GERMAN MILLS CREEK GEOMORPHIC SYSTEMS MASTER PLAN
PHASE 2 TECHNICAL MEMORANDUM
DEVELOPMENT OF ALTERNATIVE SOLUTIONS

Prepared for:
CITY OF TORONTO

Prepared by:
MATRIX SOLUTIONS INC., A MONTROSE ENVIRONMENTAL COMPANY

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December 2024
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PHASE 2 TECHNICAL MEMORANDUM

DEVELOPMENT OF ALTERNATIVE SOLUTIONS

Prepared for the City of Toronto, December 2024

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December 9, 2024

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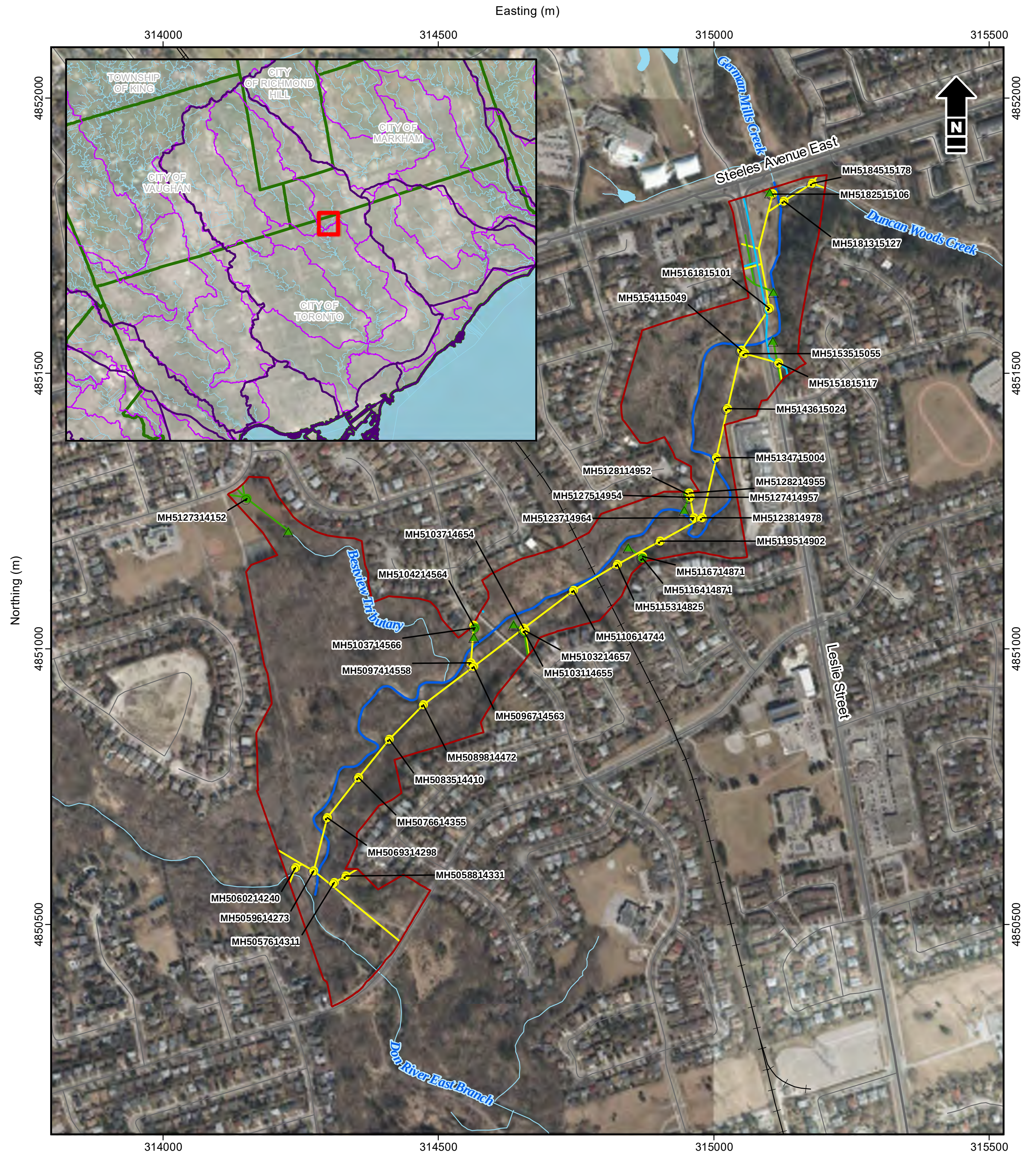
APPENDICES

1 INTRODUCTION

This technical appendix summarizes provides details regarding Phase 2 of the Master Plan, "Development of Alternative Solutions" which documented the existing conditions of German Mills Creek as well as forecasted the future conditions of the channel to help assess future risks to Toronto Water infrastructure (Figure 1-1). Finally, based on existing and future conditions, and type of risk(s) at each site, alternative solutions to specifically address erosion concerns based on the identification of 11 local erosion mitigation project areas has been proposed for evaluation through Phase 3 (Master Plan Section 4 and Appendix F).



Focused Study Area
Watershed Boundary
Subwatershed Boundary
Municipal Boundary
Watercourse
Highway
Road
Railway
German Mills Creek Within GSMP Study Area

Sanitary Sewer
Storm Sewer
Watermain
Sanitary Sewer Maintenance Hole
Storm Sewer Maintenance Hole
Stormwater Outfall

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City of Toronto
German Mills Creek GSMP EA

General Study Area

Date:	Project:	Submitter:	Reviewer:
July 2022	32227	N. Cyples	J. McDonald

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Figure
1-1

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2 GEOMORPHIC PAST CONDITIONS

2.1 Watershed Context

The study area is located within the German Mills subwatershed, which comprises a portion of the larger Don River watershed. The entirety of the German Mills Creek channel extends 26 km in length and contains a drainage area of approximately 41.7 km^2 (Ontario Flow Assessment Tool; OFAT [MNRF 2021a]). German Mills Creek originates in the southern slope of the Oak Ridges Moraine, eventually draining into the Don River East Branch. The focus of this study is on the lower-most reaches of German Mills Creek within Toronto from Steeles Avenue to the confluence with the East Don River.

The Don River watershed contains a catchment of approximately 360 km^2 and is 96% urbanized. Mean total discharge for the Don River is approximately 3.9 m^3/s and, on average, has been increasing 0.44% per year (TRCA 2009a). Baseflow accounts for approximately 49% of the total flow in the Don River watershed, in which German Mills Creek accounts for 12%. The remaining flow (51%) is derived from runoff and includes discharges from storm sewers, combined sewers, and wastewater treatment plants. The percent impervious cover within the German Mills Creek subwatershed was 39% in 2009 (TRCA 2009a) and was calculated more recently at 47% (Don River PCSWMM model, AECOM 2018). Impervious cover influences recharge rates, whereby recharge rates are reduced in more urbanized settings due to paved driveways and parking lots comprising a large amount of total area, thereby reducing the interception and infiltration of precipitation. Higher and more frequent flows are expected within the creek and will result in increased discharge from storm and combined sewers contributing to greater rates of erosion and risk of flooding.

Table 2-1 provides a simplified breakdown of landcover for the German Mills Creek subwatershed from OFAT. An example of simplified landcover is that “treed” includes results for deciduous, mixed, coniferous, plantations, and hedgerows.

TABLE 2-1 German Mills Creek Landcover

Land Cover	Proportion
Wetland	1.27%
Treed	5.38%
Agricultural/Rural	11.06%
Urban	82.29%
TOTAL	**100.00%**

2.1.1 Physiography and Surficial Geology

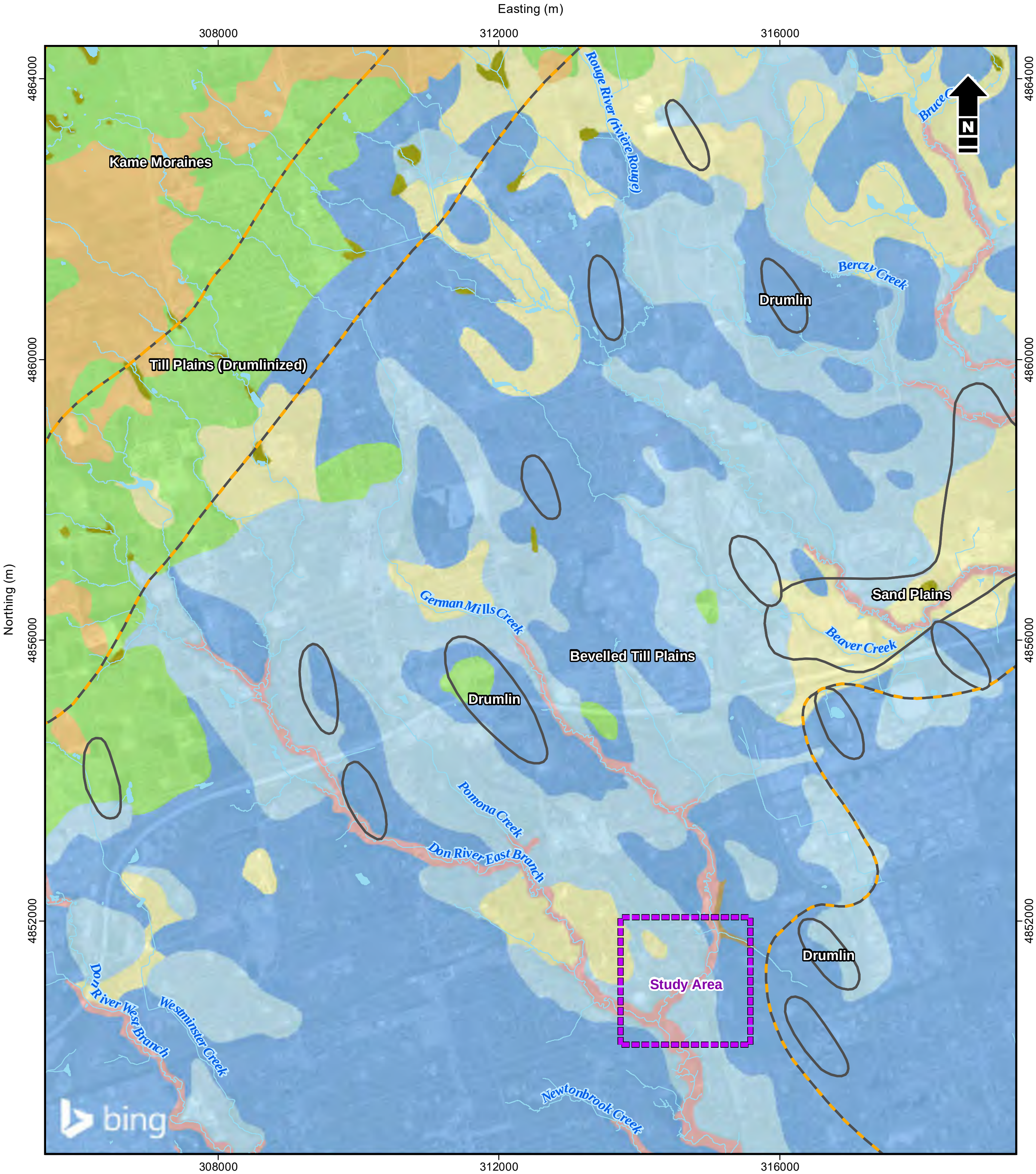
Similar to other tributaries within the Don River watershed, German Mills Creek is semi-alluvial in nature, meaning the channel contains a thin layer of alluvium that resides on top of a more resistant base material such as glacial till (TRCA 2009b). In contrast, a purely alluvial stream attains its channel configuration and floodplain entirely from the conveyance and deposition of sediment or alluvium sourced by erosion of the surrounding landscape. Semi-alluvial streams in southern Ontario are relatively young in geologic terms, with most being created after the Wisconsin glaciation starting around 10,000 years ago (also known as the Holocene Epoch). The morphology of semi-alluvial channels is partially controlled by the properties of the glacial deposits in which they flow through as opposed to solely being controlled by the characteristics of alluvium transported from upstream and stored in the floodplain deposits.

German Mills Creek is situated within the Peel Plain physiographic region of southern Ontario. This region is characterized as gently rolling terrain and topography that dips toward the Lake Ontario basin to the south (i.e., the "South Slope;" Chapman and Putnam 1984). The Peel Plain is an area of low relief with the presence of bedrock at shallow depths. Although the Peel Plain is now almost completely deforested, in the past it supported high-quality hardwood forests within well-drained areas (Region of Peel 2011). Surficial geology mapping (OGS 2010) indicates German Mills Creek consists of modern alluvium deposits (Figure 2-1). The area surrounding the modern alluvium consists of low permeability, fine-grained lacustrine deposits (sandy silt till, silt, and clay), and the Newmarket Till. These deposits significantly influence the groundwater resources in the area. The net groundwater infiltration rate in the Don River watershed is approximately 123 mm/year (TRCA 2009a); however, no significant groundwater recharge has been documented within the German Mills Creek subwatershed.

2.1.2 Stream Reaches

The parameters that influence channel form, such as the amount and size of available sediment, valley shape, land use, or vegetation cover vary over the length of a stream. Lengths of channel that exhibit similar characteristics with respect to these parameters are known as reaches. Reach lengths vary with the scale of the channel, often longer for a larger watercourse, while smaller watercourses exhibit more variability resulting in shorter reaches. Delineation of reaches is beneficial as it provides a system for collecting, analyzing, and comparing data.

Reach delineation considers external parameters such as local geology, topography, valley setting, hydrology, riparian vegetation, land use, and artificial modifications to the channel (e.g., road crossing). Stream reaches for the study area of German Mills Creek are presented in Figure 2-2 based on recent base mapping, orthophotography and verified as part of field assessment documented in Section 3.1. Channel planform, geometry, slope, as well as valley confinement and the impact of road crossings were the criteria generally used to determine reach breaks.



Physiographic Landforms
Physiographic Region
Watercourse

Surficial Geology Unit (OGS 2010)

- 2 - Lower (Drift) Deposits: till, fine-medium sand, and laminated silt and clay
- 3 - Glacial Deposits: Newmarket/ Northern/Bowmanville Till
- 4 - Glacial Deposits: Halton Till
- 5 - Moraine Deposits: fine sand to gravel
- 7 - Glacial Lake Deposits: silt and clay
- 8 - Glacial Lake Deposits: sand and silty sand
- 9 - Organic Deposits: peat, muck, and marl
- 10 - River Deposits: sand and gravel

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NAD27 MTM zone 10

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Surficial Geology

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Figure
2-1

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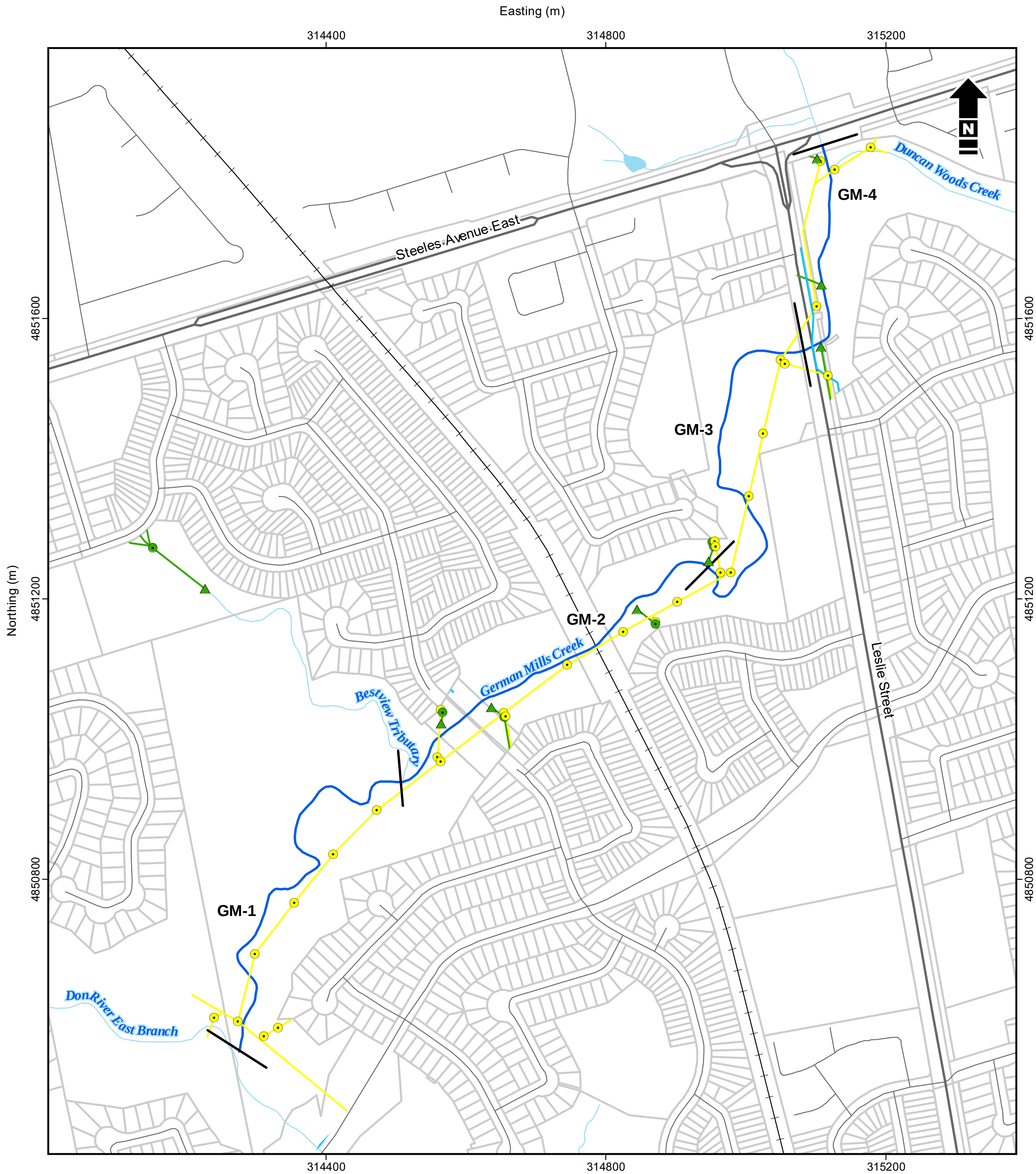

Property Boundary
Watercourse
German Mills Creek Within GSMP Study Area
Highway
Road
Railway
Reach Break

Sanitary Sewer
Storm Sewer
Watermain
Stormwater Outfall
Sanitary Sewer Maintenance Hole
Storm Sewer Maintenance Hole

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German Mills Creek GSMP EA

Reach Breaks

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Figure
2-2

2.2 Archaeological Assessment

Toronto and Region Conservation Authority (TRCA) completed a Stage 1 archaeological assessment for the study area as is typically required under the Municipal Class EA process. Available maps, aerial photographs, and related background information were reviewed to document the historical and current land uses, geographic and cultural features, and previous archaeological field work.

Archaeological potential was evaluated for the study area with respect to historic periods of area settlement including pre-contact/post-glaciation (12,000 years BP to 1650 AD), post-contact (1650 AD to 1778), and Euro-Canadian settlement (1778 to Present). It was determined that there is very high potential for encountering pre-contact Indigenous sites in the study area, and historical Euro-Canadian sites. Additionally, four archaeological sites are registered within 1 km of the study area and one heritage property is registered within 50 m (James Cummer House). As a result, Stage 2 archaeological assessments are recommended for all areas within the immediate study area, with the exception of the footprint of the multi-use trail, and recent trail and watercourse construction in the vicinity of Steeles Avenue and Leslie Street (refer to Maps 13 and 14 in Appendix C1). Thus, associated management recommendations are provided for future Stage 2 study requirements prior to any ground disturbance activities, as detailed in the full TRCA Stage 1 report provided in Appendix C1 (TRCA 2021).

2.3 Historical and Existing Land Use

Insight into the historical land and existing use of the study area has been primarily derived from aerial photograph records, archaeological assessments, and other background documents (e.g., TRCA watershed reports). Digital, geo-referenced air photographs were provided by the City include those dating from 1954, 1965, 1978, and several years from 2005 until 2018. For interim years, and those prior, online aerial photographs from the City's website have been utilized to further contextualize land use changes (1947 to 1992; City of Toronto 2021), and historical channel adjustments (refer to Section 2.4). The archaeological assessment provides pre- and early-settlement context for the study area and adjacent lands (Section 2.2; Appendix C1).

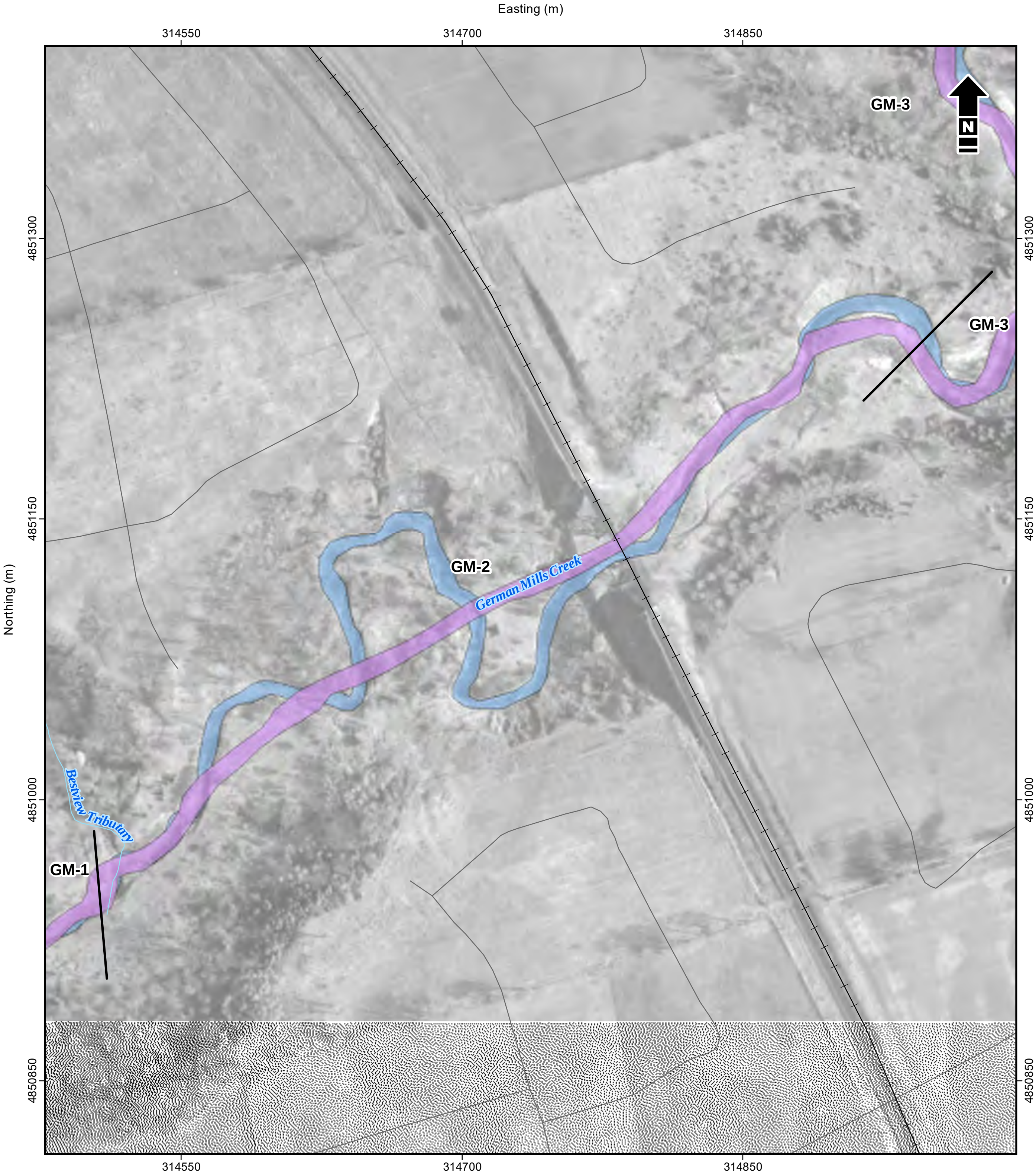
Prior to the 1820s, valleys associated with the Don River were described as dense forests comprised numerous species of tree and shrubs. Forest clearing of the Don Valley later followed and was ongoing into the 1900s (TRCA 2021). Air photograph interpretation (Section 2.4) revealed that there was still significant evidence of forest clearing, with relatively limited forest cover, compared to the current state (2018). The change from rural to urban land use with subdivision development occurred from south to north along Leslie Street and easterly along Steeles Avenue from Bayview Road beginning in the late 1960s, with subdivision construction ongoing in 1978 and into the early 1980s. Construction of asphalt roads and subsequent widening and bridge upgrades along Steeles Avenue and Leslie Street represent the only major transportation upgrades within the study area. Stormwater and sanitary sewer servicing for area developments use the valley as a point to discharge water (stormwater) or transport sewage (sanitary) via trunk gravity sewers.

Existing land use is mainly that of an urban nature (residential, transportation, institutional). However, the immediate valley comprises parkland with a multipurpose trail running longitudinally, forested valley slopes, and partially forested floodplain. The broader German Mills watershed extends northernly into York Region (City of Markham and Town of Richmond Hill) and is primarily urbanized.

2.4 Historical Channel Conditions

German Mills Creek is highly urbanized and has been subject to close to a century of direct and indirect consequence as land use changed and urban settlement expanded. The creek is naturally a sinuous, semi-alluvial stream within a well-developed floodplain and valley. It is naturally confined by steep valley contacts, and it is further influenced by interactions between soft and moderately consolidated glacial, glaciofluvial, and glaciolacustrine deposits. Over time, urbanization has led to increased stormwater runoff that has modified the prevailing flow regime and increased the magnitude and frequency of the flood response. Although, natural responses are expected and ongoing, direct modification of the channel through realignments and engineered materials for erosion control has historically had the greatest impact on channel conditions. These impacts are not only localized to specific sites of modification, but there have also been upstream and downstream impacts. Further detail on the channel history and influences, including direct modification, are included in Section 2.5.

Digitized channels from the available historical aerial photographs and orthophotography are provided in Figure 2-3 and Appendix C2, including an overview of the historical channel traces (Figures C2a to C2e; Appendix C2). The historic channel alignments revealed a pronounced and significant reduction of channel length, approximately 500 m (Figure 2-4), which has been interpreted to be primarily the result of artificial channel realignments associated with construction of the sewers. The majority of this loss occurred between 1965 and 1978, and then another 50 m was lost after 1978 (1981 according to the online photograph record). It is noted that the total length for Reach GM-2 in 1965 may be less accurate due to the obstruction by trees and shadows in the historic air photograph. However, the channel reduction was interpreted to have occurred in response to construction and protection of the sanitary sewer in 1969. Channel widening is evident in the historic analysis as a more gradual process, with less dramatic adjustment compared to length reductions, with the exception of Reach GM-1, which widened by 70% between 1954 and 2018 (Figure 2-5; Table 2-2).



Channel Planform – 1965
Channel Planform – 1978
Watercourse
Road
Railway
Reach Break

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Example of Historical Traces - Reach GM-2

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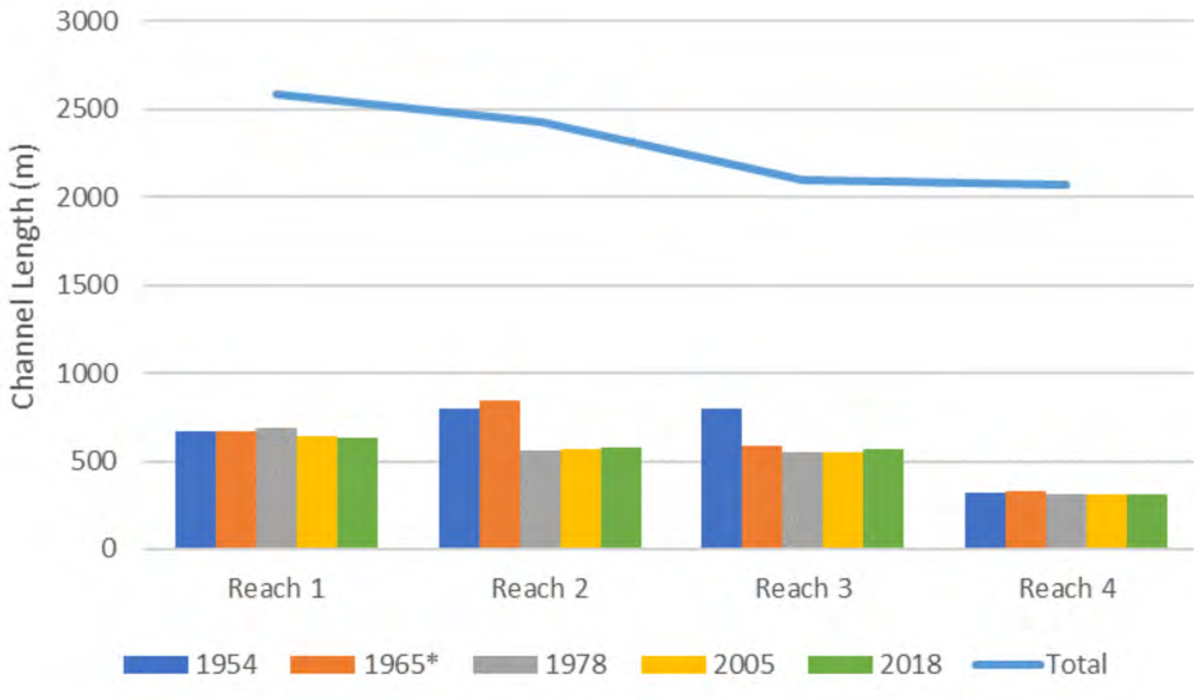
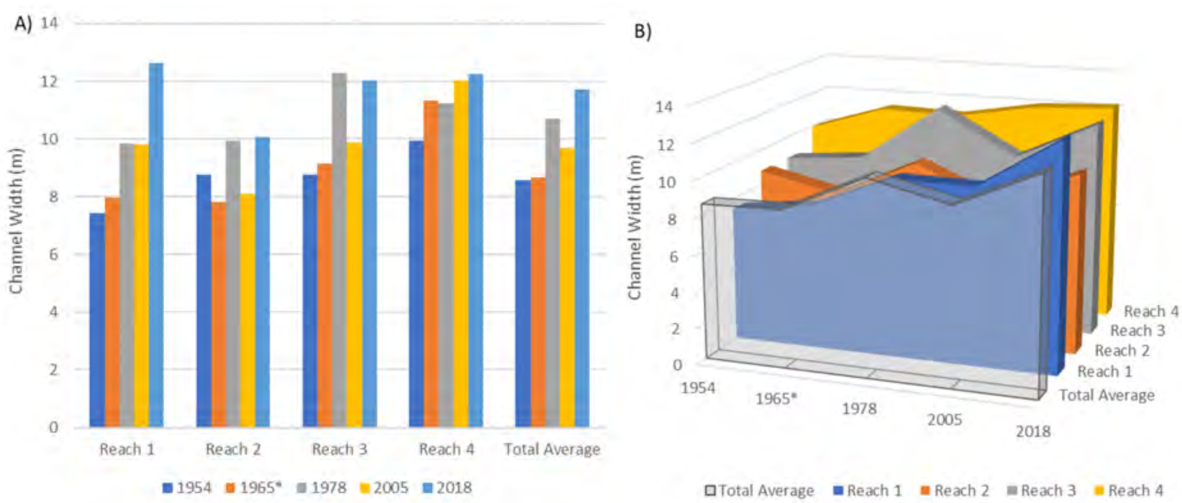
Figure
2-3



*channel partially obscured

FIGURE 2-4 Historic Changes in Channel Length Over Historic Period of Record



A) changes by reach, B) changes over period of record 1954 to 2018

FIGURE 2-5 Historic Changes in Channel Width Over Historic Period of Record

TABLE 2-2 Total and Proportional Change in Channel Length and Width Between 1954 and 2018

Reach	Length		Width	
	m	%	m	%
GM-1	-33.17	-5%	5.19	70%
GM-2	-219.06	-28%	1.29	15%
GM-3	-233.44	-29%	3.26	37%
GM-4	-12.60	-4%	2.32	23%
TOTAL	**-498.27**	**-19%**	**3.13**	**37%**

2.5 Past and Future Trends and Disturbances (Adaptive Management of Stream Corridors in Ontario Step 3)

The preceding sections provide an overview of historical land use changes and channel conditions, including a quantification at the desktop level of changes in channel length/profile, and width. The following sections seek to interpret these observed adjustments in the context of past disturbances and to outline and potentially predict future trends in channel stability. The past disturbances as summarized in the following sections, include:

- **Hydrological Flow Regime**: hydromodification of flow frequency and magnitude with historical changes in land cover and land use that tend to reduce infiltration and increase runoff in the watershed in the absence of stormwater management quantity controls.

- **Sanitary Sewer Construction**: channel disturbance and realignments starting in the late 1960s associated with major earthworks in the valley corridor to construct the sanitary and storm sewers servicing the adjacent residential developments in the table lands.

- **Valley Grading and Slope Stabilization**: cut-and-fill earthworks modifications to the valley side slopes to accommodate the residential developments in the table lands.

- **Transportation Crossing and Pedestrian Trails**: local channel modifications associated with historical road and railway construction, bridge construction and upgrades, and pedestrian trails and bridges.

- **Next Generation Stream Restoration and Channel Engineering**: more recent channel reconstruction works for Duncan Creek (Phase 1, 2013) were extended to the confluence with German Mills Creek and downstream into German Mills Creek, including rocky-riffle and armourstone rib grade control, to locally stabilize the channel.

2.5.1 Hydrological Flow Regime

Urbanization and the conversion of surfaces from pervious to impervious results in an altered flow regime, whereby increased, unmanaged runoff causes the frequency and magnitude of flood events to increase, with less pronounced seasonality (or even absent). In Toronto and surrounding urban areas, stormwater management practice is relatively recent, and older development areas, such as those draining to German Mills, lack appropriate stormwater management. The *Don River Watershed Plan, Beyond Forty Steps* (TRCA 2009a) acknowledges that there is a lack of stormwater management controls throughout the watershed, and that they have been implemented inconsistently for German Mills Creek. Refer to Section 3.4.1.1 for further discussion on stormwater management in the German Mills context.

The typical natural response to increased flows, and secondarily a decrease in the natural sediment supply, includes channel incision, widening, and planform adjustment (e.g., cut-offs). These may be complicated by direct modification and engineering; however, historical, and current engineering practices can still be at risk to natural channel adjustment.

When looking at width and length trends presented in Section 2.4, overall, reaches within the study area have become wider and shorter. Widening has occurred throughout, naturally, with limited reaches having engineered bank armouring on both sides of the channel. Widening has also been impacted by natural valley wall confinement some instances. The channel has shortened by almost 20% overall and appears to be almost entirely the result of direct modification to support development and infrastructure, rather than a response to flow regime. With that said, reaches GM-1, GM-2, and GM-3 display some slight lengthening following the initial modification in the late 1960s (discussed below). Widening and length adjustments suggest a natural response to the flow regime; however, existing channel engineering (e.g., riprap) and valley confinement likely limit the rate of adjustment.

The historical analysis of changes in width and length do not suggest any notable, natural response to extreme flooding (Section 2.4). The 1954 historical air photographs were flown prior to Hurricane Hazel, which occurred later in the same year. A review and interpretation of the 1956 photography available through the City's website reveals that there was a natural response through the study area, including channel widening, signs of incomplete avulsions, valley slumping, and sediment/vegetation stripping across point bars. However, there did not appear to be any significant modification in the planform of the channel centreline between 1954 and 1956 (note, 1956 has not been digitized as it is only available for viewing). This is an important observation, as there was roughly 100 m of anthropogenic shortening between 1954 and 1965, near the lower portion of Reach GM-3 in the vicinity of current maintenance hole (MH)-5134715004, that may have otherwise been interpreted as a flood response to Hurricane Hazel. Channel recovery to Hurricane Hazel was ongoing through 1959, with some semblance of dynamic stability in the 1960 online imagery. At this time, the area was still almost entirely agricultural, and the flow regime not impacted by unmanaged urban stormwater.

The response-recovery trajectory of a channel to floods in urban systems is often complicated by the increase in magnitude and frequency of extreme events and the compounding effect. Watercourses within the City of Toronto have been subject to recent extreme flood events including August 19, 2005; July 8, 2013; and July 17, 2019. Unfortunately, available orthophotography does not cover the 2019 event. In an attempt to evaluate recent flood response, measurements were made in GIS to determine the distance from bank to infrastructure, specifically the edge of a maintenance hole (or associated encasement). Three maintenance holes within Reach GM-3, downstream of Leslie Street, are currently exposed by lateral bank/channel migration. Measurements were made for available orthophotographs from 2005 to 2018, where photograph resolution allowed for reasonable accuracy. The photograph flights for 2005 were completed prior to the August 19, 2005, storm event. Table 2-3 provides an overview of the distance to exposure measured and Table 2-4 includes the difference between photograph sets and the corresponding annual rate of adjustment. Based on the results in Table 2-4, there does not seem to be a notable flood response to the 2005 flood, though there is the possibility that some interim works or recovery occurred in those 4 years. There does appear to be an increase in the rate of exposure between 2012 and 2014 that may be in response to the July 8, 2013, event. By 2016, all maintenance hole locations in Table 2-3 were exposed, while MH-5134715004 was already exposed in 2014.

TABLE 2-3 Distance from Bank to Maintenance Hole

Site	Distance to Exposure (m)						
	2005	2009	2011	2012	2014	2016	2018
MH-5154115049	5.39	5.32	4.33	4.36	3.14	0	-0.46
MH-5134715004	3.59	1.71	1.63	1.44	0	0	0
MH-5123714964	2.73	2.6	2.5	2.61	1.29	-0.47	-2.2

TABLE 2-4 Change in Distance to Exposure and Corresponding Annual Rate

Site	2005-2009	2009-2011	2011-2012	2012-2014	2014-2016	2016-2018
Distance to Exposure (m)						
MH-5154115049	-0.07	-0.99	0.03	-1.22	-3.14	-0.46
MH-5134715004	-1.88	-0.08	-0.19	-1.44	0	0
MH-5123714964	-0.13	-0.1	0.11	-1.32	-1.76	-1.73
Annual Rate of Migration (m/year)						
MH-5154115049	5.39	5.32	4.33	4.36	3.14	0
MH-5134715004	3.59	1.71	1.63	1.44	0	0
MH-5123714964	2.73	2.6	2.5	2.61	1.29	-0.47

Overall, reaches GM-1 and GM-3 appear to be the most active in terms of channel and bank migration. In Reach GM-3, this channel/bank migration has led to exposure at three maintenance holes. Through Reach GM-1, historical traces (Appendix C2) reveal lateral and downstream migration of two meanders, immediately downstream of the confluence with the Bestview Tributary. These processes will continue to occur in response to the current and future flow regime. Rates of adjustment may accelerate as the flow regime increases if there is no mitigation through stormwater management retrofits and upgrades or channel design.

2.5.2 Sanitary Sewer Construction

The Leslie-Steeles STS was constructed in 1969. Design drawings for the sewer from Steeles Avenue to the confluence with the Don River indicate that localized spot treatments (riprap) were proposed to provide vertical and/or lateral stability (Appendix C3). No channel realignments or cut-offs were proposed to support the STS construction based on the October 1968 design drawings; however, there was a distinct reduction in channel length by 1978 through Reach GM-3, and a review of online photographs indicates that two long meanders were cut off between 1969 and 1970, apparently to support the STS construction. Sheet 5 in Appendix C3 shows six creek crossings with riprap protection, while only two crossings remained after construction at the upstream and downstream limit: MH-5154115049 and MH-5123714964, respectively. Observations from reviewing 1969 (during construction) and 1970 (post-construction) online aerial imagery supports this interpretation (refer to Figure C3a in Appendix C3). Channel length measurements were incomplete for the 1965 orthophotograph due to obstruction of the channel due to tree cover and shadow; however, if 1954 is used as a proxy length, the channel length reduction to support the sanitary sewer was approximately 200 m compared to 1978. With the exception of riprap at the crossing near MH-5069314298, it appears that any riprap that was designed to protect sewer crossings and maintenance holes has been removed by ongoing urban flows. There are instances where it appears that relatively recent work has been completed placed riprap on the bed, but generally, armourstone has been the main mode of protection to protect the sewer at select locations in Reach GM-1 (field observations). It should be noted that concrete slabs along a valley contact in Reach GM-1 were present in the 1959 online aerial image and do not appear to be related to City infrastructure.

2.5.3 Valley Grading and Slope Stabilization

During the construction of the sanitary sewer, and prior to subdivision development, there are clear modifications to the valley slope to stabilize and extend a slope into the floodplain on either side. This occurred within Reach GM-2, extending upstream and downstream of the Canadian National Railway (CN) crossing. To facilitate this, the channel was straightened, and three meander bends were cut off and filled. Slope modifications extended along the western slope to the vicinity of the current pedestrian bridge between reaches GM-2 and GM-3, where sewer construction access was apparent in 1969. Figure C3b in Appendix C3 provides an overlay of the 1965 geometry on the 1978 air photograph, with examples of the 1969 valley grading inset. This resulted in the approximate lost of 215 m of channel and a substantial amount of floodplain area.

Between 1978 and 1981 another instance of channelization and valley regrading occurred in Reach GM-1, presumably to mitigate risk to existing properties up slope rather than in anticipation of subdivision development. Fieldwork in 2021 noted that this reach has been lined with riprap 300 to 600 mm in diameter, with a boulder drop structure in the lower third of the realigned channel. Approximately 54 m of channel was lost as the meander was cut off, and the abandoned feature was infilled. In 1983 it appears that the valley slope was regraded with fill, the slope was extended toward the design channel, and the floodplain area removed. Figure C3c in Appendix C3 provides an overlay of the 1978 alignment on the 2005 air photograph, with inset examples from 1978, 1981, and 1983 to detail the adjustment. This seems to be the last observed instance modification of this type with valley infill/regrading and channelization based on the photographic record.

2.5.4 Transportation Crossings and Pedestrian Trails

2.5.4.1 Leslie Street and Steeles Avenue

Channel modifications within Reach GM-4 associated with upgrades to Leslie Street and Steeles Avenue, and the local stormwater and sanitary network (laterals), were also extensive but did not result in any significant channel shortening as has occurred elsewhere. As-built drawings from 1972 have been made available and select sheets have been included in Appendix C3. The air photograph review indicates that both Leslie Street and Steeles Avenue were widened, requiring replacement and extension of crossing structures, respectively. Realignment involved a lateral shift of the channel away from Leslie Street, toward the east, and the placement of riprap and gabion baskets extensively throughout, including a gabion basket drop structure mid-reach. Approximately 75 to 90 m of channel was shifted. Note, 2021 fieldwork observed that the gabion basket drop structure no longer functions, and only a small portion remains within the vicinity, aligned parallel with the channel. It is assumed that the drop structure was included as grade control to minimize incision risk to a sewer crossing (lateral) further upstream. However, there is no channel profile information to further interpret the intent of the drop structure, nor any other design rationale on the drawings.

More recent slope stabilization includes a 30 m section of vertically stacked armourstone on the left bank (looking upstream), ending approximately 50 m upstream of Leslie Street; however, no design documents or drawings have been reviewed.

2.5.4.2 Railway Bridge

Based on the archaeological assessment report and historical assessment, the railway bridge over German Mills Creek within the study area was constructed in the early 1900s and was managed by the CN starting in 1918 (TRCA 2021, Appendix C1). The local railway line and subject bridge are now currently owned and managed by Metrolinx (request for engineering drawings still pending at time of reporting). In addition to the original channel realignment and channel armouring between the rail bridge piers (span ~18 m), a canopy was constructed over the recreation trail under the railway bridge that includes cylindrical concrete footings within the channel bank at risk of being exposed and undermined (note: age and design of canopy to be confirmed with TRCA).

2.5.4.3 Pedestrian Trail System

A pedestrian and recreational trail system was constructed within the valley approximately over the period of 1970s to 2010s, including the valley-spanning pedestrian bridge at Pineway Boulevard (1973), East Don Parkland trail bridges near Bruce Farm Drive (1980), Saddletree Drive (1985), and Duncan Creek trail (2017-2018; TRCA 2021, Appendix A).

2.5.5 Next Generation Stream Restoration and Channel Engineering, Duncan Creek Phase 1

In 2013, efforts were made to stabilize significant erosion issues within Duncan Creek, including issues at the confluence with German Mills Creek. Works included a meandering riffle-pool design engineered and constructed with riprap and armourstone for channel stabilization. These works, which were extended into German Mills Creek (Reach GM-4), consisted of an armoured riffle feature with traverse armourstone ribs extending approximately 30 m downstream from the confluence (Figure 2-6). This approach for channel/bed stability has been fairly common among recent designs throughout the City over the last decade. Annual monitoring reports by Aquafor Beech (2021a, 2021b, 2021c) note that there has been ongoing localized scour of the bed and banks, with rates at 0.21 m/year and 0.13 to 0.35 m/year, respectively. However, Aquafor Beech (2021c) concluded that current conditions pose “no significant risks to the adjacent assets in the short-medium term, including City’s sanitary sewer, trail systems and private properties.” Further monitoring was recommended to evaluate long-term risks associated with the ongoing adjustment.

FIGURE 2-6 Armoured Riffle with Transverse Ribs, Reach GM-4

2.5.6 Future Trends from Past Disturbances

The German Mills Creek subwatershed is essentially fully urbanized with existing developments in the cities of Toronto, Markham, and Richmond Hill (Figure 1-1), with an estimated impervious surface area of 47% (AECOM 2018). As such, any future increases in runoff and flow are not expected to be caused by new developments. Other past disturbances to German Mills Creek associated with the local urban developments, including the construction of the sewers, roads, bridges, trails, and adjacent residential properties, will have ongoing impacts on the channel, but these past disturbances can be managed through the development and evaluations of alternative solutions through the GSMP and EA study processes.

While it is possible that future stormwater management strategies implemented in the watershed, including site redevelopments and retrofits, could help to reduce historical increases in urban runoff, most of the watershed is outside of Toronto and, thus, does not fall under previous City plans to manage stormwater (see Section 3.4.1). Specifically, starting with the 2003 WWFMP (City of Toronto 2003), the proposed localized stormwater management controls within the German Mills study area would not be expected to significantly offset the lack of stormwater management controls upstream with other jurisdictions. Channel restoration will still be required to address the current conditions and maintain stability from the runoff and resulting peak flows that are generated further upstream. Further, the expected channel adjustments of widening and degradation (i.e., enlargement) due to urban hydromodification typically lags behind the watershed development, and the full system response and channel configuration may not yet be complete. As such, further analysis of potential channel enlargement and other dynamic fluvial processes, such as lateral migration and vertical scour were completed (Section 4.2) as part of the geomorphic risk assessment and prediction of the ultimate channel configuration that will be conducive to future conditions.

While possible future developments with the German Mills Creek subwatershed are not expected to significantly increase future flows to the creek, climate change poses a significant risk to the future stability of German Mills Creek and to the associated City infrastructure within the valley corridor. It is expected that climate-change-influenced increases in the intensity and total volumes of storms will exacerbate flood risks through changes in future runoff regimes. As such, a climate change assessment was completed as part of the German Mills Creek GSMP to inform alternative design approaches and their evaluation for potential for added climate resilience and/or redundancy to protect Toronto Water infrastructure over the intermediate and long term. The alternative concepts will also be evaluated based on potential for climate changes to impact the design life and maintenance requirements of any new erosion mitigation assets. As such, the design approach needs to consider how erosion mitigation infrastructure can be maintained, adapted, and effectively modified to meet future climate conditions with ongoing monitoring and watershed planning activities by the City and TRCA.

Associated with the historical degradation of the channel and future instability are impacts to ecosystems, including ongoing decreases in the quantity and quality of habitat, degradations in water quality, removals of or modifications to riparian vegetation, and additional in-stream works that may have further negative impacts to aquatic habitat and fish passage (see Section 3.4.2 for characterization of biotic communities). While new channel equilibrium within the urbanized watershed might be achieved in the fluvial system and stream restoration projects may improve historically degraded conditions, climate changes pose uncertain risks, and ecological objectives will need to be balanced with managing risks to valuable infrastructure. Stream restoration and stabilization may provide geomorphic qualities and complexities that are beneficial to the ecological systems, but the ecologic communities and species may also be different than those found prior to urbanization as a result of the new channel conditions.

3 GEOMORPHIC PRESENT CONDITIONS

3.1 Channel Characterization

3.1.1 Reach Delineation

Stream reaches are defined in Section 2.1.2 based on the desktop review and historical assessment, and reaches were subsequently confirmed in the field. Within the study area of German Mills Creek, four reaches were delineated (Figure 2-2). Reach characteristics such as reach length and sinuosity are summarized in Table 3-1.

Furthest downstream, Reach GM-1 begins at the confluence with the Don River East Branch and extends approximately 615 m upstream to the confluence with the Bestview Tributary. A reach break was placed here primarily due to the confluence with Bestview Tributary and Reach GM-1 is the only area that receives flow input from the tributary. As a result, this part of German Mills Creek may have an altered flow regime as well as sediment dynamics. Additionally, this reach exhibited a high degree of sinuosity as a whole and channel geometry and substrate were generally consistent. GM-2 extends 557 m upstream of the Bestview Tributary to the pedestrian bridge near Saddletree Drive and represents a portion of German Mills Creek that was historically straightened to accommodate the sewer construction in 1969. Channel geometry in this reach is generally narrower and of greater depth than the other reaches. The channel regains sinuosity in Reach GM-3, which extends approximately 560 m upstream to Leslie Street. The reach break at Leslie Street was placed as channel morphology and sinuosity upstream and downstream of the road varies greatly. In GM-3, the channel is generally well connected to its floodplain along inner banks, where large gravel and sand point bars have formed. Reach GM-4 then extends to the Steeles Avenue road crossing, a distance of approximately 320 m. Reach GM-4 is confined either natural by the valley wall to the east or by the road embankment to the west. This reach also contains engineered rocky ribs with large keystones to control the grade downstream of Duncan Creek. Reach summaries are presented in Section 3.2.1 with the Rapid Geomorphic Assessment (RGA) results.

TABLE 3-1 Summary of German Mills Creek Reach Characteristics

Reach	Channel Length (m)	Sinuosity
GM-1	615	1.37
GM-2	557	1.04
GM-3	560	1.67
GM-4	320	1.09

3.1.2 Field Reconnaissance

Field assessments were completed between July 2021 and September 2021 to confirm the desktop-based reach delineation and document existing channel conditions. During the field assessments, all four reaches of German Mills Creek (GM-1 to GM-4) were traversed, and the following tasks were undertaken as part of the fluvial geomorphic assessment:

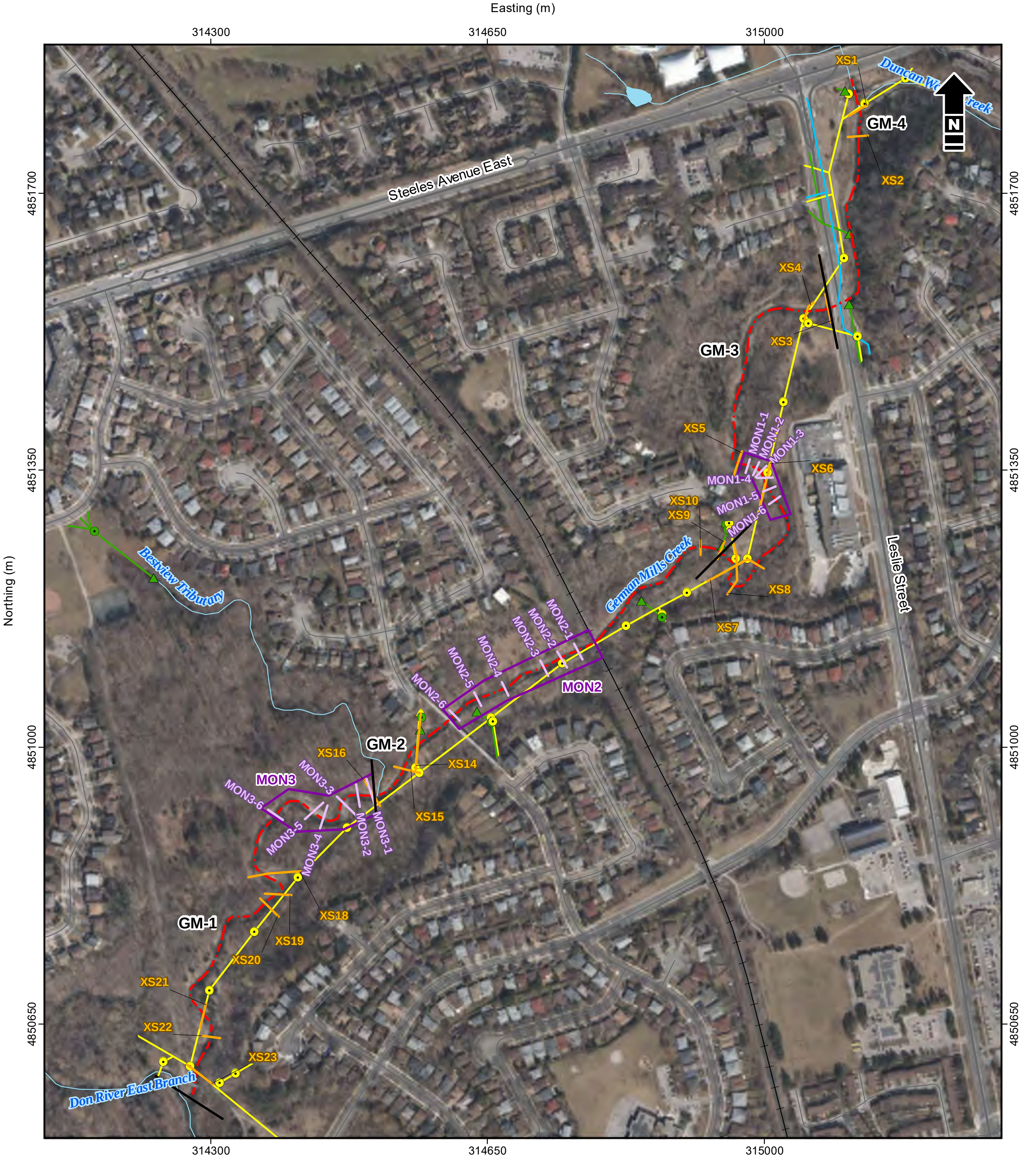
- reach characterization of channel morphology and bed/bank substrate with photographs (photograph log of each reach is located in Appendix C5)
- RGA and Rapid Stream Assessment Technique (RSAT)
- bank condition scoring in 20 m segments
- identification of geomorphic erosion risk sites
- detailed topographic survey, including geomorphic survey of German Mills Creek and proximal Toronto Water infrastructure (i.e., maintenance holes, sewer alignment, outfalls, etc.)

Further discussion regarding the rapid assessments, bank condition scoring, and erosion risk site inventory are described in Sections 3.2.1 and 3.2.3.

3.1.3 Detailed Topographic Survey and Monitoring Sites

Detailed topography of the channel and surrounding floodplain was surveyed to characterize channel geometry and sediment within the creek (Figure 3-1). The detailed channel survey also helped inform the risk assessment to depict the depth of cover over sewer crossings by comparison with as-built sewer drawings. A combination of real-time kinematic GPS and total station survey equipment was used to perform the survey. Survey data consisted of comprehensive cross-sections of the creek extended into the floodplain, a longitudinal profile of the watercourse thalweg from Steeles Avenue to the confluence with the East Don River, and aboveground infrastructure (i.e., maintenance holes, storm outfalls, bridges). A total of 23 cross-sections were surveyed, including 18 monitoring cross-sections and 5 additional cross-sections in areas of risk to infrastructure (Figure 3-1). The monitoring cross-sections surveyed in 2021 were allocated into three monitoring sites (six cross-sections per site) and were resurveyed in 2022 as part of a short-term monitoring program (results are provided in the Monitoring Report; Appendix E of the Master Plan). All survey data was georeferenced in the MTM Zone 10 to align with the City's base mapping. In select cases, the surveyed maintenance holes included both lid elevations and measure down depths to the sewer pipe inverts to support the three-dimensional (3D) model development as documented in the infrastructure engineering review (Section 3.3).

The topographic survey data was used to update the existing study area ground surface from a 2015 LiDAR dataset (details provided in Appendix C4). The updated 2015-2021 surface model was then referenced to complete the infrastructure review (Section 3.3) and hydraulic modeling review (Section 3.4.1).



Monitoring Site
Watercourse
Highway
Road
Railway
Reach Break
Surveyed Monitoring Cross-section
Surveyed Infrastructure Cross-section
Surveyed Long Profile
Sanitary Sewer
Storm Sewer
Watermain
Sanitary Sewer Maintenance Hole
Storm Sewer Maintenance Hole
Stormwater Outfall

Disclaimer: Sewers have been clipped to the Focused Study Area.

Reference: Contains information licensed under the Open Government Licence – Ontario. Imagery (2018) obtained from Canada Map Sales. used under license. Imagery provided by City of Toronto. Used under license.

1:7,000 metres
70 0 70 140
NAD27 MTM zone 10

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Toronto
German Mills Creek GSMP EA

Survey Extents

Date:	Project:	Submitter:	Reviewer:
December 2021	32227	N. Cyples	J. McDonald

Figure
3-1

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3.2 Assessment of Channel Response (Adaptive Management of Stream Corridors in Ontario Step 4)

3.2.1 Rapid Geomorphic Assessments

3.2.1.1 Methods

To provide insight into existing geomorphic conditions on a reach basis, rapid field reconnaissance was completed in July 2021. Rapid assessment techniques, RGA and RSAT were applied to determine the dominant geomorphic processes affecting each reach. The RGA and RSAT methods are described further in Appendix C5.

3.2.1.2 Results

Tables 3-2 and 3-3 and Figure 3-2 summarize the rapid assessment scores for the study area along German Mills Creek. Table 3-4 summarizes observed conditions in each reach.

TABLE 3-2 Rapid Stream Assessment Technique Summary

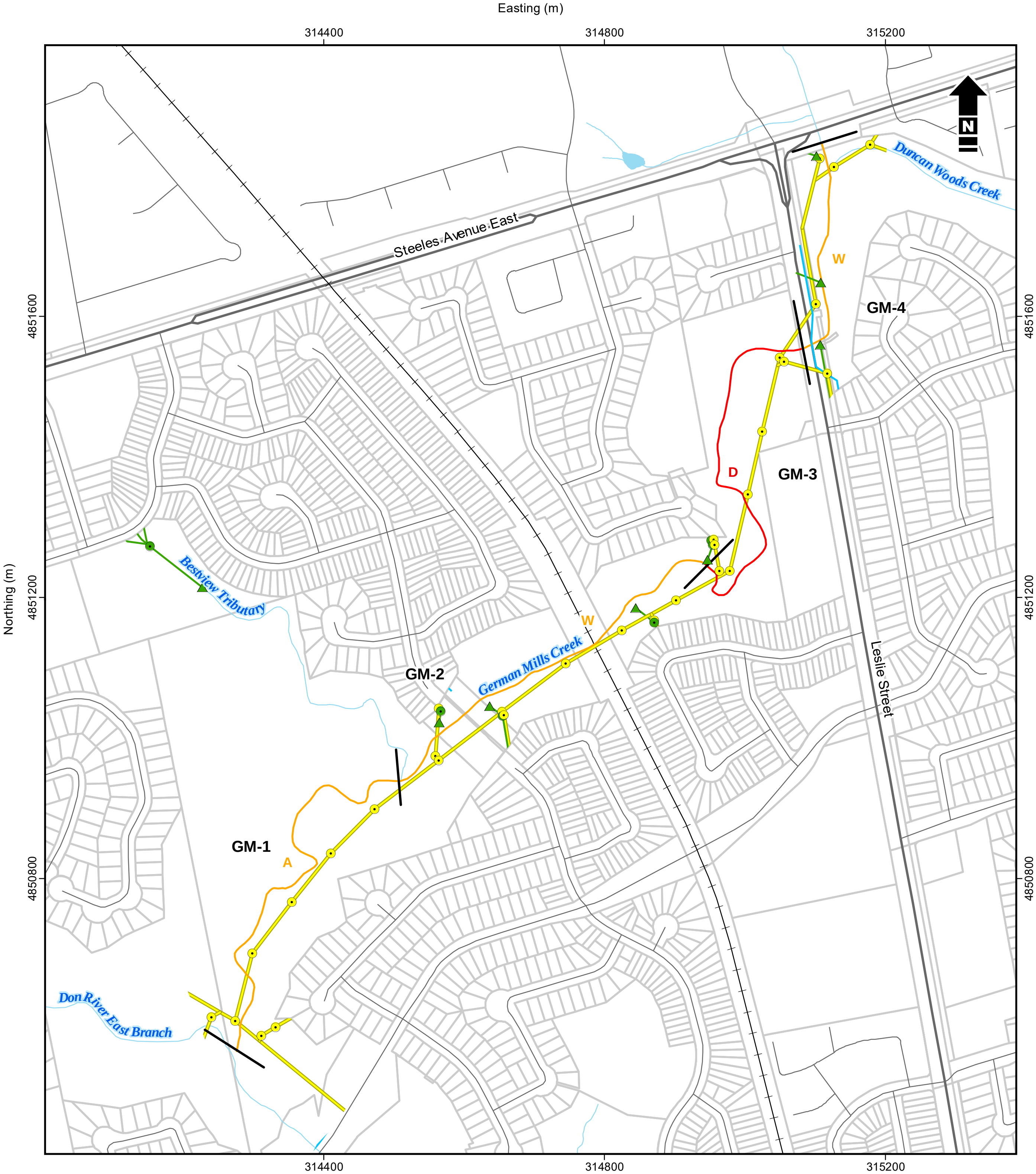
Reach	Channel Stability	Scour/ Deposition	Instream Habitat	Water Quality	Riparian Condition	Biological Indicators	Overall Score	Condition
Maximum Score	11	8	8	8	7	8	50	
GM-1	4	4	6	5	5	6	30	Moderate
GM-2	4	5	3	5	4	4	25	Moderate
GM-3	3	4	6	5	5	7	30	Moderate
GM-4	4	4	3	5	4	4	24	Moderate
Bestview Tributary (1)	2	3	3	3	6	3	20	Moderate

Notes:
(1) Lower reach of Bestview Tributary assessed. Upper reach of tributary engineered as armourstone and riprap-lined channel.

TABLE 3-3 Rapid Geomorphic Assessment Summary

Reach	Aggradation	Degradation	Widening	Planimetric Adjustment	Stability Index	Condition
Maximum Score	0.71	0.20	0.67	0.00	0.40	Transitional
GM-1	0.29	0.56	0.75	0.00	0.40	Transitional
GM-2	0.43	0.70	0.60	0.00	0.43	In Adjustment
GM-3	0.43	0.40	0.67	0.14	0.41	In Adjustment
GM-4	0.71	0.20	0.67	0.00	0.40	Transitional
Bestview Tributary (1)	0.42	0.5	0.6	0.14	0.42	In Adjustment

Notes:
(1) Lower reach of Bestview Tributary assessed. Upper reach of tributary engineered as armourstone and riprap-lined channel.



Property Boundary
Watercourse
Highway
Road
Railway
Reach Break
Sanitary Sewer
Storm Sewer
Watermain
Stormwater Outfall

Sanitary Sewer Maintenance Hole
Storm Sewer Maintenance Hole

RGA

In Adjustment
Transitional

RGA Dominant Process

A - Aggradation
D - Degradation
W - Widening

1:8,000 metres
80 0 80 160
NAD27 MTM zone 10

Disclaimer: Sewers have been clipped to the Focused Study Area.

Reference: Contains information licensed under the Open Government Licence – Ontario. Imagery (2018) obtained from Canada Map Sales. used under license. Imagery provided by . Used under license.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Toronto
German Mills Creek GSMP EA

Rapid Geomorphic Assessment Scores

Date:	Project:	Submitter:	Reviewer:
December 2021	32227	N. Cyples	J. McDonald

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Figure
3-2

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TABLE 3-4 Reach Descriptions

Reach	Description	
GM-1		Channel planform regains sinuosity in this reach and contains several large pools with high rates of lateral migration (0.5 to 0.6 m/year) in the direction of the sanitary sewer. Although entrenched in some locations, this reach has a well-developed floodplain in comparison to other reaches. Occasional valley wall contacts with vertical bank faces were noted. Mid-reach there are a series of weirs acting as grade control and large riprap armouring the banks. This reach also contains the largest riparian zone, most of which is forested.
GM-2		Historically straightened reach to accommodate the sanitary sewer constructed in 1969. This reach exhibits entrenchment and is lined with riprap and gabion baskets at bridge crossings and the railway. Riprap appears to be in good condition, however the sanitary sewer which runs parallel to the creek and is at risk of exposure. Pool-riffle morphology remains present but is better developed away from armoured areas. Riparian vegetation is typically forested and the channel is not well connected to the floodplain in this reach, causing channel incision. Incision is evidenced by exposed clay along the toe of bank, the concrete apron at outfall perched, and local bed scour near armoured areas.

Reach	Description	
GM-3		This reach has undergone substantial channel widening resulting in the exposure of three maintenance holes (downstream of Leslie St., mid-reach, and near pedestrian bridge). Previous bank armouring such as riprap and armourstone walls are in relatively poor condition and are becoming undermined. Riffle-pool morphology is well-defined, with large bank attached and medial gravel bars prevalent. Due to channel widening, bank slumps and undercut banks are also common.
GM-4		Moderately steep reach. Channel has been straightened upstream of Leslie Street. Valley is narrowed by the Leslie Street embankment. Channel is confined by valley slope to the east. Grade control rib structures have been constructed downstream of Steeles Avenue bridge and confluence with Duncan Woods Creek. Channel has scoured around gabion basket. Bank erosion is frequent, bank armouring includes rounded riverstone, armourstone, and sheet piling.
Bestview Tributary		Steep gradient, highly entrenched tributary channel. Armourstone banks and riprap-lined bed in upstream reach. Natural channel boundary in downstream reach with gravel and sand lobate bars in channel, steeply eroded banks with exposed roots in forested valley. Undisturbed overburden locally exposed, large woody debris in channel with debris jams common. Lower gradient section at confluence with German Mills Creek main channel.

The RSAT results indicate that reaches within the study area have moderate stream health. Channel stability, scour and deposition, and instream habitat are among the lowest-scoring factors. Reach GM-1 has the most natural channel cross-section within the study area with pool-riffle morphology, a meandering channel planform, and a well-developed floodplain with occasional valley contacts and local armouring. Reach GM-1 has the widest riparian forest among reaches within the study area. Reach GM-3 has a moderately natural cross-section and a meandering planform, although this reach has undergone historic modification. Reach GM-3 has riffle-pool morphology, fairly intact riparian cover, and good biological indicators. This reach also contains a large armourstone wall and an exposed maintenance hole near the pedestrian bridge. Reaches GM-2 and GM-4 have modified planforms, with a narrow riparian zone, and less developed riffle-pool morphology.

Channel stability in the downstream reaches (GM-1 and GM-2) is classified by the RGA as Transitional, but at the boundary of being In Adjustment. The upstream reaches (GM-3 and GM-4) are In Adjustment, which reflects a slightly greater degree of channel instability compared to reaches downstream. Channel processes included widening, degradation, and aggradation based on a range of field indices that suggest concurrent processes of channel enlargement and aggradational sediment dynamics.

The lower reach of the Bestview Park Tributary was also assessed within the study area based on RSAT and RGA methods. The upper reach was not scored, as it is engineered as an armourstone and riprap-lined channel. The natural reach of the tributary channel downstream of the engineered portion exhibits abundant evidence of channel instability with a moderate (borderline poor) RSAT score and unstable RGA score classified as In Adjustment. Additional photographs of each reach are provided in Appendix C5 with all references to left or right banks when looking in the upstream direction.

3.2.2 Interpretation - Channel Evolution

The present condition of the watercourse as characterized in the preceding sections should be considered in the context of the evolution of the fluvial system over time. Channel evolution models help conceptualize how alluvial channels may respond to disturbances, natural or human-induced, through a series of morphological adjustments that can be generalized into an evolutionary sequence common to streams in different physiographic settings.

A channel evolution model was recently developed for Wilket Creek in Toronto, which is within a similar physiographic and urban setting as German Mills Creek (Bevan et al. 2008). Wilket Creek is a tributary to the Don River that flows through a suburban area in northern Toronto. Like German Mills Creek, it is a semi-alluvial channel characterized by a relatively thin alluvial layer over clay till.

The Wilket Creek model classifies channel types I through V, which depict five stages of channel evolution for urban channels when underlain by semi-alluvial till. These stages are summarized below. Figure 3-3 provides a visual representation of the model from Bevan et al. (2008).

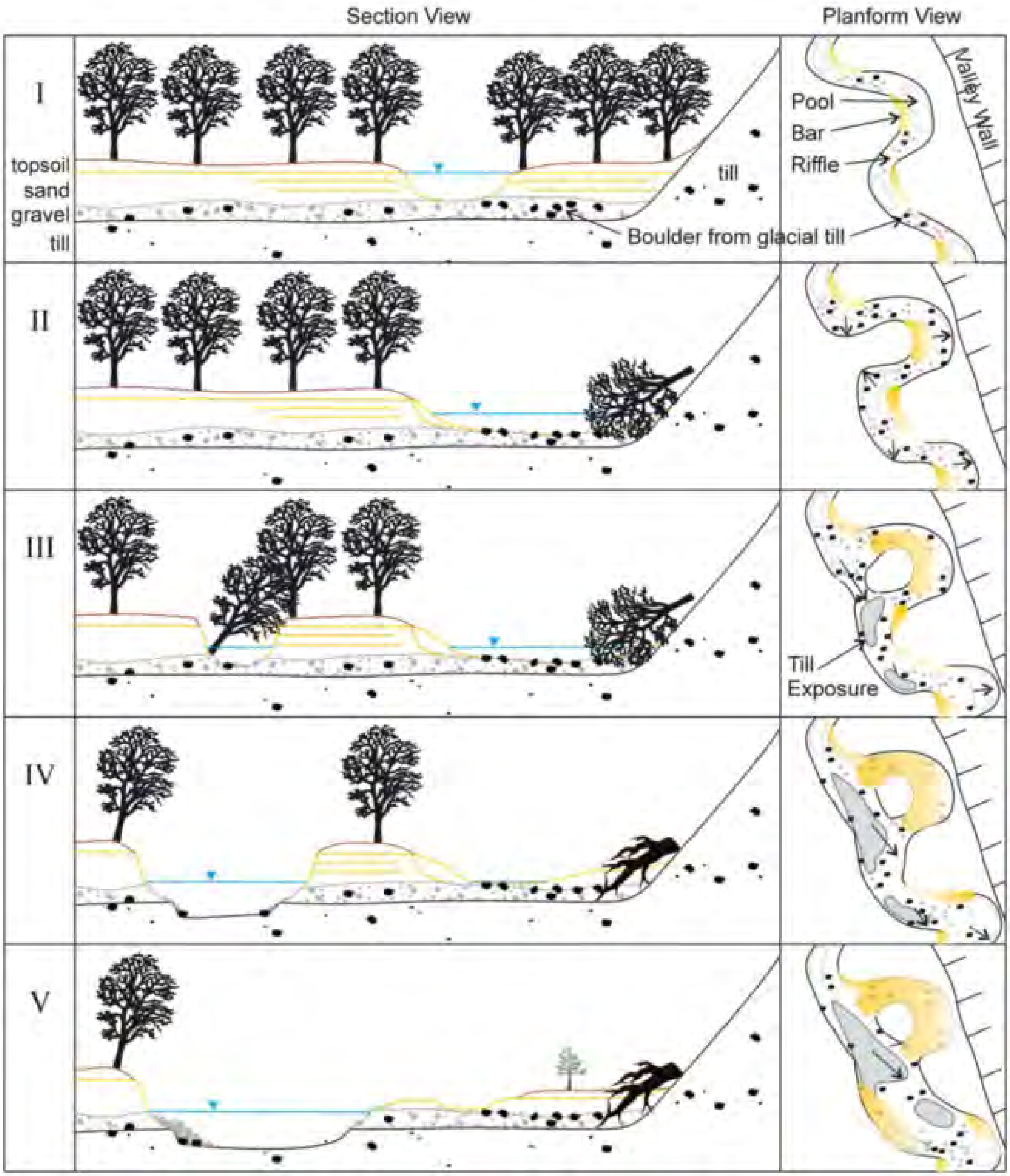


FIGURE 3-3 Stream Evolution Model: Conceptual Model of Urban Channel Evolution Where Underlain by Semi-alluvial Till (Bevan et al. 2008)

- **Stage I Pre-urban channel**: the channel is characterized by a floodplain that is well connected to the channel, dense forest cover, and a layer of gravel alluvium overlying the deeper till. Riffles contain large clasts of glacial lag material. Overall migration rates and sediment fluxes are low.

- **Stage II Widening with meander extension**: as the catchment urbanizes, flows become flashier. Due to the coarse bed material and moderately resistive till bed, the channel responds by widening and meander extension. On balance the channel cross-section enlarges.

- **Stage III Avulsion**: meander extension increases the likelihood of channel avulsion. When avulsions occur, the increased velocity downstream of the avulsion may flush away alluvial material leading to exposure of the underlying till.

- **Stage IV Incision**: the increased stream power in the steepened avulsion may mobilize the largest bed material, including steps and riffles. The erasure of bedforms leads to significant incision within and upstream of the avulsion resulting in extensive till exposures.

- **Stage V Bank Retreat**: the altered planform results in bank erosion where flow impinges on banks, causing rapid bank retreat and treefall in the riparian zone. Low sediment supply results in low rates of aggradation in ineffective flow areas, resulting in an enlarged channel cross-section.

As described in Stage I, German Mills Creek within the study area was historically connected to a forested floodplain, albeit within a distinct valley. As urbanization occurred, the flow regime would likely have become flashier due to increased catchment imperviousness, as in Stage II. Additional changes that occurred as part of urbanization included the regrading of some valley slopes to encroach into the floodplain (e.g., within monitoring site 2; MON2), channel straightening, and installation of erosion protection such as gabion baskets. Many of these changes took place in the mid- to late-1900s (refer to Section 2.4). Meander migration would have been limited where the channel was straightened and where erosion protection was installed.

While German Mills Creek has undergone (and continues to undergo) lateral channel migration, natural avulsions as described in Stage III were not observed in the historic photographic record (refer to Section 2.4). However, anthropogenic straightening may be considered similar to avulsion in that it also reduces channel length and leads to an increase in velocities and transport of downstream alluvial bed materials.

Current channel conditions indicate that the channel has incised (Stage IV). Clay till exposures were noted in the bed and lower banks in parts of all four reaches. Within reaches GM-2, GM-3, and GM-4, the creek is typically entrenched and disconnected from the floodplain. The presence of extensive bank erosion protection may serve to exacerbate the rate of incision. Based on the degree of entrenchment and the moderate increase in channel widths measured over time (Figure 2-1, Section 2.4), reaches GM-2 to GM-4 are considered to be in Stage IV. In contrast, the reach furthest downstream (GM-1) may be in Stage V, as this reach showed the greatest increase in channel width since 1954 (Figure 2-2, Section 2.4). As well, the creek in Reach GM-1 is entrenched but appears to be developing a wider floodplain at a lower elevation. However, unlike the Wilket Creek model, German Mills Creek appears to have a sufficient sediment supply such that the channel cross-sectional area does not expand indefinitely.

3.2.3 Bank Conditions and Erosion Site Assessment (Methods and Results)

The ultimate objective of the overall project is to evaluate the risk to Toronto Water infrastructure from fluvial processes and develop a prioritization and implementation plan for stabilization/remediation. Field characterization to support this includes an inventory of bank conditions and channel stability throughout and the evaluation of specific erosion risk sites where Toronto Water infrastructure is currently or potentially at risk to erosion (both lateral bank erosion and vertical bed scour). The following bank condition and erosion site field assessments form the initial component of the overall risk assessment and prioritization (Figure 3-4, with details in Figure C6a in Appendix C6)

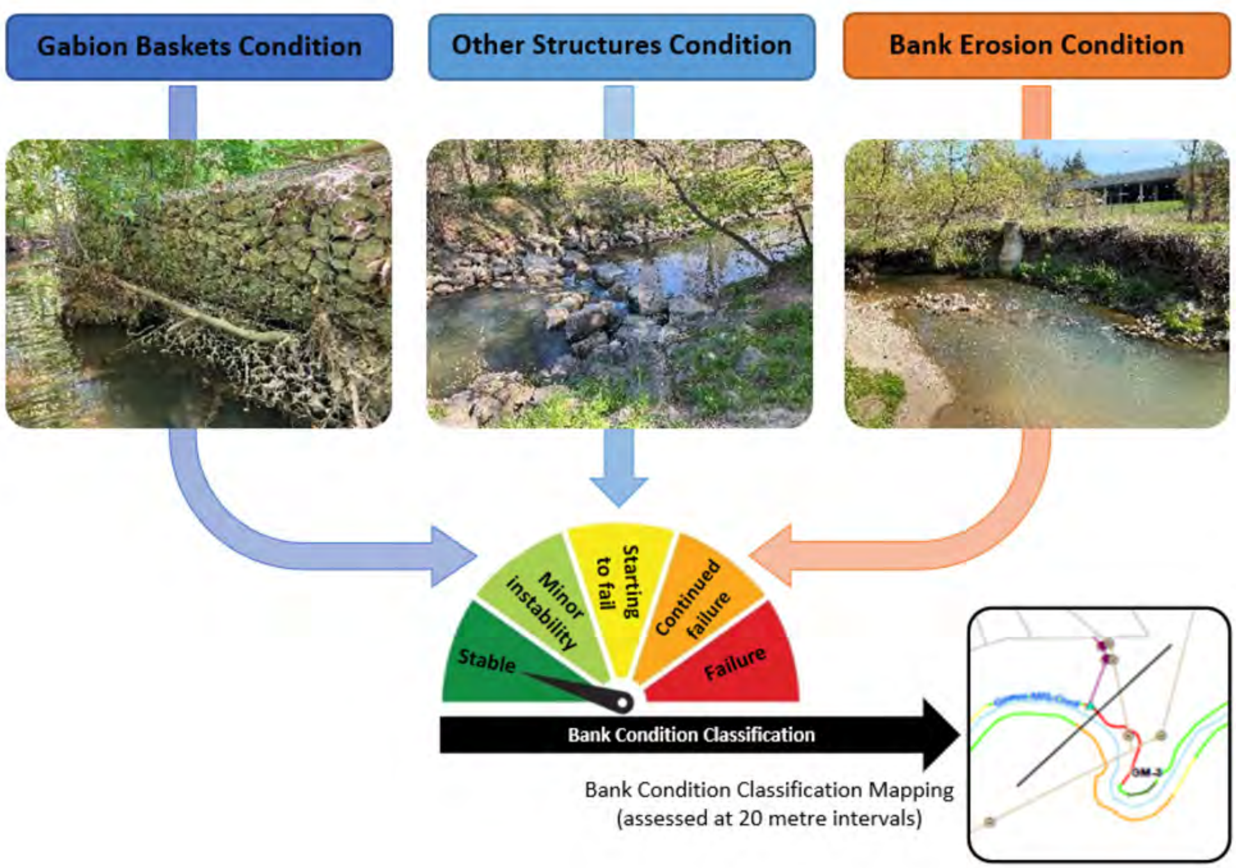


FIGURE 3-4 Bank Condition Scoring Framework (details in Appendix C6)

3.2.3.1 Bank Conditions Inventory

A standardized approach to characterizing bank materials and conditions was completed, whereby the channel banks were assessed and scored in the field at 20 m intervals along the mapped centreline of the channel using the 2018 bankfull centreline. Cutlines were plotted to intersect the digitized bank lines, and given that there is a meandering channel, the bank lengths vary for each segment. Bank condition was assessed for natural and treated (engineered) banks and was classified based on bank stability (e.g., stable, minor instability (erosion), starting to fail, continuing to fail, or complete bank failure).Figures C6b and C6c in Appendix C6 provide photograph examples to represent each bank condition score. Average and maximum scores were determined for each segment. Overall, 103 segments were assessed, resulting in 206 scores. Table 3-5 presents the distribution of maximum scores, which has been applied in the risk assessment. Mapping of maximum scores is presented on Figures C6d through C2h in Appendix C6g.

TABLE 3-5 Distribution of Maximum Scores

Score	Count	Proportion
1	36	17%
2	61	30%
3	50	24%
4	43	21%
5	16	8%
TOTAL	**206**	**100%**

3.2.3.2 Erosion Risk Sites

This section of the geomorphic risk assessment identifies erosion risk sites within the focused study area of the German Mills Creek corridor. Erosion risk sites were identified in terms of their lateral and vertical erosion hazards with respect to property and infrastructure, with a specific focus on Toronto Water sewer infrastructure. A desktop risk inventory was completed initially using City orthoimagery in conjunction with Toronto Water infrastructure (sewers, watermains, outfalls, maintenance holes, etc.) from the Toronto Water Asset Geodatabase (TWAG). Erosion sites were identified at sewer crossing locations within the creek (vertical risk) as well as locations where the creek was proximal to sewer pipes, maintenance holes, outfalls, pathways, and properties (lateral risk). A total of 56 erosion risk sites have been identified and are presented in Appendix C6. Further discussion regarding the ranking of erosion risk sites is presented in Section 4.2 as part of the geomorphic risk assessment.

TABLE 3-6 Identified Erosion Risk Sites and Associated Bank Condition Classification

Site ID	Reach	Risk	Risk Type	Distance to Structure (m)	Bank Condition Classification	Comments
1.1	GM-1	Maintenance Hole	Lateral	5	3	Maintenance hole not at immediate risk, set high above creek bed and protected with old armourstone.
1.2	GM-1	Pipe Crossing	Vertical	0.48 from Ex. Grade	4	Not at immediate risk, no sign of exposure; gravel and cobble substrate over pipe crossing.
1.3	GM-1	Bridge	Lateral (and Vertical)	0	3	Bridge footings partially exposed; erosion occurring behind concrete abutments as well on downstream side; minimal armouring around bridge.
2.1	GM-1	Pathway	Lateral	2	4	Armourstone is beginning to fail; rootwads underneath armourstone beginning to become undermined/ outflanked.
3.1	GM-1	Pipe Crossing	Vertical	1.22 from Ex. Grade	4	Riprap on channel bed and along toe, not at immediate risk; grade control weirs/ribs through area to reduce velocities and erosive potential.
4.1	GM-1	Maintenance Hole	Lateral	19	1	Maintenance hole set back from bank pretty far, low erosion risk.
5.1	GM-1	Maintenance Hole	Lateral	10	1	Maintenance hole 10 m from creek, but channel is widening in that direction and there is no bank armouring, therefore will likely want to armour bank to prevent further widening toward maintenance holes.
5.2	GM-1	Pipe Adjacent	Lateral and Vertical	1	4	Pipe not exposed but very close, creek edge almost at where sewer is mapped; bank not armoured at all and channel is widening in direction of sewer at 0.6 m/year.
5.3	GM-1	Pathway	Lateral	7	4	Channel widening in direction of pathway with a high erosion rate (0.6 m/year) and will eventually wash out the pathway. No bank armouring present.

Site ID	Reach	Risk	Risk Type	Distance to Structure (m)	Bank Condition Classification	Comments
6.1	GM-1	Maintenance Hole	Lateral	9	4	Maintenance hole 9 m from top-of-bank but channel is eroding and widening in direction of maintenance holes, will likely want to armour bank to prevent further widening toward maintenance hole.
7.1	GM-2	Pipe Adjacent	Lateral and Vertical	1	5	Active bank erosion/channel widening occurring in direction of pipe, no bank armouring, pipe nearly exposed according to desktop mapping and survey.
7.2	GM-2	Pathway	Lateral	3	5	Active bank erosion/channel widening occurring, no bank armouring and will eventually erode into pathway.
8.1	GM-2	Outfall	Lateral	8	3	Not at immediate risk, outfall set back pretty far from bank with no signs of erosion.
8.2	GM-2	Pipe Crossing	Vertical	0.37 from Ex. Grade	4	Pipe is not exposed but channel substrate is sandy with some gravel; pipe has less than 1 m depth of cover.
8.3	GM-2	Maintenance Hole	Lateral	8	1	Maintenance hole not at immediate risk but within 10 m of creek; some bank erosion in this area (vertical bank face) but can be controlled with bank armouring.
8.4	GM-2	Maintenance Hole	Lateral	15	1	Maintenance hole set back from bank pretty far, low erosion risk.
9.1	GM-2	Pedestrian Bridge	Lateral	0.5	4	Right bridge pier (looking upstream) at risk of exposure, riprap has previously been placed here and majority has eroded and washed into creek; active erosion now occurring against pier.
9.2	GM-2	Outfall	Lateral	10	4	Outfall not at immediate risk as it is set far back from creek, however local erosion around confluence with main channel is present.
11.1	GM-2	Maintenance Hole	Lateral	1	5	Not exposed in creek but erosion around maintenance hole; bank is very steep, and top of concrete of maintenance hole is exposed.

Site ID	Reach	Risk	Risk Type	Distance to Structure (m)	Bank Condition Classification	Comments
12.1	GM-2	Pathway	Lateral	1	2	Riprap stable now but pathway is very close to top-of-bank; top half of bank not armoured and bank is vertical; bank ~2.5 m high.
12.2	GM-2	Pipe Adjacent	Lateral	1	4	Creek edge very close to adjacent sewer; did not see exposure but likely very close to it.
12.3	GM-2	Maintenance Hole	Lateral	12	3	Maintenance hole set back from bank pretty far, low erosion risk.
13.1	GM-2	Outfall	Lateral	5	4	Outfall set back ~5 m from creek, riprap at confluence of outfall channel and creek, however failing; outfall at risk of undermining and concrete apron is also failing; outfall discharging into riffle and gravel point bar.
15.1	GM-2	Outfall	Lateral	0	5	Outfall possibly constructed perched/elevated; armourstone underneath and on both sides as protection (in good condition - looks recent); armourstone also embedded in creek outfall outlets at a cobble-dominated riffle - no evidence of creek bed erosion.
15.2	GM-2	Slope/Property	Lateral	10	2	Armourstone wall protecting bank in good condition.
15.3	GM-2	Pedestrian Bridge	Lateral	0	5	Active erosion under bridge on top half of bank, some riprap protection along toe, but in poor condition.
16.1	GM-3	Maintenance Hole	Lateral	0	5	Maintenance hole fully exposed on all sides; vertical bank behind maintenance holes ~2.5 m high; minimal vegetation to protect bank; significant scour around maintenance hole and scour pool has formed within channel.
16.2	GM-3	Pipe Crossing	Vertical	1.2 from Ex. Grade	5	Deep near maintenance hole (scour pool), otherwise shallow; cannot see pipe exposed under creek bed.
16.3	GM-3	Pipe on south side of exposed maintenance hole	Vertical	0.16 from Max. Pool Depth	5	Pipe very close to exposure (0.16 m depth of cover).

Site ID	Reach	Risk	Risk Type	Distance to Structure (m)	Bank Condition Classification	Comments
16.4	GM-3	Maintenance Hole	Lateral	9	5	Maintenance hole set back from bank pretty far, low erosion risk.
16.5	GM-3	Pipe Coming from Maintenance Hole - exposed on north	Lateral	0	5	Concrete lateral pipe attached to maintenance hole is exposed/elevated above creek bed on north side of maintenance holes.
17.1	GM-3	Property	Lateral	10	2	Riprap relatively stable, still providing adequate protection; minor toe erosion, bank is vertical but generally well vegetated(trees/shrubs); trees leaning over channel; bank ~2 m high.
17.2	GM-3	Property	Lateral	22	4	Property set far back from creek, but creek is migrating in direction of property at rate of 0.5 m/year.
18.1	GM-3	Maintenance Hole	Lateral	0	5	Fully exposed maintenance hole, exposed to base; minor toe erosion and cutbank; overhanging and vertical bank, bank face fully exposed; bank height ~4 m and no bank protection; only vegetated along top-of-bank.
18.2	GM-3	Pipe Crossing	Vertical	1.3 from Ex. Grade	5	Pipe crosses diagonally through shallow pool (sandy), not exposed.
19.1	GM-3	Pathway	Lateral	1	5	Armourstone is slumping, upper half of bank not protected at all (natural) and eroding; undermining of armourstone along toe and buildup of woody debris along toe; bank height ~3 m, trees/shrubs along top-of-bank.
20.1	GM-3	Pathway	Lateral	1.5	5	Vertical bank very close to pathway and actively eroding; top-of-bank well vegetated; bank height ~3 m, sand horizons visible within exposed bank face, some gravel/cobble; failed wire mesh in bank.
21.1	GM-3	Maintenance Hole	Lateral	0	5	More than half of maintenance hole exposed including concrete tower; bank is vertical with minimal vegetation to stabilize, overhanging bank; some minor toe erosion.

Site ID	Reach	Risk	Risk Type	Distance to Structure (m)	Bank Condition Classification	Comments
21.2	GM-3	Pipe Crossing	Vertical	0.92 from Ex. Grade	5	Pipe crossing in sandy pool, not exposed; no armouring on creek bed to prevent incision.
21.3	GM-3	Maintenance Hole	Lateral	9	5	Maintenance hole set pretty far back, but bank is actively eroding and there is another exposed maintenance hole ~8 m downstream.
21.4	GM-3	Pipe Crossing (Watermain)	Vertical		2	Watermain under armoured riffle and near road, unlikely to become exposed. Need to confirm pipe elevation at detailed design.
21.5	GM-3	Lateral Pipe	Vertical	1.54 from Ex. Grade	5	Not at immediate risk due to depth of cover >1 m, however creek is actively eroding (lateral migration and incision) at this location and may be at risk in future.
21.6	GM-3	Lateral Pipe	Lateral	9	5	Not at immediate risk due to distance to structure, however creek is actively laterally migrating and has exposed another maintenance holes at this location and may be at risk in future.
22.1	GM-4	Outfall	Lateral	0	2	Outfall set within sheet pile wall, unlikely to become exposed.
23.1	GM-4	Outfall	Lateral	0	1	Undermined boulders below elevated outfall; armourstone immediately downstream of outfall on right bank in good condition stacked 3 - 4 blocks tall; bottom of CSP corroding; minimal vegetation on bank.
24.1	GM-4	Pathway	Lateral	5	3	Vegetation between boulders and water is pooling in this area; right bank 3 to 4 m high, road and pathway directly adjacent to creek; small pocket upstream of boulder wall that has eroded and is no longer protected.
24.2	GM-4	Pipe Adjacent	Lateral	10	3	Pipe not at immediate risk as it is behind an armourstone wall in good condition, however, could be at risk if armourstone were to fail.

Site ID	Reach	Risk	Risk Type	Distance to Structure (m)	Bank Condition Classification	Comments
25.1	GM-4	Maintenance Hole	Lateral	12	2	Maintenance hole set 12 m back from bank, therefore low risk and bank is protected with armourstone blocks in good condition.
26.1	GM-4	Maintenance Hole	Lateral	4	2	Maintenance hole protected by armourstone blocks; no active signs of erosion.
26.2	GM-4	Pipe Crossing	Vertical	3.28 from Riffle Grade	2	Pipe not exposed, bed is sandy and does not appear to be incising in this location; depth of cover over pipe is greater than 2 m.
26.3	GM-4	Rocky Ribs	Vertical/Lateral	N/A	2	One rocky rib has settled toward right bank, likely due to local channel widening and may impact other ribs in future if not repaired.
27.1	GM-4	Outfall/Wingwall	Lateral	5	5	Outfall is in wingwall and elevated with a small scour pool at outlet; bank is 1 m tall, some vegetation in between riprap to help stabilize bank.
27.2	GM-4	Outfall (CSP)	Lateral	1	4	Outfall channel consists of an open CSP pipe (bottom of CSP lines entire channel); gabion baskets on banks and an elevated outfall; gabions are undermined and some material has washed into creek; bank is ~1 m high and vegetated on top.
27.3	GM-4	Maintenance Hole	Lateral	4	4	Maintenance hole protected by stone and not in an area actively eroding; was likely armoured with pedestrian bridge construction.
28.1	GM-BV-1	Property	Lateral	20	5	Property at moderate risk as this reach of the tributary is natural and contains no bank armouring. At this location the channel is migrating in the direction of property.
28.2	GM-BV-2	Property	Lateral	10	3	Property at low risk due to presence of armourstone wall lining channel banks, however property may be at risk if armourstone were to fail.

CSP - corrugated steel pipe

3.3 Infrastructure Engineering Review

At the onset of the project, the design team initiated the data collection for both Toronto Water assets and third-party utilities to form a composite utility plan in the project vicinity. Specifically, for Toronto Water assets (Figure 3-5), including all sewers and water mains within the study area, the following information from the City was compiled and reviewed:

- engineering drawings
- City Utility Mapping (CUMAP)
- TWAG mapping/DCAD

For the current study, a topographic survey was completed between July and September 2021 (Section 3.1.3) that included surveys of storm sewer outfalls and select sanitary sewer maintenance hole rims, with measure downs to pipe inverts at critical locations. No sewer pipes were identified as exposed within the channel of German Mills Creek during the 2021 field work, although three exposed maintenance holes were documented (Section 3.2.3).

The project area and a brief description of the project requirements were circulated to all third-party utility owners to initiate the Toronto Public Utilities Coordinating Committee process and responses have been compiled. Markups, as-builts, and plans for any future works in the area were requested and received for all utility owners with plant in the vicinity The following third-party utility owners have indicated plant in the project limits:

- Bell Canada
- Enbridge Gas
- Group Telecom
- Zayo

The infrastructure design team conducted a site walk to verify the available utility mapping information.

3.3.1 Development of Three-dimensional Model for the Sanitary Sewers

The 3D model of the Toronto Water sanitary sewer system through the project limits was generated using a combination of data sources (Appendix C7). All branch sewers within 10 m of the edge of the creek was also included in the model alongside the main trunk sewer. The 3D model is created using pipe networks in AutoCAD® Civil3D to be integrated into the greater model with the channel and includes the pipe size, material, slope, length as well as information on all structures within the project limits.

An existing ground surface was generated using a combination of topographic survey completed as part of this project work and existing LiDAR data (Section 3.1.3, Appendix C4). maintenance hole lid elevations and invert measure-downs were collected at select locations as part of the field investigation and were also compared against historical data including the following as-builts:

- STS drawings:
    - 1268-C-301
    - 1268-D-6634
    - 1268-D-6656
    - 1268-D-6657
    - 1268-D-6658
    - 1268-D-6659
    - 1268-D-6660
    - 1268-D-6661
    - 1268-D-6662
    - 1268-D-6663
    - 1268-D-731

Section 3.2.2 discusses how discrepancies between the different data sources was handled and the prioritization of data.

3.3.2 Discrepancies Between Record Information and Surveyed Information

There are discrepancies that were found between the surveyed information and what is available through record drawings. These discrepancies are found primarily in the vertical elevations of the maintenance hole rim elevations and invert elevations. These discrepancies can originate from a variety of causes including:

- shift of sewer infrastructure over time through ground settlement
- inconsistencies between coordinate systems from when the as-built drawings were initially surveyed compared to the coordinates used for this contract
    - The benchmarks and datum from the as-built set were not noted.
- differences in survey methods, equipment calibration, or errors in the field
    - Measure-downs in maintenance holes may have inaccuracies if the invert measurements were completed from the ground surface level. As not all inverts can be measured straight down from the maintenance hole access, the invert will need to be triangulated and results in a less accurate reading than a surveyed invert with man entry.
- as-built drawings not completed accurately following construction

It is not always possible to determine the cause of inaccuracy; however, large shifts in the pipe or structures would typically be reflected in the pipe condition. For example, differential settlement of the sewer would cause breaks in the sewer system due to the rigid nature, especially for larger differentials. The remaining differentials would be best accounted for at this time by prioritizing the project-specific field data due to its recency and because it was completed to current City standards. It is also noted that the primary as-built drawing set for the Leslie-Steeles STS was dated 1968, hand drawn, and in Imperial units.

When completing the model of the Toronto Water infrastructure, the following order of reliability of data in order of greatest to least is as below:

1. current topographic survey
2. as-built drawings
3. record/design drawings
4. Digital Map Owners Group (DMOG)/TWAG data

It is also noted that the following maintenance holes were not located in the field:

- MH-5069314298
- MH-5104214564
- MH-5143615024

These maintenance holes are noted to be of lower risk, as they are not located adjacent to the creek. The pipe network has been built using information available from as-built drawings.

Additionally, the following maintenance holes either could not be accessed for invert investigation or were excluded from the invert investigation as they were deemed to be low risk:

- MH-5097414558
- MH-5103714654
- MH-5110614744
- MH-5115314825
- MH-5119514902
- MH-5153515055
- MH-5161815101
- MH-5172615081
- MH-5181315127
- MH-5182515106

The pipe network for these maintenance holes was generated using historical as-built information, like that of the missing maintenance holes.

3.3.3 Review of Construction Methodology

Although not explicitly stated, the as-built drawings imply that the sewer was constructed using conventional open-cut methods, including that of the creek crossings. This is consistent with the construction means and methods of the time, given the design and construction in the 1960s. The as-built drawing set for the Leslie-Steeles STS do not provide any information on bedding or trenching methods; therefore, the bedding and fill cannot be determined at this time.

There is also no information on what flow diversion methods were used to construct the sewer through the creek crossing locations. Installation of riprap is noted in the vicinity of the crossings with the note "WIDTH OF RIP-RAP TO BE WIDTH OF TRENCH AT TOP RIVER BANK PLUS 5 FEET ON UNDISTURBED SOIL ON EACH SIDE."

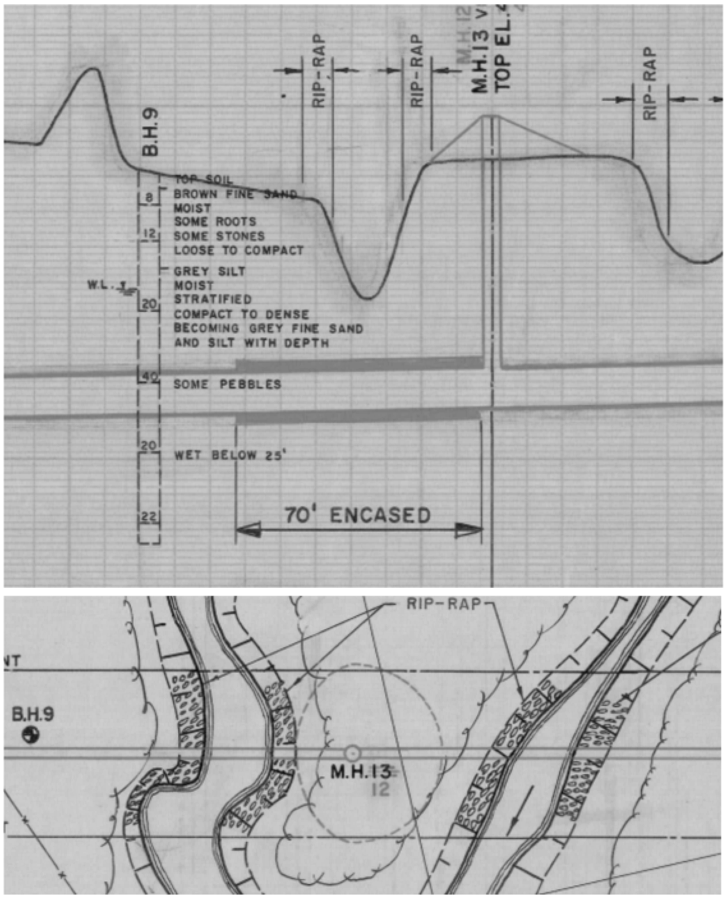


FIGURE 3-5 Excerpts from Sanitary Trunk Sewer Engineering Drawing 1268-D-6660

It is also noted that only one of the creek crossings were encased at the time of construction, at the location of the lowest ground cover shown above (Figure 3-5, Drawing 1268-D-6660). No buoyancy control measures were indicated as well throughout; however, given the reinforced concrete pipe material, this is unlikely to cause challenges due to the significant rigidity and weight of the pipe.

Should remediations be considered on the infrastructure, structural lining or encasement of the existing sewer pipes could aid in extending the service life of this infrastructure and lower the future risks.

3.4 Present Stream Functions (Adaptive Management of Stream Corridors in Ontario Step 5)

3.4.1 Hydrology and Hydraulics

3.4.1.1 Stormwater Management Review

The study area is located at the most downstream section of the watershed before the creek's confluence with the East Don River. As such, stormwater management strategies implemented throughout the German Mills watershed have the potential to reduce peak flow and erosive forces acting on the channel, which in turn could affect the proposed solutions and screening of alternatives for both short- and long-term goals. There have been various guidance documents developed over the past two decades that influence the direction of future stormwater controls within the German Mills watershed. These documents include the 2003 WWFMP (City of Toronto 2003), the *Wet Weather Flow Management Guidelines* (WWFMG; City of Toronto 2006a), the *Don River Watershed Plan, Implementation Guide* (TRCA 2009c) and TRCA's *Stormwater Management Criteria* (TRCA 2012).

Wet Weather Flow Management Master Plan (City of Toronto 2003)

The City developed the 2003 WWFMP to address issues of increased stormwater runoff related to urban development. Urbanization has modified the natural hydrologic cycle by increasing stormwater runoff volumes and peak flows; eroding watercourses; and degrading water quality, which has resulted in habitat loss, flooding, and other adverse environmental effects. The 2003 WWFMP outlines technical and financial objectives "to reduce and ultimately eliminate the adverse impacts of wet weather flow on the built and natural environmental in a timely and sustainable manner and to achieve a measurable improvement in ecosystem health of the watersheds." (City of Toronto 2003)

The 2003 WWFMP consists of a preferred strategy over the long-term (100 years) and an implementation plan for the first 25 years. Five study areas were defined within Toronto to help establish environmental objectives and targets for specific locations. The Don River has been defined as Study Area 4. A specific 2003 WWFMP document was developed for this study area by MMM Group Limited in 2003. Although the Don River encompasses and area over 360 km^2, only a portion of the watershed (south of Steeles Avenue) falls within the City of Toronto jurisdiction and subsequently the targets for the 2003 WWFMP objectives are similarly limited in scope. Three levels of targets were set at 20 reaches throughout the Don River watershed (within Toronto) to meet the 13 technical objectives, including two reaches within the German Mills watershed: Reach 16 (German Mills Creek Tributary upstream of Leslie Street) and Reach 17 (German Mills Creek Confluence with the East Don to Leslie Street/Steeles Avenue (which corresponds to the current master plan study area).

The preferred strategy includes options for source controls, conveyance controls and end-of-pipe controls. Within the Don River watershed this includes downspout disconnections, rain barrel installation, exfiltration systems and sewer replacements, new stormwater management facilities, fish barrier removals, stream restoration and elimination of basement flooding. All of these components would work to reduce stormwater peak flows, improve water quality, and restore stream and riparian habitats.

The German Mills watershed is over 40 km^2, with only a small proportion (i.e., that portion within Toronto) lying within the 2003 WWFMP area (red circle, Figure 3-6). There are several end-of-pipe strategies for the 25-year expenditure plan that have been proposed within Reach 17 on German Mills Creek including two offline valley stormwater management ponds and several Ontario Geological Survey devices. To date, it does not appear that any of these solutions have been implemented (to be confirmed by City staff).

The long-term strategy for the two reaches in German Mills Creek includes several underground facilities at the sewer outfalls to detain stormwater and reduce peaks flows. Being the most downstream reach within the German Mills Creek watershed, it is difficult to implement localized stormwater management controls that will influence channel flows enough to offset the lack of stormwater management controls upstream. While implementation of these local facilities and end of pipe controls will work to partially reduce erosive flows through the study area, restoration will still be required to address the current conditions and maintain stability from the runoff and resulting peak flows that are generated further upstream. As described in Figure 8.3.4 of the master plan (MMM 2003), stream restoration would still be required to achieve the moderate enhancement targets.

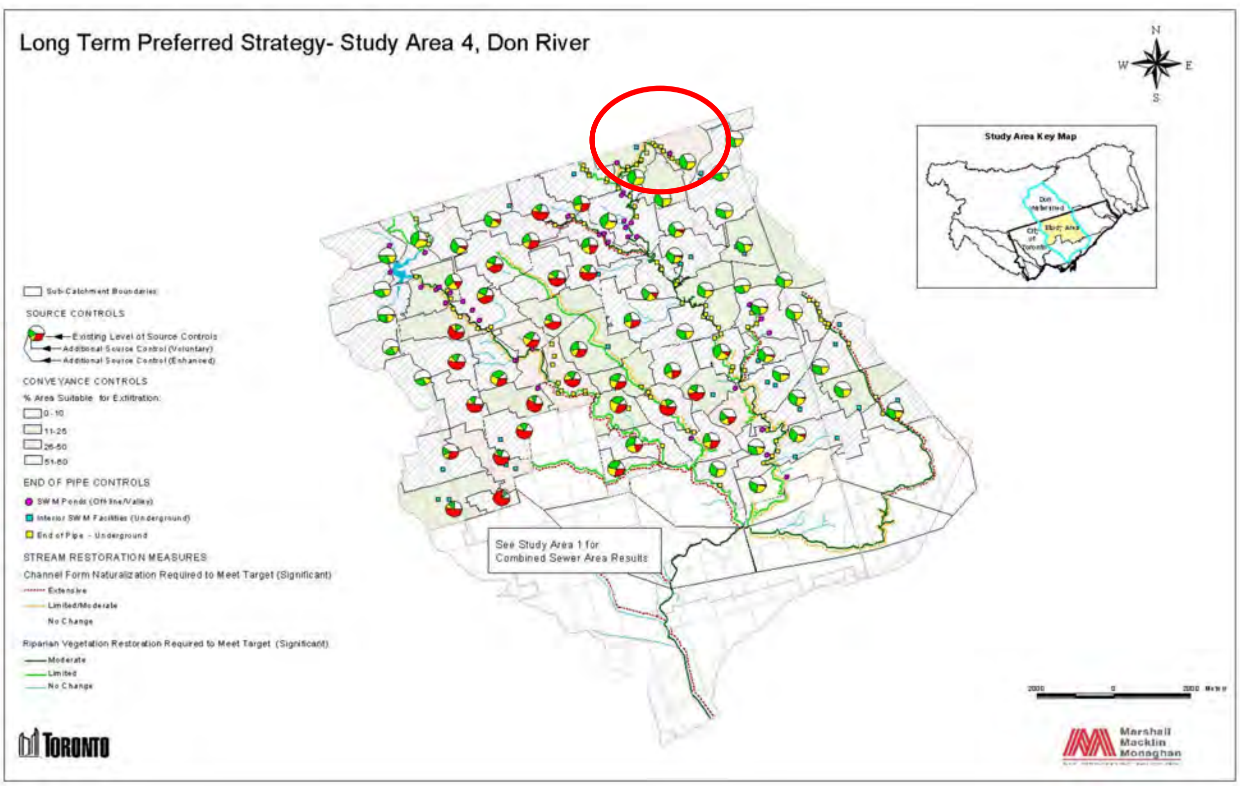


FIGURE 3-6 Long-term Preferred Strategy - Study Area 4, Don River (Source: MMM 2003)

Wet Weather Flow Management Guidelines (City of Toronto 2006)

The City of Toronto developed the WWFMG (City of Toronto 2006b) in 2006 following the implementation of the 2003 WWFMP. The document provides requirements for all new development, infilling, and redevelopments related to onsite stormwater quality and quantity, erosion and sediment control, water balance, and infrastructure connections. As most of the German Mills Creek watershed has already been developed, the guidelines are most applicable to infill and site redevelopment, which are required to achieve higher levels of quantity control, stormwater retention, and quality control prior to release. While these incremental improvements will work to reduce stormwater volumes and peak flows, the implementation of these improved standards will be dependent on the speed of individual site expansions/improvements.

Don River Watershed Plan, Implementation Guide (TRCA 2009c)

The *Don River Watershed Plan* was developed by TRCA to provide a strategic direction for watershed management. "The watershed plan is intended to inform and guide municipalities, provincial and federal governments and TRCA as they update their policies and programs for environmental protection, conservation, and regeneration within the contexts of land and water use, and the planning of future urban growth." (TRCA 2009c) A regeneration plan was developed for the German Mills Creek watershed, which includes recommendations from the City's WWFMP as well as individual stormwater retrofit studies for the Richmond Hill, Markham, and Vaughn.

The watershed plan acknowledges that there is a lack of stormwater management controls throughout the watershed, and that they have been implemented inconsistently. Two target areas of improvement are German Mills Creek north of Mackenzie Drive and the Cummer Creek subwatershed, which requires mitigation to reduce peak flow and maintain groundwater recharge. In addition to the recommendations from the WWFMP, the watershed plan identifies several stormwater opportunities north of Steeles Avenue, which includes three existing outfalls with new stormwater pond potential and four existing stormwater management ponds with retrofit potential.

Toronto and Region Conservation Authority Stormwater Management Criteria (TRCA 2012*)*

TRCA developed *Stormwater Management Criteria* to provide guidance of stormwater management strategies and objectives to provide consistency to developers, landowners, consultants, and municipalities related to the watersheds they govern. Unit flow relationships have been developed for the Don River to guide stormwater quantity control criteria, creating consistent pre-development flow targets across north of Steels Avenue. The criteria requires that post-development peak flows be controlled to pre-development levels for all storms up to an including the 100-year storm. Additional criteria related to water quality, erosion, and water balance are also provided. Similar to the WWFMG, the TRCA *Stormwater Management Guidelines* would be most applicable to site redevelopments within the German Mills watershed as opposed to new development given the existing urbanization in the watershed.

3.4.1.2 Summary of Models

The TRCA provided the following hydrologic and hydraulic information and models:

- The updated PCSWMM hydrological model for the Don River system and the associated report, completed by AECOM in 2018 (AECOM 2018). This 2018 model is the most up-to-date hydrology for the German Mills Creek subwatershed and will be used as design flow input for the hydraulic assessment.

- A one-dimensional (1D) steady-state HEC-RAS hydraulic model of the Don River system (Phase 1) and the associated report that was developed by KGS Group (2020) for the use of updating regulatory floodplain mapping. Model geometry extends from Pottery Road in the Lower Don Parklands, north to Steeles Avenue East, approximately 50 m upstream of the confluence of German Mills Creek and Duncan Creek. The 2020 HEC-RAS model report indicates that peak flows from the *Don River Hydrology Update* (AECOM 2018) have been included in the hydraulic model.

- A 1D steady-state HEC-RAS hydraulic model of the Don River and its tributaries north of Steeles Avenue (Phase 2) and the associated report developed by WSP in 2020 for the use of updating regulatory floodplain mapping. Model geometry extends from Steeles Avenue, north to Hearthside Avenue and Bathurst Street in Richmond Hill.

3.4.1.3 Hydrological Flood Event Series

Peak flows from the *Don River Hydrology Update* (AECOM 2018) have been incorporated into the hydraulic models by previous consultants. Design storms include the 2-, 5-, 10-, 25-, 50-, 100-, 350-year, and the Regional storm. For each event, peak flow values were extracted at selected locations from the hydrologic model and applied as steady-state flow values located at cross sections nearest to each hydrologic model node. Details of the application of flows can be found in the KGS Group (2020) report.

3.4.1.4 Hydraulics Model Setup

Following the review of the hydraulic models provided by TRCA, Matrix developed an “existing conditions” model to be used as a baseline to compare design alternatives. The existing conditions model is a 1D steady-state HEC-RAS model of the study area based on the Phase 1 model created by KGS Group (2020). The following sections outline the updates to the model made by Matrix to reflect the most recent available data.

Addition of Structure Geometry

Matrix extended the upstream extent of German Mills reach by 90 m to incorporate the Steeles Avenue East bridge. The location and geometry of the Steeles Avenue East bridge was taken from the Don River Phase 2 hydraulic model, developed by WSP in 2020. All data was input into the Matrix existing conditions geometry as it was received in the Phase 2 model. After reviewing flow node locations in the Phase 2 model, it was found that no additional flow inputs were located in the new 90 m extension of the reach. Therefore, the flow node previously applied to upper most cross-section of the Phase 1 model (XS 47.92) was applied upstream of the Steeles Avenue East structure at the upper most cross-section (XS 140.7) to allow for review of structure performance.

Matrix also added the newly constructed pedestrian bridge, approximately 20 m downstream of Steeles Avenue East. Additional cross sections were added to the existing conditions geometry to appropriately model expansion and contraction of flow through the structure. The structure deck and railing heights were added based on field survey data collected by Matrix.

Figure 3-7 shows the comparison of the original Phase 1 model (left) with the updated existing conditions geometry (right) which includes both new structures added to the upstream extent of the study area.

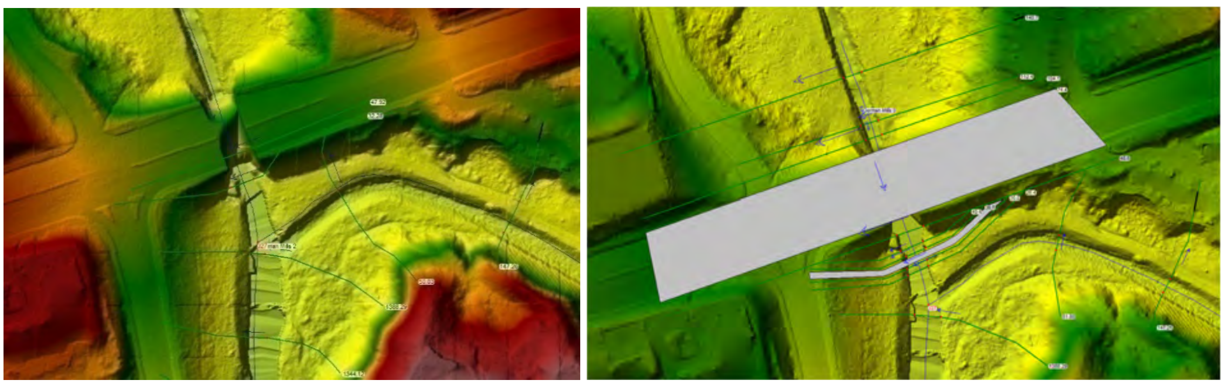


FIGURE 3-7 Comparison of Original Phase 1 Hydraulic Model with Updated Model including New Structures Added

Model Terrain Surface

As noted in the KGS (2020) report, bathymetry surveys were not completed in the study area of German Mills Creek; therefore, the existing model terrain and associated cross-sections do not represent the channel depth. For the updated existing conditions model, Matrix generated a new terrain for the study area, which incorporated the topographic field survey data collected of the channel profile and cross-section geometry.

The terrain surface was obtained through Open Data Hub Ontario and is part of the GTA 2015 Open LiDAR Catalog (please consult the website for more details). Matrix collected the incorporated survey data using differential global positioning system in August/September 2021. The surface was adjusted to CGVD 1928 to appropriately merge topographic survey and LiDAR data based on difference of +0.409 m (BM 0011960UT121; e.g., CGVD 1928 is +0.409 m higher than CGVD 2013 surface). Finally, the surface was reprojected to NAD83 UTM Zone 17N (WKID: 26917) for compliance with the hydraulic modeling space (ON83CSv1.gsb used for CSRS/NAD83 transformation). A detailed documentation of methodology is included in Appendix C4.

This updated model terrain was compared against the Phase 1 model geometry provided by TRCA and was determined provide an equivalent representation of the channel overbank within the study area. Although the updated terrain has less detail of local features within the channel banks, it appropriately represents the channel depth as it is based on the topographic profile survey.

Figure 3-8 shows cross-section 1035.3 from the KGS (2020) Phase 1 model with the original geometry compared against the Matrix generated terrain data.

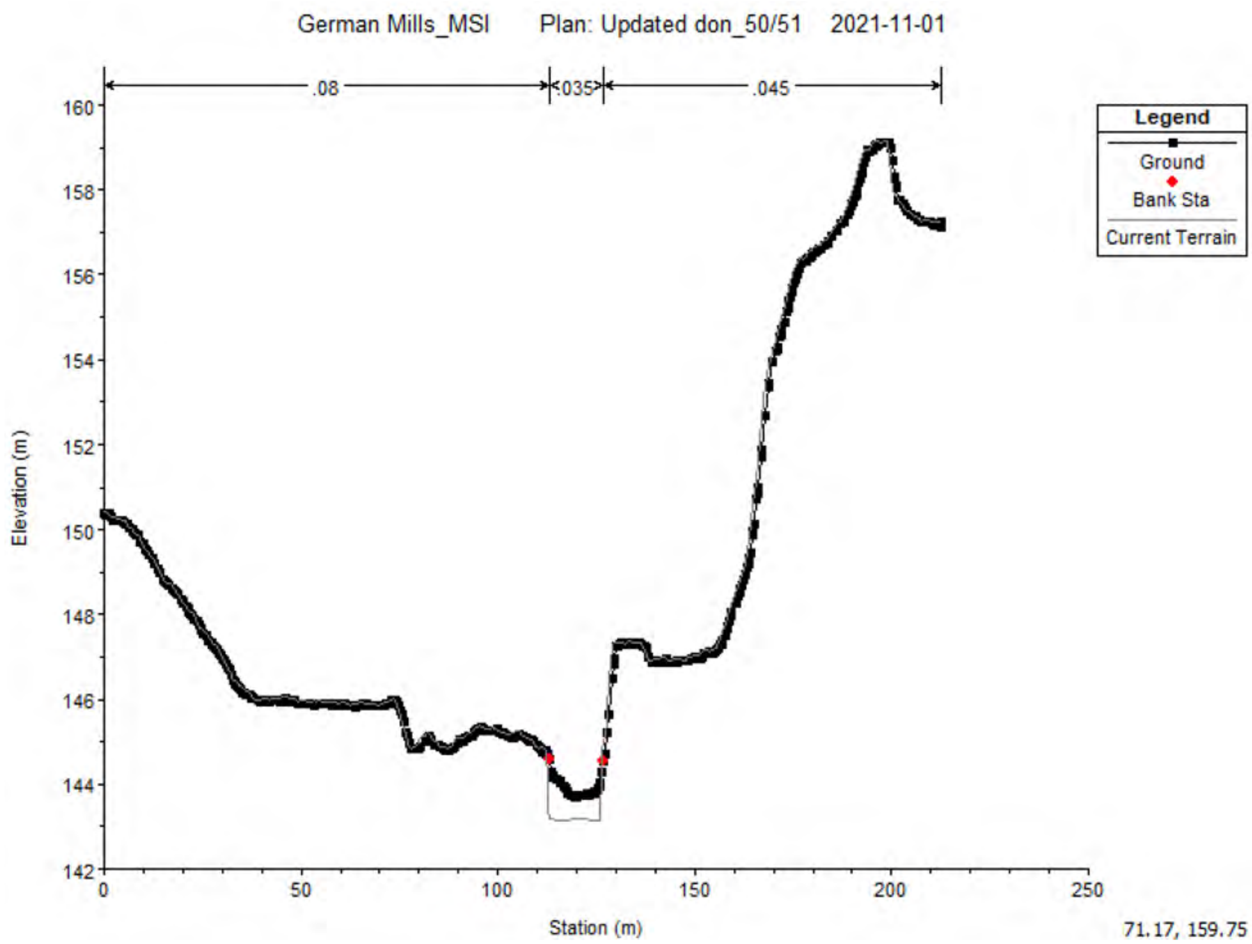


FIGURE 3-8 Comparison of Phase 1 Hydraulic Model Section with Updated Terrain Surface

Figure 3-9 shows a profile comparison of the original Phase 1 model terrain (top) against the modified model terrain (bottom). Both profiles include the same number of data points, which are based on the location of cross-sections. The variation shown in the modified terrain profile reflects the existing pools and riffles observed in the topographic survey of the channel profile.

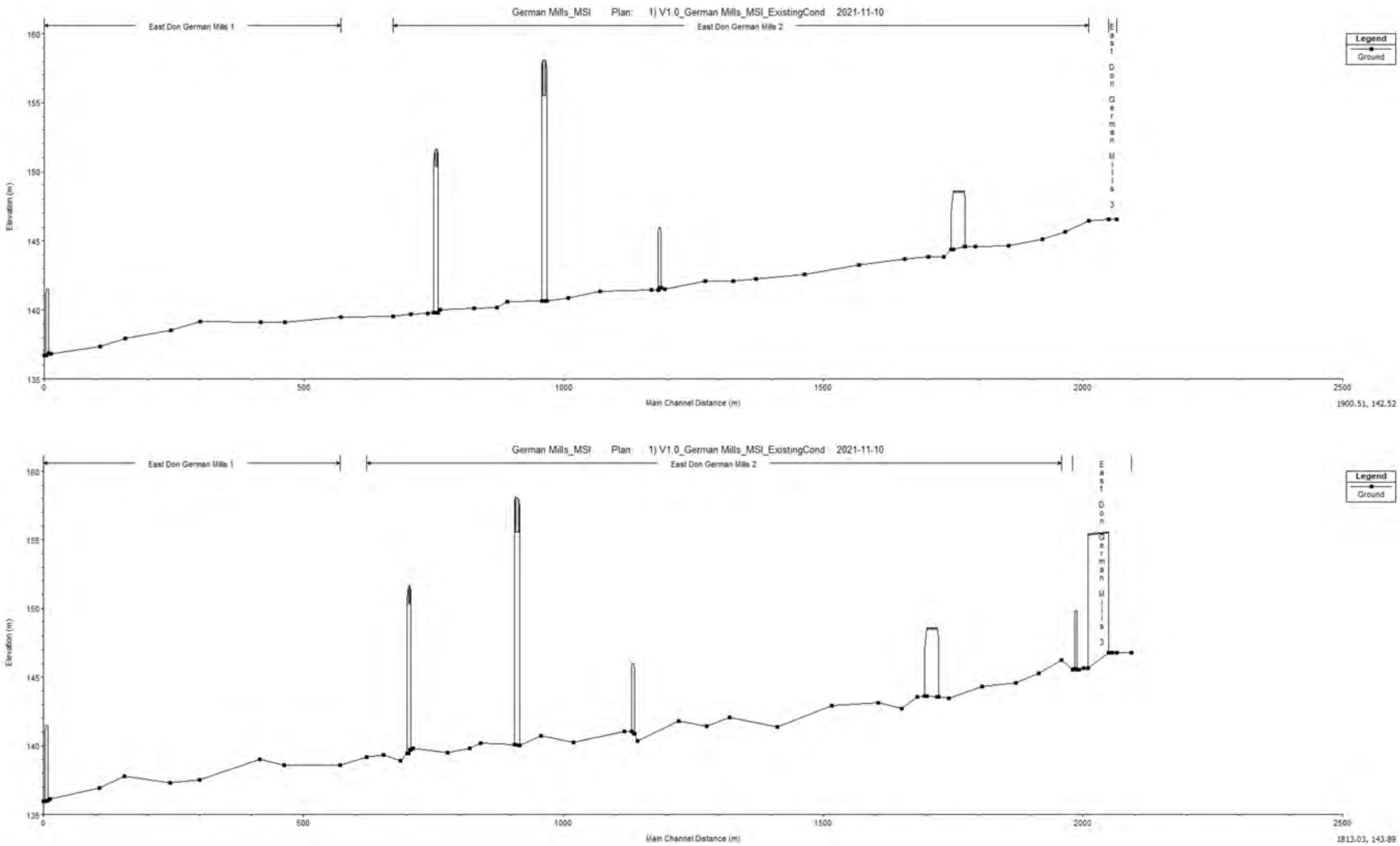


FIGURE 3-9 Comparison of Phase 1 Hydraulic Model Profile with Updated Terrain Surface

Finally, Figure 3-10 shows the comparison of the model terrains in plan view, at the approximate midpoint of the study area.

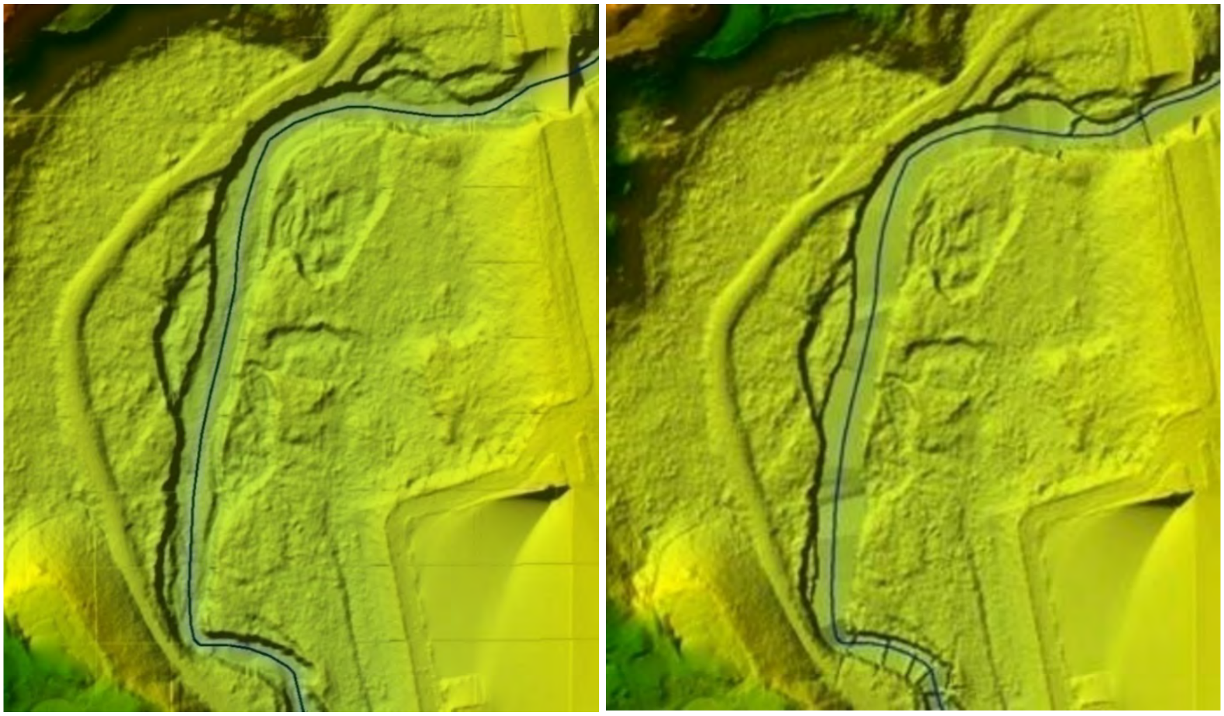
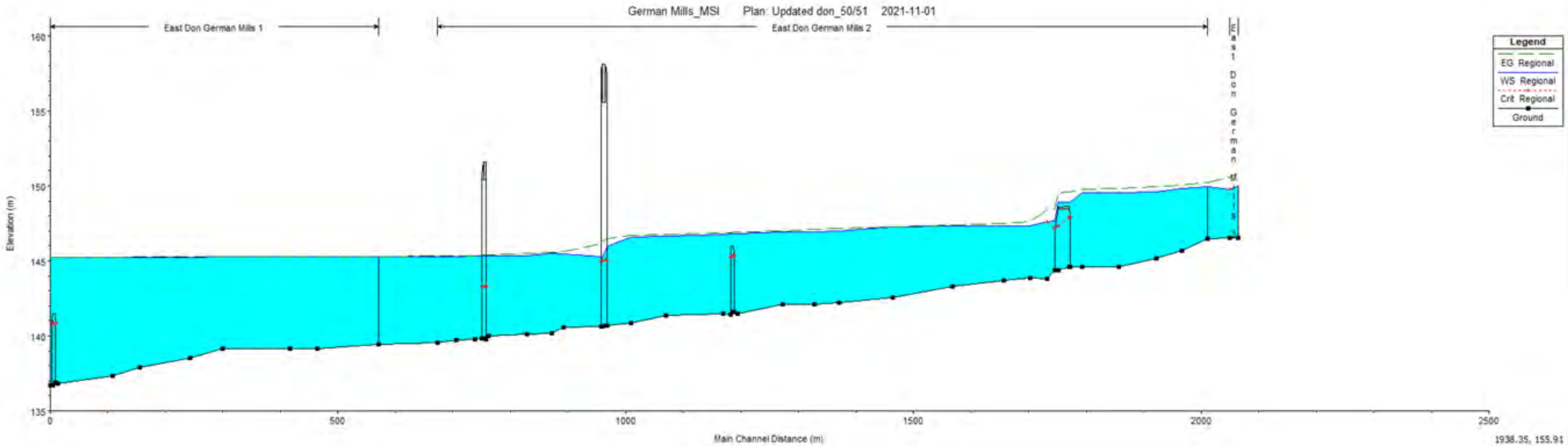


FIGURE 3-10 Comparison of Original 2015 LiDAR Model with Updated Surface Model including Integration of 2021 Topographic Survey Data

3.4.1.5 Existing Conditions Results

The Matrix existing conditions model was run using the same peak hydrology flows as the provided Phase 1 model. Figure 3-11 provides a profile view of the Regional event results for the Phase 1 model (top) and the Matrix existing conditions model (bottom).



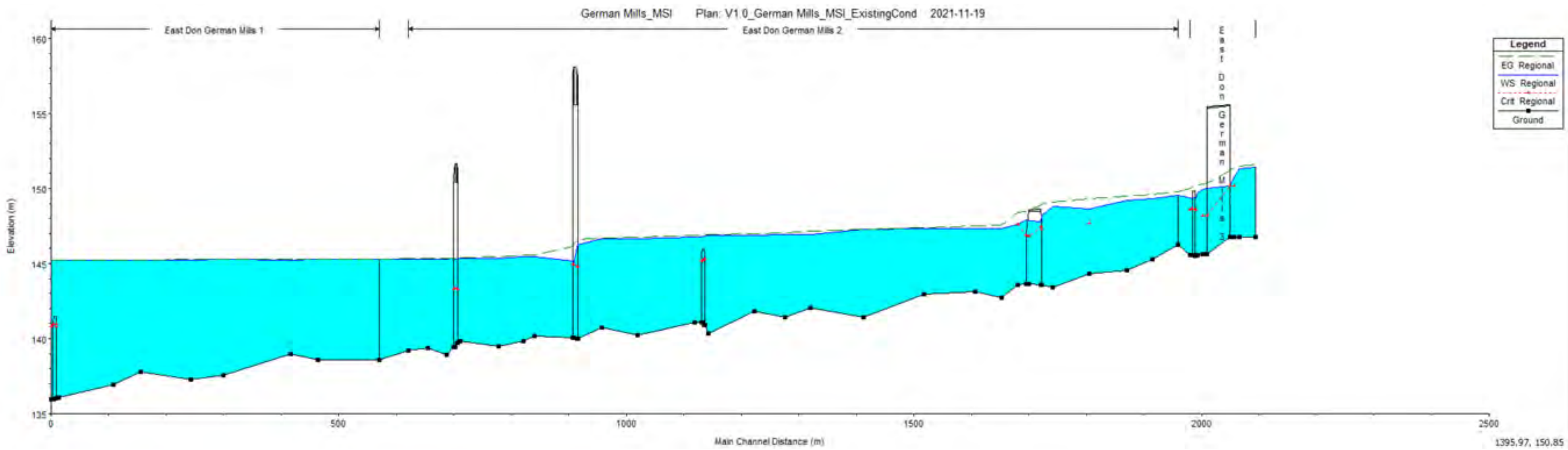


FIGURE 3-11 Comparison of Phase 1 Hydraulic Model Profile with Updated Terrain Surface, including Region Event Water Surface

Some variation in results is expected with the introduction of a new terrain surface. The most noteworthy change is the reduction of water surface elevations upstream of the Leslie Street bridge (Station 1138.88). Field surveys in this area found the channel invert to be 1.1 m lower than the existing model terrain. The additional conveyance provided by lowering the channel invert in this area has eliminated the overtopping of the Leslie Street bridge during the Regional event and reduced the associated upstream backwatering.

Overall, the updated existing conditions model will provide an effective tool for the purpose of evaluating and assessing design alternatives.

3.4.2 Characterization of Biotic Communities

To characterize the terrestrial and aquatic resources within the study area, Matrix utilized the findings from a background review and field surveys. Additional aquatic monitoring reaches were established, and the results of the monitoring is provided in the Monitoring Report (Appendix E of the Master Plan).

In this section the results from the background review, field surveys, and monitoring (methodology described in Appendix C8) as well as agency correspondence from the Ministry of the Environment, Conservation and Parks (MECP) and TRCA (Appendix C8) are documented in the terrestrial resources (Section 3.4.2.1), aquatic resource (Section 3.4.2.2), and species at risk (SAR; Section 3.4.2.3) sections.

3.4.2.1 Terrestrial Resources

This section provides results of the terrestrial resources within the study area found during the background review and field visits as described in Appendix C8.

Vegetation Communities

Using the Ecological Land Classification (ELC) maps sourced from the TRCA, a total of 30 different vegetation classes were assessed (Figure C8a). Of those, two codes showed discrepancies based on the vegetation surveys. The remaining 28 vegetation communities were confirmed to be correct. A summary of each ELC code reviewed can be found in Table 3-7. One community is considered provincially rare (i.e., S1 to S3 ranked): FOD7-4 (ranked S2S3). One community is considered locally rare (i.e., L1 to L3 ranked): MAM2-1, and six communities are considered of conservation concern in the urban matrix (i.e., L4 ranked): FOC2-2, FOC4-1, FOD5-3, FOD6-4, FOD7-4, and FOM7-2. Disturbance to these communities should be avoided where possible.

TABLE 3-7 Summary of Ecological Land Classification Communities

ELC Code	Community Description	S-rank	L-rank	Detailed Vegetation Inventory Collected	Comments
BBO1-A	Open Riparian Sand/Gravel Bar	-	L5	No	Existing TRCA code confirmed to be correct.
CUM1-A	Native Forb Meadow	-	L5	Yes	Existing TRCA code confirmed to be correct.
CUM1-b	Exotic Cool-season Grass Graminoid Meadow	-	L+	Yes	Existing TRCA code confirmed to be correct.
CUM1-b	Exotic Cool-season Grass Graminoid Meadow	-	L+	Yes	Not a meadow along Cummer Avenue, more likely a sumac thicket.
CUM1-c	Exotic Forb Meadow	-	L+	Yes	Not a meadow, over 25% treed.
CUP1-c	Locust Deciduous Plantation	-	L+	Yes	Existing TRCA code confirmed to be correct.
CUW1-b	Exotic Successional Woodland	-	L+	Yes	Existing TRCA code confirmed to be correct.
CUT1-1	Sumac Deciduous Thicket	-	L5	Yes	Existing TRCA code confirmed to be correct.
CUT1-A2	Native Mixed Sampling Regeneration Thicket	-	L5	Yes	Existing TRCA code confirmed to be correct.
CUW1-A3	Native Deciduous Successional Woodland	-	L5	Yes	Existing TRCA code confirmed to be correct.
FOC2-2	Dry-Fresh White Cedar Coniferous Forest	S5	L4	No	Existing TRCA code confirmed to be correct.
FOC4-1	Fresh-Moist White Cedar Coniferous Forest	-	L4	Yes	Existing TRCA code confirmed to be correct.
FOD4-2	Dry-Fresh White Ash Deciduous Forest	S5	L5	Yes	Existing TRCA code confirmed to be correct.
FOD5-1	Dry-Fresh Sugar Maple Deciduous Forest	S5	L5	No	Existing TRCA code confirmed to be correct.
FOD5-2	Dry-Fresh Sugar Maple - Beech Deciduous Forest	S5	L5	No	Existing TRCA code confirmed to be correct.
FOD5-3	Dry-Fresh Sugar Maple - Oak Deciduous Forest	S5	L4	Yes	Existing TRCA code confirmed to be correct.
FOD5-4	Dry-Fresh Sugar Maple - Ironwood Deciduous Forest	S5	L5	No	Existing TRCA code confirmed to be correct.
FOD6-4	Fresh-Moist Sugar Maple - White Elm Deciduous Forest	S5	L4	Yes	Existing TRCA code confirmed to be correct.
FOD7-2	Fresh-Moist Ash Deciduous Forest	S5	L5	Yes	Existing TRCA code confirmed to be correct.
FOD7-3	Fresh-Moist Willow Lowland Deciduous Forest	-	L5	Yes	Existing TRCA code confirmed to be correct.
FOD7-4	Fresh-Moist Black Walnut Lowland Deciduous Forest	S2S3	L4	Yes	Existing TRCA code confirmed to be correct.

ELC Code	Community Description	S-rank	L-rank	Detailed Vegetation Inventory Collected	Comments
FOD7-a	Fresh-Moist Manitoba Maple Lowland Deciduous Forest	-	L5	Yes	Existing TRCA code confirmed to be correct.
FOD8-1	Fresh-Moist Poplar Deciduous Forest	S5	L5	Yes	Existing TRCA code confirmed to be correct.
FOM7-2	Fresh-Moist White Cedar - Hardwood Mixed Forest	S5	L4	No	Existing TRCA code confirmed to be correct.
MAM2-1	Bluejoint Mineral Meadow Marsh	S5	L3	Yes	Existing TRCA code confirmed to be correct.
MAM2-10	Forb Mineral Meadow Marsh	S4S5	L5	Yes	Existing TRCA code confirmed to be correct.
MAM2-5	Narrow-leaved Sedge Mineral Meadow Marsh	S5	L3	Yes	Existing TRCA code confirmed to be correct.
MAS2-1b	Narrow-leaved Cattail Mineral Shallow Marsh	-	L+	Yes	Existing TRCA code confirmed to be correct.
MAS2-a	Common Reed Mineral Shallow Marsh	-	L+	Yes	Existing TRCA code confirmed to be correct.
SWD4-b	European Alder Mineral Deciduous Swamp	-	L+	Yes	Existing TRCA code confirmed to be correct.

Flora

A total of 94 plant species were recorded during the detailed investigation (Appendix C8; Table C8g)). Of these 94 species, no SAR or provincially ranked as S1, S2, and S3 species were observed. Based on the TRCA local rankings, there were no L1 species, three L2 species, and three L3 species. Disturbance to these species should be avoided where possible.

Invasive Species

Eleven invasive species, as per the Ontario Invasive Species Council, were recorded within the study area. The most prolific invasive species recorded was Dog Strangling Vine (*Vincetoxicum rossicum*). Dog Strangling Vine was present in nearly every vegetation community. The City has a spraying program in place to help reduce this plants presence but it still has a large population within the valley corridor.

Wildlife and Wildlife Habitat

Incidental Wildlife Observations

Any incidental wildlife observed while conducting field work was recorded. Two species listed as special concern were recorded including Eastern Wood Pewee and Monarch as well as two invasive species including Goldfish and Japanese Beetle (see Section 3.4.2.3 and Appendix C8; Table C8h). The remaining incidental observations are summarized in Table 3-8. No provincially rare species (i.e., S1 to S3 ranked) were observed; however, one locally rare species (i.e., L1 to L3 ranked) was observed.

TABLE 3-8 Incidental Wildlife Observed within the Study Area

Common Name	Scientific Name	ESA	SARA	S-rank	L-rank
American Goldfinch	*Spinus tristis*	-	-	S5	
Blue Jay	*Cyanocitta cristata*	-	-	S5	L5
Common Red Soldier Beetle	*Rhagonycha fulva*	-	-	SNA	
Dogbane Leaf Beetle	*Chrysochus auratus*	-	-	S4S5	
Eastern Wood-Pewee	*Contopus virens*	SC	SC	S4B	
Field Sparrow	*Spizella pusilla*	-	-	S4B	L4
Goldenrod Bunch Gall Midge	*Rhopalomyia solidaginis*	-	-	-	-
Goldfish(1)	*Carassius auratus*	-	-	SNA	L+
Gray Cat Bird	*Dumetella carolinensis*	-	-	S5B, S3N	L4
Great Blue Heron	*Ardea herodias*	-	-	S4	L3
Red-tailed Hawk	*Buteo jamaicensis*	-	-	-	-
Japanese Beetle(1)	*Popillia japonica*	-	-	SNA	L+
Mallard	*Anas platyrhynchos*	-	-	S5	
Monarch	*Danaus plexippus*	SC	SC	S2N, S4B	-
Muskrat	*Ondatra zibethicus*	-	-	S5	
Northern Cardinal	*Cardinalis*	-	-	S5	
White-tailed Deer	*Odocoileus virginianus*	-	-	S5	L4
Willow Pinecone Gall Midge	*Rabdophaga strobiloides*	-	-	NNR	

Notes:
(1) indicates invasive species
ESA - *Endangered Species Act*
SARA - *Species at Risk Act*

Significant Wildlife Habitat

The assessment of significant wildlife habitat (SWH) follows the guidelines in the NHRM (MNR 2010) and the criteria from the *Significant Wildlife Habitat Criteria Schedules for Ecoregion 7E* (MNRF 2015), with support from the SWHTG (MNR 2000) as appropriate. There are four categories of SWH which include the following:

- seasonal concentration areas of animals
- rare vegetation communities or specialized habitat for wildlife
- habitat for species of conservation concern (SCC)
- animal movement corridors

Each of these categories includes various SWH types and with criteria to evaluate significance. These four categories were assessed based on aerial photography, background review, and field investigations performed by Matrix. A full SWH evaluation is provided in Appendix C8; Table C8h, with a summary of the confirmed or candidate SWH is provided in Table 3-9. To support the evaluation of SCC habitat in Appendix C8, a specific evaluation with regards to SCC and their potential to occur within the study area is provided in Appendix C8; Table C8i.

TABLE 3-9 Significant Wildlife Habitat Assessment Summary

Category	Wildlife Habitat Feature	Confirmed/Candidate
Seasonal Concentration Areas of Animals	Raptor Wintering Area	Candidate - Upland and forested areas are within the study site.
	Bat Maternity Colonies	Candidate - FOD and SWD communities are present.
Rare Vegetation Communities and Specialized Habitat for Wildlife	Other Rare Vegetation Communities	Confirmed - FOD7-4 (S2S3) present.
	Bald Eagle and Osprey Nesting/Foraging/Perching	Candidate - Woodland communities are directly adjacent to riparian areas.
	Amphibian Breeding Habitat (Woodland)	Candidate - vernal pooling may be present within the FOD, FOM, FOC, and SWD communities.
Habitat for Species of Conservation Concern	Marsh Breeding Bird Habitat	Candidate - Wetland habitat with shallow water and emergent aquatic vegetation is present.
	Terrestrial Crayfish	Candidate - MAM, MAS, and SWD habitat communities present.
	Special Concern and Rare Wildlife Species	Confirmed - Eastern Wood-Pewee Candidate - Monarch Butterflies, Northern Map Turtle, and Snapping Turtle.
Animal Movement Corridors	Amphibian Movement Corridor	Candidate - Ecosites associated with water (i.e., SWD, MAM, etc.) are present but significant breeding habitat is unconfirmed at this time.

3.4.2.2 Aquatic Resources

Aquatic Habitat

High-level Study Area Aquatic Habitat

Based on the information collected through the high-level aquatic habitat field mapping exercise (Appendix C8), German Mills Creek throughout the study area has a defined riffle-pool system. The system is generally sinuous with some extended areas of straight channel. The surrounding land use consists of a forested valley corridor with a multi-use trail following along side the watercourse. The downstream end of the study area includes the Don River with the tributary of German Mills Creek meeting the Don River approximately 150 m upstream of Cummer Avenue. Approximately 400 m upstream of the German Mills Creek and Don River confluence there is another tributary connection that begins at an outlet adjacent to Bestview Park.

The watercourse has predominantly natural banks; however, there are multiple sections that have been armoured with armourstone, gabion baskets, or boulders. This has likely been installed historically to prevent erosion and to protect the adjacent multi-use trail.

Throughout the study area the wetted width ranges from 5 to 10 m and the water depth ranges from 0.05 to 0.17 m in riffles and 0.5 to 1.5 m in pools. There are some distinct areas of the channel that are completely shaded (often by large Willow trees) but majority of the watercourse is wide enough that it is in direct sun for at least a portion of the day. Fish habitat features were recorded and include the following features:

- undercut banks
- woody debris
- backwatered areas of refuge
- overhanging vegetation
- instream vegetation (limited)

These features have been mapped in relation to the riffle, runs, and pools in Figures H4-2 to H4-16 (Appendix C8). There are many opportunities for fish to spawn, feed, and find refuge throughout the watercourse. Schools of fish were observed during field visits at multiple points throughout the watercourse. Based on the information collected and the observation of many fish throughout the system, German Mills Creek can be deemed as high-quality aquatic habitat.

Two areas, as seen on Figures C8e and C8n (Appendix C8) have the potential to be a barrier to fish during normal flow conditions. Knowing that this creek has a fish community of mostly small bait fish it is possible that the boulders could prevent fish from moving upstream. In high flow conditions, the water would be high enough to overtop the boulders and they would no longer be considered a barrier.

More detailed aquatic habitat monitoring was completed at the monitoring stations and results are provided in the Monitoring Report (Appendix E of the Master Plan). Water quality sampling and benthic monitoring are also included in the Monitoring Report.

Fish Community

No fish community data was collected for this project. However, existing fish community data exists for areas near the study area. The Schedule B German Mills EA (TRCA 2019a) provides information on fish collected at monitoring station DN008WM, which is located in the same branch as the current study area, just upstream of Steeles Avenue. The *Don River Watershed Plan Aquatic System - Report on Current Conditions* (TRCA 2009d) also provides fish community information within the German Mills Creek subwatershed. This information is based on collections from 2002-2005. Fish community data is summarized in Table 3-10. None of the species collected at this station are listed as at risk either provincially or federally.

TABLE 3-10 Fish Community Data

Common Name	Scientific Name	German Mills Subwatershed Collected 2002 to 2005 (TRCA 2009d)	Station DN008WM Collected July 31, 2021 (TRCA 2019a)
Blacknose Dace	*Rhinichthys atratulus*	X	X
Bluntnose Minnow	*Pimephales notatus*	X	
Creek Chub	*Semotilus atromaculatus*	X	X
Common Shiner	*Luxilus cornutus*	X	X
Fathead Minnow	*Pimephales promelas*	X	X
Goldfish	*Carassius auratus*	X	
Johnny Darter	*Etheostoma nigrum*	X	X
Longnose Dace	*Rhinichthys cataractae*	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X
White Sucker	*Catostomus commersonii*	X	X

Based on the fish community data and the thermal regime results in the *Don River Watershed Plan* (TRCA 2009d), German Mills Creek is classified warm/cool water system. All fish species observed are species are common and secure in Ontario. One invasive fish species was recorded: Goldfish. It was recorded in 2005 but not recorded at station DN008WM upstream of Steeles Avenue. However, Goldfish were visually observed downstream of Monitoring Station 1 and, as a result, would still be considered a record for the German Mills study area.

As discussed earlier there are two locations along the watercourse within the study area that may act as potential fish barriers during baseflow conditions (Figures C8e and C8n, Appendix C8).

3.4.2.3 Species at Risk

Species at Risk Screening Results

SAR are defined in this report to include the following provincial and federal designations:

- *Endangered Species Act* (ESA; provincial): all provincially designated species that are listed as extirpated, endangered, or threatened on the Species at Risk in Ontario list and protected under the ESA; species listed as special concern are considered a SCC, as they are not protected under the ESA.
- *Species at Risk Act* (SARA; federal): only applies to fish and migratory birds protected under the *Migratory Birds Convention Act*, anywhere they occur (e.g., includes non-federal land), that are designated as extirpated, endangered, and/or threatened under the SARA. All other species are only protected if special provisions or executive orders are made.

The background review identified potential SAR that could occur within the study area (Table 3-11). All SAR identified were screened to determine the likelihood of occurrence and whether suitable habitat is present. To determine if suitable habitat for SAR is available within the study area, the preferred habitat requirements for reported SAR were compared to vegetation communities, aquatic habitats, and niche habitats identified during field inventories and the background review.

TABLE 3-11 Potential Species at Risk

Common Name	Scientific Name	ESA Status	SARA Status
Plants			
Butternut	*Juglans cinerea*	Endangered	Endangered
Fish			
Redside Dace	*Clinostomus elongatus*	Endangered	Endangered
Reptiles			
Blanding's Turtle	*Emydoidea blandingii*	Threatened	Threatened
Northern Map Turtle	*Graptemys geographica*	Special Concern	Special Concern
Snapping Turtle	*Chelydra serpentina*	Special Concern	Special Concern
Birds			
Bank Swallow	*Riparia*	Threatened	Threatened
Barn Swallow	*Hirundo rustica*	Threatened	Threatened
Bobolink	*Dolichonyx oryzivorus*	Threatened	Threatened
Chimney Swift	*Chaetura pelagica*	Threatened	Threatened
Common Nighthawk	*Chordeiles minor*	Special Concern	Threatened
Eastern Meadowlark	*Sturnella magna*	Threatened	Threatened
Eastern Wood-pewee	*Contopus virens*	Special Concern	Special Concern
Peregrine Falcon	*Falco peregrinus*	Special Concern	Special Concern
Wood Thrush	*Hylocichla mustelina*	Special Concern	Threatened
Insects			
Monarch	*Danaus plexippus*	Special Concern	Special Concern
Mammals			
Eastern Small-footed Myotis	*Myotis leibii*	Endangered	-
Little Brown Bat	*Myotis lucifugus*	Endangered	Endangered
Northern Myotis	*Myotis septentionalis*	Endangered	Endangered
Tri-colored Bat	*Perimyotis subflavus*	Endangered	Endangered

Notes:
ESA - *Endangered Species Act*
SARA - *Species at Risk Act*

As noted previously, SAR species that are designated as special concern listing in Table 3-11, do not receive habitat protection under the ESA and are therefore considered SCC. SCC species are discussed in the context of SWH in Section 3.4.2.1.

Species at Risk Assessment

A total of 14 SAR was identified as potentially occurring within the study area based on the background review and site investigations (Table 3-15). To identify likelihood of species occurrences within the study area each species was assessed based on the habitat criteria of that species and the availability of habitat.

A full evaluation is provided in Appendix C8; Table C8l. The results of the assessment indicated that five species were unlikely to inhabit the area based on the lack of appropriate habitat. Nine species were identified as potentially occurring within the study area and are discussed below.

- **Butternut**: a medium to large deciduous tree, is commonly found in riparian habitats as well as rich, moist, well-drained loams and well-grained gravels, especially those of limestone origin (COSEWIC 2017). The moist, wooded riparian zone adjacent to German Mills Creek is potential habitat for Butternut. At this time no Butternut trees were identified, however more detailed searches should be conducted once construction boundaries are known.

- **Redside Dace:** have historically (1948) been recorded in German Mills Creek. No recent records have been documented and recent DFO SAR mapping does not indicate that Redside Dace are present. They are known to thrive in coldwater systems that have gravel substrate for spawning (MECP 2021a).

- **Bank Swallow:** this bird species nests in burrows in natural and human-made setting where there are vertical faces in sand and silt deposits (MECP 2021b). There are areas of the watercourse that have vertical banks that could act as potential habitat for Bank Swallow. At this time no Bank Swallow nests were observed along the banks; however, more detailed searches should be conducted once construction boundaries are known.

- **Barn Swallows:** this species is known to nest on buildings and other anthropogenic structures, particularly if they have wooden struts or trusses (Heagy et al. 2014). The pedestrian, train, and road bridges within the study area that may act as Barn Swallow nesting habitat. At this time no Barn Swallow nests were observed within the study area, however more detailed searches should be conducted once construction boundaries are known.

- **SAR Bats (Little Brown Myotis, Northern Myotis, Tri-colored Bat, and Eastern Small footed Myotis):** are all small insectivorous bats. They roost in a variety of locations including crevices within buildings, trees (cavities, under bark), barns, and other anthropogenic structures (CWF 2020, ECCC 2018). Potential habitat exists within the wooded vegetation communities.

3.4.3 Geomorphic Evaluation

A detailed geomorphological assessment was completed as part of the establishment of the erosion monitoring sites for German Mills Creek. Detailed geomorphic data was collected within three erosion monitoring areas:

- MON1: located downstream of Steeles Avenue, upstream of pedestrian bridge
- MON2: located between trail bridge and downstream pedestrian bridge
- MON3: located downstream of confluence

Monitoring site locations are presented in Figure 3-1. The full assessment is provided in the Monitoring Report (Appendix E of the Master Plan).

3.4.3.1 Channel Geometry

Bankfull channel dimensions are presented in the Tables A, B, and C of the Monitoring Report (Appendix E of the Master Plan). Bankfull widths measured among all sites ranged from 7.07 to 15.55 m among all surveyed cross-sections in 2021 and 2022. The average bankfull width was smallest in MON2 (<10 m), larger in MON1 (11 to 12 m) and widest in MON3 (12 to 13 m). The average bankfull depth among all sites ranged from 0.53 to 1.21 m among all surveyed cross-sections. The maximum bankfull depth was 2.09 m within the riprap-lined section below MON-. The average bankfull cross-sectional area among all sites was 13.34 m^2 in 2021 and 13.29 m^2 in 2022. The north bank of cross-section MON2-1 is confined by a valley contact and railway embankment with an elevation of approximately 5.0 m. At MON3-6 the channel flows along the toe of a valley wall contact, and the north bank height is 4.5 m.

Entrenchment ratios were calculated based on the cross-sectional dimensions measured in 2021 (Table D of the Monitoring Report; Appendix E of the Master Plan). This was done by dividing the flood-prone width (the width at two times the bankfull elevation) by the bankfull width. Based on the Rosgen (1994) classification of river channels, an entrenchment ratio of 1.0:1.4 indicates that the channel is "entrenched." Entrenchment ratios of 1.41:2.2 represent "moderate entrenchment." The cross-sections measured in MON1 and MON2 are generally classified as either "entrenched" or "moderately entrenched," where the sections are long enough to confirm entrenchment ratios. The most severely entrenched cross-section among all sites is MON1-5, which has an entrenchment ratio of 1.06. MON3 has the best floodplain connection of the three monitoring sites with a mixture of moderately entrenched and not entrenched channel cross-sections.

3.4.3.2 Channel Hydraulics

Bankfull and top of bank hydraulics were estimated for each erosion monitoring site (Table 3-12). The former was based on bankfull indicators as described above, while the latter evaluated the channel hydraulics at the inflection between the main channel and the floodplain of this incised system. The intent here is to evaluate the hydraulics that likely have the greatest in-stream velocity and shear stresses prior to attracting relief or attenuation across the broader floodplain. An assumed Manning's roughness of 0.035, and bankfull slopes, and HEC-RAS derived energy gradients were applied (see note on Table 3-12). The estimation of in-channel hydraulics allows for direct comparison to particle entrainment values for assumed index particle sizes in the erosion threshold analysis (Section 4.3.3).

When compared to values obtained from HEC-RAS for stations that roughly correspond to those of the monitoring sites (Table 3-13), bankfull flows are 38% to 74% of the 2-year flow for corresponding river stations. Top of bank flows for monitoring sites 1 and 2 exceed the 100-year event, while the same flow in monitoring site 3 falls between the 25- and 50-year event discharges. Cross-sectional plots in HEC-RAS suggest that the cross-section, in several cases contain up to the 100-year event prior to spilling into the floodplain, with many in the 25- to 50-year range at the floodplain elevation.

TABLE 3-12 Channel Hydraulic Results

Average Estimated Hydraulics	MON-1 (Reach GM-3)		MON-2 (Reach GM-2)		MON-3 (Reach GM-1)	
	Bankfull	Top of Bank	Bankfull	Top of Bank	Bankfull	Top of Bank
Slope (m/m)	0.005	0.005 (1)	0.004	0.006 (1)	0.0015	0.002 (1)
Manning's Roughness	0.035	0.035	0.035	0.035	0.035	0.035
Maximum Depth (m)	1.06	2.45	1.04	2.19	1.10	2.12
Area (m^2)	8.74	26.56	7.45	20.59	10.45	29.49
Wetted Perimeter (m)	12.16	16.41	10.33	14.92	14.62	23.22
Total Width (m)	11.54	14.17	9.54	13.20	13.85	21.20
Hydraulic Radius (m)	0.72	1.62	0.73	1.39	0.72	1.29
Velocity (m/s)	1.62	2.78	1.46	2.75	0.89	1.51
Discharge (m^3/s)	14.36	74.00	10.95	56.65	9.28	44.43
Average Bed Shear Stress (N/m^2)	35.32	79.28	28.66	81.61	10.58	25.27
Stream Power (W/m)	704.10	3628.24	429.69	3333.00	136.48	871.37
Stream Power per Unit Width (W/m^2)	61.14	256.42	46.89	257.80	9.95	42.32

Note:
(1) HEC-RAS derived energy gradients were used for the 100-year event rather than the field-measured floodplain slope. The field-based slopes overestimated flows considerably compared to the HEC-RAS flood frequency tables.

TABLE 3-13 Comparison of Estimated Discharge to HEC-RAS Return Periods

	MON-1 (Reach GM-3)	MON-2 (Reach GM-2)	MON-3 (Reach GM-1)
Field-based Estimates (m^3/s)			
Bankfull	20.97	10.95	22.32
Top of Bank/Floodplain	74.00	56.65	44.43
HEC-RAS Values (m^3/s)			
2-year	28.34	28.38	30.23
5-year	28.34	28.38	30.23
10-year	33.11	33.21	35.36
25-year	39.42	39.53	42.05
50-year	43.26	43.36	46.32
100-year	49.23	49.28	52.38
350-year	65.95	66.09	70.21
Regional	218.94	218.59	233.31

3.4.3.3 Erosions Thresholds

A preliminary erosion threshold analysis was completed for the median particle size reported for each monitoring site (Table 3-14) for each reach. Erosion thresholds are used to determine the hydraulic conditions (i.e., discharge, channel depth, average channel velocity, etc.) that would entrain bed and/or bank materials of a given particle size. This estimates the “threshold” condition that will start to mobilize sediment.

The goal of the erosion threshold analysis is to determine the discharge that will begin to entrain boundary materials for a watercourse. However, selective transport of finer materials below the dominant threshold may also play an important role in sediment transport within some systems. Erosion and deposition are natural processes that are necessary for the maintenance of channel form and function. Flows will periodically naturally exceed the threshold discharge driving erosion/transport and sediment/deposition throughout the channel. As such, to maintain the natural function and equilibrium, a typical objective is to ensure that hydrological conditions from future changes do not result in channel flow exceeding the threshold discharge more frequently than under existing conditions. In this study, the estimated erosion thresholds are used to characterize the existing condition and potential for erosion. These thresholds may be refined if stormwater retrofits are planned for the study area.

There are many methods to determine velocity or shear stress to mobilize a given particle, from which a critical discharge may be determined. The Komar (1987) approach for critical velocity was applied in this instance as it is suitable for gravel bed streams.

Table 3-14 provides estimates of in-channel hydraulics at the critical velocity. These have been averaged for riffle/run cross-sections within each monitoring site, similar to those values presented in Table 3-13. This analysis can be repeated with greater detail on focused representative sites in future studies.

The results reveal that the median particle may be expected to mobilize within reaches GM-3 and GM-2 relatively frequently with the critical discharge at 20% of the estimated bankfull discharge, or close to bankfull, respectively. Based on the preliminary calculations, considerably larger events, perhaps exceeding the 100-year flood, would be expected before the median particle size on the bed is entrained for Reach GM-1 due to the low gradient (0.1%); however, this initial calculation is considered to be oversimplified given the large amount of finer sand material deposited in bars especially within MON-3. Differences in channel adjustment may support these thresholds whereby channel widening, and planform adjustment were primarily observed within monitoring site 3 (Reach GM-1), while bed incision and entrenchment were most evident through monitoring sites 1 and 2 (reaches GM-3 and GM-2, respectively).

TABLE 3-14 Preliminary Channel Erosion Threshold Results

	MON-1 (Reach GM- 3)	MON-2 (Reach GM-2)	MON-3 (Reach GM-1)
D_{50} (mm)	29.9	77.8	75.8
Critical Velocity (m/s): Komar (1987)	0.94	1.46	1.45
Bankfull Slope (m/m)	0.0050	0.004	0.0015
Average Threshold Hydraulics			
Maximum Depth (m)	0.52	1.02	2.70
Area (m^2)	3.17	7.66	46.79
Wetted Perimeter (m)	9.94	10.49	31.28
Total Width (m)	9.69	9.73	28.94
Hydraulic Radius (m)	0.32	0.73	1.50
Velocity (m/s)	0.94	1.47	1.45
Critical Discharge (m^3/s)	2.99	11.23	67.71
Critical:Bankfull Discharge (%)	20%	102%	730%
Average Bed Shear Stress (N/m^2)	15.64	28.64	22.00
Stream Power (W/m)	146.68	440.32	996.01
Stream Power per Unit Width (W/m^2)	15.12	45.70	34.72

4 GEOMORPHIC FUTURE CONDITIONS

The assessment of past and present conditions for German Mills Creek provides a basis from which to forecast future geomorphic conditions. The changes documented for the watershed and valley system in terms of historical land use change and urbanization have modified the channel directly associated with infrastructure development and indirectly through hydromodification. Changes in the flow regime due to urbanization are well-documented to destabilize stream channels, including widening and degradation, resulting in overall channel enlargement (Chin 2006, Hammer 1972, Pizzuto et al. 2000); however, the channel response to this perturbation tends to have a response time of many decades and lags behind the ongoing changes in urban development within the catchment. Further, ongoing changes in climate add a second perturbation to the hydrological regime of the fluvial system that will impact historical trends and current functions of the watercourse. This section of the report focuses on forecasting the future conditions of the channel with respect to historical land use changes and existing channel conditions and assesses the associated erosion risks to Toronto Water infrastructure. A climate change assessment was completed to address the potential impacts of changing volumes and patterns of rainfall, and potentially temperature changes, on hydrological flows and geomorphological processes.

The purpose of the following analysis is to synthesize future trends and functions of the watercourse reaches based on predictions from the past trends identified, which are assumed to be primarily due to historical land use changes and urban hydromodification (i.e., climate change was assessed separately). The initial step is to assess the trends toward an “ultimate channel configuration” which is a concept helpful to evaluate future equilibrium states of the channel especially in terms of channel cross-section capacity and width-to-depth ratios, but also with respect to compatible geomorphic scales of channel planform (i.e., meandering sinuosity) and bed morphology (i.e., riffle and pool spacing). The assessment of future channel conditions also forms the basis to complete a geomorphic risk assessment, considering both lateral and vertical erosion hazards with respect to the surrounding infrastructure and land uses. The results of the geomorphic risk assessment are then used to prioritize erosion sites within the study area and develop alternative solutions to address issues associated with fluvial erosion.

4.1 Forecast Ultimate Configuration (AMSC Step 6)

An overarching concept for the assessment of future geomorphic conditions is the “ultimate channel configuration” that forecasts future channel conditions in terms of bankfull channel dimensions and capacity, along with the associated scaling of channel planform sinuosity and riffle-pool spacings.

4.1.1 Cross-sectional Enlargement

Expected cross-sectional enlargement following urbanization can occur over several decades (Chin 2006); a period over which a cross-section may enlarge, with enlargement ratios varying between 1.5 and 15 times the pre-urban geometry (Booth and Henshaw 2001, Chin 2006, Hammer 1972, Hawley et al. 2012). This range in the enlargement ratio is dependant on physiography, surficial geology, area land use, and intervention. Bevean et al. (2018) evaluated channel enlargement for Wilket Creek, another tributary to the Don River in Toronto, similar to German Mills, being fully urbanized with an identical impervious area at 47%. However, urban development within Wilket Creek precedes that of German Mills by approximately 20 years (City of Toronto 2003), with suburban development initializing in the 1950s, while German Mills followed beginning in the late 1960s, through the 1970s and into the early 2000s, progressing northward. Stormwater management has been a more recent development over the last 20 to 30 years. As such, German Mills is still responding to urban hydromodification, and with the assessment of channel enlargement it is expected that the channel will continue to widen and degrade for some decades to come.

In the Wilket Creek study, an enlargement ratio of 2.6 was determined for the top-of-bank cross-section (floodplain elevation) by comparing a recent average channel area against, historical average values estimated from infrastructure construction drawings (1958). A similar comparison with a relic channel resulted in an enlargement ratio of 4.6, and use of empirical relations for southern Ontario

(Annable 1996; Thayer and Phillips 2016) suggest that the current area of Wilket Creek is 8.2 times greater than the "rural" condition (Bevean et al. 2018). With the exception of the "rural" value for Wilket Creek (which is only a rough estimate), these enlargement ratios are comparable to those plotted by MacRae and DeAndrea (1999) for a similar percentage of impervious area with watershed urbanization (Figure 4-1).

For the current study of German Mills Creek, 1969 to 2021 enlargement ratios were estimated using historical sewer construction drawings, current surveys (width, depth, area) for the German Mills GSMP at the floodplain elevation (as opposed to an inset bankfull channel). Tables 4-1 and 4-2 summarize measurements used in this analysis. Overall, the channel is much larger today than historically. Table 4-2 reveals a possible tendency for Reach GM-1 to near a cross-section equilibrium by having a larger width-to-depth ratio of 11.41 in 2021, that is more representative of gravel bed rivers when compared to other reaches.

TABLE 4-1 Reach-Averaged Summary Geometry based on Historical Measurements (Sewer Engineering Drawings)

	GM-1	GM-2 [1]	GM-3	GM-4	Total
Width (m)	8.09	11.47	6.25	4.62	7.41
Depth (m)	1.72	0.71	1.42	1.49	1.41
Area (m^2)	13.46	7.50	8.36	6.75	9.58
W:D	4.71	16.15	4.41	3.10	6.86

Note:
(1) Results for GM-2 likely over-exaggerated based on the skew of the channel relative to sewer crossing in profile

TABLE 4-2 Site Averaged Summary Channel Geometry from 2021 Monitoring Surveys (Floodplain Elevation)

	Reach 1 (MON-3)	Reach 2 (MON-2)	Reach 3 (MON-1)	Total
Width (m)	25.83	13.10	15.27	18.07
Maximum Depth (m)	2.26	2.45	2.60	2.44
Area (m^2)	34.28	22.29	27.78	28.11
W:D	11.41	5.36	5.88	7.55

On average, the survey-based cross-sectional area enlargement ratio for 1960s (sewer drawings) to 2021 is 2.9, with a model prediction of 4.3 (Figure 4-1). This indicates an additional 47% increase in channel area from 2021 values (Table 4-3; 9.50 m^2 historical to 28.11 m^2 in 2021 to 41.19 m^2 ultimate). Enlargement ratios determined for the Toronto Wet Weather Flow Master Plan substituted channel width for area as an assumption. Here, a similar assumption is carried forward whereby the enlargement ratio of 4.3 has also been applied to channel width to predict an expected outcome (Table 4-3). Using an assumed W:D, the ultimate depth was then calculated, which is shallower than the current average depth. It is expected that without intervention, the channel cross-section will be wider and shallower as a new floodplain may develop. Evidence of new floodplain development (i.e., lower benches accessible to more frequent flooding) exists within the monitoring site at Reach GM-1 in the vicinity of the Bestview Tributary.

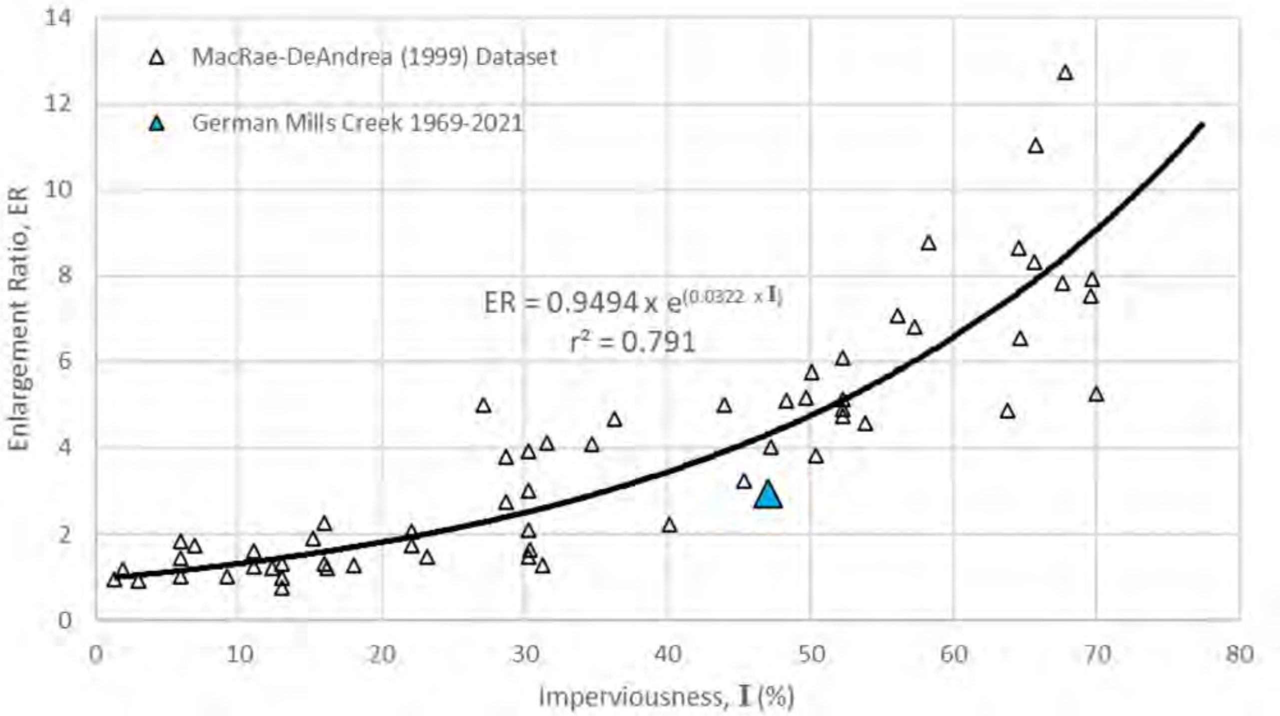


FIGURE 4-1 Survey-based Enlargement Ratio for German Mills Imposed on Data Adapted from MacRae and DeAndrea (1999)

TABLE 4-3 Average Historical and Existing Surveyed Geometry and Expected Geometry

Parameter	Historic (Sewer Drawings)	Current (GSMP Monitoring)	Expected Geometry (1)
Width (m)	7.41	18.07	31.86
Depth (m)	1.41	2.44	2.12
Area (m^2)	9.58	28.11	41.19
W:D	6.86	7.55	15 (2)

Notes:
(1) Ultimate predicted dimensions based on MacRae and D'Andrea (1999) model for historic urbanization response, not including future climate changes.
(2) Expected Width-to-Depth ratio assumed to be 15 for equilibrium gravel bed rivers.

4.1.2 Channel Form and Alignment

With the expectation of ongoing channel enlargement with future channel widening and degradation on German Mills Creek, predictions of future channel form and alignment can be constrained based on our understanding of channel evolution and hydraulic geometry for natural and modified fluvial systems. The stream evolution model interpretation prepared in Section 3.2.2 described five stages of channel evolution developed by Bevean et al. (2018) for Wilket Creek, another urbanized tributary of the Don

River, with a similar land use, physiographic, and geological setting to the GMGSMP study area. Based on a review of the historical assessment and contemporary conditions, it was determined that reaches within the study area are within Stage IV (incision) as it is disconnected from floodplain, and incised into glacial till, with the exception of portions of Reach GM-4 which provided evidence of Stage V (bank retreat) with substantial widening relative to upstream reaches, and floodplain development at lower elevations. The channel geometry comparison and enlargement ratios presented above support the suggested channel evolution stages from the model. Reaches GM-2 and GM-3 have lower width-to-depth ratios, indicative of incision, while GM-1 has recent w:d approaching the range of natural, equilibrium gravel bed channels (W:D of 12 to 15). Average enlargement ratios with an assumed W:D of 15 suggest that, overall, that bank retreat or widening should be expected to continue in the future.

In terms of channel planform and sinuosity, the loss of length has resulted in a reduction of channel sinuosity of what would be a naturally sinuous channel (Figure 4-2). The stream evolution assessment likened the impact of intentional straightening to that of avulsions (Stage III), which mostly occurred between 1965 and 1978. Earlier in the photograph record, sinuosity varied from 1.1 (Reach GM-4) to 2.4 (Reach GM-3), with an average of 1.6. Valley modifications occurred through all but GM-3, consequently narrowing the floodplain area. Therefore, the pre-urbanization (1954) sinuosity of GM-3 can be considered the ideal future scenario where the creek is free to migrate through the floodplain (i.e., without considering the constraints imposed by Toronto Water infrastructure). However, GM-3 also had the greatest loss in channel length to accommodate the construction of the sanitary sewer in 1969. Current sinuosity based on 2018 orthophoto interpretation ranges from 1.1 (Reaches GM-2 and GM-4) to 1.7 with an average of 1.3. Given that there are reach-scale constraints (e.g., sanitary sewer, trail, valley toe) and local constraints (e.g., bridges), it is unlikely that a higher sinuosity of 2.4 is achievable, especially through reaches GM-2 and GM-4 that are mostly limited to their current alignments. Reaches GM-1 and GM-3 are naturally regaining sinuosity since sewer installation. For reaches GM-1 and GM-3, the ultimate configuration may be able to aim for a design sinuosity of 1.5 or greater. While for GM-3, a higher target approaching a sinuosity of 2 might be achievable given the relatively greater floodplain area, pending considerations for recreational use (i.e., trail alignments).

Note: Reach GM-3 incomplete measurement due to photograph obstruction. More likely to have a similar sinuosity as in 1954.

FIGURE 4-2 Sinuosity Over Time for Study Area

In profile, the current average riffle-pool spacing is 49.9 m (Section 4.2.2.3), with a mean channel width of 11.7 (based on GIS measurements) or 18.07 based on 2021 monitoring surveys. Respectively, the riffle-pool spacing is approximately 4.5 to 2.7 channel widths on average under existing conditions. The GIS width is the average of the entire study area, while the surveyed widths in Tables 4-2 and 4-3 represent only the detailed monitoring stations for the study. The average channel width in 1954 was 8.5 m (GIS) and 7.41 in 1969 (STS engineering drawings). If an enlargement ratio of 4.3 is applied (Section 4.1.1), the expected mean channel width for the study area would be 36.55 and 31.86, respectively (Table 4-3). If the typical riffle-pool spacing of approximately five channel widths is used as a target, the resulting pool-riffle spacing would be in the range of 150 to 200 m, which is not favourable, nor achievable in design. However, the approximately 30 m potential width may be envisioned as the width at the current floodplain elevation, with a new floodplain developing at lower elevations (as per channel evolution model Stage V).

Trends from the channel evolution model and evidence from GM-1 suggest that the channel is trending to develop a lower floodplain and bankfull channel. Given this trend, there is potential to increase pool-riffle spacing (approximately five to seven widths) with added sinuosity, for a channel that conveys a more frequent event, with a lower, accessible floodplain set within the enlarged cross-section. It is possible to allow future enlargement and channel development to occur naturally where constraints are less imposing. This is most achievable through GM-3 and GM-1 to an extent. But there are some opportunities through GM-2 and GM-4, which would require design due to the higher degree of constraints.

For future conditions and design purposes, it may be possible to maintain smaller scale riffle-pool spacings in range of five channel widths based on an inset bankfull channel width of 10 to 20 m, but if the larger-scale channel width in the future is in range of 20 to 30 m wide, the associated riffle-pool spacing would need to be doubled to 100 m which would only be possible to design at the reach-scale. It is likely that riffle-pool spacing, and design will need to consider multiple scales of channel between a more frequent flow bankfull channel (nested) and larger floodway channel, also with two scales of riffle-pool features (i.e., more frequent and dynamic features nested on larger spaced riffle structures that may be less dynamic).

Generally, future channel designs for study area should reference channel geometry for a range of existing conditions to provide variable geomorphic form and function, while also considering the scale and flexibility required to meet future ultimate channel conditions. Accommodating future channel forms and alignments with respect to both existing and ultimate conditions may be accomplished by combining a range of “hard” and “soft” design approaches, depending on project extents, connectivity with natural sections, and phasing.

4.2 Geomorphic Risk Assessment

Building on the forecasts of ultimate channel configuration, the study methodology is based on assessment of geomorphic risk with respect to Toronto Water infrastructure in particular, while also considering risks to other public infrastructure and private property. Risk assessments are typically structured based on an evaluation of the probability of an occurrence and its severity. To quantify geomorphic risk to Toronto Water infrastructure in terms of probability, basic time to exposure (TTE) methods are proposed. In terms of risk severity for this study, the exposure of Toronto Water infrastructure within the active channel is considered to be of the highest potential severity assuming a high probability of structural and functional failure during a large flood event. Other public infrastructure and private property may be assigned lower severities within a geomorphic risk matrix. The following components of the geomorphic risk assessment are documented in the current report:

- **Erosion Hazard Assessment** - defining of long-term horizontal and vertical erosion hazard limits (100-year), including identification of associated locations of geotechnical stable slope hazards
- **Erosion Risk Inventory -** desktop and field-based inventories of lateral and vertical risk sites due to existing channel conditions and predicted future channel movement
    - Erosion Risk Inventory Methodology
    - Horizontal Risk Assessment
    - Vertical Risk Assessment

4.2.1 Erosion Hazard Assessment

Streams are dynamic features that change their horizontal configuration and position within a floodplain by means of erosion, meander evolution, and migration processes. When meanders change shape and position, the associated erosion processes that occur both horizontally (lateral migration) and vertically (scour) can cause loss or damage to property and infrastructure. Therefore, it is beneficial to forecast the extent of erosion hazards to determine the time that infrastructure, such as sanitary sewers and associated maintenance holes, is expected to be exposed. This section discusses the methods and results of the horizontal and vertical erosion hazard assessments with respect to Toronto Water infrastructure, other public infrastructure, and private property within the German Mills Creek corridor. The erosion hazard assessment includes delineation of a meander belt width as well as the calculated scour hazard limit (below riffle grade), which accounts for both natural scour (i.e., degradation) and general scour (i.e., scour pools).

4.2.1.1 Horizontal Erosion Hazard

Sustainable long-term management strategies for watercourses promote natural fluvial process to occur within an erodible corridor or an erosion hazard limit. In addition to applying predicted (e.g., 100-year erosion limit) or generic erosion allowances on either side of the existing channel, erosion hazards for unconfined stream reaches are typically delineated as a corridor termed a "meander belt width" (MNR 2002, PARISH 2004). The meander belt width defines the area that an unconfined, meandering watercourse currently occupies and is expected to occupy in the future. The degree to which a channel may be meander is heavily dependent on the channel's hydrological flow regime as well as other controlling factors such as vegetation, geology, and historical channel alterations. The meander belt encompasses the natural erosion hazard associated with active channel migration and avulsion, outside of which adjacent property and infrastructure are at a lower risk to damage. Furthermore, limiting development within the meander belt helps to protect the long-term integrity and natural processes of watercourses. This hazard is delineated by mapping planform characteristics (current and historical), and/or empirical relationships.

Although there are generally several limitations associated with applying the meander belt concept to urbanized watercourses, in particular with streams that have a history of channel realignment, artificial stabilization and confinement, applying the meander belt concept to German Mills Creek within the GSMP study area was completed to confirm the extent of Toronto Water infrastructure within the long-term erosion hazard and to support further detailed assessments of shorter term erosion hazard risks. The meander belt width assessment is also useful for this study because the channel has only undergone localized areas of channel realignment and the creek has the potential to laterally migrate within a relatively wide floodplain prior to hitting the valley bottom in which it is confined in. The meander belt width for the GMGSMP study area generally follows the valley trend and encompasses areas of the historical channel alignment. The meander belt width values range from 44 to 90 m, with narrower belt widths in reaches that have undergone channel realignment and straightening such as reaches GM-2 and

GM-3, which were historically straightened between 1965 and 1978 to accommodate the sewer. Localized areas where the channel exhibits valley-wall contacts and the meander belt width are beyond the valley toe; potential geotechnical hazard areas have been identified for further investigation through future studies. Additional potential geotechnical sites were noted in areas where there was an actively eroding steep slope (that was not the valley bottom) within the vicinity of the channel. Mapping of the meander belt in the context of the Toronto Water infrastructure as well as potential geotechnical hazard areas within the study area are presented in Figure C9a in Appendix C9.

4.2.1.2 Vertical Erosion Hazard

Scour hazards are generally defined as the risks of vertical erosion and/or degradation of stream and river channels. The CVC (2019) *Fluvial Geomorphic Guidelines: Factsheet VI Scour Analysis* has been referenced to assess the scour hazards of German Mills Creek (Figure 4-3), which defines three types of scour based on other sources including Ministry of Transportation Ontario (MTO; MTO 2016) and United States Department of Agriculture (USDA; USDA 2007) in a Technical Supplement 14B Report on Scour Calculations. Using this framework, the long-term (100-year) scour hazard limit (SHL) is defined by some combination of local, general, and natural scour depending on the location of the analysis relative to in-stream structures such as culverts, weirs, and/or bridge piers. Typically, local and general scour can be assessed based on calculations and/or reach-scale channel surveys to predict maximum bed scour in pools at the channel scale. Natural scour, representing reach-scale channel degradation referenced to the riffle grade, tends to be a longer-term process that may be assessed using generic minimum standards, historical measurements, or other rational methods. The CVC (2019) methodology also recommends factors of safety (FS) be applied to the SHL.

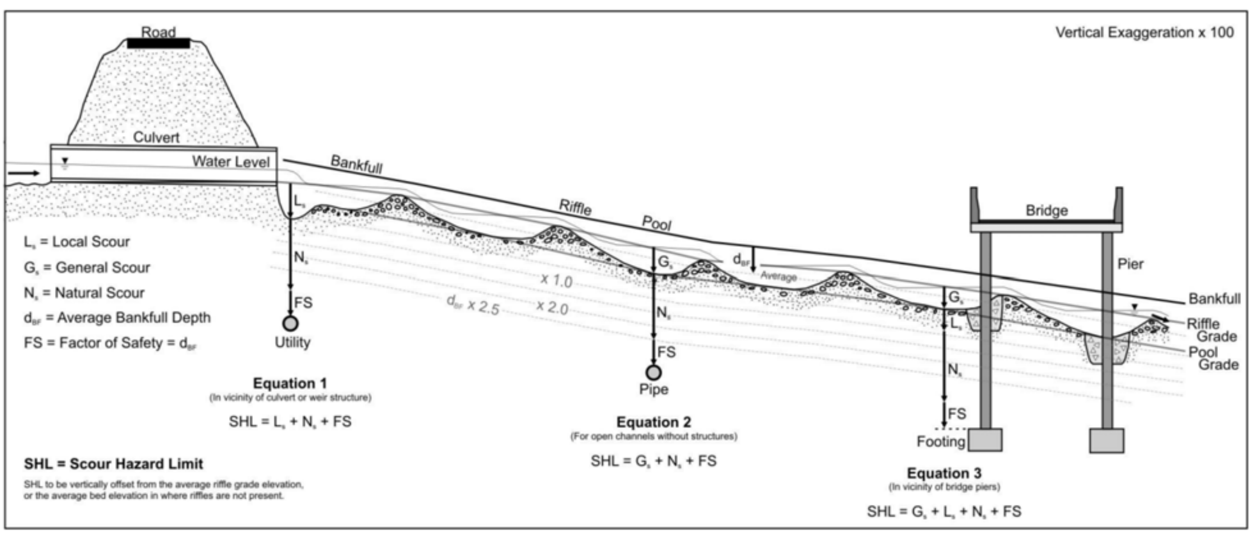


FIGURE 4-3 Graphical representation of the three types of scours to define the SHL from CVC (2019)

For German Mills Creek, the SHL was assessed for the study area reaches based on general and natural scour. Because the study focus is on estimating the TTE of existing Toronto Water infrastructure from vertical erosion processes and is not associated with construction of new pipe crossings, an additional factor of safety parameter was not included in the assessment. As such, the SHL for German Mills Creek within the study area has been defined by the following Equation 2 from CVC (2019) not including FS:

$$SHL = G_s + N_s$$

Where G_s is general scour evaluated using the maximum pool depth below the riffle-grade elevation within the study area and N_s is natural scour calculated based on historical rates of channel degradation. For general scour (G_s), the maximum pool depth below the riffle-grade elevation surveyed through the study area in 2021 was 1.6 m. Further details of the profile analysis are presented in Section 4.2.2.3.

While historical records of channel degradation to represent natural scour (N_s) tend to be limited, within the Toronto Region there are previous studies that can be referenced. As documented in CVC (2019) and the Taylor-Massey Risk Assessment (Aquafor Beech 2021), depths of channel degradation over time periods of 10 to 60 years have been estimated for Cooksville, Highland, and Taylor-Massey Creeks. Using similar methods, the historical depths and rates of channel degradation for German Mills Creek have been measured by comparing the 1969 channel bed elevations in the STS engineering drawings for the sanitary trunk sewer with the most recent 2021 field survey. The results of this analysis are presented in Table 4-4. From these results an average degradation rate is 1.6 cm/year, and 1.6 m per century has been advanced for the risk assessment in Section 4.2.2.3. For comparison with previous studies, the historical scour depth data for German Mills Creek has been added to the dataset with other creeks in the region as presented in Figure 4-4, however it is noted that this dataset represents channel degradation rates that have been accentuated by land use impacts from historic urbanization and hydromodification (i.e., an exceptional response to urban runoff).

With reference to the CVC (2019) framework for scour hazard assessment, the recommended scour 100-year SHL for the German Mills Creek within the study area is 3.2 m below the average riffle grade, based on a maximum general scour of 1.6 m and an average natural scour of 1.6 m. The potential for progressively smaller SHL values in the upstream reaches was considered to be outside the statistical error and scale of the presented analysis, and thus the recommended value of 3.2 m has been applied to all reaches of German Mills Creek within the study area.

However, the historical depth of scour measured for German Mills and other creeks in the region, as presented in Figure 4-4, represent exceptional impacts due to land use change and urbanization in the catchment, and may or may not be appropriate for extrapolation to predict future degradation over the next 100 years. While the average vertical erosion rate of 1.6 cm/year from historical measurements may in fact be conservatively high, climate change impacts are likely to add an additional perturbation to increase erosion in the fluvial system, so a conservative estimate is warranted. The vertical risk assessment for Toronto Water infrastructure associated with the SHL is further presented in Section 4.2.2.3.

TABLE 4-4 Historical depths of Cover for Degradation Rate

Risk ID (1)	STS Station	Historic Depth of Cover (m) (2)	Existing Depth of Cover (m)	Difference (m)	Rate (cm/year) (m/100-year)	Time to Obvert Elevation (years) (4)
1.2	-0+010.00	1.65	0.54	1.11	2.10	<u>29.8</u>
3.1	0+071.05	1.81	1.31	0.50	0.95	<u>138.4</u>
(4.1)	0+111.80	2.38	1.41	0.97	1.84	76.8
-	0+160.19	2.52	1.77	0.75	1.42	124.7
5.2	0+250.78	2.51	1.68	0.83	1.57	106.9
(5.1)	0+262.94	2.49	1.93	0.56	1.06	182.1
7.1	0+407.75	2.38	1.43	0.95	1.80	79.5
7.1	0+508	2.25	1.64	0.61	1.15	142.0
8.2	Lateral	0.95	0.18	0.77	1.49	<u>12.1</u>
12.2	0+762.97	2.88	1.17	1.71	3.24	36.2
(12.3)	0+790.32	2.78	1.47	1.31	2.48	59.3
16.2	0+956.43	2.88	1.06	1.82	3.44	<u>30.8</u>
18.2	1+089.38	2.78	1.12	1.66	3.14	<u>35.7</u>
-	1+179.94	1.40	2.12	-0.72 (3)	-1.36	-
-	1+208.79	2.05	2.37	-0.32 (3)	-0.61	-
-	1+240.88	2.91	2.26	0.65	1.23	183.7
-	1+264.33	2.41	1.92	0.49	0.93	207.0
21.2	1+306.79	3.13	1.40	1.73	3.27	<u>42.8</u>
(24.2)	1+474.46	2.71	1.54	1.17	2.21	69.5
Average		**2.36**	**1.49**	**0.87**	**1.65**	**91.6**
Standard Deviation		**0.57**	**0.55**	**0.66**	**1.25**	**61.4**
Percentiles						
90%		2.89	2.15	1.71	3.24	182.7
75%		2.78	1.85	1.24	2.35	138.4
50% (Median)		2.49	1.47	0.83	**1.57**	76.8
25%		2.15	1.24	0.59	1.11	36.1
10%		1.60	0.96	0.33	0.62	30.4

Notes:
(1) Risk sites are mapped in Figure C10a; Appendix C10; some STS stations that are not immediately adjacent to a risk site are denoted with a nearby site ID in brackets
(2) Historical dates of drawings for site IDs 1.2 and 8.2 are May 1960 and January 1970, respectively; the historical date for all other sites is October 1968
(3) Historical depths of cover measured in pools at some sites may result in negative differences (i.e., apparent aggradation) where current channel feature is a riffle; negative values have been included in the averages and other statistics
(4) Hypothetical extrapolation of time for channel to degrade to the obvert elevation of the STS pipe; only existing channel crossings are identified with underlined values

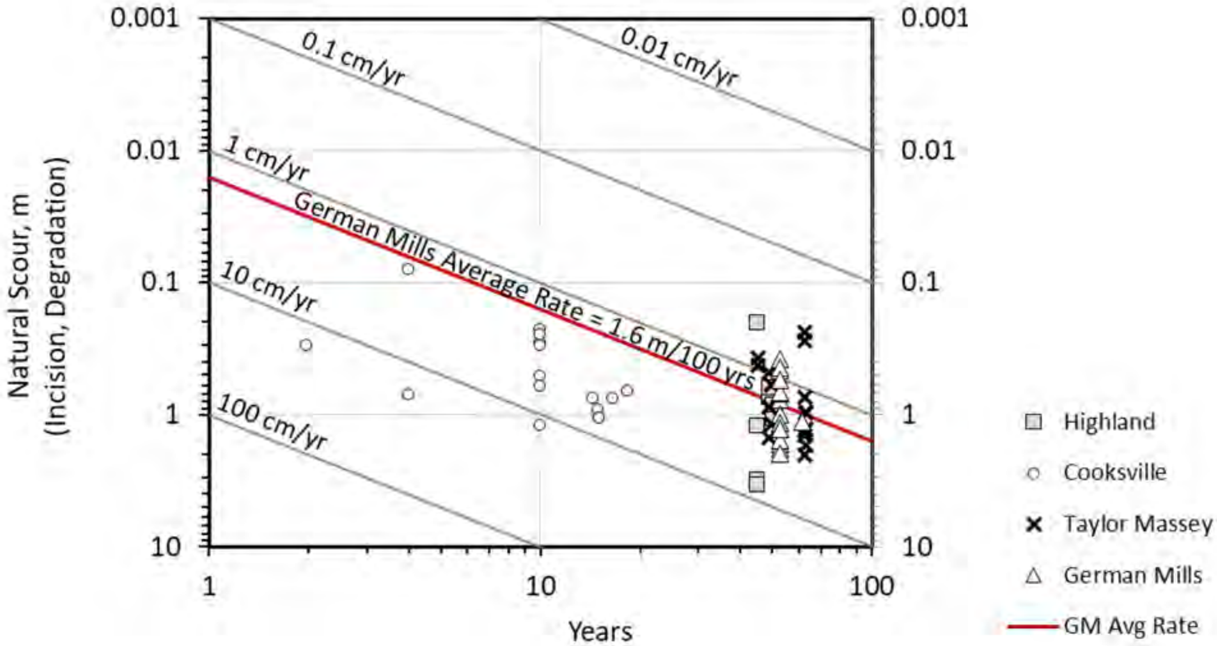


FIGURE 4-4 Historical Channel Degradation Dataset for Natural Scour (m) including German Mills Data and Average Degradation rate of 1.6 m/100 years (adapted from CVC (2019) and ABL (2020))

4.2.1.3 Erosion Hazard Assessment Summary

Based on the erosion hazard assessments, nearly all of Toronto Water infrastructure within the valley of German Mills Creek within the study area is considered to be within the long-term horizontal and vertical erosion hazards. TTE of Toronto Water infrastructure with respect to the creek will be assessed in more detail through the erosion risk inventory and will then be prioritized based on the highest risk probability (from TTE) and severity (type of infrastructure).

4.2.2 Erosion Risk Inventory

4.2.2.1 Erosion Risk Inventory Methodology

Erosion risk sites were identified in terms of their lateral and vertical erosion hazards with respect to property and infrastructure, with a specific focus on Toronto Water sewer infrastructure. A desktop risk inventory was completed initially using City ortho-imagery in conjunction with Toronto Water infrastructure (sewers, watermains, outfalls, maintenance holes, etc.) from the TWAG. Erosion sites were identified at sewer crossing locations within the creek (vertical risk) as well as locations where the creek was proximal to sewer pipes, maintenance holes, outfalls, pathways, and properties (lateral risk). A total of 56 lateral and vertical erosion risk sites have been identified. Each risk site is identified as an isolated location where there is risk of the channel coming in contact with Toronto Water infrastructure as well as private infrastructure and property. The channel thalweg and cross-sections across areas of channel proximal to Toronto Water infrastructure were surveyed and topographic data was used to compare to as-built drawings to determine the vertical and horizontal distance between Toronto Water infrastructure. An example of nine risk sites identified, including vertical and lateral risks, are show below in Figure 4-5. An initial summary of erosion risk sites, risk type, distance to structure, and bank condition classification was presented in Section 3.2.3. and considered in the overall ranking of erosion risk sites.

- Reach Break
- Sanitary Sewer Constructed in 1969
- Storm Sewer
- Stormwater Outfall
- Sanitary Sewer Maintenance Hole
- Storm Sewer Maintenance Hole
- Erosion Risk Site

1:500 metres
5 0 5 10
NAD27 MTM zone 10

Reference: Contains information licensed under the Open Government Licence – Ontario. Imagery (1965) obtained from Canada Map Sales. used under license. Imagery provided by . Used under license.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

City of Toronto
German Mills Creek GSMP EA

Example of Erosion Risk Sites Identified

Date:	Project:	Submitter:	Reviewer:
June 2022	32227	N. Cyples	J. McDonald

Figure 4.5

I:\CityofToronto\32227\FiguresAndTables\GMY\2022\ReportPhase2B\Figure-4-5-Example_of_Erosion_Risk_Sites_Identified.mxd - Letter_P - 20-Jun-22, 05:37 PM - lmwright - TID001

4.2.2.2 Horizontal Risk Assessment

The horizontal risk to Toronto Water infrastructure, private infrastructure, and private property was assessed where proximal to the active channel and considered at risk over the next 100 years. A combination of base mapping, engineering drawings of infrastructure, and detailed field surveys were reviewed to determine the horizontal distance currently between the infrastructure and the channel. The horizontal TTE was then calculated using erosion rates determined at a site-specific or reach-scale from the historic planform analysis.

Historical aerial imagery was assessed to understand the evolution of the creek valley and channel planform, particularly in response to the urbanization of the watershed. German Mills Creek within the GSMP study area exhibits a highly sinuous, meandering planform, and contains areas that were historically sinuous; however, sections are now realigned or straightened to accommodate Toronto Water or City infrastructure (i.e., sewer infrastructure, pedestrian bridges, pathways, etc.). A historical assessment of the creek is useful in understanding historical channel patterns and provides better insight into the future channel trajectory. This analysis also helps determine specific locations where infrastructure may be at risk in the future due to lateral channel migration.

Historical aerial imagery was provided by the City of Toronto for the years 1954, 1965, 1978, 2005, 2009, 2011, 2021, 2014, 2016, and 2018. The historic channel alignments revealed a significant reduction of channel length, approximately 500 m, which has been interpreted to be primarily the result of artificial channel realignments associated with construction of the sewers. The majority of this loss occurred between 1965 and 1978.Bankfull channel planform traces were digitized for the years 1954, 1965, 1978, 2005, and 2018 (Appendix C2) and 100-year lateral migration rates were estimated from the historical meander migration (Figure C9c; Appendix C9).

Migration rates varied between reaches, but generally ranged between 0.2 m/year (20 m per 100 years) and 0.6 m/year (60 m per 100 years). Yearly migration rates were applied to each erosion risk site to determine the estimated horizontal TTE of Toronto Water infrastructure. TTE represents the estimated time the active channel will come into contact with infrastructure, resulting in exposure and/or failure of the infrastructure and is further discussed in Section 4.3.1. Average calculated migration rates and their associated standard deviation are presented below in Table 4-5 based on a sample size of 50 individual migration measurements. Migration rates were calculated between each individual time period (i.e., 1954 to 1965, 1965 to 1978, etc.) representing a more conservative average, as well as calculated generally as the total migration across the entire time span divided by 64 years (1954 to 2018).

Rationale for the selection of migration rates applied to erosion risk sites is summarized in Table 4-6 and includes the application of migration rates related to the high- and low-end reach-scale rates, post-sewer realignment rates, as well as site-specific migration rates where it was possible to calculate migration at a specific erosion site. In cases where erosion risk sites were at high risk of lateral migration (i.e., on an actively eroding migratory bend) the more conservative migration rate for the reach was applied (0.5 to 0.6 m/year). Where erosion risk sites were previously realigned to accommodate the sewer constructed in 1969, a post-sewer realignment migration rate of 0.3 m/year was applied, which coincidently aligns with the 50th percentile average migration rates across 1954 to 2018. In most cases, these segments of channel were not actively eroding at the time of our assessment and had been historically straightened. Where an erosion risk site was at low risk of lateral migration (i.e., on the inside of a meander bend), the lower end migration rate was applied (0.2 m/year).

In specific locations where an erosion risk site was identified at an area where lateral meander migration could be calculated, the site-specific migration rate was applied to the erosion risk site. In most cases, the reach-averaged migration rate was applied to the risk site if the risk site was not situated at a migratory bend. The average migration rate post-sewer construction of 0.3 m/year (i.e., after 1969) was also calculated to be applied to risk sites within a reach that was either realigned or hardened following the construction of the sewer.

TABLE 4-5 Migration Rate Statistics (Not Reach Specific) (n = 50)

	Migration (m/year)					
	1954 to 1965	1965 to 1978	1978 to 2005	2005 to 2018	Average of four time periods	Average 1954 to 2018
Average	1.28	0.56	0.52	0.32	0.59	0.36
Standard Deviation	1.03	0.23	0.34	0.19	0.26	0.21
Percentiles						
0.9	1.74	0.82	0.88	0.57	0.91	0.63
0.75	1.65	0.75	0.74	0.43	0.70	0.47
0.5	1.15	0.53	0.43	0.31	0.54	0.32
0.25	0.65	0.36	0.29	0.20	0.43	0.21
0.1	0.37	0.34	0.20	0.12	0.33	0.14

TABLE 4-6 Rationale for Selection of Migration Rates Per Reach for Risk Assessment

Reach	Rate (m/year)	Explanation
GM-1	0.2	Average migration rate at specific risk site in GM-1
	0.3	Post-sewer realignment average migration; applied to risk sites affected by realignment from sewer
	0.6	Highest migration rate of all migration sites in GM-1; applied to risk sites on a meander and at high risk of migration
GM-2	0.2	Average migration rate between historically straightened sections; applied to risk sites not at high risk of migration
	0.3	Post-sewer realignment average migration rate; applied to risk sites affected by realignment from sewer
	0.5	Average migration rate for entire reach based off of migration sites at bends; applied to risk sties at high risk of migration
GM-3	0.3	Average migration rate at specific risk site in GM-3
	0.5	Average migration rate for entire reach based off of migration sites at bends; applied to risk sties at high risk of migration

Reach	Rate (m/year)	Explanation
GM-4	0.2	Lower end of calculated migration rate for entire reach; applied to risk sites not at high risk of migration (i.e., straight segment of reach, on inside bend of meander)
	0.3	Highest migration rate of all migration sites in GM-1; applied to risk sites on a meander and at high risk of migration **OR** post-sewer realignment average migration rate; applied to risk sites affected by realignment from sewer

The migration rates in Table 4-6 have been utilized to determine a 25-year erosion limit, to provide a refined understanding of risk when compared to the meander belt width (MBW) analysis. The MBW presented in Section 4.2.1.1 delineated a corridor within which current, historical, and potentially future erosion processes are likely to occur (in absence of any confinement or intervention). This corridor delineation is a useful planning tool when evaluating overall erosion risk to existing or proposed land use plans, and infrastructure siting, while also maintaining a natural corridor. The MBW presented in the current study may be considered preliminary as it lacks a factor of safety, with governing meanders in contact with the limit. Typically, a factor of safety is added to finalize the hazard corridor, such as a measured 100-year erosion rate, or a proportion of preliminary width (e.g., 20% of MBW). Therefore, there is potential for localized bank migration to fall beyond the MBW at these governing meander bends. While the MBW plus the 100-year erosion rate may be ideal when planning development or linear infrastructure projects, they do not provide a detailed estimate of risk over a shorter planning horizon.

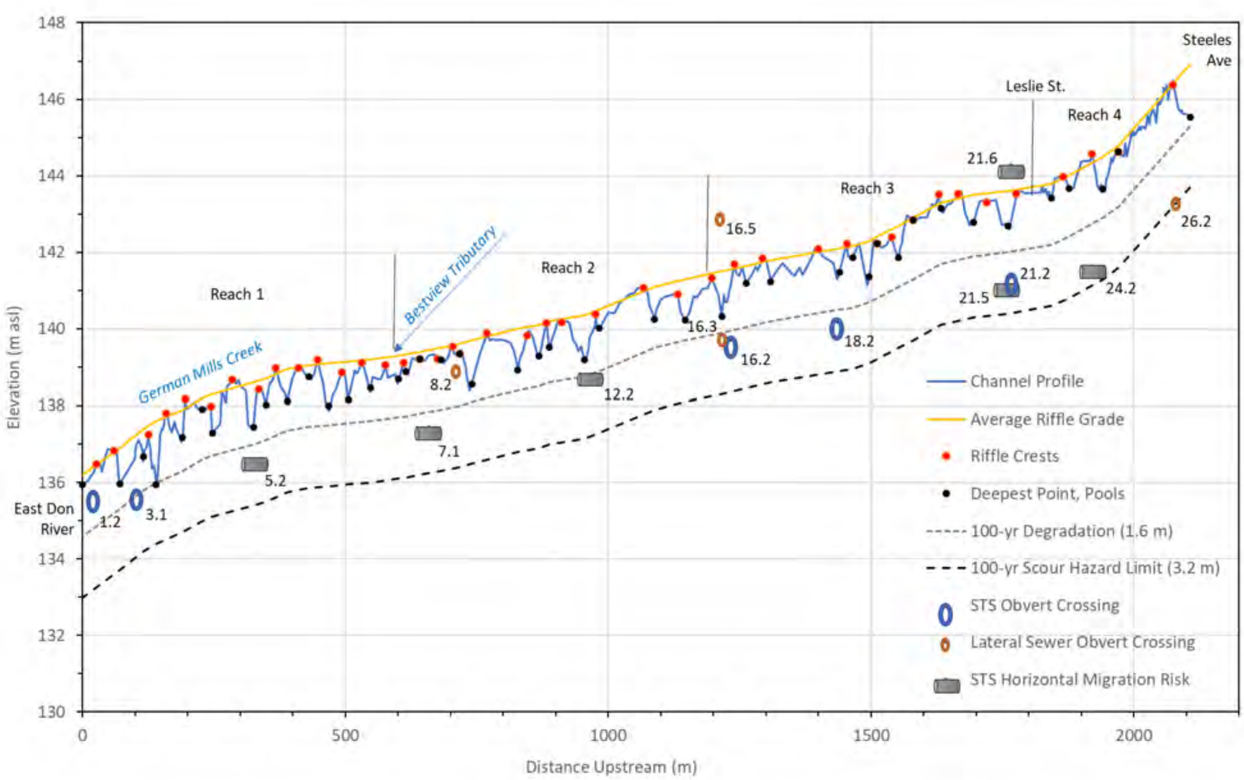
Figure C9b (Appendix C9) presents the projected 25-year erosion limit, offset from 2018 bank lines. The 2018 bank lines were segmented at the sub-reach-scale to apply appropriate erosion rates based on observations made during the bank inventory, and measured migration rates at the 14 sites in Figure C9c (Appendix C9). Colour coding along the bank lines represent annual rates ranging from 0.2 to 0.6 m/year. The 25-year offset was applied to each segment and combined into one polyline. This limit represents the potential location of the channel within 25-years, without intervention or topographical/geological confinement.

Several maintenance holes and adjacent STS (“pipe adjacent” - Figure C9b; Appendix C9) sites fall within the 25-year projection. However, the risk ranking and prioritization may vary for sites seemingly at the same level of risk, depending on existing treatments (e.g., armourstone; riprap) that have been accounted for through an erosion “credit” (Section 4.3.1.1). The rates applied and 25-year projection, in the context of lateral risk sites can help to identify the potential extent of erosion risk mitigation projects, and group individual sites into larger-scale designs.

4.2.2.3 Vertical Risk Assessment

As reported in Section 4.2.1.2, a vertical erosion hazard assessment has been completed to predict the maximum scour depth below the creek bed and associated risk to Toronto Water infrastructure where the sewer pipe crosses below or is adjacent to the creek. A channel profile analysis for German Mills Creek is presented in Figure 4-6 to delineate the average riffle grade line relative to riffle crests and pool inverts. With reference to the CVC (2019), the 100-year SHL was calculated using estimates of general and natural scour as defined in the guidelines. A natural scour rate of 0.016 m/year below riffle grade was calculated with reference to historical channel bed inverts at pipe crossing locations from engineering drawings (Table 4-4, Section 4.2.1.2), which translates to a 1.6 m offset and 100-year degradation limit below the riffle grade line (i.e., natural scour; CVC 2019). The total SHL recommended in Section 4.2.1.2 is 3.2 m offset from the riffle grade line which combines the 100-year channel degradation limit (natural scour, 1.6 m) with the maximum potential pool depth (general scour, 1.6 m). As the risk assessment is to evaluate the TTE for existing infrastructure, a factor of safety was not added to the SHL.

Figure 4-6 displays the location of Toronto Water infrastructure relative to the 100-year natural scour hazard (1.6 m below riffle grade) and the overall 100-year SHL (natural scour and general scour) of 3.2 m. As summarized in Table 4-7, one lateral sewer pipe is exposed (erosion site 16.5, behind exposed maintenance hole), three pipe crossings are within the 100-year degradation limit, and five pipe crossings are within the SHL. In addition, there are six sections of the STS and lateral sewer identified where future horizontal migration risks could generate new crossings where pipes would also be within the SHL (note: STS Horizontal Migration Risk points in Figure 4-6 are offset horizontally from the channel profile and thus are not currently crossings). Credit for existing erosion controls on the channel bed have not been accounted for in the delineated SHL but are included in the TTE calculations presented in Section 4.3 (e.g., Site ID 26.2 is located below armoured rocky ramp).



Note: symbols for sewer crossings and lateral risks are not to scale.

FIGURE 4-6 Profile Analysis for Delineation of the Scour Hazard Limit with Respect to Sanitary Sewer Infrastructure (including Lateral Migration Risks as symbolized)

TABLE 4-7 Summary of Vertical Risk Assessment Sites within Scour Hazard Limit

Site ID	Type of Risk (1)	Obvert Elev. (m asl)	Bed Elev. (m asl)	Depth of Cover (m)	Riffle Grade (m asl)	Depth from Riffle Grade (m)	Hazard Zone (2)			
							Above Bed Elev.	100-year Degrad. (1.6 m)	Scour Hazard Limit (3.2 m)	Add Horzon. Migrat. Risk
1.2	STS-VC	135.72	136.26	0.54	136.48	0.76		✓		
3.1	STS-VC	135.78	137.09	1.31	137.25	1.47		✓		
5.2	STS-Lat-H	136.60	138.28	1.68	138.6	2			✓	✓
7.1	STS-Lat-H	137.44	139.08	1.64	139.4	1.96			✓	✓
8.2	Lat-VC	139.00	139.18	0.18	139.65	0.65		✓		
12.2	STS-Lat-H	138.80	139.97	1.17	140.4	1.6		✓		✓
16.2	STS-VC	139.71	140.77	1.06	141.6	1.89			✓	
16.3	Lat-VC	139.74	140.80	1.06	141.55	1.81			✓	
16.5	Lat-VC	142.95	140.77	0.00	141.5	-1.45	✓			
18.2	STS-VC	140.20	141.32	1.12	142.1	1.9			✓	
21.2	STS-VC	141.37	142.77	1.40	143.6	2.23			✓	
21.5	STS-Lat-H	141.14	142.54	1.40	143.6	2.46			✓	✓
21.6	STS-Lat-H	144.28	142.54	0.00	143.6	-0.68	✓			✓
24.2	STS-Lat-H	141.63	143.17	1.54	144.4	2.77			✓	✓
26.2	Lat-V	143.32	145.72	2.40	146.6	3.28			✓	

Notes:
(1) STS-VC = STS Vertical Risk Crossing; Lat-VC = Lateral Sewer Risk Crossing;
STS-Lat-H = STS or Lateral Horizontal Migration Risk
(2) Hazard Zone identifies if the vertical risk site is above the channel bed elevation, within the 100-year degradation zone (1.6 m offset from riffle grade), or within the SHL (3.2 m offset from riffle grade). For sites identified within the horizontal migration risk zone, these sites are at risk from the combination of vertical and horizontal risks (based on horizontal risk assessments in Sections 4.2.2.2 and 4.3.1).

4.3 Erosion Site Prioritization

This section presents the results of the German Mills Creek geomorphic risk assessment with respect to the horizontal (lateral) and vertical (scour) erosion hazards associated with Toronto Water and private infrastructure. The risk assessment particularly focuses on the risk to Toronto Water sewer infrastructure within the vicinity of the creek and rankings were determined based on results of the erosion risk site inventory and erosion hazard rates discussed in Section 4.2. The erosion hazard rates were then used to derive the TTE to infrastructure, in other words the estimated time the active channel will come in contact with infrastructure, followed by the application of an erosion credit based on the existing life expectancy of erosion control structures on the channel bed and/or banks. Erosion sites were allocated a final risk score based on their risk probability (TTE) and risk severity (type of infrastructure at risk). A total of 56 erosion risk sites were identified, and the risk assessment serves as the basis to prioritize the most at-risk sites threatening Toronto Water infrastructure and in which 13 localized erosion mitigation projects have been identified. This risk assessment forecasts future channel erosion based on historic rates and patterns of geomorphic change caused by natural processes and land use impacts in the watershed. The potential for new perturbations to the system due to climate change was assessed in a separate report.

4.3.1 Time to Exposure and Erosion Control Credit

The TTE concept represents the estimated time in years the active channel will come into contact with infrastructure, from either horizontal erosion or vertical scour, resulting in exposure and/or failure of the infrastructure. For horizontal risks, TTE is calculated by the horizontal distance to infrastructure divided by the erosion hazard rate, while TTE for vertical risks is calculated by the depth of cover over infrastructure divided by the scour rate (Table 4-8). For this study, an erosion control credit has also been added for existing channel treatments where natural rates of erosion would be inhibited (Section 4.3.1.1). For some erosion risk sites, the TTE was calculated for both horizontal and vertical erosion risks, but only the smallest TTE is reported for the prioritization. In two cases (erosion risk sites 1.2 and 8.2), horizontal erosion rates were used to estimate the downstream migration of scour pools that could potentially expose the sewer pipes, but in both cases the vertical TTE was less.

TABLE 4-8 Calculation of Time to Exposure by Risk Type

Risk Type	Time to Exposure (TTE, Years)
Horizontal (Lateral) Erosion Hazard Limit (Section 4.2.1.1)	$\textbf{TTE} = \left(\frac{\text{Distance}^{*}\text{ (m)}}{\text{Erosion Hazard Rate (m/year)}}\right) + \text{Erosion Control Credit (year)}$
Vertical (Crossing) Scour Hazard Limit (Section 4.2.1.2)	$\textbf{TTE} = \left(\frac{\text{Depth of Cover (m)}}{\text{Scour Hazard Rate (m/year)}}\right) + \text{Erosion Control Credit (year)}$

4.3.1.1 Erosion Control Credit

Using an approach adapted from the Taylor-Massey Risk Assessment Study (Aquafor Beech 2021), the life expectancy of existing erosion control works is based on an upper limit of 60 years for armourstone. In terms of a life-cycle process for hard engineering approaches such as armourstone, the following framework has been used based on the age of the channel engineering works:

- 50 to 60 years life expectancy (0 to 10 years old) - immediate post-construction phase, when some monitoring and maintenance may be required over the vegetation stabilization period.
- 25 to 50 years life expectancy (10 to 35 years old) - main functional phase of works, when likely little to no monitoring or maintenance required unless subjected to a rare flooding event.
- 5 to 25 years life expectancy (35 to 55 years old) - terminal phase of functional life, when monitoring and maintenance are expected to support continued functions and/or to potentially extend the design life.
- 0 to 5 years life expectancy (55 to 60+ years old) - end of life phase, when probability of failure is high or failure has already occurred, and when the final phase of planning, design, and (re)construction is required.

The above life-cycle framework was applied to erosion control structures on German Mills Creek using the bank conditions scores as documented in the field assessment (Section 3.2.3). Application of the bank condition scores to the erosion control credits is described in Table 4-9. Only bank or bed erosion control structures were assigned an erosion control credit, with all other natural banks assigned no credit (i.e., credit = zero).

TABLE 4-9 Description of Erosion Control Credit Relative to Bank Conditions Scores

Bank Condition Classification	Erosion Control Credit (Years)	Description
All Classifications *	0	*Natural bank or high risk to erosion at meander apex
Failure	10	Bank or bed structures in failed into channel but still present
Continuing to fail	20	Bank or bed structures locally failing or in poor to very poor condition
Starting to fail	30	Bank or bed structures in functional state, fair to poor condition
Minor instability (erosion)	40	Bank or bed structures in stable state, good to fair condition
Stable	50	Bank or bed structures in stable state, good condition
Stable**	60	**Recently constructed armourstone structures within last ~10 years

Note:
Field scoring for 20 m sections of bank reinterpreted for local bank conditions for some erosion sites

Compared to other recent studies in Toronto, German Mills Creek contains fewer erosion control structures and thus most erosion risk sites were not assigned erosion control credit. The following general observations provide a summary for each reach:

- Reach 1 (GM-1) - mostly natural banks with small number of local bank or bed erosion control structures (armourstone or riprap)
- Reach 2 (GM-2) - some natural banks but also significant riprap along banks in straightened section through railway bridge crossing (mid-reach), and armourstone in upstream section, all in fair to poor condition
- Reach 3 (GM-3) - mostly natural banks with some local riprap or armourstone protection trails, pedestrian bridge, and watermain crossing at Leslie Street
- Reach 4 (GM-4) - comparatively very few natural banks with a variety of structures including sheet pile, gabion baskets, vegetated riprap/stone buttress, and armourstone, varying from very poor to very good condition

4.3.2 Erosion Site and Local Project Prioritization

Erosion risk sites were each assigned an individual site ranking (1 to 56) based on a total risk assessment score (Figures C10a to C10e; Appendix C10). The total risk assessment score is the product of the risk probability (TTE = 1 to 5) and the risk severity (asset ranking 1 to 5, with Toronto Water sewers and watermains scoring 5) with final values ranging from 1 to 25 (Figure 4-7). The full listing of the erosion risk sites is provided in Appendix C12. Based on the top 12 erosion risk sites (primary), the remaining sites (secondary) were grouped with the primary sites in close proximity to generate local erosion mitigation projects. A twelfth project was identified for the upper reaches of Bestview Tributary and the entire Bestview Tributary has been evaluated as a single site for this study as instability downstream can eventually pose risk to the upper reach. These top 12 local projects will be advanced through development and evaluation of alternative EA process for the German Mills Creek GSMP. An initial development of alternatives is presented in Section 5.

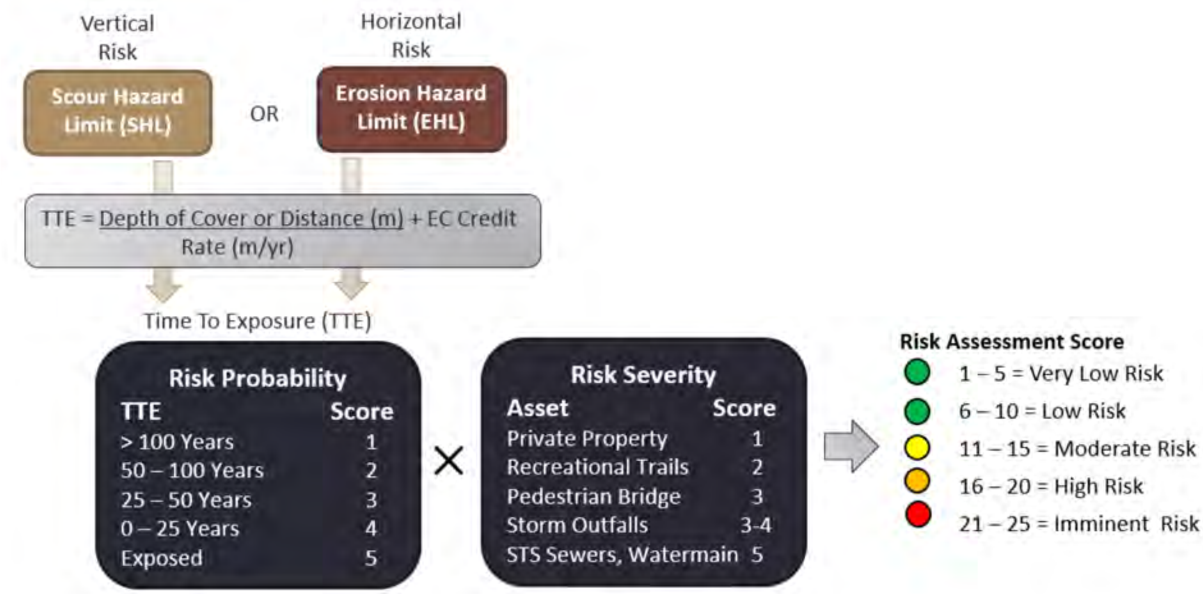


FIGURE 4-7 Summary of Total Risk Assessment Score

TABLE 4-10 Project Ranking 1 to 121 Based on Highest Priority Sites and Associated Secondary Sites

Project	Priority Site ID	Risk (Priority Site)	Distance to Structure (m)	Erosion/Scour Rate (m/year)	Erosion Credit (Years)	TTE Priority Site (Years)	Secondary Site IDs
1	16.1	Maintenance Hole	0	0.5	0	0	15.1, 15.2, 15.3, 16.2, 16.3, 16.4, 16.5, 17.2
2	18.1	Maintenance Hole	0	0.5	0	0	17.1, 18.2, 19.1
3	21.1	Maintenance Hole	0	0.5	0	0	20.1, 21.2, 21.3, 21.4, 21.5, 21.6
4	5.2	Pipe Adjacent	1	0.6	0	2	5.1, 5.3
5	7.1	Pipe Adjacent	1	0.6	0	2	6.1, 7.2
6	11.1	Maintenance Hole	1	0.3	0	3	12.1, 12.2, 12.3, 13.1
7	8.2	Pipe Crossing	0.37*	0.016	0	23	8.1, 8.3, 8.4, 9.1, 9.2
8	1.1	Maintenance Hole	5	0.3	10	27	1.2, 1.3
9	3.1	Pipe Crossing	1.22*	0.016	0	76	2.1, 4.1
10	24.2	Pipe Adjacent	10	0.2	30	80	22.1, 23.1, 24.1, 25.1
11	26.1	Maintenance Hole	4	0.2	60	80	26.2, 26.3, 27.1, 27.2, 27.3
12	28.1	Property	20	0.2	0	100	

*Depth of cover from existing channel grade

5 DEVELOPMENT OF ALTERNATIVES

5.1 Feasibility of Intervention

Section 1.2 of the Master Plan provides an overview of the Project Goals and Objectives, and to achieve those goals and objectives, design intervention is required at varying scales along the watercourse. It is evident from the assessment of existing conditions and occurring processes in the creek that further damage will occur without any intervention in German Mills Creek, within Toronto, Ontario . Feasibility of intervention can be examined at different scales (watershed, reach-based, and site-specific), and generally, the approach is based on the extent of the affected processes.

On a watershed and subwatershed scale, an approach to mitigate further erosion potential by decreasing peak flows and reducing energy in the system would primarily be an exercise in stormwater management (SWM). This can involve land use planning to increase infiltration (reducing imperviousness) or storage, the implementation of source controls and conveyance controls, and the introduction of end-of-pipe facilities. Examples include introducing detention ponds/facilities, disconnecting downspouts, installing rain barrels, and installing exfiltration systems to assist in providing mitigation of stream erosion. These measures would require to be as intensively practiced as in areas of new urban development. Such implementation is typically not feasible in a retrofit situation, such as within the mature urban development of Toronto, and areas of new development primarily exist within other municipalities north of Toronto. An end-of-pipe study was completed as part of the 2003 WWFMP, which includes German Mills Creek (Don River, Area 4, Reach 17 in the 2003 WWFMP).

The 2003 WWFMP long-term strategy for German Mills Creek includes several underground facilities at the sewer outfalls to detain stormwater and reduce peaks flows. Being the most downstream reach within the German Mills Creek watershed, it is difficult to implement localized SWM controls that will influence channel flows enough to offset the lack of SWM controls upstream. While implementation of these local facilities and end-of-pipe controls will work to partially reduce erosive flows through the study area, restoration will still be required to address the current conditions and maintain stability from the runoff and resulting peak flows that are generated further upstream. The 2003 WWFMP suggests that stream restoration would still be required to achieve the moderate enhancement targets.

The analysis of the 2003 WWFMP concluded that source controls, even if implemented on significant areas of the watershed, are insufficient to significantly reduce channel erosion; source controls such as low impact development measures make a minor contribution to improve the stream geomorphic function. This is further documented in a paper titled *Development of a Wet Weather Flow Master Plan for the City of Toronto* (D'Andrea et al. 2005), which includes an analysis of intervention options based on a "hydrogeomorphic index" for the stability of stream systems in Toronto. The results indicate that regardless of what degree of infiltration and evaporation controls is considered, the hydrogeomorphic index remains largely in the unstable region and well above even the moderate target.

With watershed scale solutions being unfeasible, potential options have been developed and evaluated at the reach scale (channel lengths >200 m), and local or subreach scale (channel lengths <200 m). At both scales, channel lengths with common hydraulic/morphologic characteristics are selected for intervention based on the issues observed along the reach. However, the local scale allows for existing areas of lesser or low risk and relative stability to continue to adjust and to adjust to any interventions completed at the local scale.

Based on these results, it was determined that direct intervention should be the mandated approach for stream rehabilitation and restoration in the study area. For the purposes of the Master Plan, only reach-scale and local-scale (subreach) options are deemed appropriate for consideration to fulfill the stated objectives summarized in Section 1.2 of the GSMP.

The following list briefly summarizes considerations and constraints in the developing alternative solutions and the evaluation criteria:

- minimize risk to and protect sanitary sewer (trunk and lateral) and maintenance holes
- enhance geomorphic form and function through cross-section, planform, and profile designs and create a “nested” bankfull channel with accessible floodplain
- avoid increasing floodlines and reduce where possible (TRCA mandates)
- work with and avoid destabilizing existing design elements (e.g., Duncan Creek design) or repair/enhance where required (e.g. existing armourstone treatments)
- valley constraints (avoid toe erosion and slope destabilization)
- avoid/reduce risks to private property
- minimize risks to park users (human safety) throughout and specifically along the multi-purpose trail and at pedestrian bridges. Consider realignment and/or replacement of park features where warranted (e.g., crossings that impose unfavourable channel alignments, and/or undersized crossings, realign trail, move benches)
- avoid or minimize/mitigate risk to terrestrial resources and habitat (e.g., tree damage/removal, wetlands)
- avoid or minimize/mitigate risk to aquatic resources and habitat and consider thermal regime or target thermal regime
- consider protection of species at risk and protection or of species at risk habitat

- protect and integrate channel design with other infrastructure, including rail corridor and crossing, city roads and bridges, stormwater infrastructure, water mains, gas lines, and street lights
- design and construction cost considerations and efficiencies
- avoid disruption to archaeological resources - completion of Stage 2 and Stage 3 investigations, are required and should support the detailed design
- Seek acceptability by agencies, public, and First Nations, through timely, comprehensive, and responsive consultations.

As part of the Phase 2 EA process, the following list of alternative solutions were developed for the German Mills Creek GSMP study to specifically address the erosion concerns documented in the top twelve (12) local erosion mitigation project sites, as identified in Section 4.3.2. The term “reach scale” or “sub-reach scale” throughout the development of alternatives is not with reference to the four reaches delineated for the study area, but rather an approximate threshold channel length of 200 m for proposed works, with anything greater than 200 m being within a reach scale, while less than is within a sub-reach scale:

1. **Alternative 1 - Do Nothing** - leaving existing conditions as-is with no design mitigation, resulting in further channel degradation and erosion, with potential or continued exposure and/or undermining Toronto Water infrastructure; could consist of continued monitoring where priority sites are already exposed and are likely to require emergency works (local placement of riprap rock protection).Monitoring may also be recommended for sites where erosion risk may be lower, or TTE longer.
2. **Alternative 2 – Local Works (sub-reach scale, <200 m length)** - local erosion mitigation projects of less than 200 m in channel length, including adjustments to both the channel bed and banks, to address high priority sites and nearby secondary sites which typically fall within the project extents of local works designs, with a range of design options to be considered.
3. **Alternative 3 – Local Works with Reach-Scale Floodplain Connections** - local works (Alternative 2, bed and bank modifications, less than 200 m) and enhancing floodplain connectivity with bank modifications in between the local works sites to strategically increase floodplain conveyance, balancing proposed works with tree removals.
4. **Alternative Reach Works (>200 m length)** - reach-scale channel works of greater than 200 m in channel length to realign and/or restore the channel and floodplain connectivity in a new configuration, including some level of erosion control, with a range of design options to be considered to address a collection of local erosion mitigation project sites.

A variety of erosion mitigation approaches are available to address the erosion risk identified in this study, including structural bank treatments (e.g., armourstone, vegetated rock buttresses, rock toe protection), in-stream treatments and grade controls (e.g., armoured riffles and rocky ramps, rib structures, flow deflectors), bioengineering (e.g., live staking and brush layering, log crib-walls, sod matts and vegetated coir-warp soils), and channel realignments (e.g., meandering, terraced floodplain, stream training). Specifically for Alternatives 2 and 3 (local works) and Alternative 4 (reach works), there is a spectrum of design options ranging from “harder” to “softer” approaches, but also hybrid and mixed combinations of approaches are possible:

- “Harder” river engineering approaches relying heavily on in-channel structures to balance fluvial dynamics more toward channel stability. These are to be utilized at high-risk sites with imposing constraints and/or higher in-stream stresses.

- “Softer” channel realignments relying more strategically on channel realignments, buried erosion control structures (set within the floodplain, between the active channel and TW infrastructure), and bioengineering to balance fluvial dynamics more toward channel flexibility. These softer approaches are to be utilized at lower-risk sites, where lower in-stream stresses lend to the sustainability of these features and/or the channel has limited constraints and more lateral freedoms.

A hybrid approach may be recommended to allow for some flexibility within an erodible corridor, with softer approaches being applied along the active channel (e.g., vegetated banks or other bioengineering), but harder, buried erosion protection for Toronto Water infrastructure set back in the floodplain that has a greater TTE (e.g., buried armourstone along a pipe at horizontal risk).

Alternatives 2 through 4 propose a nested ‘bankfull’ channel with a constructed, accessible floodplain, set within a larger cross-section as slopes grade up to the existing floodplain. This results in a varying top width and substantial material removals (soil and vegetation), and considerations for disposal (excess soil), and tree plantings (onsite and offsite), respectively. As a preferred alternative is selected, the top width should be refined to balance between hydraulic capacity of larger flood events and excess soils and mature tree removals. The intent of the larger cross-section is to provide attenuation of in-stream stresses on the bankfull channel under less frequent events, allowing for a more sustainable bankfull channel and stabilization measures.

Appendix F1 provides conceptual drawings for the application of each alternative.

6 REFERENCES

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