Figure 3-47 shows the annual total precipitation for all scenarios and timeframes. All three RCPs are expected to result in an annual precipitation increase of about 3% by the 2050s. Increased precipitation is also estimated through to the 2080s. The relative increases range from about +4% for the RCP4.5 scenario and up to +7% for the RCP8.5 scenario. The corresponding 10th and 90th percentile GCM values for precipitation range about +/- 6% around the 7% value. This represents relatively good agreement among GCMs, although less confidence is associated with these models for precipitation than for air temperature estimates.

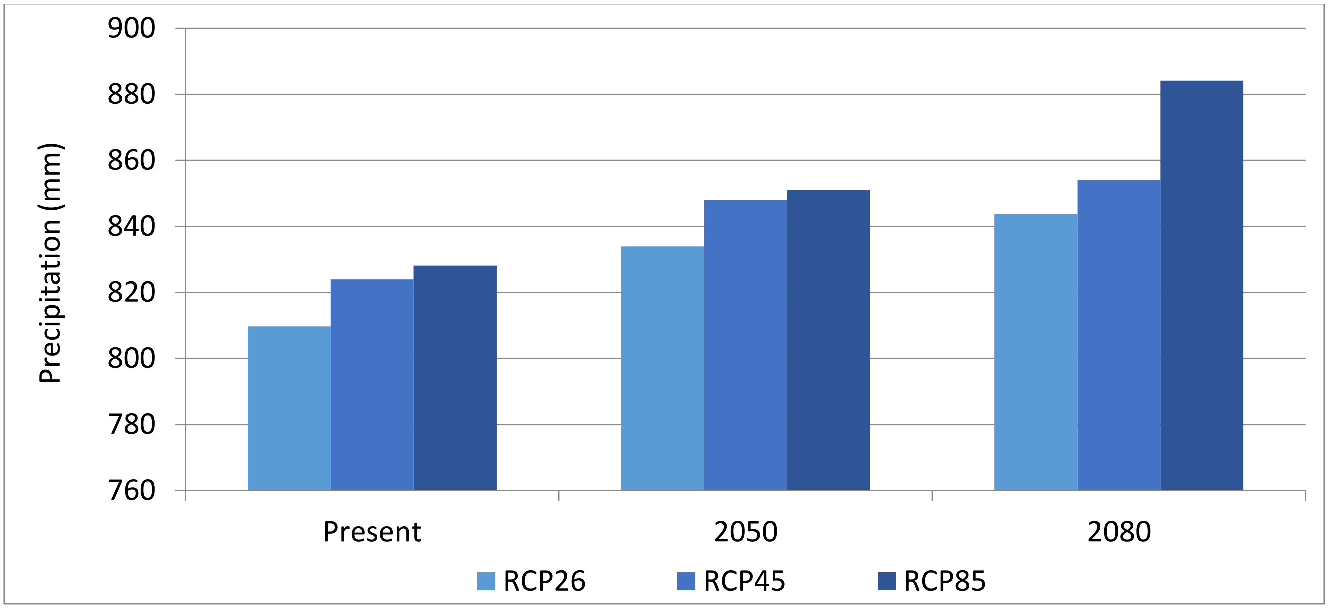

Figure 3-47: Annual Total Precipitation Volumes in the 2050s and 2080s Compared with the Present-Day Reference Period (2003-2022) for RCP2.6, RCP4.5 and RCP 8.5

The general patterns of precipitation estimated for the future are largely explained by anticipated changes in atmospheric water holding capacity, evaporation and energy increases. The general trend to higher precipitation during colder months can be credited to the relatively higher air temperatures and associated higher atmospheric water holding capacity anticipated in the future. Water holding capacity is directly related to air temperature. During the warmer months the increased future temperatures will also result in higher potential for the atmosphere to hold water, although less so than in winter.

The role of evaporation in the water balance is complex. From a meteorological perspective, warmer air in the future would provide the added energy to support higher rates of evaporation. However, the actual rates of evaporation depend upon the availability of surface water (i.e., ponds, wet lands, lakes and reservoirs). In the Great Lakes region, the presence or absence of ice cover on the large lakes is an important factor in determining the water available for evaporation and later precipitation in winter. Ice cover is expected to decrease significantly in a warming future contributing to higher winter precipitation.

From a water balance perspective, higher future evapotranspiration would directly remove water from the watershed soils and surface storage resulting in reduced baseflow.

Figure 3-48 displays the potential impact of future warming on potential evapotranspiration (PEVT) for the RCPs and time periods examined. This figure shows that warming future air temperatures can result in increased evaporation potential allowing for higher precipitation as well as higher evaporation leading to lower levels of standing surface waters. PEVT is estimated to increase up to 20%, in the worst-case scenario (RCP8.5), due to air temperature increases. This change has the potential to significantly affect the typical annual water balance in the study area.

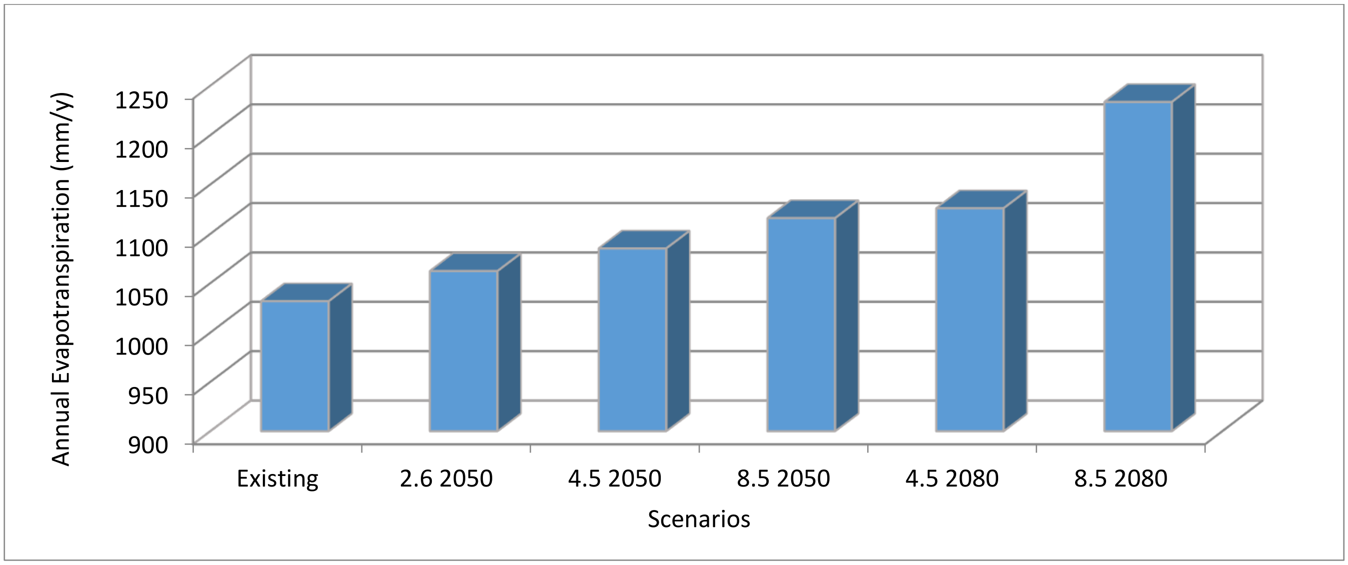

Figure 3-48: Six Year Average Annual Potential Evapotranspiration Calculated for Each Scenario

3.1.6.1.4 Hydrologic Impacts

3.1.6.1.4.1 Hydrologic Model Setup

As mentioned above, the hydrological model HSPF was applied to the TWWFMMP using land use and meteorological data from the mid-1990s. The model was calibrated against non-winter conditions. This model has been updated with land use and meteorological data from the period 2011 to 2016. Therefore, this model is considered relevant for the present day. Baseline climate, in this assessment has been taken as the model calibration and validation periods. In order to characterize present day climate, the average monthly air temperature and precipitation have been determined for the period 2003 to 2022. Twenty years is used for this determination to reduce the effect of outlying data on the results.

3.1.6.1.4.2 Hydrology of Newtonbrook and Blue Ridge Creeks

The study area creeks display hydrologic characteristics typical of creeks draining highly urbanized and a temperate climate. Creek streamflow responds quickly to precipitation as much of the watershed surfaces are impervious, covering roadways, roofs, parking areas and sidewalks. A relatively small portion of precipitation falls on pervious surfaces, infiltrates and takes the much slower groundwater and interflow pathways to the stream channel and Lake Ontario. Since flashy runoff has little time to evaporate or be taken up by plants, the importance of ET in the annual water balance of the watershed is modest. Baseflow contributions to overall water balance are also relatively small. These characteristics exist upstream of the City of Toronto portion of the watershed as well as within the City portion.

The regional climate in the study area is typical of the Great Lakes temperate zone with warm to hot summers and cold winters. Therefore, some winter precipitation is temporarily stored in the snowpack until melting occurs. Precipitation is relatively evenly distributed over the whole year, with no pronounced rainy or dry seasons. Annual precipitation totals range from about 700 mm to over 1000 mm., see **Figure 3-47**. Warm weather precipitation often comes in the form of thunderstorms with potentially high rates of rainfall over short periods of time. These events are conducive to flashy runoff. Winter runoff is due to snowmelt events and typically less intense rainfall events, resulting in less flashy runoff and more sustained baseflow conditions. A diurnal streamflow cycle can often be observed in streams during warmer winter days as streamflows at night are reduced due to local freezing and increased during the day due to some local thawing.

3.1.6.1.4.3 Anticipated Impacts

After reviewing the characteristics of the climate scenarios selected for this assessment, and with consideration of the hydrological nature of the Newtonbrook and Blue Ridge catchments, it is reasonable to expect certain results from the assessment modelling. During the **colder months** the anticipated effects of climate change should be as follows:

- Air temperature increases should be larger in winter than in summer. Therefore, change related impacts should be more significant in winter than in summer.
- Nighttime air temperature increases should be larger than daytime increases. Therefore, nighttime change related impacts should be larger at night than during the daytime.
- More precipitation should occur as rainfall and thus, the snowpack should be diminished or eliminated as a source of runoff.
- The typical spring freshet should either not occur or be reduced in volume.
- There should be a trend to more winter runoff due to the higher temperatures in winter (i.e., less snowpack) and also because winter precipitation is expected to significantly increase beyond present day totals.
- ET should increase in winter but remain a minor factor in the Creeks water balance.

During the **warmer months** the anticipated impacts are the following:

- Less precipitation in the months of June, July and August should result in worsening likelihood of droughts and less streamflow in this period while precipitation and streamflow in other warmer months (i.e., May, October) should be less obvious.
- Warmer air temperatures should increase storm intensity when surface water is available.
- Higher ET in the warmer months should further aggravate lower baseflow rates.

Trends regarding the impacts of storms cannot be inferred from these results. These are addressed in Part 2 of the CCA.

While various types of droughts are defined according to physical and social factors and consequences, the hydrological drought is of interest in this study. The hydrological drought is characterized by low moisture (i.e., precipitation and snowmelt) propagating to low surface and subsurface waters. This condition is particularly evident at times of very low flow when streambed surfaces lie exposed.

Western Canada is well known for devastating historical droughts and much climate research has concentrated in that region (Mortsch, Cohen and Koshida 2015). However, droughts do occur in Southern Ontario albeit generally they are less severe and localized in extent (Mitsch and Reeder, 1992).

In a study of how drought has changed in recent years (1950 to 2016) across Canada (Yang *et al*., 2020), it was observed that there has been a wetting trend across most of the country while drought frequency and severity have declined in most areas of Southern Canada. Drought duration has increased since 2005 in Southern Canada. The authors of this study noted that the high levels of drought in the 1950s accounts for many declining trends across Canada following that period. In the future, drought characteristics are likely to be strongly influenced by warming temperatures driving evapotranspiration. Intuition would suggest that drought across Canada would be more problematic in a warmer future.

Droughts have been shown to be influenced by global ocean-atmosphere circulation systems in that these influence regional climate variability. The complexity of that system and the codependence of hydrological drought on moisture and temperature greatly complicates the prediction of trends in future drought onset, duration and severity. Nevertheless, climate modelling of future RCP emission scenarios has informed researchers on the likely trends.

Global scale investigations modelled as part of the CMIP5 (Coupled Model Intercomparison Project, Phase 5) program have shown that climate warming is likely to cause widespread increases in severe drought frequency, including in Ontario (Tam *et al*., 2019). This Canada -wide study used CMIP5 results for 29 GCMs and the same three RCPs as used in this study (i.e., RCP2.6, RCP4.5 and RCP8.5). It was noted that increases are modest for the lowest forcing function and that in all cases the increases in drought are much more pronounced in the latter half of the century.

Zhao *et al.* (2020) examined the likelihood of changes in the frequency (i.e., return period) of extreme summer droughts over North America. Their study involved two future climate model ensembles and the RCP8.5 forcing function with future time periods through to the end of this century. Their results indicate a worsening in drought conditions over time in Southern Ontario. While both model ensembles predicted increases in drought frequency one ensemble predicted very large increases in drought frequency.

Byun *et al*. (2019) studied the impacts of warming climate on seasonal hydrologic regimes in the Great Lakes region and extremes over the Midwestern and Great Lakes regions of the US. Using downscaled GCM data, RCPs of 4.5 and 8.5 and looking at the 2050 and 2080 time frames it was found that very low flows, as indicated by the 7Q10, are likely to increase by 0 to 2%. The authors mentioned that the changes in the 7Q10 are widely disparate across all GCMs used. This result is inconclusive and suggests that the rate of change and direction of change in the frequency and severity of future droughts are uncertain.

While quantification of the anticipated increases in drought conditions for local areas is not possible from these studies, the general trends towards worsening are consistent across large areas of Southern Canada. Scenarios that involve higher radiative forcing (i.e., RCP8.5) result in the worst future drought conditions among the range of rates examined. Regardless of changes in precipitation anticipated in the future, the warming temperatures leading to higher potential evapotranspiration are sufficient to greatly increase surface drying and drought frequency and severity.

3.1.6.1.4.4 Observed Hydrologic Impacts

This section summarizes the hydrologic impacts noted when comparing the runoff time series for the present day with those for the three future RCP scenarios and two timeframes. **Table 3-19** to **Table 3-21** lists the 5-year total simulated streamflow volumes by month, season and six-year period total. The extremes (i.e., minimum and maximum instantaneous streamflow rates) are also included. It should be noted that the July 2013 storm was excluded due to interrupted monitoring.

Table 3-19: Six Year (2011-2016) Monthly Total Streamflow Volumes (Mm^3) in the Study Area and Extreme Rates for the Existing Climate, 3 RCP Scenarios and 2 Timeframes (2050 and 2080)

	Existing Climate	2050			2080	
Month	**(2011-2016)**	**RCP 2.6**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
January	1.20	1.22	1.24	1.20	1.22	1.32
February	1.21	1.24	1.31	1.29	1.32	1.37
March	1.17	1.29	1.22	1.22	1.26	1.36
April	1.43	1.58	1.44	1.56	1.47	1.70
May	1.29	1.39	1.36	1.33	1.35	1.42
June	1.33	1.34	1.35	1.31	1.32	1.29
Jully	1.51	1.42	1.45	1.41	1.47	1.39
August	0.87	0.88	0.85	0.79	0.85	0.77
September	1.11	1.16	1.14	1.14	1.09	0.99
October	1.23	1.23	1.29	1.27	1.20	1.26
November	1.06	1.02	1.07	1.06	1.04	1.08
December	1.14	1.24	1.27	1.31	1.30	1.32

Table 3-20: Six Year Seasonal Total Streamflow Volumes (Mm^3) in the Study Area and Extreme Rates for the Existing Climate, 3 RCP Scenarios and 2 Timeframes (2050 and 2080)

	Existing Climate	2050			2080	
Month	**(2011-2016)**	**RCP 2.6**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Winter(D-F), Mm3	3.34	3.70	3.81	3.81	3.84	4.01
Spring(M-M), Mm3	3.90	4.25	4.01	4.11	4.08	4.48
Summer(J-A), Mm3	3.64	3.57	3.58	3.44	3.58	3.38
Autumn(S-N), Mm3	3.40	3.42	3.49	3.47	3.33	3.33

Table 3-21: Six Year Annual Total Streamflow Volumes (Mm^3) in the Study Area and Extreme Rates for the Existing Climate, 3 RCP Scenarios and 2 Timeframes (2050 and 2080)

	Existing Climate	2050			2080	
Month	**(2011-2016)**	**RCP 2.6**	**RCP 4.5**	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Annual Average,	2.41	2.48	2.47	2.46	2.46	2.52
6-year Total, Mm3	14.47	14.89	14.85	14.77	14.76	15.10
2011-2016:						
Maximum, m3/s	7.35	6.61	6.89	6.67	7.14	6.61
Average, m3/s	0.076	0.079	0.078	0.078	0.078	0.080
Minimum, m3/s	0.0066	0.0067	0.0065	0.0060	0.0064	0.0059

Table 3-22 indicates that Newtonbrook and Blue Ridge Creeks contribute about 71.5% and 28.5%, respectively, to the whole study area runoff.

Table 3-22: Six Year (2011-2016) and Annual Total Streamflow Summary for the Whole Study Area and the Two Contributing Creeks

	Newtonbrook Creek	Blue Ridge Creek	Study Area
Annual Average, Mm^3	1.726	0.544	2.412
Six Year Total, Mm^3	10.35	3.262	14.5
Maximum, m^3/s	5.4	2.1	7.4
Average, m^3/s	0.055	0.017	0.076
Minimum, m^3/s	0.005	0.001	0.007

Figure 3-49 to **Figure 3-51** illustrate **Table 3-19** results in annual, monthly and seasonal timeframes. The vertical scale used in **Figure 3-49** exaggerates the difference between scenarios for interpretive purposes. However, relative differences among the three climate scenarios and two timeframes and the existing case are minor at about 2.9%, 2.6%, 2.1%, 2.0% and 4.4%, respectively. Precipitation changes for these scenarios amounted to increases of 3.0%, 4.7%, 2.7%, 5.4% and 9.2%, respectively, slightly higher but similar to the observed increases in flow.

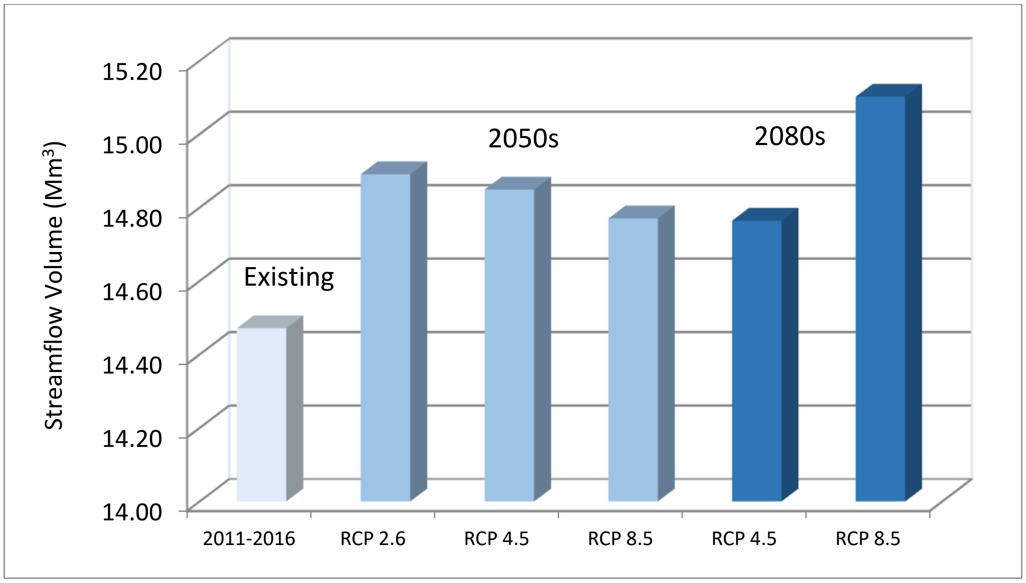

Figure 3-49: Six Year Total Study Area Streamflow Volume, 3 GHG Scenarios and 2 Timeframes

Rising ET in future climates tends to offset the effect of increased precipitation. Reviewing monthly and seasonal patterns helps to understand the effects on these water balance components. **Figure 3-50** shows the trend for future streamflow to be higher in all scenarios in December through May, and lower in June to August. Higher streamflows are particularly obvious during the traditional freshet period in March while August displays trends to lower streamflows. March will experience more precipitation and just slightly more evapotranspiration in the future. Streamflow in August will be reduced due to lower precipitation and higher potential evapotranspiration.

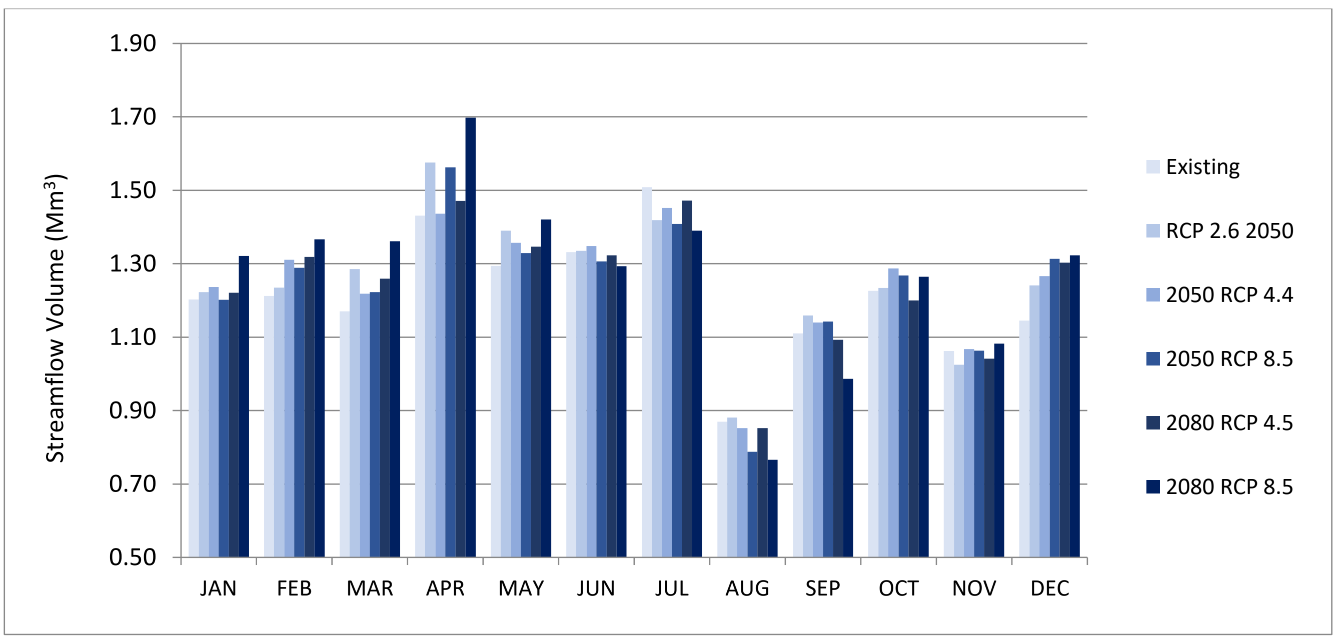

Figure 3-50: Six Year Streamflow Volume by Month, 3 GHG Scenarios and 2 Timeframes

Figure 3-51 confirms these seasonal trends. Winter streamflow is shown to rise into the future in all scenarios while summer streamflow decreases modestly.

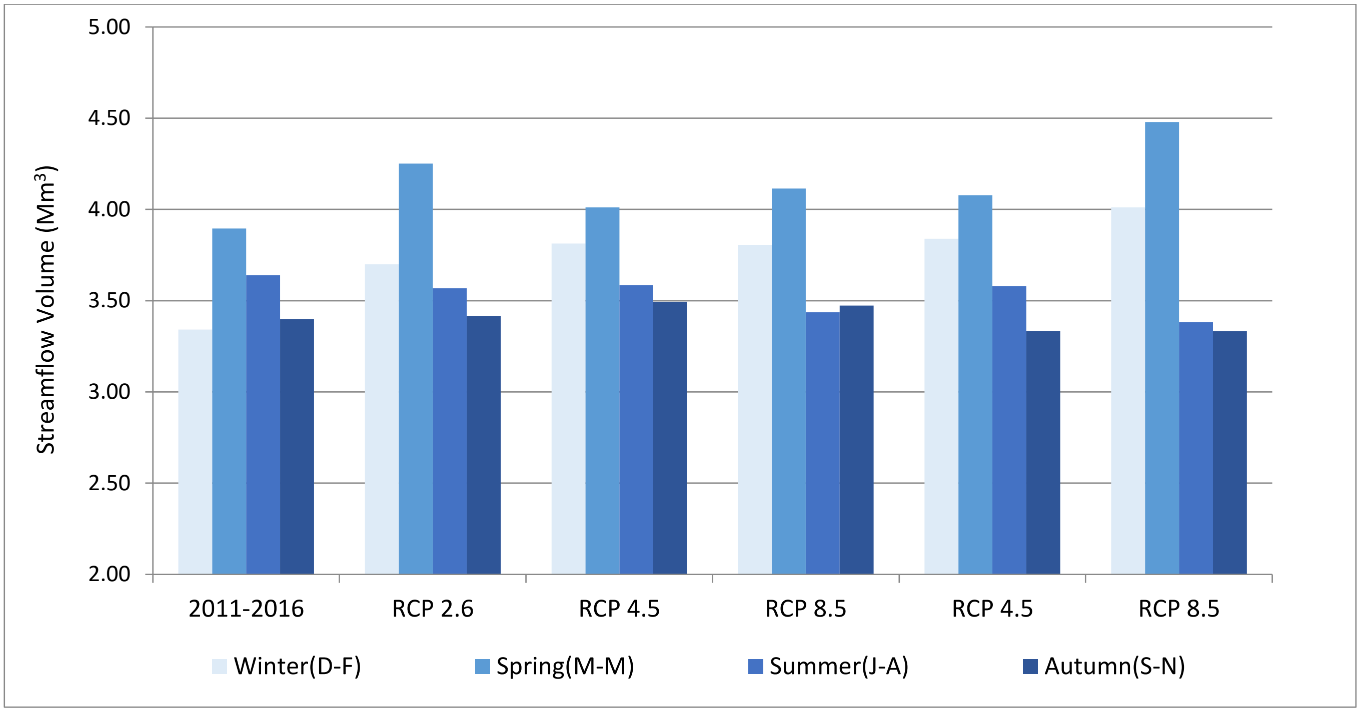

Figure 3-51: Six Year Streamflow Volume by Season, 3 Climate Scenarios and 2 Timeframes

Figure 3-52 displays the streamflow frequency distribution for the 6-year period of simulations (i.e., 2011-2016) and six scenarios. Frequency distributions display the full spectrum of streamflows experienced in a watercourse over time and the tendencies and risks associated with extreme flow rates. In this case, the stream displays a wide range of streamflow rates spanning three orders of magnitude. The left side of the plot displays the low flow portion and the right side, the peak flow portion of the curve. Well over 90% of the time the flows are within a relatively narrow range from about 50 m^3/h to about 500 m^3/h. This distribution informs the risk assessment in identifying the probabilities and magnitudes associated with local storm events and droughts. Droughts are characterized by stream flows as low as 20 to 30 m^3/h or less than 10 l/s. Storms may result in peak runoff exceeding 10000 m^3/h. As indicated in **Table 3-19** streamflow peak runoff rates for the study baseline climate period (2011 to 2016) exceeded 6 m^3/s. Note that this plot has a logarithmic scale for the streamflow to highlight the lower flow region of the curve.

Figure 3-52 does not provide a clear picture of differences across scenarios in terms of flow frequencies. However small changes in the extreme ends of the curve can be highly impactful. High flow impacts of climate change are not well represented by this part of the assessment and are discussed in the next section.

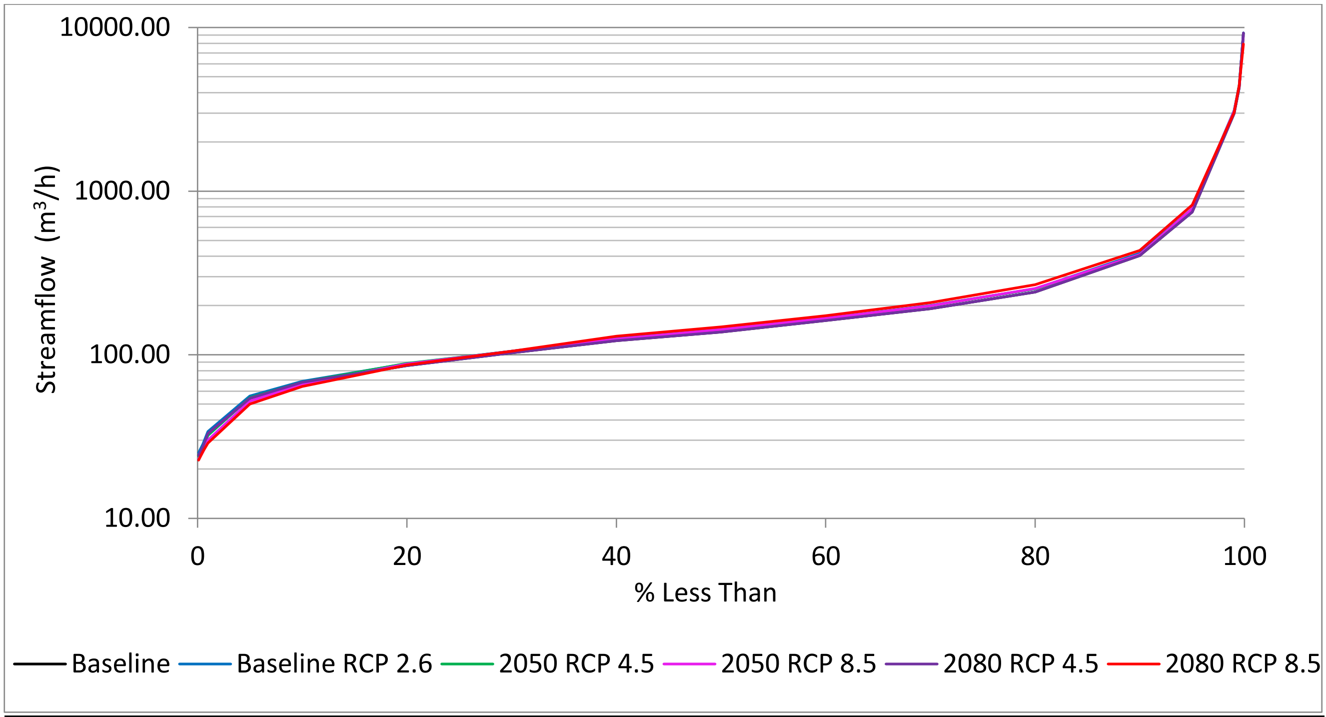

Figure 3-52: Six Year Streamflow Frequency Distribution, 3 Climate Scenarios and 2 Timeframes

Figure 3-53 is a blowup of the leftmost portion of **Figure 3-52**, which shows the probabilities associated with the lowest hourly flow rates over the six-year simulation period. This representation can be used as a simple indicator of drought risk and a means of comparing climate scenarios in this regard. For example, under the Existing Climate a very low flow rate of 30 m^3/h or less flow occurred about 0.7% of the time. With the worst-case scenarios, RCP 8.5 in both 2050 and 2080, the same low flow or less flow occurred up to 1.3% of the time. Thus, a worsening of drought conditions with climate warming could be inferred.

Alternately, the RCP 2.6 scenario shows a small reduction in the occurrence of very low flows in this analysis. The RCP 4.5 scenario curves are both very close to the Existing climate curve.

These trends, at the very low flow end of the local hydrograph, indicate a trend to worsening future drought conditions under the RCP 8.5 scenarios. This trend is in line with the likelihood of higher ET and reduced precipitation in summer months with climate warming. Both changes increase low flow stress on a seasonal basis in the study area.

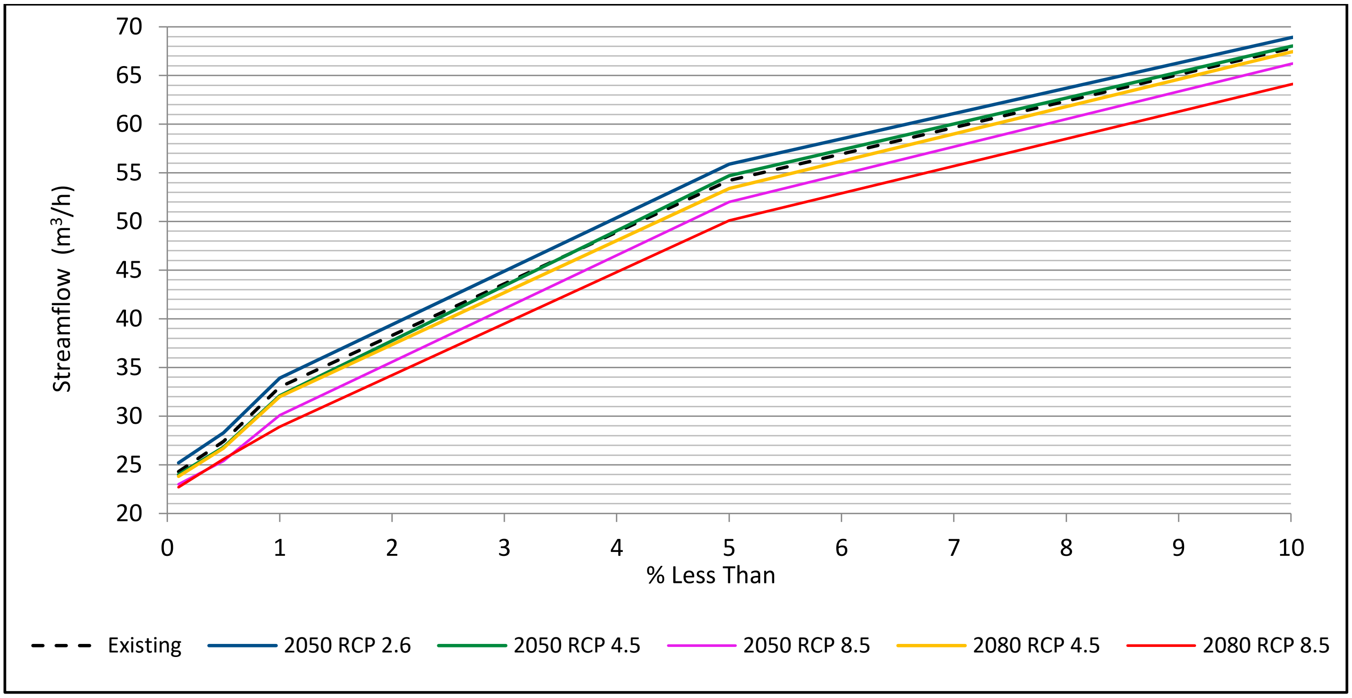

Figure 3-53: Six Year Streamflow Low Flow Frequency Distribution, 3 Climate Scenarios and 2 Timeframes

While drought conditions are most likely to occur in summer due to the high potential evapotranspiration rates, the frequency of occurrence of drought in colder months is likely to increase as well. Winter ET is usually assumed to be very low. However, in the future, warmer temperatures will increase winter ET and contribute to low streamflow.

Snowpack development and the amount of moisture stored in the watershed in a frozen state is significantly affected by climate warming. The existing condition climate results in a significant amount of water stored as snow and ice through this period. The snowpack is continually modified by snowfall and snowmelt events until the end of March. The future climates will result in less winter snowpack and more short-lived snowpack conditions.

Figure 3-54 and **Figure 3-55** display March (2014 and 2015) time series of study area runoff under Existing climate conditions and five warming scenarios.

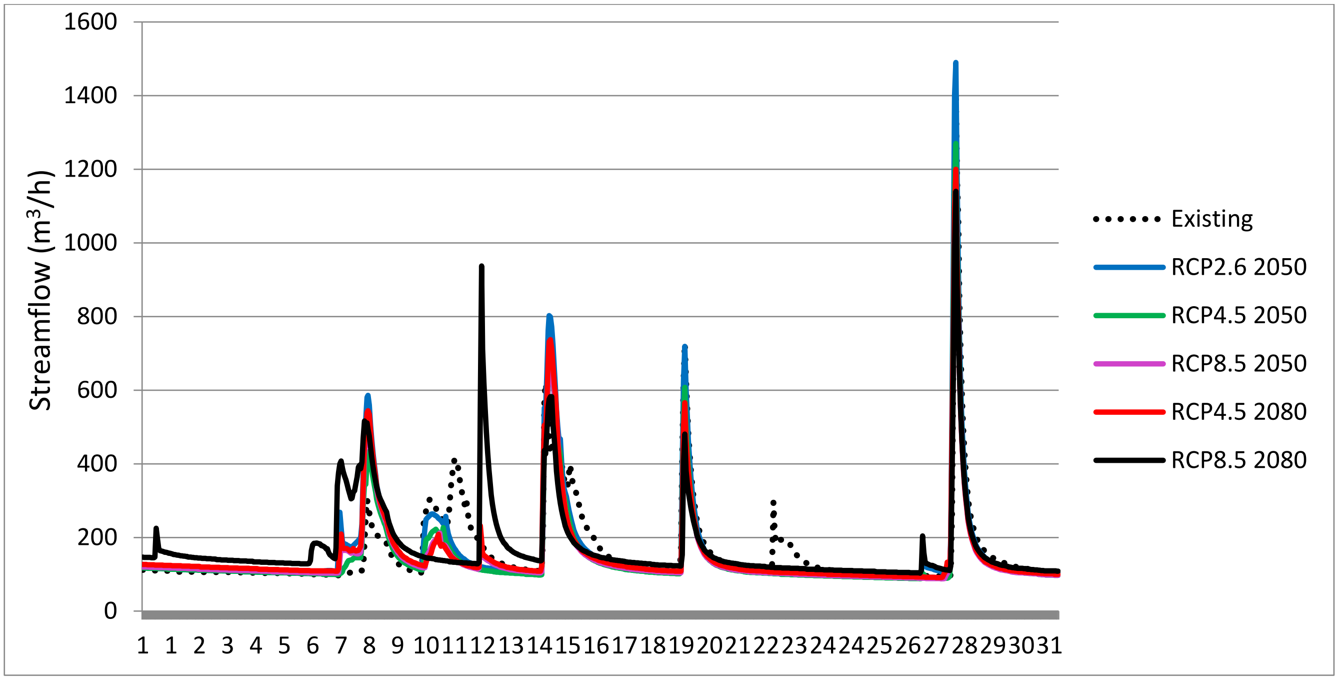

Figure 3-54: Simulated Streamflow in the Study Area in March of 2014 with Existing and Five Future Climates

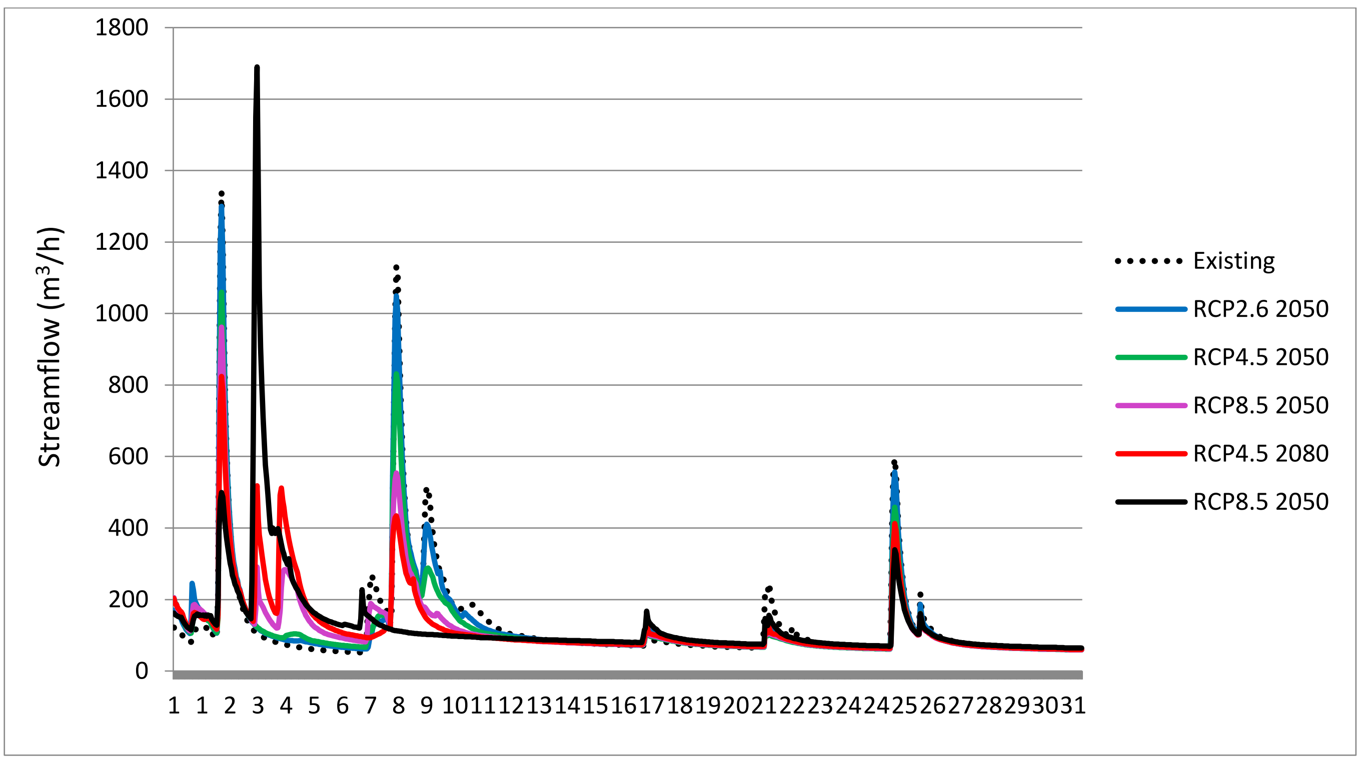

Figure 3-55: Simulated Streamflow in the Study Area in March of 2015 with Existing and Five Future Climates

Figure 3-56 is **Figure 3-55** in a logarithmic scale, as a way of highlighting the low flow range. These springtime conditions are periods of snow and ice occurrence and transformation. Runoff is highly sensitive to precipitation events and temperature, from scenario to scenario. Both peak flows and base flows are affected by the climate factor.

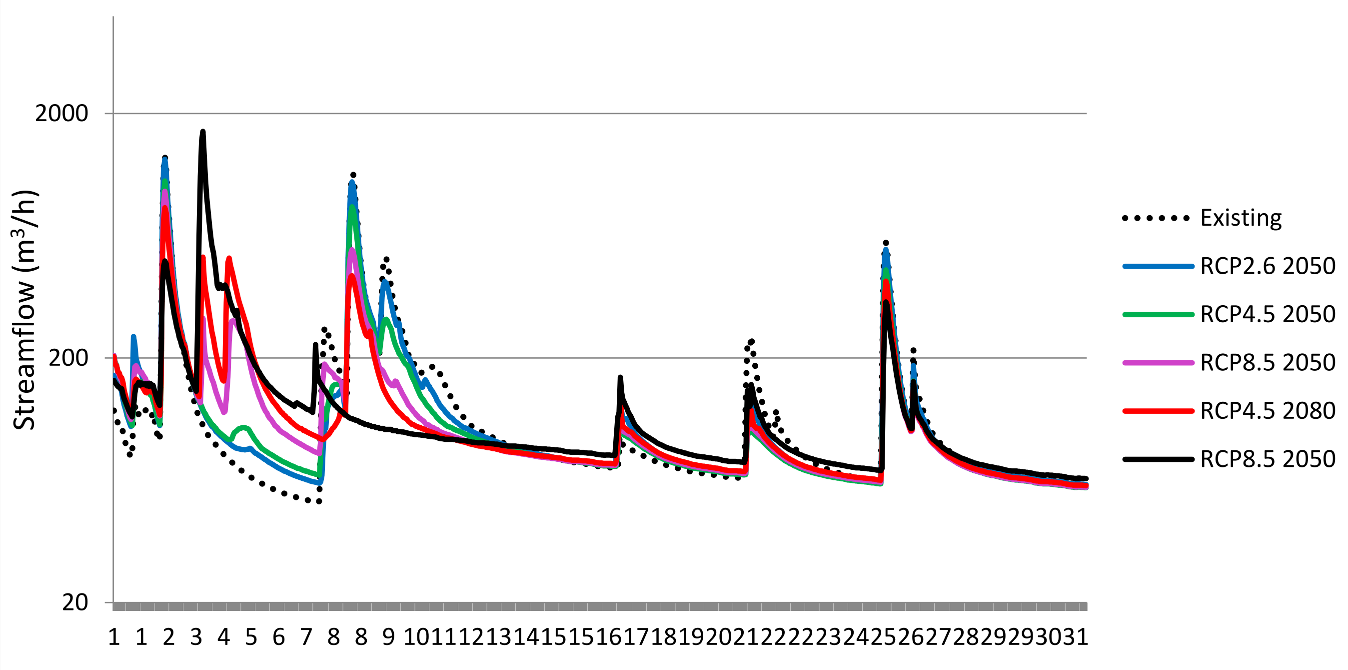

Figure 3-56: Logarithmic View of Simulated Streamflow in the Study Area in March of 2015 with Existing and Five Future Climates

3.1.6.2 Climate Change Assessment Part 2: Climate Change and Storms

3.1.6.2.1 Approach

Climate change scientists are in general agreement that warmer climates will contain more frequent large storms and that storms, larger than those previously experienced, may occur (IPCC, 2018). This conclusion derives from observation of storm trends over recent decades as well as climate modelling. However, as mentioned earlier, GCMs are not of sufficient spatial and temporal detail to simulate short term localized storm events, including thunderstorms. RCMs do contain much higher spatial detail and have been observed to reflect local storm events, but are still not of sufficient spatial and temporal detail for hydrological modelling.

The approach developed in this study for assessing the potential hydrologic impacts of future storms on geomorphological systems relies upon the RCM simulations conducted across North America and focusses upon the largest storms typically observed in the study area. This rational approach relates storm severity in the future to air temperature increase. It follows that atmospheric water holding capacity will increase as global warming worsens and, under ideal storm generation conditions, it is more likely that storms will be able to accumulate more moisture. This worsening of storms should be realized in terms of storm magnitude (i.e., intensity and duration) as well as frequency.

The World Meteorological Organization (WMO) has published definitions and procedures for estimating a hydrometeorologic expression termed Probable Maximum Precipitation (PMP)(WMO, 2009). PMP is defined as the greatest depth of precipitation for a given duration meteorologically possible for a watershed or location at a particular time of year. No allowance is given for climate trends. PMP is generally estimated as the product of precipitable water (PW) and precipitation efficiency (PE). PE is a measure of the potential for moisture to be stripped from the clouds and to fall as rain. PMP is traditionally used as a dam safety parameter for estimating probable maximum flood.

Ben Alaya *et al*. (2019, 2020) applied RCMs to studying future trends in PMP across North America. It was hypothesized that PMP is temperature dependent and should not be considered constant into the future. Further, increases in PMP in a particular area may be directly related to warming and thus, increase in the future as global and local temperatures rise. This rise would be due to the atmosphere's water holding capacity increasing at an expected rate of about 7% per C° (i.e., the Clausius-Clapeyron rate). In this North American based study researchers selected temperature as a covariate in a bivariate extreme value model (precipitable water and precipitation efficiency) to account for nonstationarity into the future as climate warms.

In the Ben Alaya PMP study, future climates were projected over North America using two Canadian RCMs (CanRCM4 and CRCM5). The PMP was taken as the moisture at the bottom of the atmospheric column. Across the continent, in non-mountainous areas, the model runs displayed an average trend for PMP to increase about 4% per C° into the future. It was determined that almost all of the increase was due to an increase in observed precipitable water. No significant change was credited to precipitation efficiency. The same 4% increase in PMP per C° was projected in the Great Lakes region as across the continent. So, while researchers observed a statistically valid trend in PMP as simulated by RCMs, the rate is less than the theoretical possibility of 7% per C°. Nevertheless, 4% per C° is a large increase in the context of the potential increases in temperature projected into the future. Consistency across the continent and the statistical validation of this result suggests that this trend is likely.

The approach taken in this part of the CCA is derived from the observations, climate modelling and statistical confidence ascertained in recent research around major storms. Based upon the results of this research it is most likely that climate warming will influence storm generation in the future, namely through more available energy in the form of warmer air and surface waters enabling the transfer of more moisture into the overlying atmosphere. As the moisture holding capacity of the atmosphere increases with warming, it is probable that the volume of rainwater will also increase under these conditions. Consequences of warmer air are likely to include more severe storms releasing more moisture.

In this CCA, future major storms relevant to Newtonbrook/Blue Ridge Creeks catchments, are synthesized by adjusting precipitation volumes proportionally to increases in temperature. Adjustments are meant to reflect increases in the PMP and are guided by the Ben Alaya study reporting. Hydrologic model runs were made to simulate the storm responses (i.e., hydrologic impacts) for the present day and future time periods.

3.1.6.2.2 Design Storms

Design storms are theoretical storms with specific return periods, or occurrence frequencies (F) for a particular area. The storm intensity (I) and duration (D) are determined based upon historical observation and statistical analysis. These storms are used to estimate levels of potential flooding and other related impacts associated with the major storms. The frequency of these storms is known and therefore flood risk can be associated with each return period. The design storms are essential in stormwater management, infrastructure design, risk management and for building in resilience in urban systems.

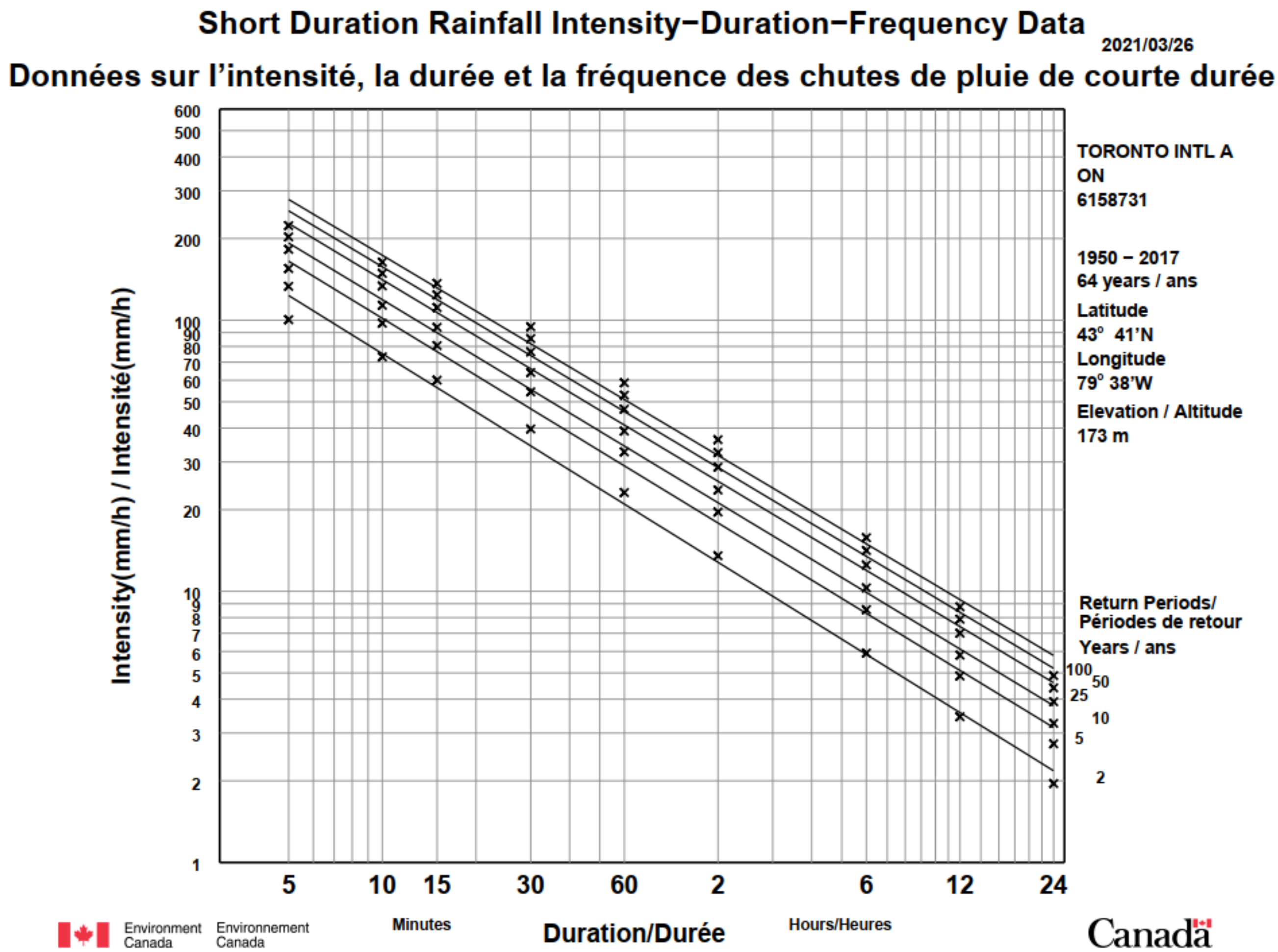

Figure 3-57: IDF Curve from Lester B. Pearson International Airport based on data from 1950 – 2017 (Sourced from ClimateData.ca)

Figure 3-57 was copied from ClimateData.ca, and represents the IDF curves determined for the Lester B. Pearson International Airport site from the period 1950 to 2017. The curves represent the depth of precipitation associated with various Return Periods across a range of average storm intensities and durations. The curves were developed from over 60 years of observation and can be considered representative of the observation period (i.e., 1950 – 2017). The mid-1980s lies in the middle of this range and represents the reference period for the IDF curve. This is a period during which climate warming emerged, and the earliest measurable signs were noted. Warming has accelerated since that time. Since IDF curves must be considered nonstationary over the past several decades, it is necessary to qualify them according to their relevant historical period.

There are five relevant timeframes in this CCA, as follows:

- IPCC reference period before climate change, 1850 to 1900
- IDF curve reference period, 1980s
- NCGSMP modelling climate reference period, 2011 to 2016
- Future timeframe 2050 (2040 to 2060), and
- Future timeframe 2080 (2070 to 2090)

Global warming from the IPCC reference period to the NCGSMP reference period (i.e., 115 years) was likely 0.8 to 1.3 C° (IPCC 2023). Climate warming from the IPCC reference period to the mid-1980s was likely less than 0.5 C°. The warming experienced between the mid-1980s and this CCA reference period (2011-2016) is probably about 0.4-0.5 C°.

For Part 2 of this CCA, the degree of climate warming was determined for the same two future time periods included in Part 1 (the 2050s and the 2080s) with the middle emission scenario, RCP4.5. As discussed above, the RCP4.5 scenario displays average annual temperature warming of about 1.6 and 2.3 C° respectively, above the NCGSMP reference time period and about 2.0 and 2.75 C° above the IDF curve reference period (1980s). To reflect corresponding future increases in PMP, the hydrologic model precipitation inputs for major storms have been increased by the following amounts:

- Scenario RCP4.5-2050: 2.00 C° X 4% = +8.0%
- Scenario RCP4.5-2080: 2.75 C° X 4% = +11%

This part of the assessment includes seven design storms and three storms that occurred within the reference period (i.e., 2011-2016) . The total storm precipitation depths are displayed in **Figure 3-58** for the ten storms included. Design storms include the 2-year, 5-year, 10-year, 25-year, 50-year, 100-year return period storms and the Regional storm based upon Hurricane Hazel in 1954. The three selected storms were the largest observed during the five-year hydrologic model calibration period.

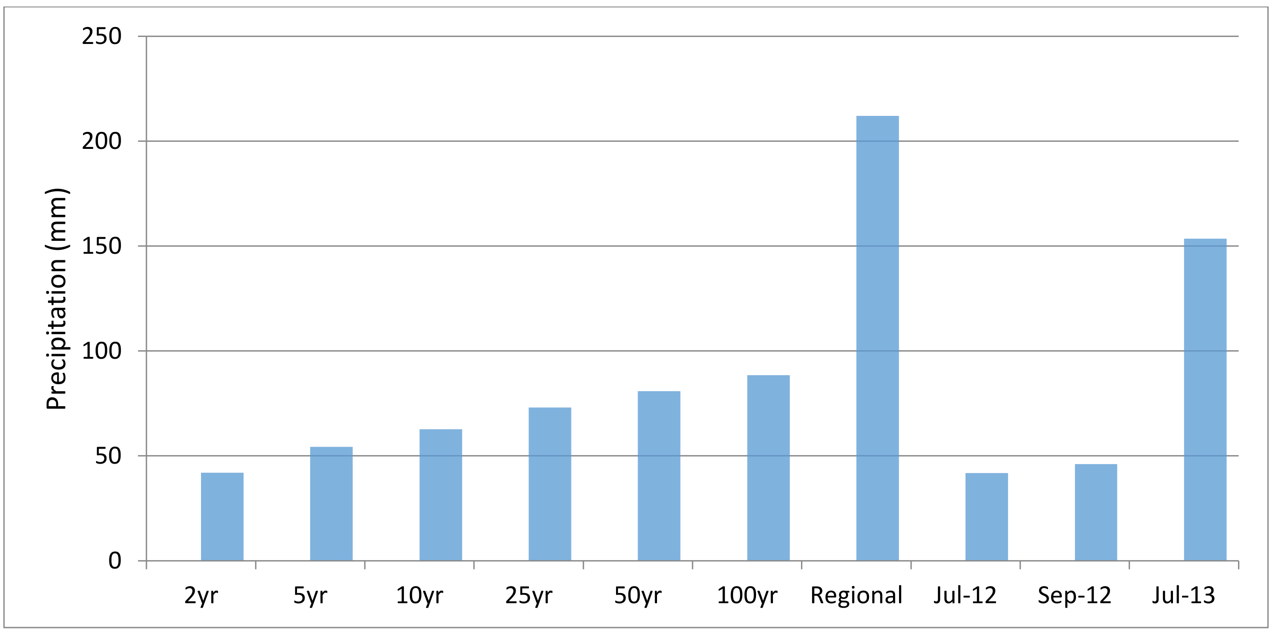

Figure 3-58: Total Event Precipitation for 7 Design Storms and 3 Historical Events

This group of storms (i.e., design storms and actual observed storms) display levels of precipitation that reflect various levels of risk and potential damage from stormwater runoff. It is interesting to note that the 3 observed historical storms occurred from July 2012 to July 2013, over just 13 months. This group of storms, containing two storms of similar intensity to the 2-year storm and one that greatly exceeded the 100-year storm, demonstrate how weather can deviate sharply from the statistics (i.e., climate normals) that we tend to trust. Trusting that storms will occur in accordance with past observation is poor policy. Past trends cannot be relied upon to repeat in a climate warming future. Nonstationarity due to climate warming renders historical characterizations (i.e., IDF curves and climate normals) as unreliable gauges of future weather and related risk.

The approach to assessing the potential impacts of climate warming on storms and instream conditions is not an attempt to recreate typical annual or longer-term weather time series. The current modelling used in climate change science is not of sufficient accuracy to simulate very high-resolution weather into the distant future. The approach used here recognizes that from a geomorphological perspective, the majority of instream stress occurs during the relatively rare severe storms and droughts. Over the long term, streambanks and infrastructure are surely to be subjected to an assortment of storms that would include many of the 2-year return magnitude, several of the 5-year size, lesser of the 10-year size and so forth. Within the timeframes assessed in this part of the CCA, watersheds are likely to experience the cumulative effect of many storms occurring approximately as probabilities would suggest. Of course, climate change is altering those probabilities, necessitating examination of a future with increasing probabilities associated with severe storms.

3.1.6.2.3 Hydrologic Impacts of Climate Warming Storms

In this study the hydrologic model has been run with a synthesized time series of precipitation inputs that include each of the ten storms of interest (i.e., seven design storms and three historical storms). The time series also includes small amounts of precipitation between the design and observed storms so that the watershed remains in a worst-case high moisture state leading up to each storm event. Runs were executed for three time periods; present day, 2050s and 2080s. Simulation results have been examined in terms of the total volume of runoff and the maximum streamflow rate (averaged hourly) simulated for each storm for the combined study area channels. Comparisons are presented in **Figure 3-59** to **Figure 3-62**. These include direct comparisons of storm volumes and maximum streamflow rates as well as comparisons between the 2050s period and the 2080s in terms of the observed increases (as ratios) in simulated volumes and peak streamflow rates.

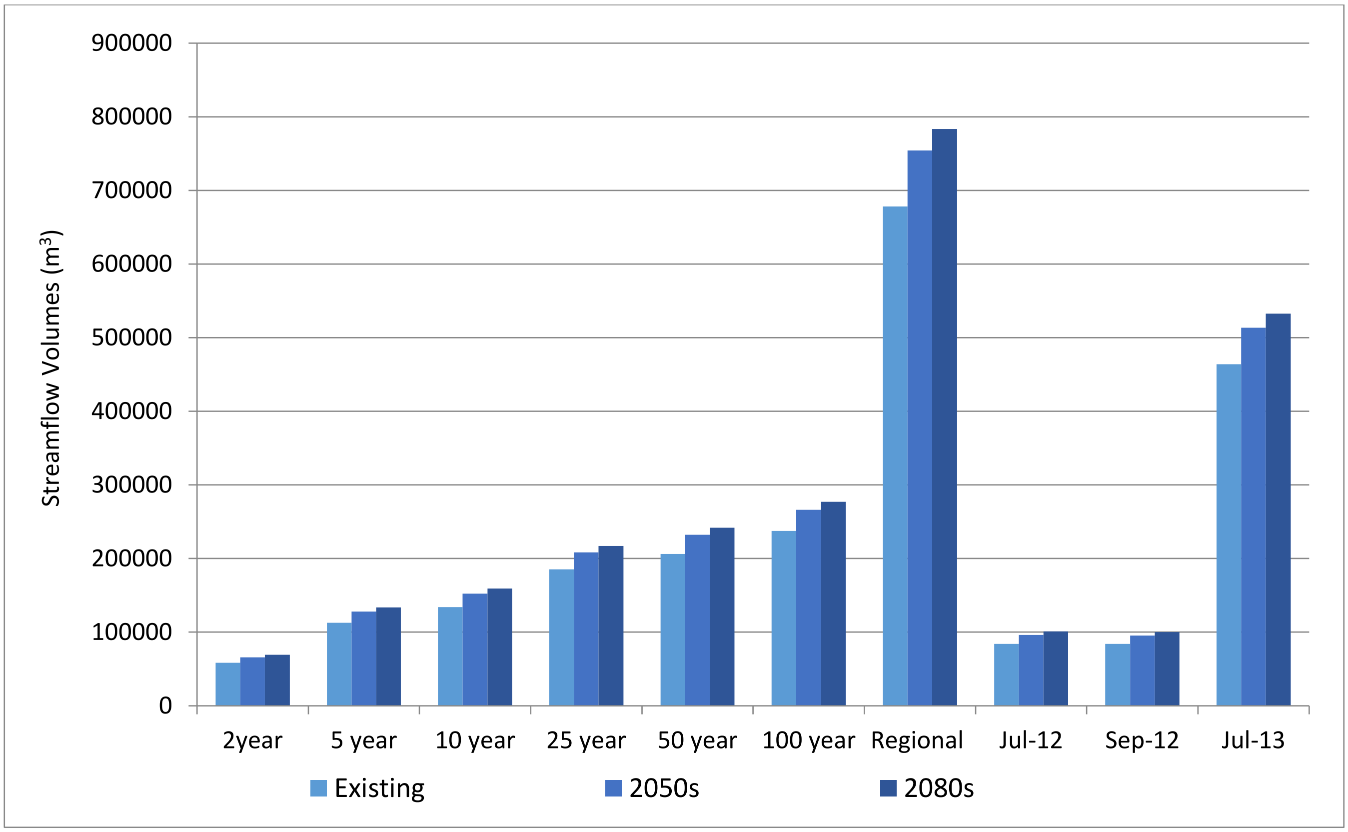

Figure 3-59: Study Area Simulated Total Event Streamflow Volumes for Design and Historical Storms

Figure 3-59 shows total storm runoff volumes for the three time periods. Not surprisingly, storm volumes are simulated to increase in the warming scenarios. As noted above, the hypothetical future storms representing a warmer climate contain 8 to 11% more moisture than the 2011-2016 storms. However, **Figure 3-60** shows that in both future timelines the ratios of future to present day storm volume exceeds the increases in precipitation alone. Note that the volume ratios for the 2050s and 2080s were about 1.13 and 1.18 for a two-year storm, or 13 and 18% above the present-day storm volume. The difference is due to the inherent capacity of watersheds to retain and delay stormwater runoff, buffering the storm yield when measured in percentage terms (i.e., total storm runoff as a percentage of precipitation applied over the total area). Larger storms tend to display higher yields than small storms and so the relative effect of the increased precipitation is more apparent in the smaller design storms. In all cases the higher precipitation intensity of a warmer future is expected to result in significant increases in runoff volume.

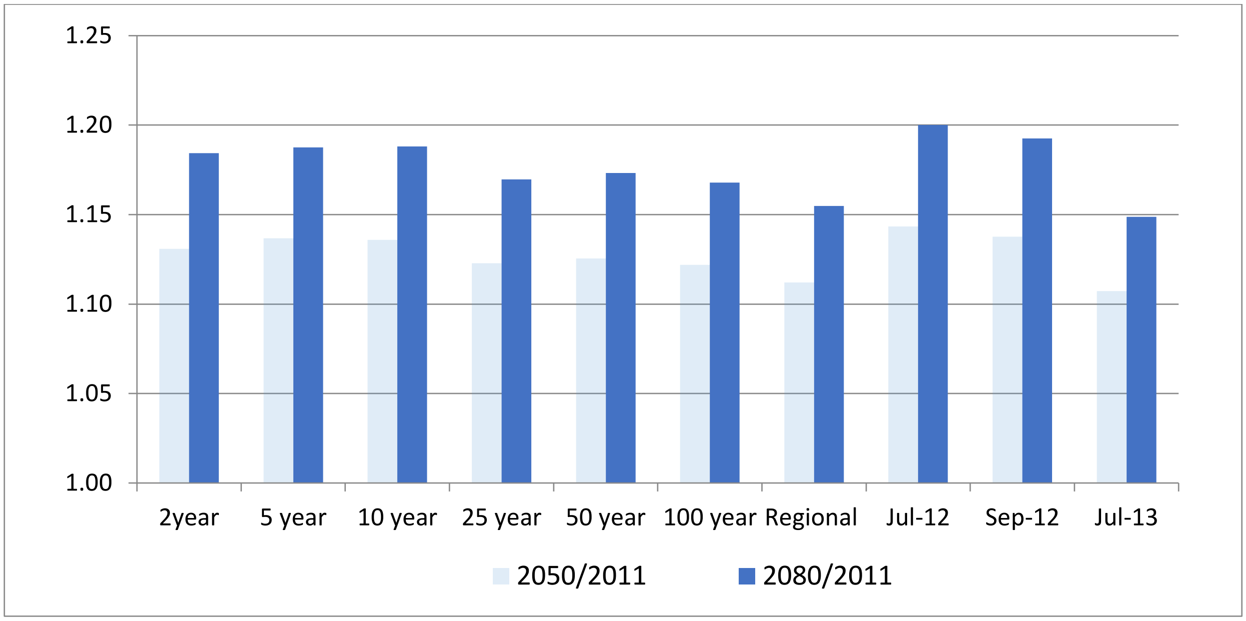

Figure 3-60: The Ratios of the Total Stormwater Volumes (Future/Present) for 10 Storms

Figure 3-61 and **Figure 3-62** compare the climate changed storm related streamflow peaks and ratios of peaks at the Creek mouth, with present day storm peaks. The general patterns are similar to those observed for stormwater volumes. However, in all cases, the modelled increases in streamflow peaks are more pronounced than the increases in storm volumes and precipitation. For example, the 2-year peak storm flowrates were simulated to increase by almost 18% and 27% for the 2050s and the 2080s scenarios, respectively. Whereas, increases in storm volume for the same storms was 13% and 18%, respectively. This pattern holds for the larger design storms although the differences between time periods becomes smaller, in terms of volume and streamflow rates.

The historical storms observed in July and September of 2012 and July of 2013 display very similar trends to the design storms. The historic storm of July 2013 displays very similar response as the Regional storm, both greatly exceeding the precipitation and volumes of the 100-year storm.

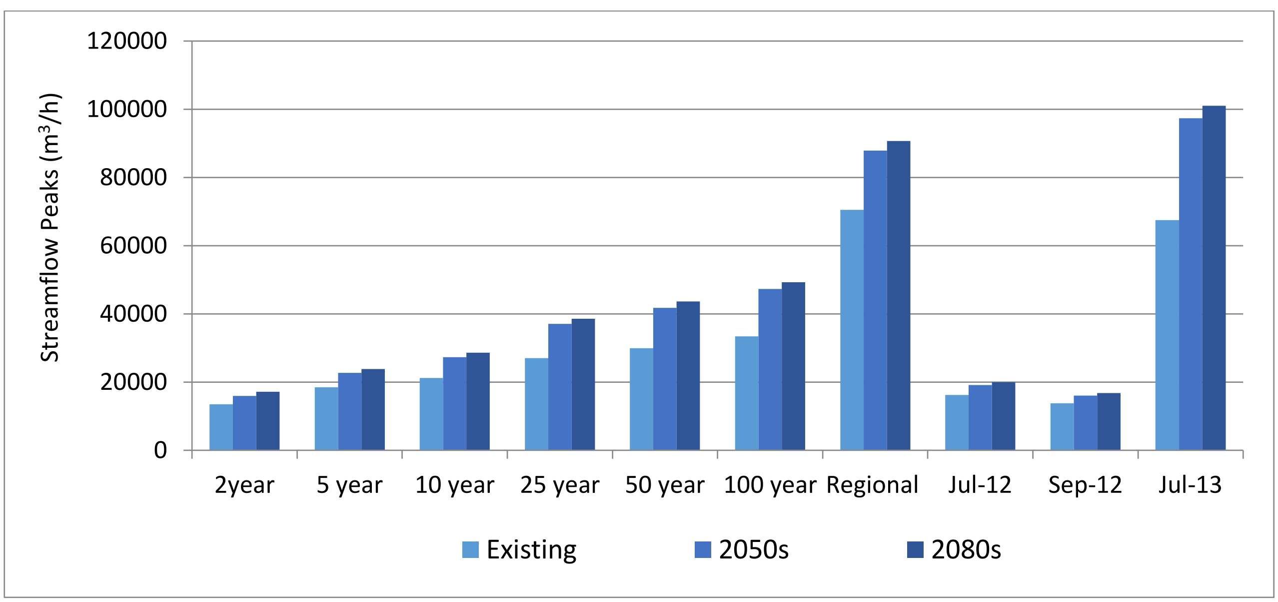

Figure 3-61: Study Area Simulated Streamflow Peaks for Design and Historical Storms

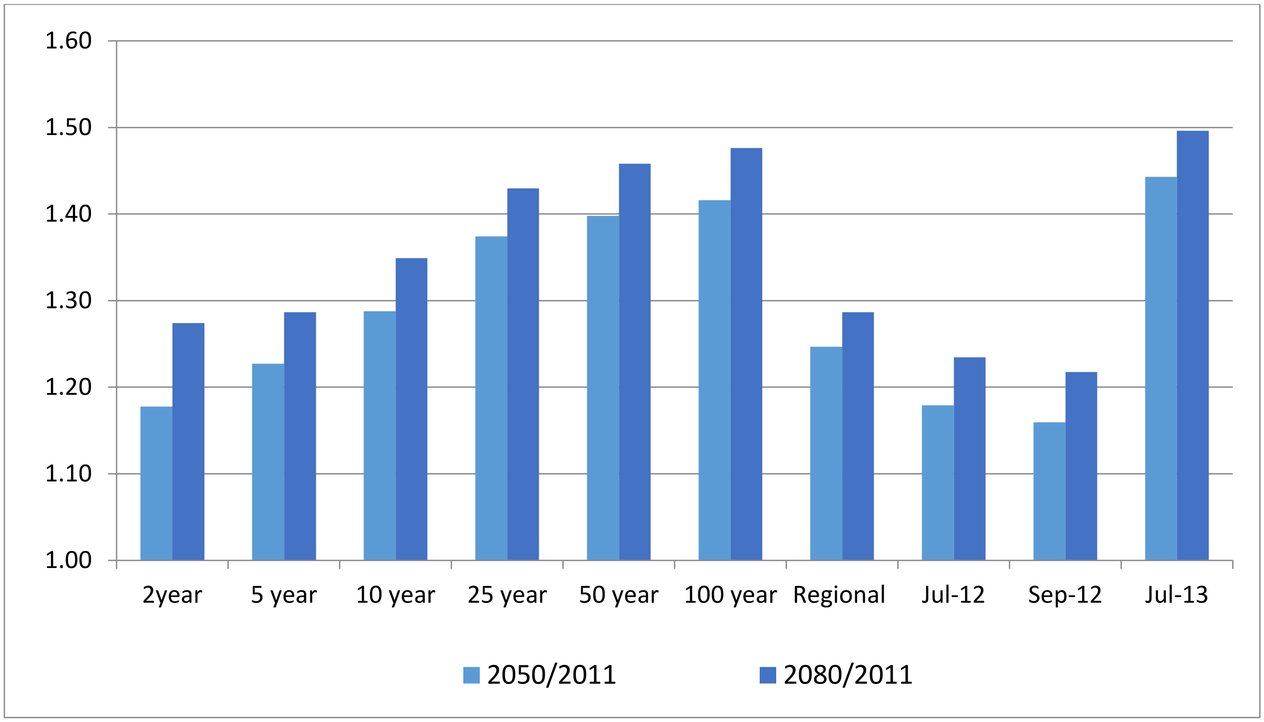

Figure 3-62: The ratios of the peak storm event flow rates (future/present) for ten storms

It is widely expected that a warming future will result in more frequent severe storms. This change in storm probability suggests that IDF curves will transition as climate warming occurs. The changes in storm severity proposed in this assessment are offered as a way to account for the effect of a warmer climate on atmospheric moisture holding capacity and storm intensity. The extent of warming to the 2050s and 2080s under an intermediate level emission scenario, RCP4.5, could increase the PMP in large storms by +8% and +11% as air temperatures increase by 2 to 2.75 C^{o}, on average. This trend approximately corresponds to decreasing the return period of a design storm or increasing the rainfall intensity for the same return period, similar to shifting the curves upwards. By interpolating **Figure 3-47** and using the precipitation intensities applied in this study, IDF curves would change as follows:

- Todays 50-year storm would return every 32 years and 28 years by the 2050s and 2080s, respectively
- Todays 2-year storm would return every 19 months and 17 months by the 2050s and 2080s, respectively.
- Todays 100-year storm would return every 50 years by the 2080s
- The 100-year storm in 2050 will be equivalent to a 150-year storm today
- The 100-year storm in 2080 will be equivalent to a 200-year storm today

3.1.6.3 Summary of Hydrologic Impacts and Implications.

3.1.6.3.1 Monthly and Seasonal Impacts

Part 1 of the CCA has identified trends and changes in stream hydrology and its seasonality due to climate change, expressed in terms of air temperature, precipitation and potential evapotranspiration. These climate change-related impacts differ somewhat through the annual period and therefore have been summarized for the warm seasons and the cold seasons. During the **warmer months** (i.e., May to October), the following trends are apparent:

- All scenarios trend towards lower summer precipitation in the future, thus, lower average summer streamflow in Newtonbrook/Blue Ridge Creeks is expected during these months. This further increases the frequency of low baseflow and the possibility of severe drought. This trend worsens over time under the RCP4.5 and RCP8.5 cases. These trends are similar but minor in the RCP2.6 scenario through the century ahead.

- Average stream water temperatures will be warmer especially at nighttime. The degree of change is small to significant depending on the RCP scenario and the future time frame examined.
- Higher potential evapotranspiration (PEVT) is expected as air and water temperatures increase, stressing already low baseflows.
- Warmer spring and autumn climate will likely increase the risk of severe thunderstorms, discussed below.

During the **colder months** (i.e., November to April), the following trends are apparent:

- Snowpack development will be significantly reduced and nearly eliminated with the worst-case scenarios in the future due to less frozen precipitation in general and more frequent snowmelt.
- With the loss of snowpack and warming, surface waters will be subject to evaporation during winter leading to less winter storage of water across the watershed.
- More streamflow will occur throughout winter due to more precipitation as rainfall, more frequent snowmelt and higher precipitation in general.
- The likelihood of a typical spring freshet is reduced.
- Winter thunderstorms, discussed below, will become more frequent, extending the period of potential damage by erosion to year-round.
- Evapotranspiration will increase in winter months as more above freezing days are experienced. These will have a minor impact on streamflow.
- Average stream water temperatures will be warmer especially at nighttime. Winter changes in stream temperature will be larger than those in the warm months.

Impacts and consequences of climate warming by scenario follows:

- RCP2.6 - The lowest emission scenario results in temperature increases over the next thirty years, after which temperatures stabilize. The degree of change in temperature and precipitation in this case is modest by comparison to other scenarios. Changes in the seasonality of runoff are minor. While temperature warming may create significant stress in biological communities, the impacts upon hydrology are relatively minor. Small increases in precipitation could offset low flow conditions aggravated by higher evaporative losses. Instream habitat will be stressed in summer due to warming of air and water.
- RCP4.5 – This intermediate emission scenario results in global warming to the year 2100, followed by temperature stabilization. The degrees of warming and precipitation change are significant. On annual average air temperature terms, this scenario is estimated to cause more than two times the change (+ 2.3 C^o) by 2080 as the lowest emission scenario. These will lead to shifts in the seasonality of the water balance, gradual disappearance of winter conditions and frozen precipitation and storage. Summer drought is more likely due to lower anticipated precipitation and increased evaporation. Warmer water temperatures will impact instream habitat.
- RCP8.5 – This high emission scenario results in continual global and local warming through this century and beyond. The degree of warming and changes in precipitation are very significant. On annual average air temperature terms, this scenario is estimated to cause about 4 times the change (+ 4.3 C^o) by 2080 as the lowest emission scenario. These changes will lead to a loss of winter conditions and significant change in the water balance in the watershed. Summer drought will be more frequent and severe. Instream habitat will be significantly impacted.

3.1.6.3.2 Storms Impacts

Part 2 of the CCA has identified potential impacts of warming climates in the study area upon the potential severity of storms and the subsequent impact on storm runoff. Many GCMs are in agreement on the trend to moderately more annual precipitation in the study area as climate warms. The warmer future climate will increase the potential for more severe storms to occur, in part, due to increasing atmospheric water holding capacity and in part due to a relative abundance of large water bodies near enough to fuel large storms in the area. The climate in this area is greatly influenced by the Great Lakes and some storm systems affecting the area are supplied with moisture from the Atlantic Ocean and the Gulf of Mexico.

A consequence of climate warming is likely to be more severe storms. This study has adopted a rationale that estimates that major storm rainfall may increase by factors of 8% to represent 2050 major storms and 11% to represent 2080 storms. These are very approximate estimates of future storm severity based upon principles of hydrometeorology and GCM-modelled estimates of future average air temperatures in the study area. The precipitation changes must be considered “order of magnitude estimates”. Further research and observation are necessary to test these trends. If the probable maximum precipitation estimates for the future prove to be a valid measure of future storm severity as a function of temperature, then this method can be a useful tool to estimating risk and instream stress leading to erosion.

The consequence of higher storm rainfall intensity applied in this study is shown to be as expected, namely higher storm volumes and peak stormwater flowrates. Runoff increases reflect the magnitude of the rainfall increases applied, with modest differences between the smaller storms and the very large storms. In the long term, increases in storm runoff would likely accompany a shift from present day patterns to future weather with larger and more frequent storms and longer dry periods with drought-like conditions. Thus, the expected trend in effect is towards an annual runoff distribution that is more skewed to the extreme.

From a geomorphological perspective, the nature of future storms should cause some concern. Future increases in runoff volume and peak flowrates will result in disproportionate increases in the duration and impact during periods with excess shear stress. This increase in stresses translates into instream risk and damage to streambanks and infrastructure. Extended periods of bedrock exposure during drought could also be disproportionately increased.

In addition to higher risks to streambanks and infrastructure, due to climate warming, instream habitats are under similar stresses of physical damage. As habitat is stressed and damaged, aquatic communities (i.e., flora and fauna) are stressed. Likewise, flooding could be more common and more severe as the probabilities indicate. Public safety concerns run parallel to increasing risk of flooding. As is the case with geomorphological issues, these stresses may be much more impactful than the percentage increases in storm precipitation, volume or peak flow would suggest.

3.1.6.3.3 Climate Change Recommendations

Due to inherent uncertainties in articulating future climate and the nature of future storms and drought conditions, the climate change assessment of Newtonbrook and Blue Ridge Creeks should be revisited within 10 years and subsequently at a reasonable frequency. Future assessments should delineate and update the climate at the time and determine the future climates for the study area, using the best available modelling. Over the intervening period, the actual rates of GHG emissions and most probable future rates can be refined. Also, the local and global climate changes occurring over the intervening years can be accurately quantified. Research into the nature and frequency of storms in a warming future will undoubtedly reveal some predictability and allow for trend analysis at a local scale. Modified IDF curves accounting for climate change may become available. The geomorphological Risk Assessment portion of future studies would be informed by climate updates in terms of assessing the risk of erosion and streambed weathering.

The hydrologic assessment of Newtonbrook and Blue Ridge Creeks should be revisited as recommended above for the climate change component. The future assessment should compare the streamflow and precipitation records for the intervening years to those reported here for the historical period. Comparisons could focus on the monitoring sites for streamflow rates and meteorology noted above . Observations should be noted regarding any emerging trends over the previous years, in line with those discussed in this report, or otherwise. Any major storms occurring over the intervening years should be assessed in terms of any instream erosion and any storm-related damage that may be notable. The study area streamflow should be simulated for future climates, integrating the various updates and advances in climate modelling.

It is recommended that meteorological monitoring continue at the airport location (Environment Canada 6158733) and that streamflow monitoring continue on the Don River. Future studies would benefit from site specific hydrological and meteorological monitoring in the study area during the intervening years.

Stream management in the future presents old and new challenges. Adapting to climate warming and urbanization are the most salient of these. In general, the stream's hydrologic regime and habitat benefit from naturalization in as much as this retains water on the landscape; encourages infiltration; provides shading and habitat; amours against erosion and buffers against storms. It is recommended that the land adjacent to the study area channels be naturalized wherever possible and that private property owners be made aware of good stream stewardship practices and ways to minimize carbon footprints. In terms of the design of erosion protection, it is recommended that more robust solutions are employed using higher factors of safety to ensure resilience to the increased flow intensities experienced as part of a changing climate. It is recommended these factors be considered as part of the upcoming detailed design processes.

3.1.7 Archaeological & Heritage Resources Assessment

Archaeological Services Inc. (ASI) was subcontracted by Aquafor Beech Limited to conduct a Stage 1 Archaeological Assessment as part of the NCGSMP. In April of 2022, ASI prepared a technical memorandum (included as **Appendix G**) presenting results from a desktop assessment undertaken to identify existing archaeological conditions and areas of archaeological potential within the study area (**Figure 3-63**). A brief summary of the findings from the Stage 1 archaeological assessment and property inspection is provided below, including an overview of historical indigenous land use, treaties, and historical Euro-Canadian land-use.

3.1.7.1 Indigenous Land Use and Settlement

Southern Ontario has been occupied by human populations since the retreat of the Laurentide glacier approximately 13,000 years before present (B.P.). Populations at this time would have been highly mobile, inhabiting a boreal-parkland similar to the modern sub-arctic. By approximately 10,000 B.P., the environment had progressively warmed and populations now occupied less extensive territories.

Between approximately 10,000-5,500 B.P., the Great Lakes basins experienced low-water levels, and many sites which would have been located on those former shorelines are now submerged. This period produces the earliest evidence of heavy wood working tools, an indication of greater investment of labour in felling trees for fuel, to build shelter, and watercraft production. These activities suggest prolonged seasonal residency at occupation sites. Polished stone and native copper implements were being produced by approximately 8,000 B.P.; the latter was acquired from the north shore of Lake Superior, providing evidence of extensive exchange networks throughout the Great Lakes region. The earliest evidence for cemeteries dates to approximately 4,500-3,000 B.P. and is indicative of increased social organization, investment of labour into social infrastructure, and the establishment of socially prescribed territories.

Between 3,000-2,500 B.P., populations continued to practice residential mobility and to harvest seasonally available resources, including spawning fish. The Woodland period begins around 2,500 B.P. and exchange and interaction networks broaden at this time and by approximately 2,000 B.P., evidence exists for small community camps, focusing on the seasonal harvesting of resources. By 1,500 B.P. there is macro botanical evidence for maize in southern Ontario, and it is thought that maize only supplemented people's diet. There is earlier phytolithic evidence for maize in central New York State by 2,300 B.P. – it is likely that once similar analyses are conducted on Ontario ceramic vessels of the same period, the same evidence will be found. As is evident in detailed Anishinaabek ethnographies, winter was a period during which some families would depart from the larger group as it was easier to sustain smaller populations. It is generally understood that these populations were Algonquian-speakers during these millennia of settlement and land use.

From the beginning of the Late Woodland period at approximately 1,000 B.P., lifeways became more similar to that described in early historical documents. Between approximately 1000-1300 Common Era (C.E.), the communal site is replaced by the village focused on horticulture. Seasonal disintegration of the community for the exploitation of a wider territory and more varied resource base was still practised. By 1300-1450 C.E., this episodic community disintegration was no longer practised and populations now communally occupied sites throughout the year. By the mid-sixteenth century these small villages had coalesced into larger communities. Through this process, the socio-political organization of the First Nations, as described historically by the French and English explorers who first visited southern Ontario, was developed.

By 1600 C.E., the communities within Simcoe County had formed the Confederation of Nations encountered by the first European explorers and missionaries. In the 1640s, the traditional enmity between the Haudenosaunee and the Huron-Wendat (and their Algonquian allies such as the Nippissing and Odawa) led to the dispersal of the Huron-Wendat. Shortly afterwards, the Haudenosaunee established a series of settlements at strategic locations along the trade routes inland from the north shore of Lake Ontario. By the 1690s however, the Anishinaabeg were the only communities with a permanent presence in southern Ontario. From the beginning of the eighteenth century to the assertion of British sovereignty in 1763, there was no interruption to Anishinaabeg control and use of southern Ontario.

3.1.7.2 Treaties

The Study Area is within Treaty 13. In 1787, representatives of the Crown met with members of the Mississaugas at the Bay of Quinte to negotiate the sale of lands along the shore of Lake Ontario near the settlement of York, the seat of the colonial government. Due to disputes over the boundaries, a new agreement was created and the Toronto Purchase Treaty 13 was signed on August 1, 1805, in which the Mississaugas ceded to the Crown 250,830 acres of land. Both the 1787 Purchase and its 1805 Indenture are known as Treaty 13. The Mississaugas claimed that the Toronto Islands and other lands were not part of the purchase, and a land claim settlement was reached for these areas in 2010.

3.1.7.3 Post Contact Settlement

Historically, the Study Area is located in the Former York Township, County of York in Lots 20-22 & Concessions 1 East of Yonge Street, and Lots 17-20 & Concessions 2 East of Yonge Street.

The S & G stipulates that areas of early Euro-Canadian settlement (pioneer homesteads, isolated cabins, farmstead complexes), early wharf or dock complexes, pioneer churches, and early cemeteries are considered to have archaeological potential. Early historical transportation routes (trails, passes, roads, railways, portage routes, etc.), properties listed on a municipal register or designated under the Ontario Heritage Act or a federal, provincial, or municipal historic landmark or site are also considered to have archaeological potential.

For the Euro-Canadian period, the majority of early nineteenth century farmsteads (i.e., those that are arguably the most potentially significant resources and whose locations are rarely recorded on nineteenth century maps) are likely to be located in proximity to water. The development of the network of concession roads and railroads through the course of the nineteenth century frequently influenced the siting of farmsteads and businesses. Accordingly, undisturbed lands within 100 metres of an early settlement road are also considered to have potential for the presence of Euro-Canadian archaeological sites.

The first Europeans to arrive in the area were transient merchants and traders from France and England, who followed Indigenous pathways and set up trading posts at strategic locations along the well-traveled river routes. All of these occupations occurred at sites that afforded both natural landfalls and convenient access, by means of the various waterways and overland trails, into the hinterlands. Early transportation routes followed existing Indigenous trails, both along the lakeshore and adjacent to various creeks and rivers.

3.1.7.4 Previous Archaeological Research and Archaeological Potential

In Ontario, information concerning archaeological sites is stored in the Ontario Archaeological Sites Database (O.A.S.D.) maintained by the Ministry of Heritage, Sport, Tourism and Culture Industries (MHSTCI). This database contains archaeological sites registered within the Borden system. Under the Borden system, Canada has been divided into grid blocks based on latitude and longitude. A Borden block is approximately 13 kilometres east to west, and approximately 18.5 kilometres north to south. Each Borden block is referenced by a four-letter designator, and sites within a block are numbered sequentially as they are found. The Study Area under review is located in Borden block *AkGu.*

According to the O.A.S.D., one previously registered archaeological site (AkGu-88) is located within one kilometre of the Study Area (**Figure 3-64**), which is also within the Study Area. AkGu-88 is noted to have further cultural heritage value or interest. A summary of the site is provided in **Table 3-23**.

Table 3-23: Registered Sites within one Kilometer of the study area.

Borden number	Site name	Temporal/Cultural Affiliation	Site type	Researcher
AkGu-88	N/A	Woodland	Unknown	TRCA

Site AkGu-88, is within the Study Area. Test pit survey encountered three lithics and one Woodland period ceramic sherd which were included with fill that was brought in during the construction and leveling activities of the hydro corridor in the 1950s. The exact nature of the site was unclear, and it was determined the presence of an in-situ site in the area should be considered. Should future disturbance threaten the site, a Stage 3 archaeological assessment is recommended at this location by TRCA.

According to the background research, twelve (12) previous reports detail fieldwork within 50 metres of the Study Area. Following completion of this Stage 1 Archaeological Assessment, ASI has determined that parts of the study area exhibit archaeological potential, therefore a Stage 2 assessment is recommended prior to any proposed construction activities on these lands.

Figure 3-63: Archaeological Potential from the City of Toronto Archaeological Management Plan

Figure 3-64: Detailed Site Location of *AkGu-88*

3.2 Site-Based Risk Assessment of Toronto Water Infrastructure

Taking into consideration the results from each of the technical assessments described above, on an asset-by-asset basis, the condition and associated risk to Toronto Water infrastructure within the Newtonbrook and Blue Ridge Creek Study Area was evaluated as part of **Phase 2**. Nineteen (x19) vertical risks, twenty-two (x22) horizontal risks, and thirty-one (x31) storm water outfall risks were assessed, totalling seventy-two (x72) risks to Toronto Water infrastructure within the study area. These risks were ranked on a score out of fifteen, and the twenty-four (x24) highest scoring sites to be addressed as part of the NCGSMP were identified, as described in the following subsections.

3.2.1 Assessment of Toronto Water Infrastructure and Erosion Control Structures

Toronto Water infrastructure is abundantly present within the Newtonbrook Creek and Blue Ridge Creek corridors. A trunk sewer was constructed in the late 1950's and early 1960's which now follows the alignment of Newtonbrook Creek. A second sanitary sewer line follows the alignment of the downstream section of Blue Ridge Creek. These trunk sewers generally flow from North to South before joining with the major trunk sewer along the East Don River. In addition, sewer mains join the main trunk sewer along Newtonbrook Creek in the upper reaches. Sanitary sewers cross Newtonbrook Creek a total of sixteen (16) times and Blue Ridge Creek a total of two (2) times. This represents about 4 km of sanitary sewer lines with diameters ranging from 250 – 1,350 mm. Constructed materials include PVC, asbestos cement, and reinforced and unreinforced concrete. The spatial distribution of sanitary sewer crossings within the study area is illustrated in **Figure 3-65**. In addition to the Toronto Water sanitary sewers, one (1) watermain crosses Newtonbrook Creek near Manorcrest Road. This watermain was constructed in 1971, later than the major trunk sewer along Newtonbrook Creek and is composed of steel. Its location relative to the sanitary sewer crossings can be seen in **Figure 3-65.**

Prior to 1990, by which most of the sanitary sewers, watermain, and storm outfalls were already constructed, stormwater management measures emphasized fast and efficient conveyance of runoff to watercourses to prevent water from ponding in developed areas. This management philosophy altered natural drainage patterns, reduced infiltration opportunities and shortened the watershed time of concentration, creating a flashier rainfall-runoff response. The end result is a significantly altered watershed that is susceptible to continued ongoing erosion as the watershed attempts to establish a new state of quasi-equilibrium. Newtonbrook and Blue Ridge Creek are good examples of the result of such practices, with several exposed sewer crossings, maintenance holes and outflanked storm water outfalls.

In addition, air photo analysis and Engineering drawings show Newtonbrook Creek was re-aligned, straightened, and hardened at several points since the main trunk sewer was constructed, likely due to the increasing erosion and pressure on the underlying trunk sewer. This re-construction includes numerous erosion control structures such as gabion basket and armourstone walls. Channel hardening will, at times, force the channel to erode vertically rather than laterally, causing scour and premature exposure of the buried infrastructure. City of Toronto standards require a minimum of one (1) metre of cover over sanitary sewer & watermain crossings. In many instances active channel incision has led to exposed infrastructure crossings. As sewers become exposed, they begin to act as a grade control structures and may become undermined if the channel bed continues to erode around them.

A key component of the NCGSMP is the documentation of all risks to TW infrastructure in the Newtonbrook and Blue Ridge Creek Study Area, to facilitate the prioritization of the twenty-four (24) highest risk sites, and subsequent development of conceptual designs to address these erosion-related issues.

Sections 3.2.1.1 to **3.2.1.3** delineate Aquafor's approach to document and evaluate the condition of Toronto Water infrastructure within the Newtonbrook and Blue Ridge Creek Study Area using a combination of field and desktop assessments. While, the emphasis of the NCGSMP is on quantifying risks to Toronto Water infrastructure, as part of the Environmental Assessment Process Aquafor has also documented and evaluated the condition of erosion control structures & erosion hazard sites that impact non-municipal infrastructure and private property as described in **Section 3.2.1.4**.

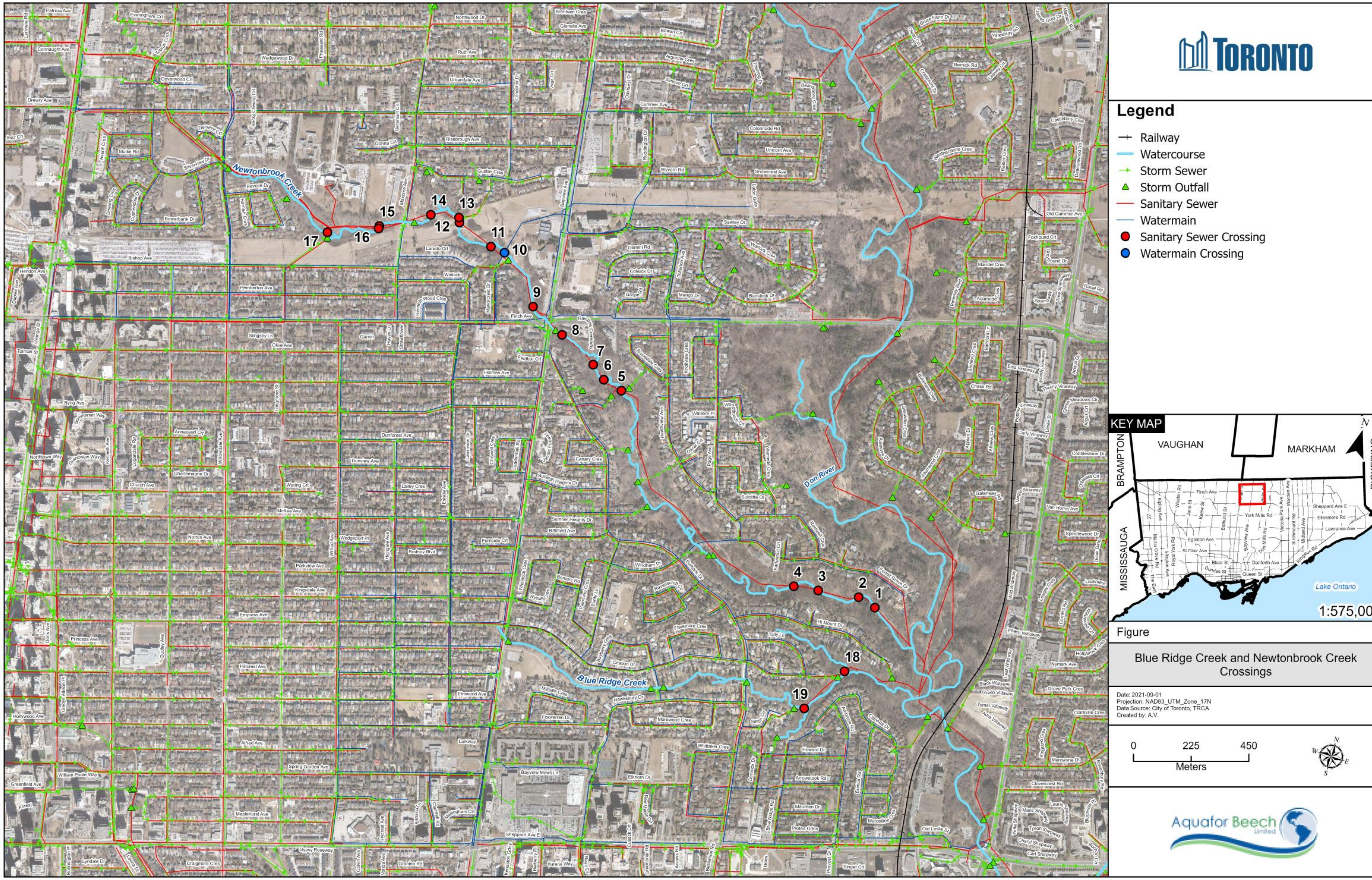

Figure 3-65: Spatial Distribution of Toronto Water Infrastructure Crossing Newtonbrook and Blue Ridge Creeks.

3.2.1.1 Sanitary Sewer & Watermain Crossings

Through a combination of desktop analysis and in-field assessments it was determined that there is a total of nineteen (x19) infrastructure (sanitary sewer or watermain) crossings within the NCGSMP study area. Aquafor assigned a number to each crossing along the main branch of either Newtonbrook Creek or Blue Ridge Creek, starting at the downstream end. Aquafor's assessment of Sanitary Sewer & Watermain Crossings involved completing a detailed topographic survey at each crossing location. Topographic surveys were completed from August to December of 2021 using a combination of robotic total station and GPS technologies. All survey data was referenced to the Modified Transverse Mercator (MTM) projection as per City of Toronto Standards, with all elevations consistent with geodetic controls. Key parameters of the topographic surveys included:

- Longitudinal Profile of the Creek extending approximately 20 metres upstream and downstream of each crossing
- Cross-sections along each sewer crossing extending roughly 5 metres beyond the top of bank on either side of the creek.
- General channel planform including bottom of bank and top of bank lines
- Local bed and bank erosion control structures
- Local storm sewer outfalls including invert and obvert elevations

Leveraging the collected survey data and photographic inventories, CAD drawings delineating the existing site conditions were generated for each crossing. Drawings for all inventoried sites, (including one watermain crossing) are found in **Appendix H**. Aquafor integrated buried sanitary sewer profiles into the existing condition drawings by using as-built engineering records and/or invert elevations available on DCAD.

For many sites, engineering as-built records were not available. To confirm and resolve issues with the lack of as-built records, Aquafor assessed all sanitary sewer invert elevations through a Maintenance Hole Invert Assessment, completed in December of 2021. This assessment involved opening bounding maintenance holes on either side of a sanitary sewer crossing and surveying or measuring the invert depths. A tabular summary of the infrastructure crossing assessment, including key parameters such as estimates of the depth of cover for both sanitary sewers and watermains crossings, is provided in **Appendix I.**

Overall, out of the nineteen (19) infrastructure crossings evaluated in the NCGSMP, there are eight (8) exposed crossings, five (5) exposed maintenance holes and one (1) exposed watermain chamber. Over 70% of the crossings have either less than 1.0 metres of vertical cover or less than 5.0 metres of lateral cover and therefore likely require some degree of engineered erosion control works to prevent long-term exposure. A summary of this conditions assessment is presented in pie-chart format in **Figure 3-66** and **Figure 3-67**. A sample Existing Conditions drawing for a sanitary sewer crossing is presented in **Figure 3-68**.

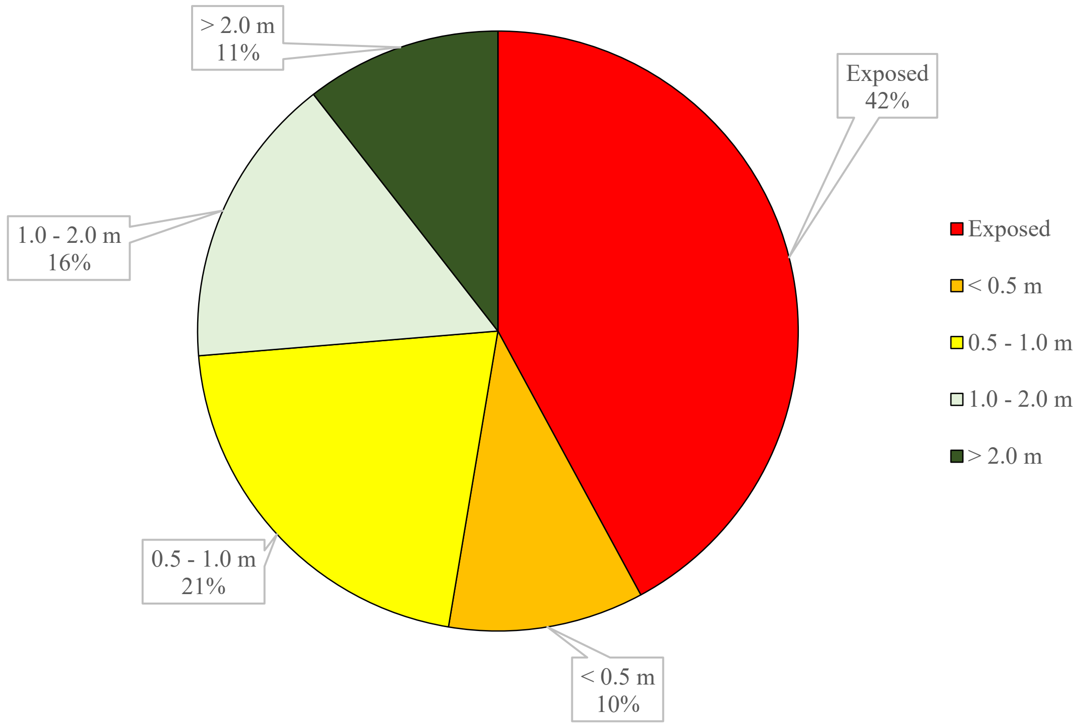

Figure 3-66: Vertical Depth of Cover (m) Categorization of Infrastructure Crossings

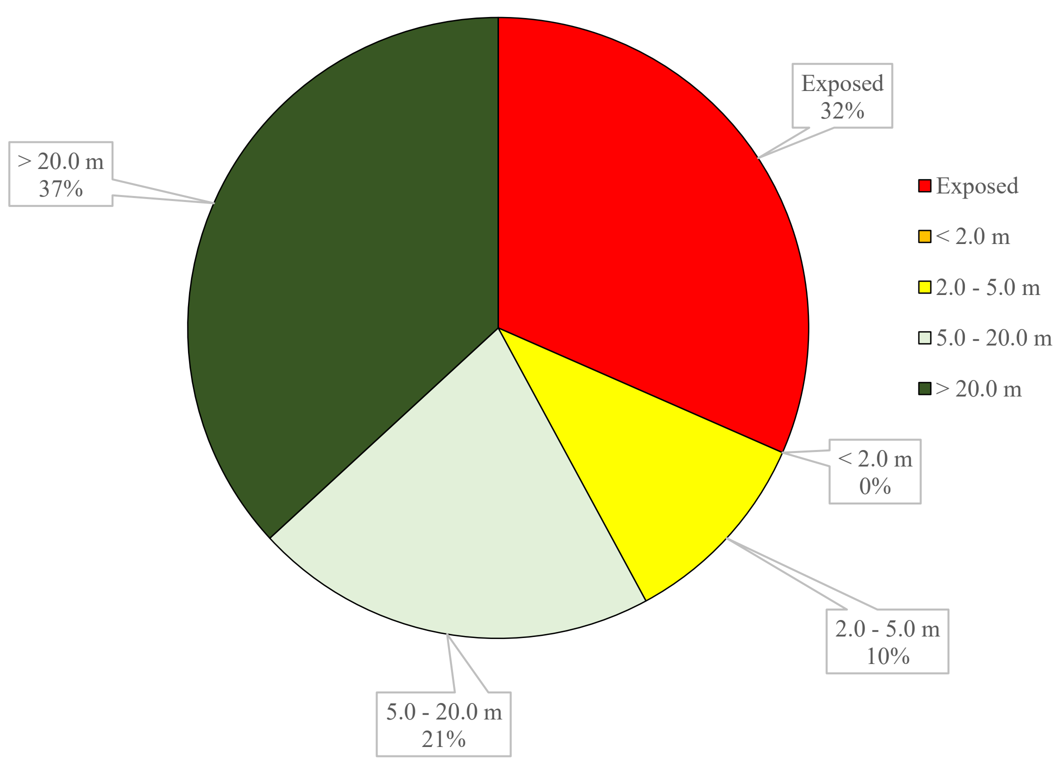

Figure 3-67: Horizontal Offsets (m) Categorization for Infrastructure Crossings

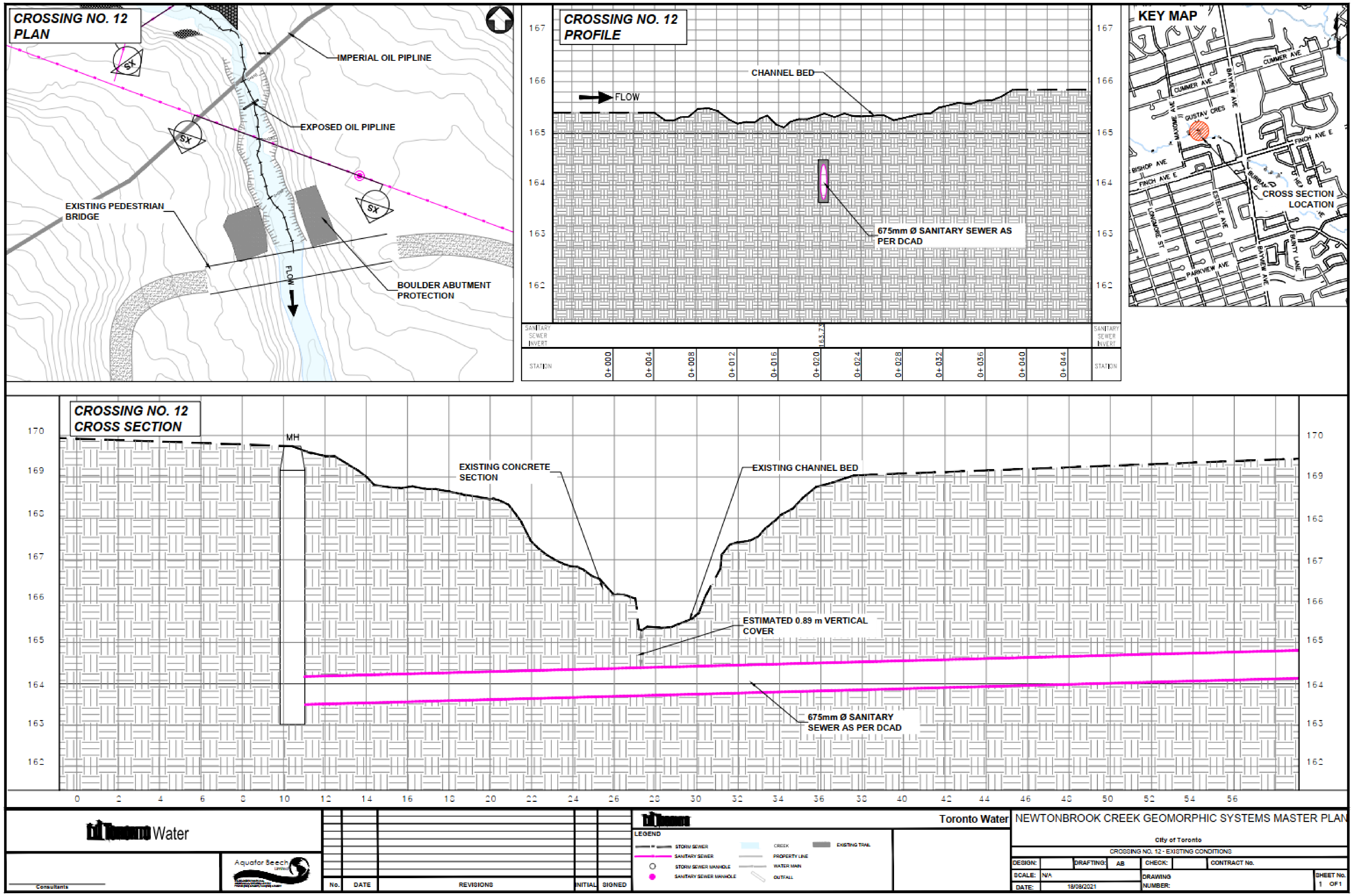

Figure 3-68: Sample Existing Conditions Drawing Based on Topographic Survey Results for Crossing #12

3.2.1.2 Lateral Risks to Sanitary Sewer Infrastructure

Using aerial imagery and base-mapping information provided by the City of Toronto, Aquafor completed a desktop analysis to identify additional lateral risks to sanitary sewer infrastructure not covered through the sanitary sewer crossing assessment. Sewer lines and maintenance holes in close proximity to the channel banks are at risk of exposure due to lateral channel migration and should be considered in the risk assessment process. Aquafor's fluvial geomorphology team estimated annual rates of lateral erosion for each reach by comparing the channel profiles from as-built engineering drawings to updated 2021 topographic surveys undertaken at the same channel cross-section. The highest rate of lateral erosion was observed in reach BR1.

To account for all infrastructure with the potential for exposure within the next 100 years, Aquafor's lateral risk assessment documented all the additional sanitary sewer infrastructure within 20 metres of the toe of slope. Planview analysis reveals that much of the trunk sewer infrastructure along Newtonbrook and Blue Ridge Creek is within 20 metres of the creek, therefore an additional criterion is used. To be identified as a lateral risk, a sanitary sewer must be located along a cut bank of the creek. Field photos from Aquafor's various field investigations, including geomorphic site walks, were leveraged to identify the presence and condition of erosion control structures at the lateral risk sites. Any auxiliary risks to private property or other infrastructure assets were also documented.

A sample summary sheet delineating the location of an additional lateral risk site is provided in **Figure 3-69**. A total of twenty-two (22) additional lateral risk sites were identified. Summary sheets for all inventoried Additional Lateral Risk Sites are found in **Appendix J**. Categorization of all evaluated lateral risk sites into a color-coded system based on horizontal offset distance is presented in pie-chart format in **Figure 3-70**. A tabular summary of the identified additional lateral risk sites is provided in **Appendix K**, detailing the key parameters associated with each site including lateral depths of cover. Furthermore, the key parameters used to define existing conditions and guide the risk assessment for these risk sites are documented in **Section 3.2.2**.

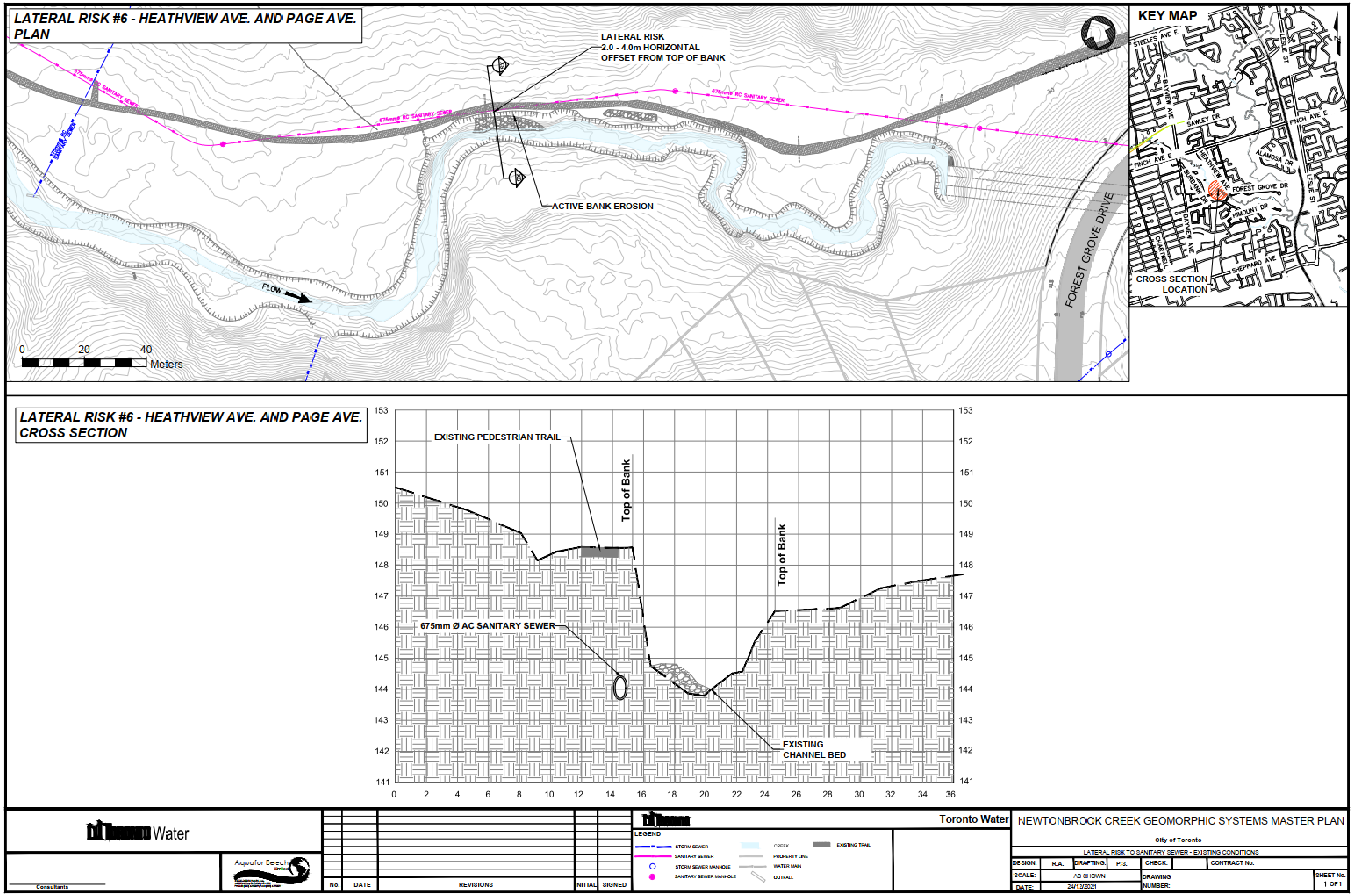

Figure 3-69: Sample Existing Conditions Drawing Based on Lateral Risk Site #6

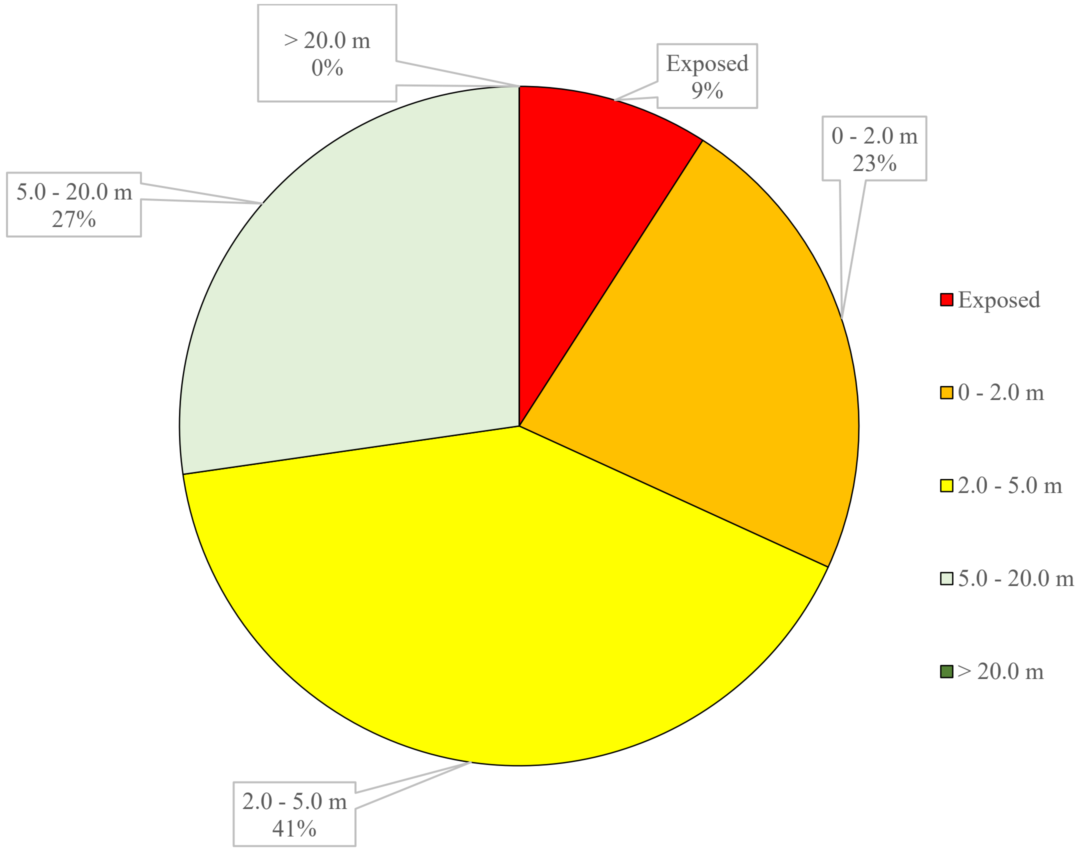

Figure 3-70: Horizontal Offset (m) Categorization for Lateral Risk Sites

3.2.1.3 Storm Sewer Outfalls

Aquafor's initial desktop assessment identified twenty-four (24) storm sewer outfalls within the NCGSMP study area. Nineteen (19) of these outfalls were successfully located and assessed in the field as part of Aquafor's geomorphic site walk. In addition, eight (8) outfalls not found on the basemapping were found in the field. This accounts for a total of thirty-two (32) outfalls along both creeks, with twenty-four (24) on Newtonbrook Creek and eight (8) on Blue Ridge Creek. For this study, outfalls were numbered starting at the downstream end of Newtonbrook Creek and Blue Ridge Creek and proceeding upstream. The location of these outfalls with the respective TW asset ID is presented in **Figure 3-71**.

Two (2) private property outfalls were also identified in the field, however these outfalls were excluded from the Storm Sewer Outfall Condition and Risk Assessments.

3.2.1.3.1 Condition Assessment

Each evaluated outfall was given one the following condition grades:

- **Excellent:** The outfall is well maintained and in good condition. No significant signs of structural degradation or risk of failure due to channel erosion processes (i.e., undercutting or outflanking). This ranking is typically only applied to relatively new or recently rehabilitated infrastructure.
- **Moderate:** Acceptable or approaching the mid-stage of the outfall's expected service life. The outfall is still functioning as intended as is not at imminent risk of failure.
- **Poor:** The outfall is approaching the end of its service life and is exhibiting notable signs of deterioration. The outfall is at risk of failure due to continued channel erosion within the near term or is barely able to provide its intended function.
- **Failed:** The outfall is no longer functioning as intended. This ranking is typically reserved for outfalls that have become fully detached from their inletting storm sewers or are buried and are no longer able to provide sufficient drainage.
- **Not Assessed:** Some outfalls not included in the City Basemapping were not fully assessed. This is due to inadequate knowledge on the origin, purpose, material, and other properties of the outfall. In addition, outfalls available on City Basemapping but not accessible or found in the field are labelled as Not Assessed.

3.2.1.3.2 Erosion Protection Works

If an outfall was protected by any erosion protection works it was noted, acknowledging that outfalls with scour pads are less likely to be undermined and outfalls adjoined by bank protection works are less likely to be outflanked. The condition of all observed erosion protection works was also assessed.

Efforts were also made to verify the size, headwall configuration and location of each outfall as part of Aquafor's field assessments. Size of each outfall was categorized based on pipe diameter, and placed in three groups: Small (<250 mm), Medium (250 - 1200 mm), and Large (>1200mm). A summary of the storm sewer outfall assessment including outfall size, condition and notes on both headwall and erosion control assets associated with each outfall is located in **Appendix L.**

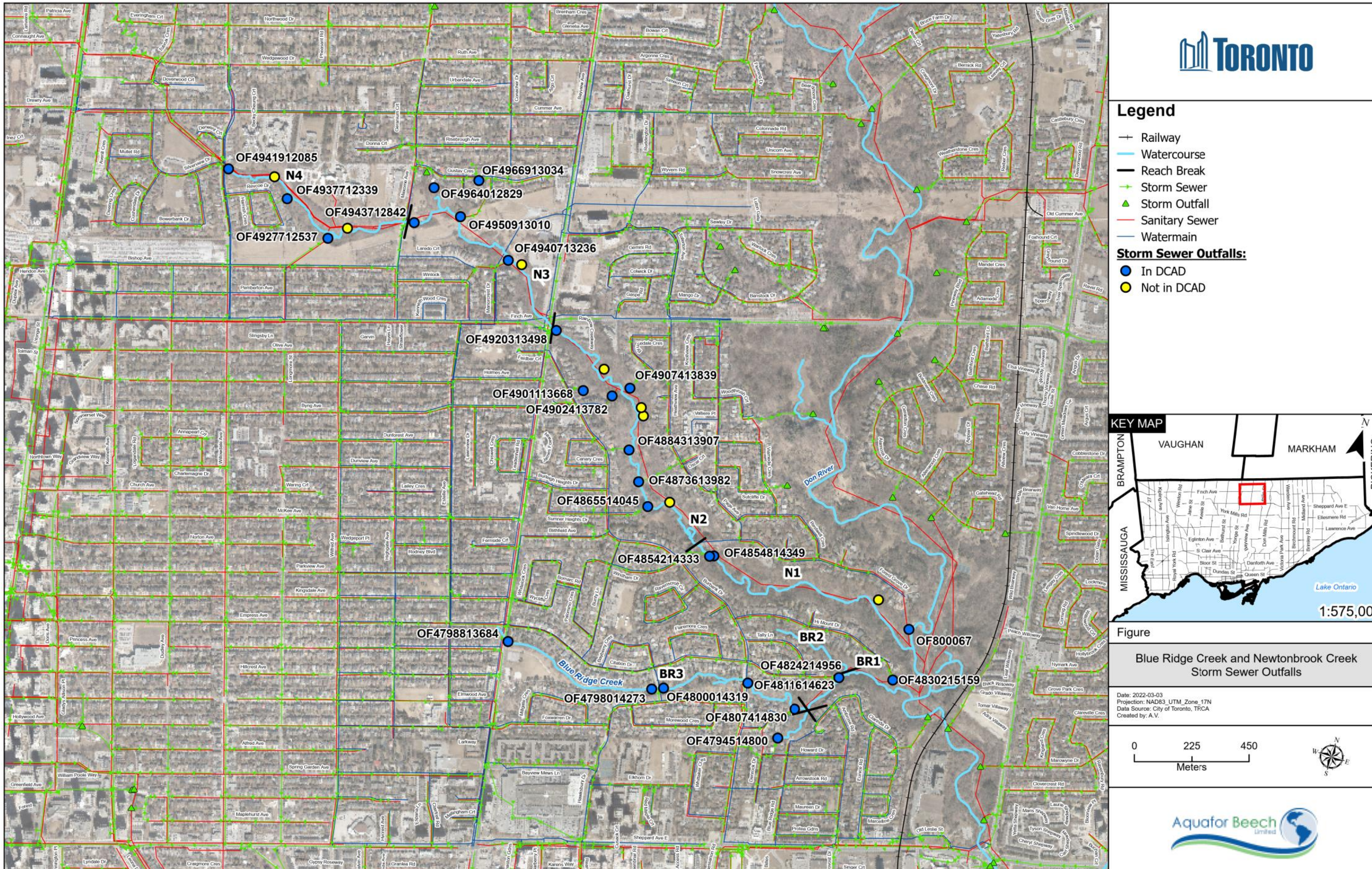

Figure 3-71: Spatial Distribution of Storm Sewer Outfalls in Newtonbrook and Blue Ridge Creek Study Area

3.2.1.4 Erosion Control Structures & Erosion Hazard Sites

While the emphasis of the NCGSMP is on the evaluation of erosion related risks to Toronto Water infrastructure, it is acknowledged that ongoing erosion, within the NCGSMP Study Area, also impacts non-municipal infrastructure and private properties. Erosion related risks to private property are predominately managed by the Toronto and Region Conservation Authority through their Erosion Control Structures (ECS) and Erosion Hazard Sites (EHS) monitoring programs.

The ECS monitoring program evaluates the condition of various erosion control structures designed to mitigate erosion related risks to private properties. The program documents the condition of each structure and assesses attributes such as recent movement, gullying, slope instability, and future instability. Background information for nineteen (19) Erosion Control Assets have been delivered by TRCA. A table summarizing the Erosion Control Structures present within the study area is provided in **Appendix M.**

TRCA also implements an EHS monitoring program for a number of erosion hazard sites. These sites may be flagged by TRCA staff during general inspections or by private property owners. Many of these sites threaten private or municipal property but to varying degrees of severity and urgency. Similar to the Erosion Control Asset program, these sites are inspected annually to evaluate any changes to the hazard site, especially for changes affecting or possibly affecting nearby private structures. For the erosion hazard sites in Newtonbrook Creek, the correlated Toronto Water infrastructure, if any, was included. A table showing the Erosion Hazard Sites present within the study area is provided in **Appendix N,** while a tabular summary of recent and ongoing TRCA projects within the NCGSMP study area is presented in **Appendix O.**

3.2.2 Geomorphic Risk Assessment Of Toronto Water Infrastructure

This section presents the results of the Newtonbrook Creek Geomorphic Risk Assessment in terms of the horizontal (lateral erosion) and vertical (scour) hazards to Toronto Water infrastructure. In addition, storm outfalls are assessed as a separate category. The risk assessment presented in this section provides the basis to: prioritize the risk sites to be mitigated; to develop projects, alternative solutions, and conceptual designs; and to recommend an implementation plan in consultation with Toronto Water for scheduling and capital budgeting.

3.2.2.1 Vertical Risk Assessment (Sanitary Sewer and Watermain Crossings)

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 and Blue Ridge Creek—have cut vertically down to expose previously buried sewer pipes. 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.

Vertical risk was assessed within the study area at locations where sanitary sewers & watermains cross beneath the watercourse. A technical scoring methodology was developed to assess the vertical erosion risk. Each sanitary sewer and watermain crossing location were given a score out of 10, with larger scores representing sites with higher levels of risk. **Table 3-24** summarizes the technical scoring approach, including the evaluation criteria of each scoring component.

Table 3-24: Vertical Risk Scoring – Detailed Evaluation Criteria

Category	Vertical Risk Score				
	1	2	3	4	5
Time to Contact	Time to Contact > 50 Years	Time to Contact 25-50 Years	Time to Contact 10-25 Years	Time to Contact 1-10 Years	Sewer is Exposed
Downstream Bed Level Change	Bed level drop of < 0.25 m	Bed level drop of 0.25 – 0.5 m	Bed level drop of 0.5 – 0.75 m	Bed level drop of 0.75 – 1.0 m	Bed level drop of ≥ 1.0 m
Susceptibility of Bed Armour to Erosion	Engineered bed works in condition to continue armouring the bed.	Unprotected natural channel with cobble bed substrate	Unprotected natural channel bed with gravel bed substrate	Unprotected natural channel with sandy or silty substrate	Failed engineered bed works, exposure of pipes, sewer, or other previously buried infrastructures

The vertical risk component includes a time of contact score out of 5, a downstream bed level change score out of 5, and a susceptibility of bed armour to erosion score out of 5. The total score out of 15 provides a semi-quantitative measure of risk and opportunity to guide subsequent decisions regarding stream restoration opportunities. The vertical risk component categories are described in greater detail below.

3.2.2.1.1 Time to Contact

Time to contact is the time for expected vertical erosion processes to result in the exposure of linear infrastructure crossing beneath the active channel. In other words, the expected time until the active channel comes into contact with the infrastructure at risk, measured in years. Time to contact is evaluated by dividing the vertical depth of cover at each risk site by the average vertical erosion rate of the associated reach. Credit is then given to the remaining lifespan of any erosion control measures if present:

$$Time\ to\ Contact\ (years) = \frac{Depth\ of\ Cover\ (m)}{Vertical\ Erosion\ Rate\ (m/year)} - Remaining\ Erosion\ Control\ Lifespan\ (years)$$

The first step in evaluating vertical time to contact is to estimate the depth of cover over sanitary sewer & watermain crossings, where depth of cover is defined as:

$$Depth\ of\ Cover\ (m) = Channel\ Thalweg\ Elevation\ (m) - Sewer\ Obvert\ Elevation\ (m)$$

Sewer & watermain obvert elevations were sourced from DCAD 2.0, Engineering As-Built Records, and Topographic Survey Results. Channel thalweg elevations were based on 2021 topographic surveys, and supplemented with LiDAR data in a few locations within the valley corridor.

Once depth of cover is evaluated, the rates of vertical erosion are determined on a reach-by-reach basis by comparing the cross-sectional profiles of the creek overtop of sanitary sewer & watermain crossings from historic as-built engineering drawings to recent topographic survey data at the same location.

More specifically, for each infrastructure crossing that was surveyed as part of the NCGSMP, as-built drawings provided by the City of Toronto were overlain onto the surveyed cross-sectional profile, where available, to illustrate the magnitude of vertical erosion between the time of construction and time of the updated survey. The difference in elevation from the as-built thalweg to the existing mean substrate elevation is assumed to represent the value of net degradation or aggradation. **Figure 3-72** provides an illustration of this process, which was repeated for multiple locations in each reach in order to determine representative rates of vertical erosion for all reaches.

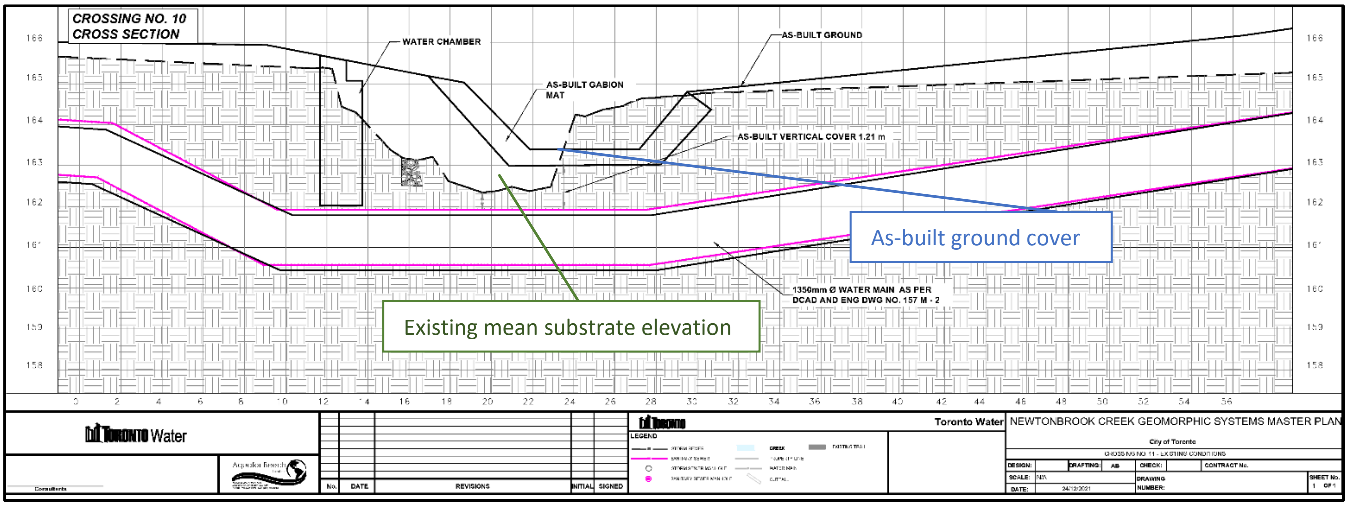

Figure 3-72: As-built drawing of Crossing #10, Reach N3, showing the existing mean substrate elevation (green), the as-built ground cover (blue)

Then by dividing the net erosion value by the time between the date of the survey and the date of the as-built drawing, historic annual rates of erosion in both the horizontal and vertical directions are obtained.

3.2.2.1.2 Downstream Bed Level Change

Vertical risk was also assessed based on the magnitude of bed level change downstream of an infrastructure crossing. Downstream bed level change was measured as the change in elevation from a sanitary sewer crossing to the bottom of the grade control structure immediately downstream of the crossing. If a grade control structure was not present, the grade change was instead measured over a distance of two (2) – three (3) channel widths downstream of the crossing. Higher risk was associated with higher magnitudes of bed level change, due to the risk of a sewer or watermain crossing becoming undermined as result of the failure of downstream grade control structures and/or head cutting.

3.2.2.1.3 Susceptibility of Bed Armour to Erosion

The susceptibility of the channel bed to erosion was qualitatively assessed at each crossing location, taking into consideration substrate material overtop of the crossing as well as the presence and condition of any engineered bed protection works (or grade control structures) either overtop of the crossing or immediately downstream. Crossings located at storm sewer outfalls were also generally assigned a higher level of risk to account for the impact of outfall discharge on localized scour. Sites with exposed infrastructure crossings, or signs of localized scour, were also given higher risk scores for this component.

3.2.2.1.4 Vertical Risk Assessment Results

The Vertical risk scoring results for all eighteen (18) sanitary sewer crossings and one (1) watermain crossing are presented in **Appendix P**. Generally, vertical erosion sites were then classified as ranging from very low risk to very high risk based on their vertical erosion risk score. The classification of risk is as follows:

- **Very High Risk:** Vertical erosion risk score of 13 – 15, Colored Red
- **High Risk:** Vertical erosion risk score of 11 – 12, Colored Orange

- **Moderate Risk:** Vertical erosion risk score of 8 – 10, Colored Yellow
- **Low Risk:** Vertical erosion risk score of 5 – 7, Colored Green
- **Very Low Risk:** Vertical erosion risk score of 3 – 4, Colored Dark Green

3.2.2.2 Horizontal Risk Assessment (Lateral Risks to Sanitary Sewers and Watermains)

Risk due to channel migration and valley wall erosion was evaluated through analysis of aerial photographs (current and historic) and detailed examinations of meander geometry in addition to topographic survey measurements. In a number of locations throughout Newtonbrook Creek, risk due to horizontal channel movement has been reduced due to the presence of engineered bank treatments. However, in many cases, these bank treatments have failed or are failing. Where the channel bank toe has not been hardened and the banks are poorly vegetated, infrastructure adjacent to channel banks is at an increased risk of failure. Lateral risk was assessed at locations where sanitary sewers or watermains, including sanitary sewer lines, sanitary sewer maintenance holes, watermain lines and water chambers, are located within 20 metres of the edge of the top of bank. Because the main trunk sewer runs parallel to the main creeks, a minimum distance of 20 metres accounts for most of Newtonbrook and Blue Ridge Creek. Thus, only infrastructure along a cut bank is considered to be a horizontal risk site.

A technical scoring methodology was developed to assess the lateral erosion risk. Each potential risk location was given a score out of 15, with larger scores representing sites with higher levels of erosion risk. **Table 3-25** summarizes the technical scoring approach, including the evaluation criteria of each scoring component.

Table 3-25: Lateral Risk Scoring – Detailed Evaluation Criteria

Category	Lateral Risk Score				
	1	**2**	**3**	**4**	**5**
Time to Contact	Time to Contact > 50 Years	Time to Contact 25-50 Years	Time to Contact 10-25 Years	Time to Contact 1-10 Years	Sewer is Exposed
Radius of Curvature to Width Ratio	9-11	7-9	5-7	3-5	<3
Lateral Infrastructure Condition	Erosion protection works in excellent condition	Erosion protection works in good condition	Erosion protection works in fair condition	Erosion protection works in poor condition	Erosion protection works have failed or no works in place

The lateral risk component includes a time to contact score out of 5, a radius of curvature to width ratio risk score out of 5, and a lateral infrastructure condition score out of 5. The total score out of 15 provides a semi-quantitative measure of risk and an opportunity to guide subsequent decisions regarding stream restoration opportunities. The lateral risk component categories are described in greater detail below.

3.2.2.2.1 Time to Contact

The time to contact is the time for expected lateral erosion processes to result in the exposure of infrastructure running adjacent to the active channel. In other words, the expected time until the active channel comes into contact with the infrastructure at risk, measured in years. The time to contact is based on the horizontal offset or lateral depth of cover at the risk site divided by the average lateral erosion rate of the associated reach. Credit is then given to the remaining lifespan of any erosion control measures if present:

$$Time\ to\ Contact\ (years) = \frac{Lateral\ Depth\ of\ Cover\ (m)}{Lateral\ Erosion\ Rate\ (m/year)} - Remaining\ Erosion\ Control\ Lifespan\ (years)$$

The first step in evaluating horizontal time to contact is to estimate the horizontal offset or lateral depth of cover, defined as the minimum distance from the lateral infrastructure to the edge of banks. Lateral depths of cover (or offset) were calculated using a combination of as-built drawings, 2021 topographic survey data, updated base mapping and aerial imagery. A net erosion value was calculated for each reach, based on the lateral erosion seen from as-built drawing overlays and derived from aerial imagery. A time to contact is then calculated by dividing the depth of cover by the erosion rates. Where there was a vertical component to the point of contact, the vertical rates of scour were also confirmed to ensure that the time-to-contact reached the asset in both the vertical axis and horizontal axis.

3.2.2.2.2 Radius of Curvature to Width Ratio (Rc/w)

Theoretical expectations for lateral migration rates have been related to radius of curvature, or specifically the radius of curvature to width ratio (Rc/w; Hickin and Nanson, 1984; and Hooke, 1991). The expectation is that bend "tightness" (or Rc/w) influences the migration rate, where the highest migration rates can be expected between low Rc/w values of 2 and 3 (i.e., Rc/w = 2.5). The radius of curvature and channel width were measured for the meander bend adjacent to each lateral risk location, and used to calculate the Rc/w ratio:

$$Rc/w = \frac{Radius\ of\ Curvature\ (m)}{Channel\ Width\ (m)}$$

Risk locations with lower Rc/w ratios were assigned a higher level of risk.

3.2.2.2.3 Lateral Infrastructure Condition

The condition of bank protection works proximal to each Toronto Water infrastructure asset was visually assessed, with lowest risk scores applied if works were "like-new", and highest risk scores applied if the works had failed or the banks were completely unprotected.

3.2.2.2.4 Horizontal Risk Assessment Results

The horizontal risk scoring results for all of Newtonbrook and Blue Ridge Creek are presented in **Appendix Q.** Generally, horizontal erosion sites were then classified as ranging from very low risk to very high risk based on their horizontal erosion risk score. The classification of risk is as follows:

- **Very High Risk:** Horizontal erosion risk score of 13 – 15, Colored Red
- **High Risk:** Horizontal erosion risk score of 11 – 12, Colored Orange
- **Moderate Risk:** Horizontal erosion risk score of 8 – 10, Colored Yellow
- **Low Risk:** Horizontal erosion risk score of 5 – 7, Colored Light Green
- **Very Low Risk:** Horizontal erosion risk score of 3 – 4, Colored Dark Green

3.2.2.3 Storm Sewer Outfall Risk Assessment

Storm sewer outfalls are typically designed to discharge directly to the receiving watercourse, and consequently are susceptible to failure from channel erosion processes. The most common modes of failure for outfall infrastructure are undercutting and outflanking. Channel incision and poorly managed energy dissipation can contribute to the formation of scour pools at the base of outfalls. As these pools deepen, they begin to undercut and undermine storm sewer outfalls leading to failed infrastructure. In a similar fashion lateral channel migration can expose the side of an outfall to constant hydrodynamic loadings, eventually causing failure of the exposed infrastructure. In many cases the best form of protection for storm sewer infrastructure against channel erosion processes is the construction of local bed and bank protection works to protect against undercutting and outflanking, coupled with setting the outfall back from the main channel corridor to provide distance for the channel to migrate without impacting the integrity of storm sewer infrastructure. Naturally, outfalls may also fail from structural deterioration. Giving consideration to all of these factors the following risk scoring system, as defined in **Table 3-26**, was developed for the storm sewer outfall risk assessment. Scores ranged from 3-15 with larger scores representing a higher level of erosion related risk.

Table 3-26: Storm Sewer Outfall Risk Scoring – Detailed Evaluation Criteria

Category	Storm Sewer Outfall Risk Score				
	1	**2**	**3**	**4**	**5**
Outfall Condition	Outfall is in excellent condition	Outfall is in good condition	Outfall is in fair to moderate condition	Outfall is in poor condition	Outfall has failed
Setback from Main Channel	Setback is > 20.0 m	Setback ranges from 5 – 20 m	Setback ranges from 2-5 m	Setback ranges from 0 – 2 m	Outfall outlets directly to the watercourse or is currently outflanked
Erosion Protection Works Condition	Erosion protection works in excellent condition	Erosion protection works in good condition	Erosion protection works in fair condition	Erosion protection works in poor condition	Erosion protection works have failed or no works in place

The storm sewer outfall risk assessment includes an outfall condition score out of 5, a setback from the main channel score out of 5, and an erosion protection works condition score out of 5. The total score out of 15 provides a semi-quantitative measure of risk and opportunity to guide subsequent decisions regarding storm outfall restoration opportunities. The storm sewer outfall risk component categories are described in greater detail below.

3.2.2.3.1 Outfall Condition

The condition of each storm sewer outfall was visually assessed, with lowest risk scores applied if outfall structures were "like-new", and highest risk scores applied if the outfall had failed.

3.2.2.3.2 Setback from Main Channel

The degree to which each outfall was setback from the main branch of Newtonbrook/Blue Ridge Creek was assessed using a combination of survey data, base mapping, remote sensing products and updated aerial imagery. Lowest risk scores were applied to outfalls setback over 20.0 metres from the edge of the valley corridor while highest risk scores were assigned to infrastructure discharging directly to the creek.

3.2.2.3.3 Erosion Protection Works Condition

The condition of bed & bank protection works in the vicinity of each outfall were visually assessed, with lowest risk scores applied if works were "like-new", and highest risk scores applied if the works had failed or were not in place.

3.2.2.3.4 Storm Sewer Outfall Risk Assessment Results

The storm sewer outfall risk assessment results for all thirty-two (32) storm sewer outfalls located and assessed in the field are provided in **Appendix R.** Generally, storm outfall sites were then classified as ranging from very low risk to very high risk based on their storm sewer outfall risk score. The classification of risk is as follows:

Very High Risk: Storm Outfall risk score of 13 – 15, Colored Red
High Risk: Storm Outfall risk score of 11 – 12, Colored Orange
Moderate Risk: Storm Outfall risk score of 8 – 10, Colored Yellow
Low Risk: Storm Outfall risk score of 5 – 7, Colored Light Green
Very Low Risk: Storm Outfall risk score of 3 – 4, Colored Dark Green

3.2.3 Geomorphic Risk Assessment Results

Through the vertical, horizontal, and storm sewer geomorphic risk assessment process, the seventy-two (72) risk sites were prioritized based on overall risk. It was determined, through consultation with the City of Toronto, that only the twenty-four (24) highest priority sites be carried forward to conceptual design. These sites contain fourteen (14) sites where there is an immediate risk of infrastructure failure (i.e., exposed sewer crossing or a failed outfall) **(Table 3-27)**, as well as ten (10) additional sites where unmitigated erosion processes are expected to create an immediate risk to municipal infrastructure within the next 5-50 years (**Table 3-28**).

Table 3-27: Summary of Priority Sites with Exposed Assets at Immediate Risk of Failure

Priority Rank	Project Description	Risk ID	Asset ID	Reach	Risk Score
1	Exposed Sanitary Sewer Maintenance Hole and Lateral Risk to Sanitary Sewer Near Pedestrian Trail	Lateral Risk #1 and Crossing #2	SL4033582 MH4856914969 SL4033032	N1	12
2	Exposed Sanitary Sewer Crossing at Restwell Crescent	Crossing #3	SL4032406	N1	11
3	Failed Storm Water Outfall at Forest Grove Drive	Outfall #3	OF4854214333	N1	11
4	Failed Storm Water Outfall at Canary Crescent	Outfall #7	OF4884313907	N2	13
5	Exposed Sanitary Sewer Crossing at Farmingdale Road	Crossing #5	SL4031857	N2	15
6	Exposed Sanitary Sewer Crossing upstream of Farmingdale Road	Crossing #6	SL4031887	N2	12
7	Exposed Sanitary Sewer Crossing Downstream of Finch Avenue and Bayview Avenue	Crossing #7	SL4031887	N2	15
8	Exposed Sanitary Sewer Maintenance Hole and Lateral Risk to Sanitary Sewer Downstream of Finch and Bayview Avenue	Lateral Risk #10	SL4031888	N2	15
9	Exposed Sanitary Sewer Crossing at Finch and Bayview Avenue	Crossing #8	SL4033483	N2	13
10	Exposed Watermain Chamber at Manorcrest Drive	Crossing #10	LN24062	N3	9
11	Exposed Sanitary Sewer Crossing upstream of Blessed Trinity Parish	Crossing #13	SL4032523	N3	9
12	Failed Storm Sewer Outfall at Hi Mount Drive	Outfall #25	OF4830215159	Br1	11
13	Failed Storm Sewer Outfall at Citation Drive	Outfall#26	OF4824214956	Br1	14
14	Exposed Sanitary Sewer Crossing at Sifton Court	Crossing #19	SL4029711	Br3	15

Table 3-28: Summary of Priority Sites with Secondary (Non-Immediate) Risks

Priority Rank	Project Description	Risk ID	Asset ID	Reach	Risk Score
15	Lateral Risk to Sanitary Sewer downstream of Sifton Court	Lateral Risk #22	SL4030293	Br1	13
16	Lateral Risk to Sanitary Sewer at Heathview and Page Avenue	Lateral Risk #6	SL4033585	N2	13
17	Lateral Risk to Sanitary Sewer upstream of Maxome Avenue	Lateral Risk #12	SL4032958	N4	13
18	Lateral Risk to Sanitary Sewer upstream of Forest Grove Drive	Lateral Risk #5	SL4034031	N2	13
19	Lateral Risk to Sanitary Sewer at Finchgate Court	Lateral Risk #7	SL4032401	N2	12
20	Lateral Risk to Sanitary Sewer at Brucedale Crescent	Lateral Risk #9	SL4031887	N2	12
21	Lateral Risk to Sanitary Sewer at Ambrose Road	Lateral Risk #20	SL4030487	Br1	11
22	Lateral Risk to Sanitary Sewer Downstream of Finch Avenue and Bayview Avenue	Lateral Risk #11	SL4033483 MH4918613545 SL4031888	N2	11
23	Lateral Risk to Sanitary Sewer at Hi Mount Drive	Lateral Risk #17	SL4053177	Br1	11
24	Lateral Risk to Sanitary Sewer downstream of Forest Grove Drive	Lateral Risk #4	SL4033584	N1	11

A map illustrating the spatial distribution of the top twenty-four (24) Priority Sites across the NCGSMP study area is provided as **Figure 3-73**.

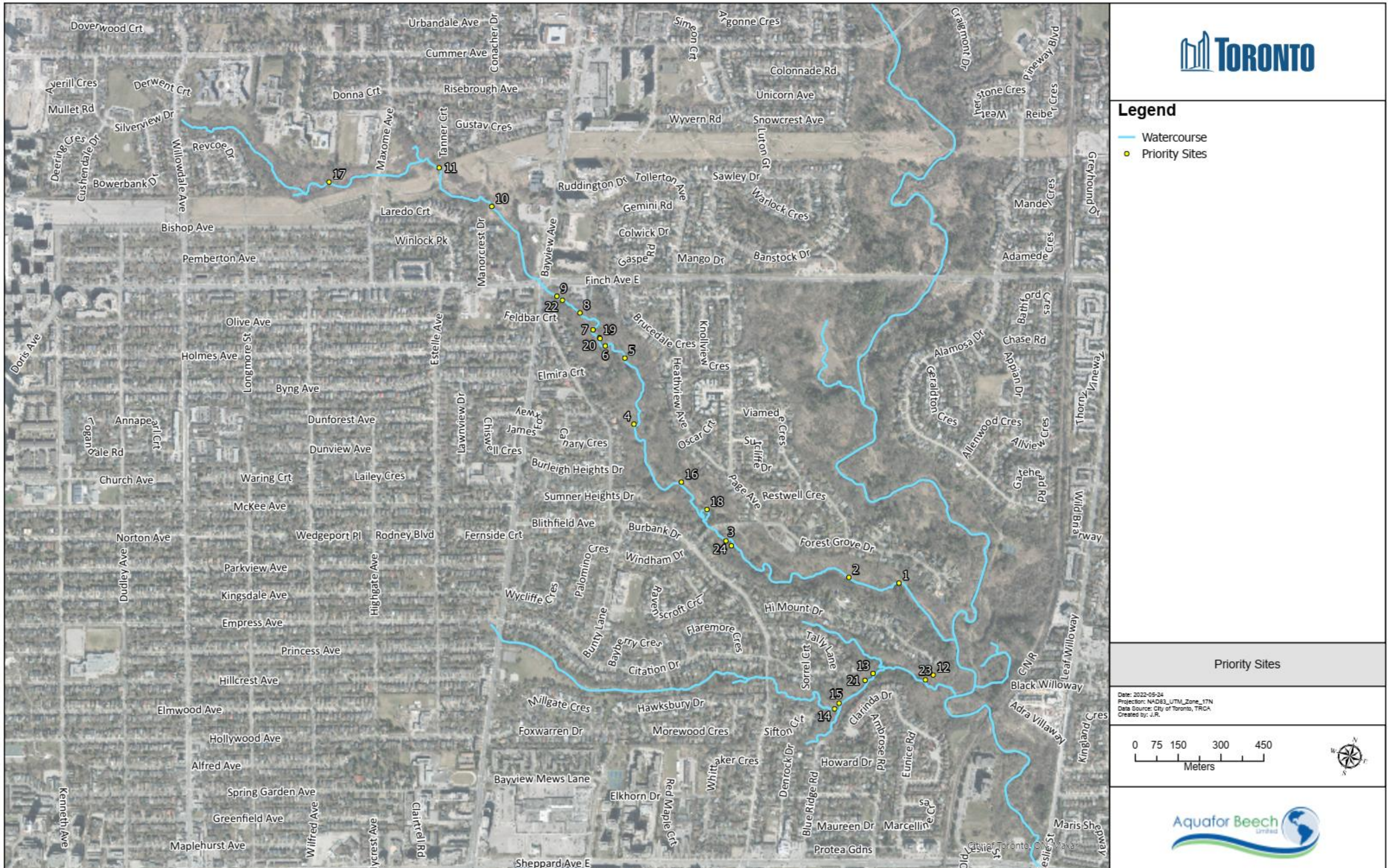

Figure 3-73: Spatial Distribution of Twenty-Four (x24) High-Priority Sites