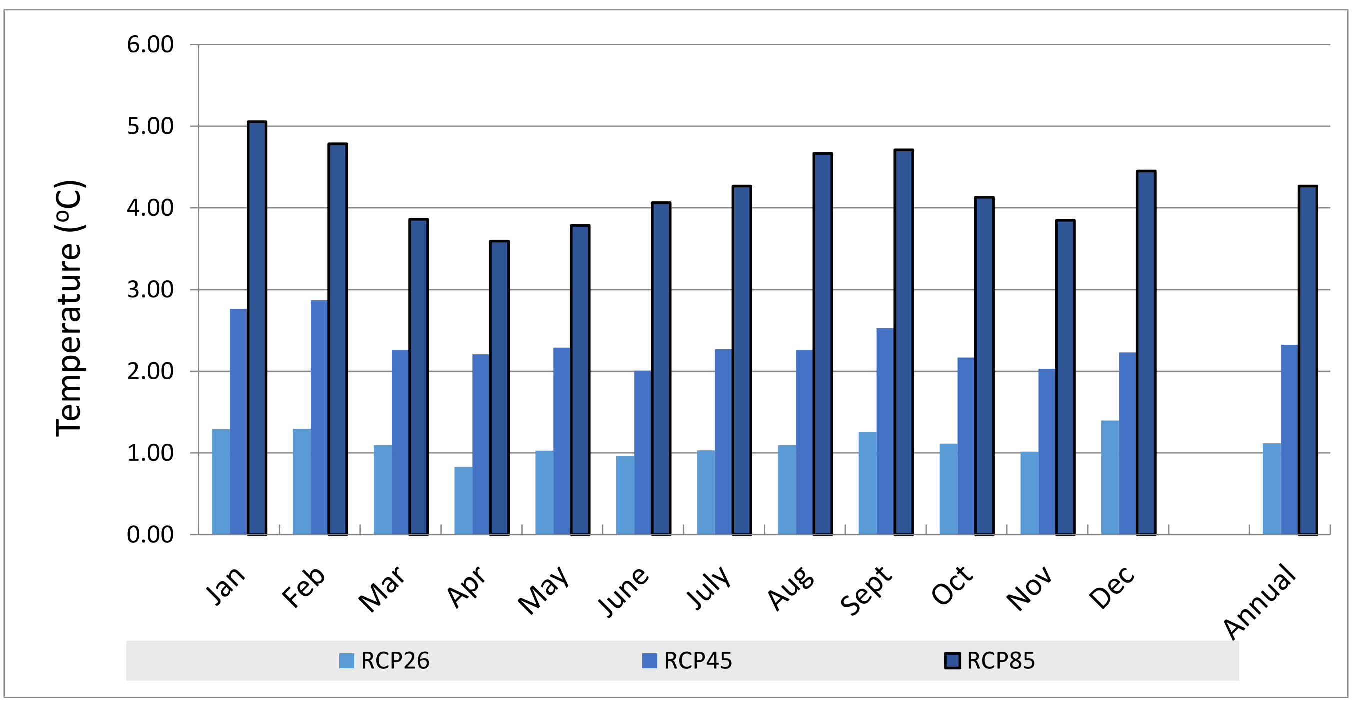

Figure 3-39: Annual and Monthly Average Temperature Increases for RCP2.6, RCP4.5 and RCP 8.5 from the Present to the 2080s

Regarding predictive confidence in GCM air temperature estimates; the increase of 4.3 C° for the worst case (RCP8.5) from the present to 2080 was compared to the prediction outcome from the GCMs that represented the 10th and 90th percentile of outcomes. Remember, the results used in this assessment were taken from the 50th percentile of outcomes. The 10th and 90th percentile results in this case were +4.0 and 4.7 C° or about +/- 0.3 to 0.4 C° (i.e., +/- 8%) compared with the 50th percentile. Similar relative ranges apply to the other scenarios, suggesting that, for temperature, there is good agreement across the large number of GCMs involved and thus, good confidence in future temperature estimation.

The rates of temperature increase observed are variable from month to month. In general, temperature increases are lowest in the spring (April to June) while the largest increases occur in the winter months (December to February). This trend is consistent for the three RCP scenarios.

Daily average minimum and maximum temperatures display the same general trends as mean temperature across the scenarios and time periods. The magnitude of the changes differs only slightly as shown in **Figure 3-40** to **Figure 3-43** for the 2050s and 2080s, respectively. On close inspection, there is a more pronounced difference between winter and summer minimum daily temperatures in both future time periods than for maximum temperatures. This trend is particularly apparent for the RCP8.5 scenario. In this case, the range of monthly minimum daily temperatures for the year is from 3.9 C° (June) to 5.6 C° (January) a difference of 1.7 C°, while maximum temperature increases in those months are 4.3 C° (June) and 4.4 C° (January) (i.e., 0.1 C° difference). This result suggests that warming is likely to be more pronounced in the winter than summer and at night more than during the daytime. Also, the typical thunderstorm season is likely to be extended into late spring and early autumn, increasing the risk of severe storms in those seasons.

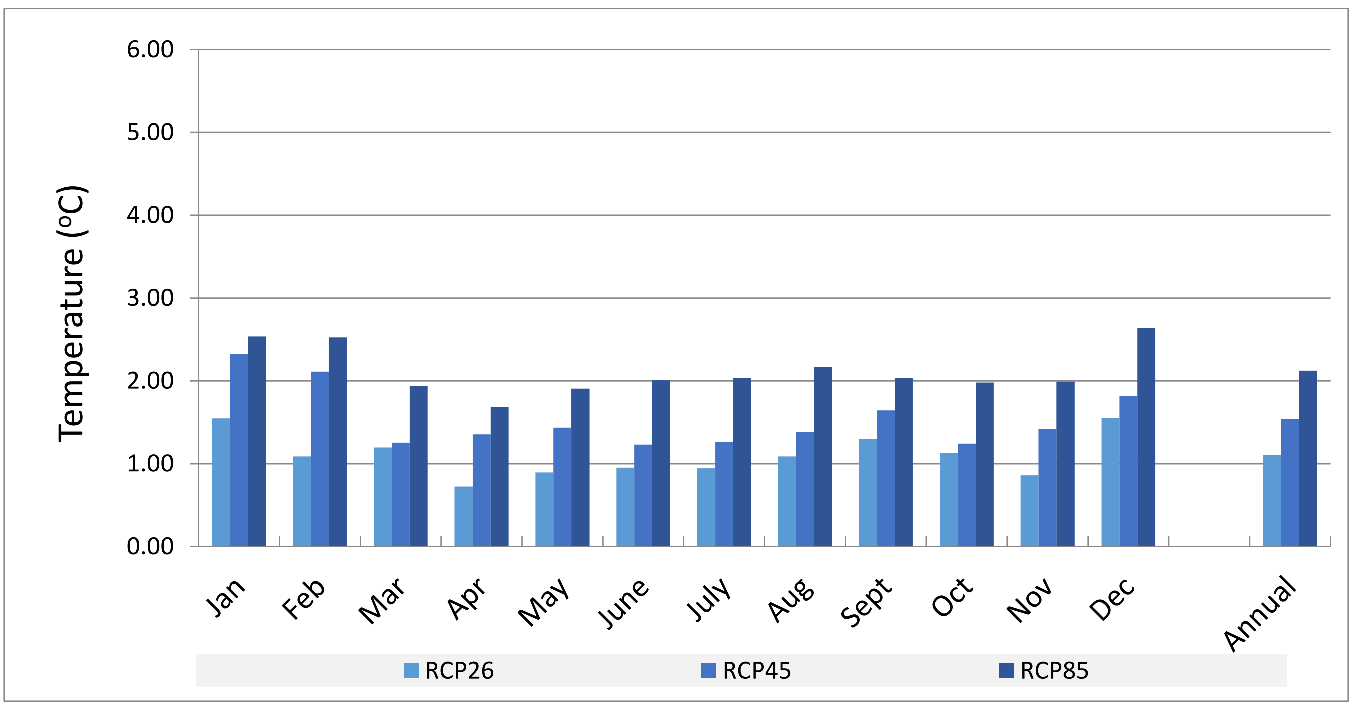

Figure 3-40: Annual and Monthly Average Minimum Daily Temperature Increases for RCP2.6, RCP4.5 and RCP 8.5 from the Present to the 2050s

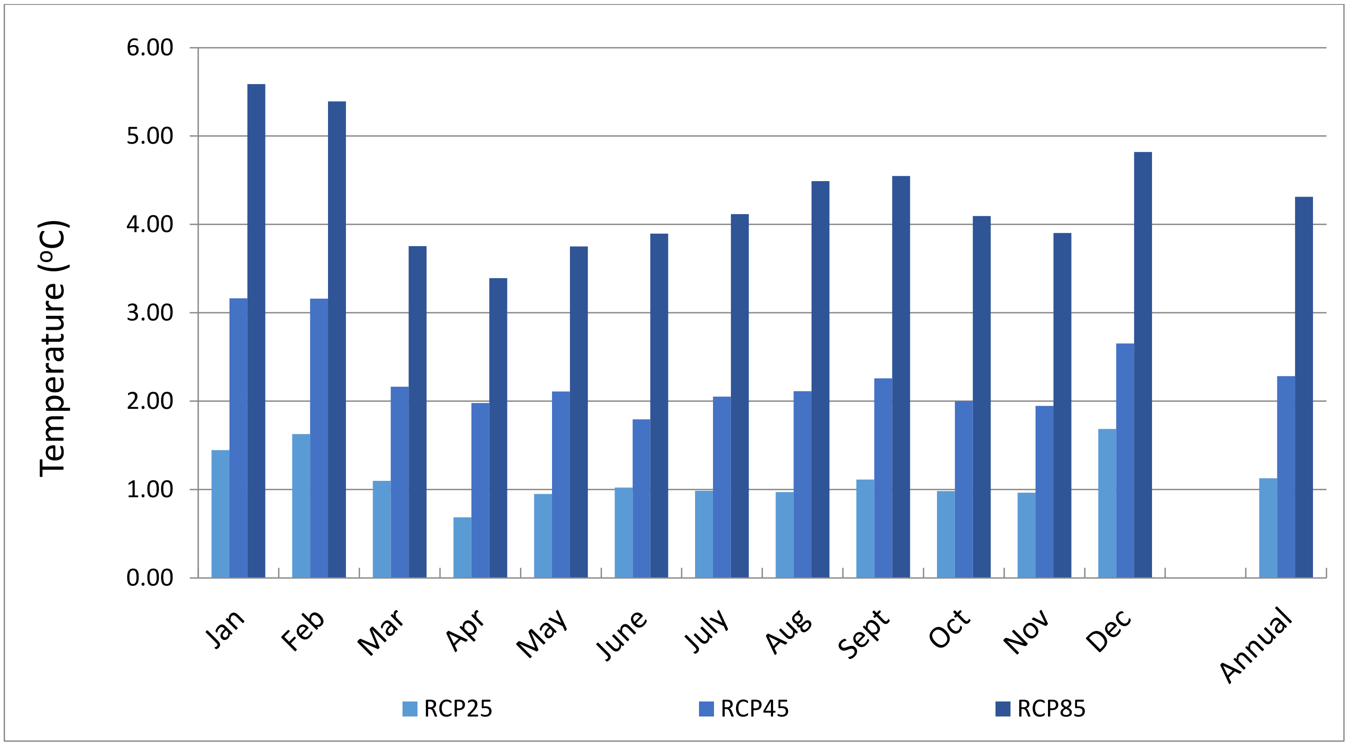

Figure 3-41: Annual and Monthly Average Minimum Daily Temperature Increases for RCP2.6, RCP4.5 and RCP 8.5 from the Present to the 2080s

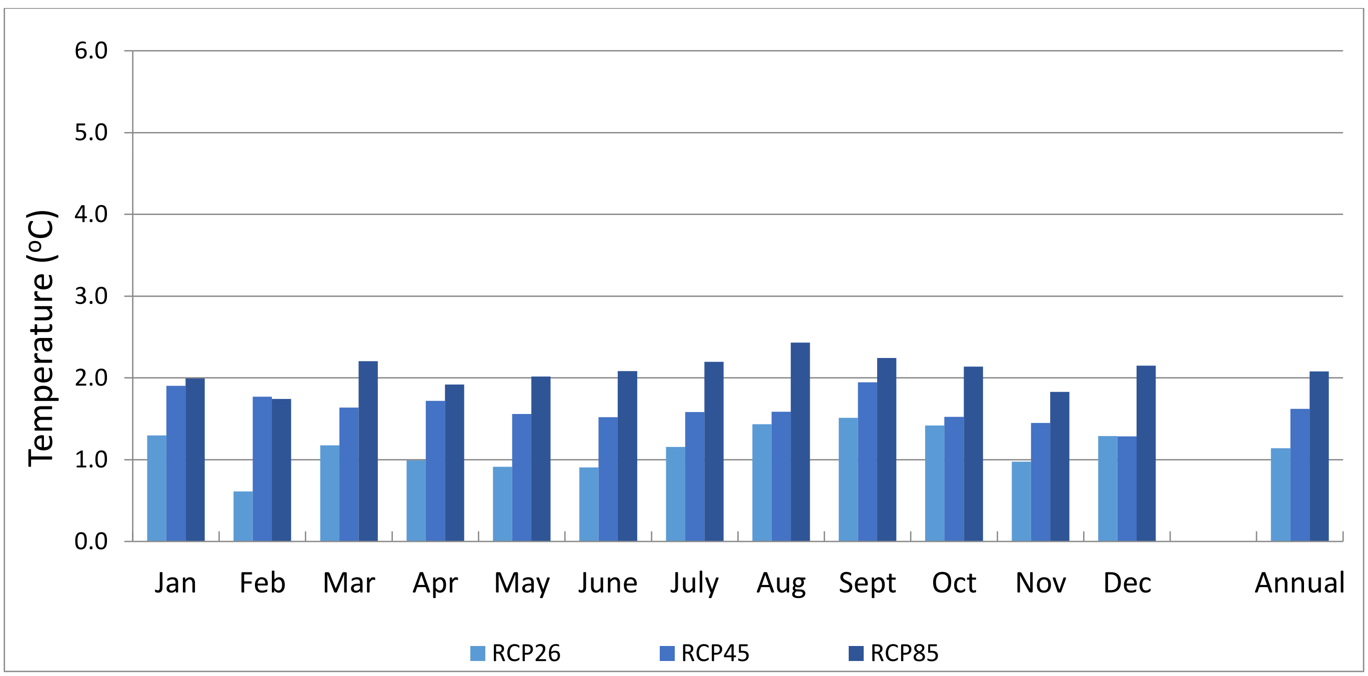

Figure 3-42: Annual and Monthly Average Maximum Daily Temperature Increases for RCP2.6, RCP4.5 and RCP 8.5 from the Present to the 2050s

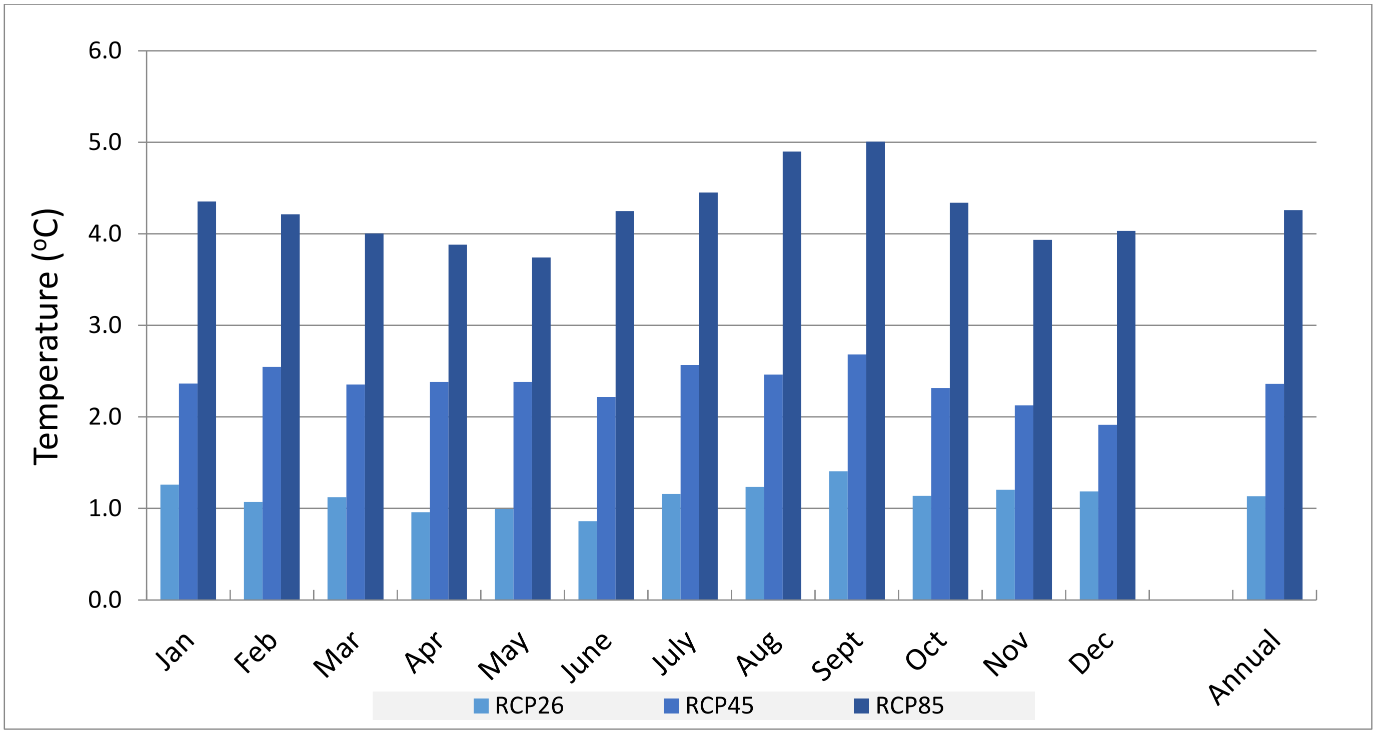

Figure 3-43: Annual and Monthly Average Maximum Daily Temperature Increases for RCP2.6, RCP4.5 and RCP 8.5 from the Present to the 2080s

3.1.6.1.3.3 Precipitation

This section describes the patterns in annual and monthly precipitation volume when comparing the modelled future climate change scenarios to present day. **Figure 3-44** displays the average monthly total precipitation volume simulated by the three RCPs for the 2003 to 2022 reference period. Typically, the study area does not experience pronounced wet and dry seasons and therefore monthly averages fall within a narrow range. As with temperature, these values are very similar since historical RCPs are input to the GCMs equally in the historical part of the simulation period.

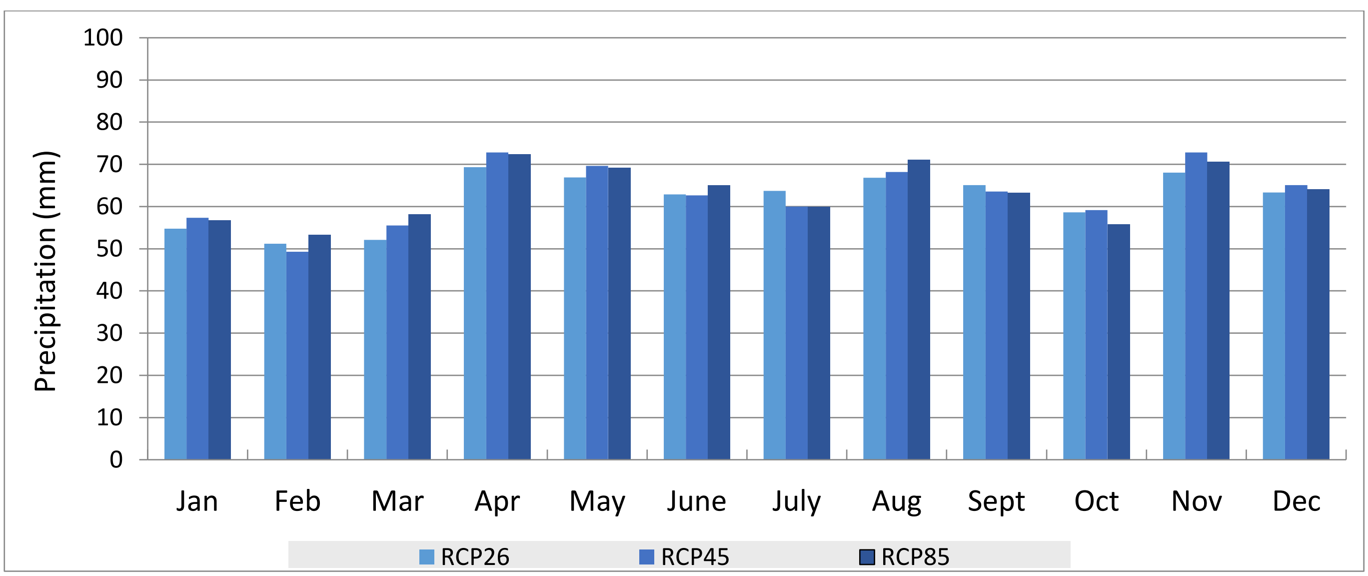

Figure 3-44: Monthly Average Precipitation Volumes in the 2003-2022 (Present Day) Reference Period

Figure 3-45 and **Figure 3-46** display the relative amounts of monthly precipitation for the RCPs in the 2050s and 2080s compared to the reference period. That is, the reference period precipitation lies on the 100% line in all months and the future monthly values rise above or fall below that line. Future projected precipitation is shown to follow an annual pattern with higher than present day precipitation through winter and early spring. Departures from the reference period range up to +16% (RCP2.6) for the 2050s and up to 21% (RCP8.5) for the 2080s. Conversely, summer (June to September) precipitation volumes are estimated to decrease by as much as 8.9% (RCP8.5) for the 2080s.

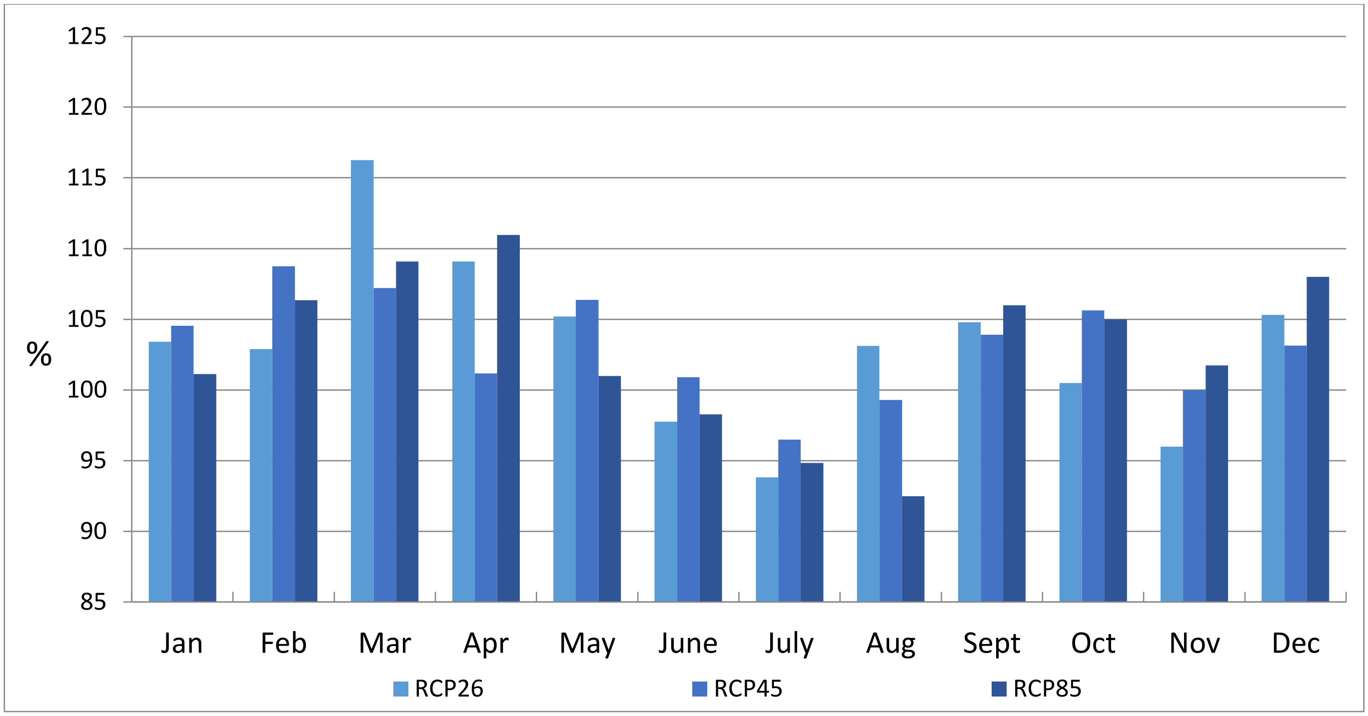

Figure 3-45: Monthly Average Precipitation Volumes in the 2050s Compared with the Present Day for RCP2.6, RCP4.5 and RCP 8.5

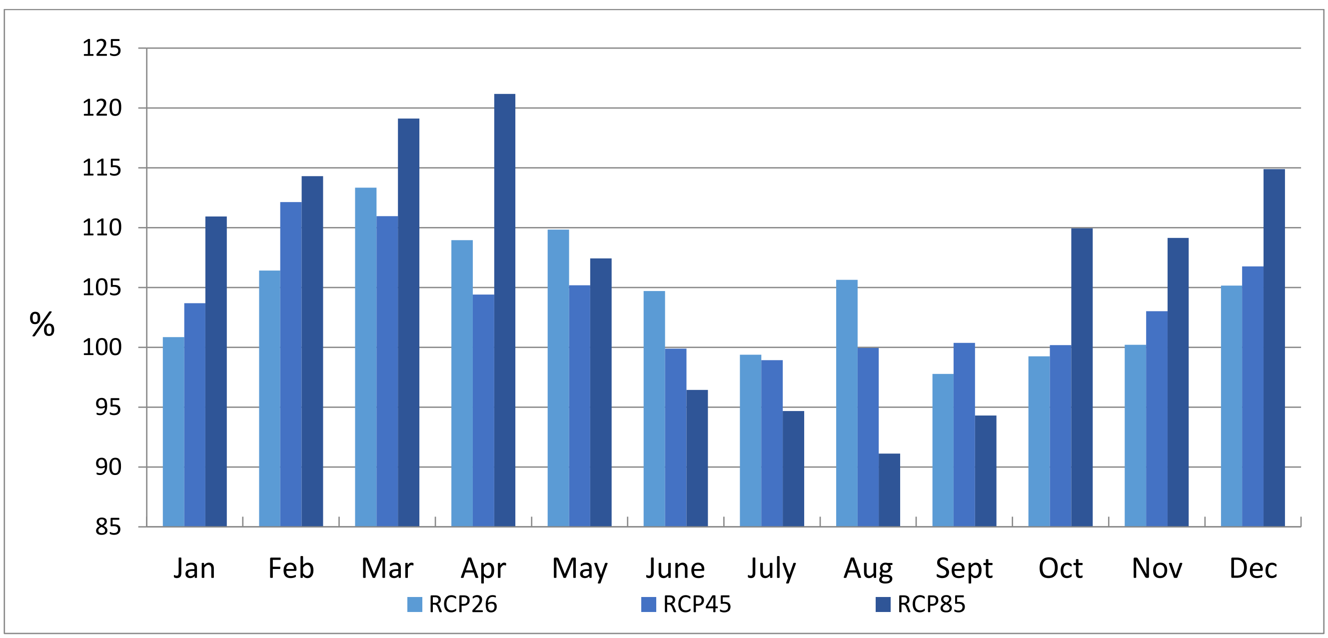

Figure 3-46: Monthly Average Precipitation Volumes in the 2080s Compared with the Present Day for RCP2.6, RCP4.5 and RCP 8.5