

Appendix L – Fluvial Geomorphological Assessments (GEOMorphix Ltd.)

Middle, East and Ellis Creeks Fluvial Geomorphological Assessments

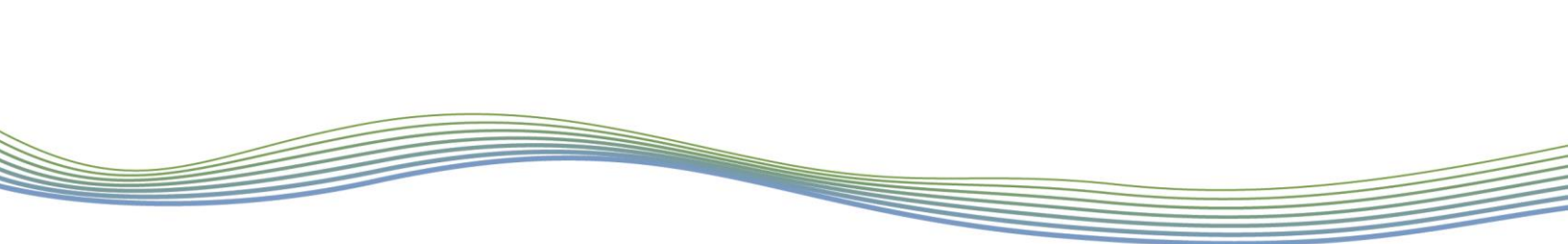
**Maple Grove Road Class EA
Fountain Street to Hespeler Road
The Regional Municipality of Waterloo**



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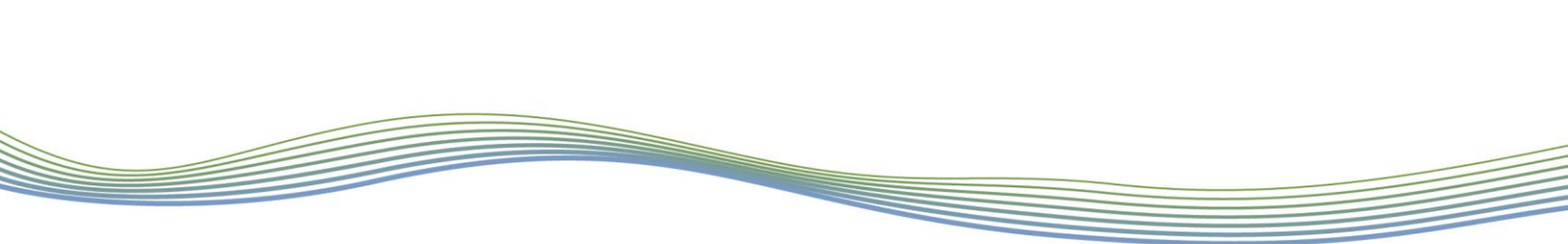


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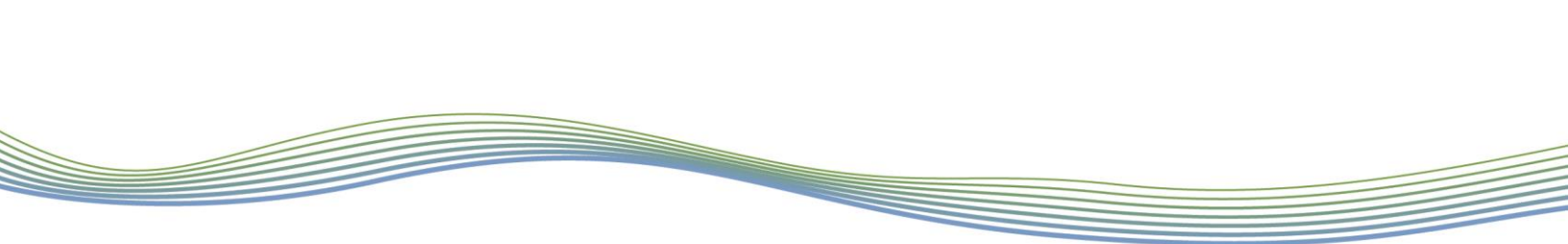
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1 Introduction

The Regional Municipality of Waterloo (Region of Waterloo) previously completed a Class Environmental Assessment (EA) in 2004 to widen Sportsworld Drive and Maple Grove Road from King Street to Hespeler Road. The Region of Waterloo, more recently, determined that a new Schedule "C" Class EA was warranted for Maple Grove Road, between Fountain Street and Hespeler Road, due to changes in legislation and to follow recommendations in other studies, including the draft 2018 Regional Transportation Master Plan.

The Region of Waterloo retained IBI Group, as the prime consultant, to complete the new Class EA study and prepare the preliminary design of the preferred alternative. As part of the consulting team, GEO Morphix Ltd. is responsible for completing a fluvial geomorphological assessment of each watercourse that crosses Maple Grove Road between Fountain Street and Hespeler Road. From west to east, these watercourses include Middle Creek, East Creek and Chilligo Creek. With respect to Middle Creek, the portion of channel that travels along Maple Grove Road is also known as Hunsperger Drain. Furthermore, Chilligo Creek is also known as Ellis Creek; however, the former name will be used in this report.

Herein, a distinction is made between "Project Areas" and "Study Areas." A Project Area is roughly defined as the portion of channel, and 5 m of riparian area on each side of the channel, within the Region of Waterloo's right-of-way plus an additional 10 m beyond the property line. The Project Area therefore represents the potential area of direct impact to the creek resulting from any work associated with the road or crossing structures. The Study Area extends beyond the Project Area, along the general creek alignment, to provide context. The Project Area and Study Area of each watercourse are shown in **Figure 1**.

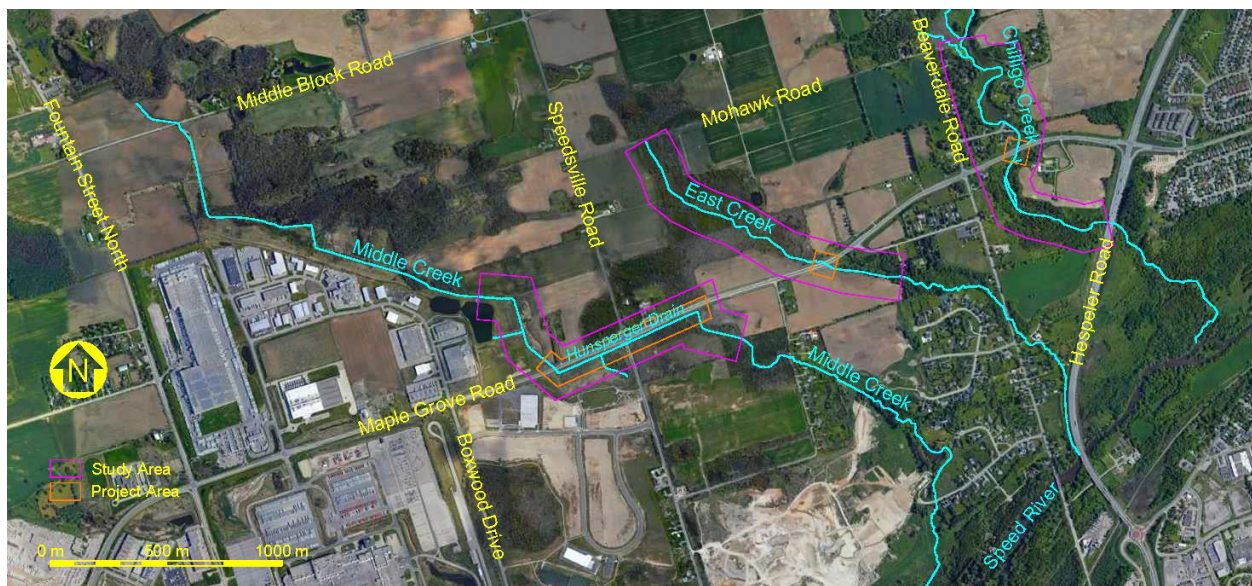
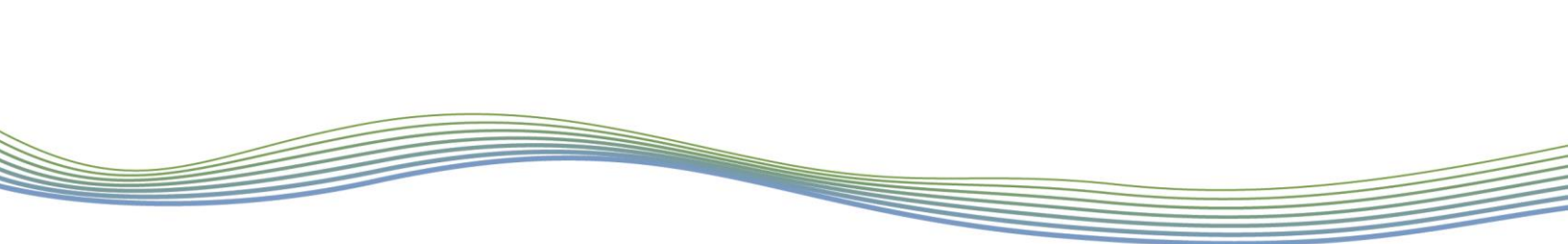


Figure 1: Creeks within Class EA study area

Middle, East and Chilligo Creeks may be impacted if Maple Grove Road is widened. Even if there are no direct impacts to these watercourses, they may be erosion hazards to the road by way of their natural tendency to migrate. Conversely, existing and proposed crossing structures may affect natural channel form and function. These considerations are assessed through the completion of fluvial



geomorphological investigations, the results of which are presented in this report. Moreover, recommendations with respect to replacement crossing structure types and sizes, and channel modifications and enhancements will be provided for the detailed design stage.

2 Study Site History

A series of historical aerial photographs were reviewed to determine changes to the channel and surrounding land use/cover. This information, in part, provides an understanding of the historical factors that have contributed to current channel morphodynamics.

Aerial photographs from 1945 (scale 1:20,000), 1951 (scale 1:40,000), 1964 (scale 1:20,000), 1982 (scale 1:25,000) and 1988 (scale 1:12,000), and 2006, 2012 and 2017 satellite imagery from Google Earth Pro were reviewed to complete the historical assessment. Additionally, historical information from other sources, such as previous studies, are included to provide a more complete picture.

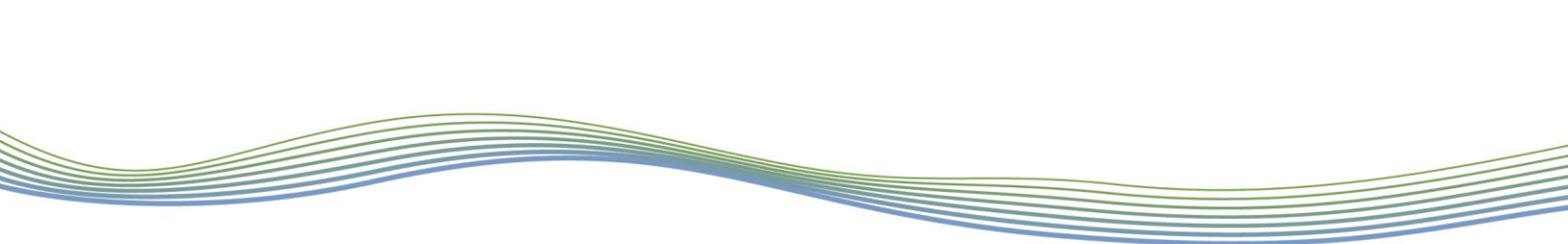
In 1945, the Middle, East and Chilligo Subwatersheds were almost entirely dominated by agricultural land. Of the three watercourses, Middle Creek was the most affected by farming as much of it had previously been straightened, particularly along and upstream of Maple Grove Road, and most of the channel had little to no woody riparian vegetation. East Creek, on the other hand, had a woody riparian zone in the vicinity of Maple Grove Road and only lost this cover near the crossing at Beaverdale Road and farther downstream to the confluence with Speed River. There was also no tree cover or defined channel for approximately 300 m south of Mohawk Road. The Chilligo Creek channel corridor was mostly forested except for the area upstream of Chilligo Road.

Chilligo Creek was dammed at Chilligo Road in the early 1800s to support operations at Fisher Mills, which was originally a sawmill, then either repurposed for other uses or multi-purposed until its most recent use as a feed mill to 1990 (Waterloo Region Record, 2003; PEIL, 2004). The dam impounded the flows of Chilligo Creek and the backwater extended at least 400 m (Euclidian distance) upstream of the dam to the confluence of the Klassen Drain with Chilligo Creek, near the eastern terminus of Mohawk Road.

The creeks and surrounding land use remained generally unchanged between 1945 and 1982, except for an increase in forest cover along Middle Creek downstream of Maple Grove Road and, in particular, upstream of Briardean Drive. East Creek was channelized south of Mohawk Road for approximately 200 m. Prior to channelization, there was no defined channel in this area as it was a wetland. It was also apparent that the water level in the Fisher Mills Pond fluctuate over time as it was relatively high in 1964 and low in 1982.

In 1988, the water level in Fisher Mills Pond was again high. Land development pressure was evidently increasing as a residential subdivision was under construction immediately south of East Creek and on the west side of Beaverdale Road. Maple Grove Road was also reconstructed, west of East Creek, eliminating a jog in the road at Speedville Road. This road reconstruction also necessitated the realignment of the portion of Middle Creek that travelled along the south side of the road.

Between 1988 and 2006, the land on the north side of Maple Grove Road, between the road and Middle Creek, was developed. This was accompanied by the construction of a stormwater management facility, which discharged directly to the creek. In mid-2006, land clearing commenced in an area enveloped by Maple Grove Road and East Creek to the north, Briardeen Road to the west and the residential development along Beaverdale Road (note above) to the east. This clearing combined with the previous development resulted in little to no woody riparian buffer along the south side of East Creek between Maple Grove Road and Beaverdale Road. The downstream end of East Creek, near the confluence with Speed River, was also directly impacted by the construction of Hespeler Road (Regional Road 24) as the



original creek and proposed road alignments crossed. The channel was therefore realigned to travel along the west side of the road for 350 m.

By 2006, Maple Grove Road was also realigned east of East Creek and extended beyond Beaverdale Road to connect with Fisher Mills Road at Hespeler Road. The road extension involved the construction of a bridge over Chilligo Creek. At the crossing location, the creek was shifted roughly 50 m to the west, essentially eliminating a meander bend, to provide a more linear connection with the channel farther downstream. The channel was also armoured between Maple Grove Road and Fisher Mills Road. Fisher Mills was in operation until 1990 (Waterloo Region Record, 2003) and the dam was removed in 2005 (GRCA, 2014).

3 Subwatershed Characteristics

3.1 Drainage Characteristics

Middle, East and Chilligo Creeks convey flows in a southerly direction to Speed River. Chilligo Creek is the most significant in terms of subwatershed area, channel length and channel size. The same parameters are lower for Middle Creek and lowest for East Creek. Subwatershed area and channel length have been quantified and are presented in **Table 1**. The drainage areas and channel lengths (main stem only) were obtained from the GIS catchment and watercourse layers provided by the Grand River Conservation Authority (GRCA).

Table 1: Subwatershed areas and channel lengths

Watercourse	Drainage Area (km ²)	Channel length (km)
Middle Creek	5.7	5.67
East Creek	1.5	2.76
Chilligo Creek	50.2	26.31

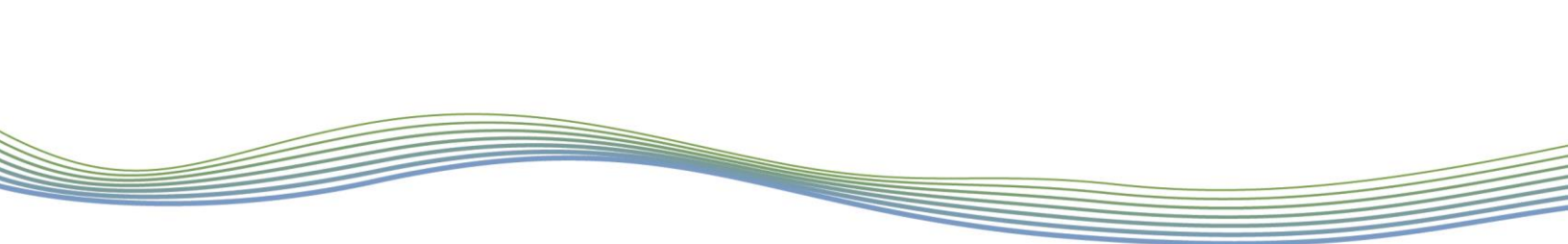
Middle Creek originates on the north side of Middle Block Road, east of Fountain Street, and most of the channel was historically channelized to what was known as Hunsperger Drain. East Creek originates just north of Mohawk Road and, as previously noted, was channelized for approximately 200 m on the south side of the road. In contrast to Middle Creek, the East Creek riparian zone is largely wooded to Beaverdale Road, beyond which the riparian area is relatively narrow and sparsely vegetated.

Chilligo Creek has a significant east branch (Gingrich Drain) in the headwaters as well as two relatively small west tributaries (southern tributary named Klassen Drain) downstream of the confluence of Chilligo Creek and Gingrich Drain. According to GRCA (2014), over 78% of the subwatershed area is used for agricultural production. The land immediately surrounding Chilligo Creek is mostly either agricultural or forest. The channel itself is channelized, generally straight or sinuous, but these channel patterns do not correlate with any particular land use.

3.2 Physical Setting

Channel morphodynamics are largely governed by the flow regime and the availability and type of sediments (i.e., surficial geology) within the stream corridor. Secondary variables that affect the channel include land use and riparian vegetation. These factors are explored as they not only offer insight into existing conditions, but also potential changes that could be expected in the future as they relate to a proposed activity.

All three watercourses in the vicinity of the crossings are located in the Guelph Drumlin Field physiographic region, with the Waterloo Hills to the west and the Horseshoe Moraines to the east (Chapman and Putnam, 1984). More specifically, only the Middle Creek, north of Maple Grove Road is



located in the drumlinized till plain, while most of the subwatersheds associated with East and Chilligo Creeks are in the glacial spillways (Chapman and Putnam, 2007). The till plain and drumlins are largely composed of sandy Wentworth Till and therefore readily erodible by fluvial action. It should be noted that there are no drumlins in the Middle and East Creek Subwatersheds and they are only found in the upper Chilligo Creek Subwatershed, north of Kossuth Road. The landscape is therefore generally flat and slopes down towards Speed River.

With respect to surficial geology, Middle Creek travels through glaciofluvial deposits, comprised of alluvial sand north of Maple Grove Road, and sandy silt to silty sand till south of Maple Grove Road. East Creek travels through an area almost entirely comprised of glaciofluvial deposits. Chilligo, being the largest and longest of the three watercourses, flows through modern alluvial deposits (clay, silt, sand, gravel and possibly organic remains (OGS, 2010). Again, the composition of the surficial material suggests that the watercourses are potentially dynamic. Moreover, the sand provides a highly permeable medium and therefore precipitation in this area would contribute to groundwater recharge and the maintenance of channel baseflow.

Much of the subject watercourses has riparian wetlands, which attenuate creek flows by capturing precipitation and runoff then slowly releasing to the watercourses. While wetland channels may have a relatively low erosion potential due to their low gradients, this phenomenon also decreases downstream channel erosion potential. However, the impact of these riparian wetlands is limited by their capacity, as erosion potential does not decrease if they are full; only when they are below capacity can they attenuate flows (GRCA, 2014).

The subwatersheds are located in the Huron and South Slope climate regions, in which average annual precipitation ranges from 850 to 950 mm. The amount of precipitation is generally uniform throughout the year, but its characteristics vary by season. Convective storms produce high intensity, short rain events during summer, while snowfall dominates during the winter. Spring offers heavy rainfalls and fall produces prolonged rain events (GRCA, 2014).

These seasonal differences in precipitation type, intensity and duration, combined with the local geology and largely agricultural land use, likely result in watercourses that have season-dependent erosion and adjustment potential. For example, the potential for channel morphology change would be greatest during spring when there is heavy rainfall and snowmelt, and possibly during summer when there are unusually intense storm events.

4 Watercourse Characteristics

The Study Area for each subject watercourse (see **Figure 1**) was investigated to provide an understanding of channel form and function in the vicinity of Maple Grove Road. While the understanding of current channel morphodynamics is largely based on field work completed on December 4, 2018, additional observations and conclusions from other studies are also summarized for completeness.

4.1 Reach Delineation

Reaches are generally homogeneous segments of channel used in geomorphological investigations. They are delineated based on changes such as hydrology, channel gradient, confinement, planform (i.e., channel pattern), geology, surrounding land use and anthropogenic disturbances (e.g., crossing structures, dams, straightening/channelization, armouring). Each reach can then be studied semi-independently as it is expected to function in a manner that is distinct from adjoining reaches.

Middle, East and Chilligo Creeks were segmented into reaches, from upstream to downstream, following scientifically-defensible methodology outlined by Montgomery and Buffington (1997), Richards *et al.*

(1997) and the Toronto and Region Conservation Authority (2004). The reaches are shown in **Figure 2**, and a summary of the primary characteristics that define and distinguish each reach are provided in **Table 2**.

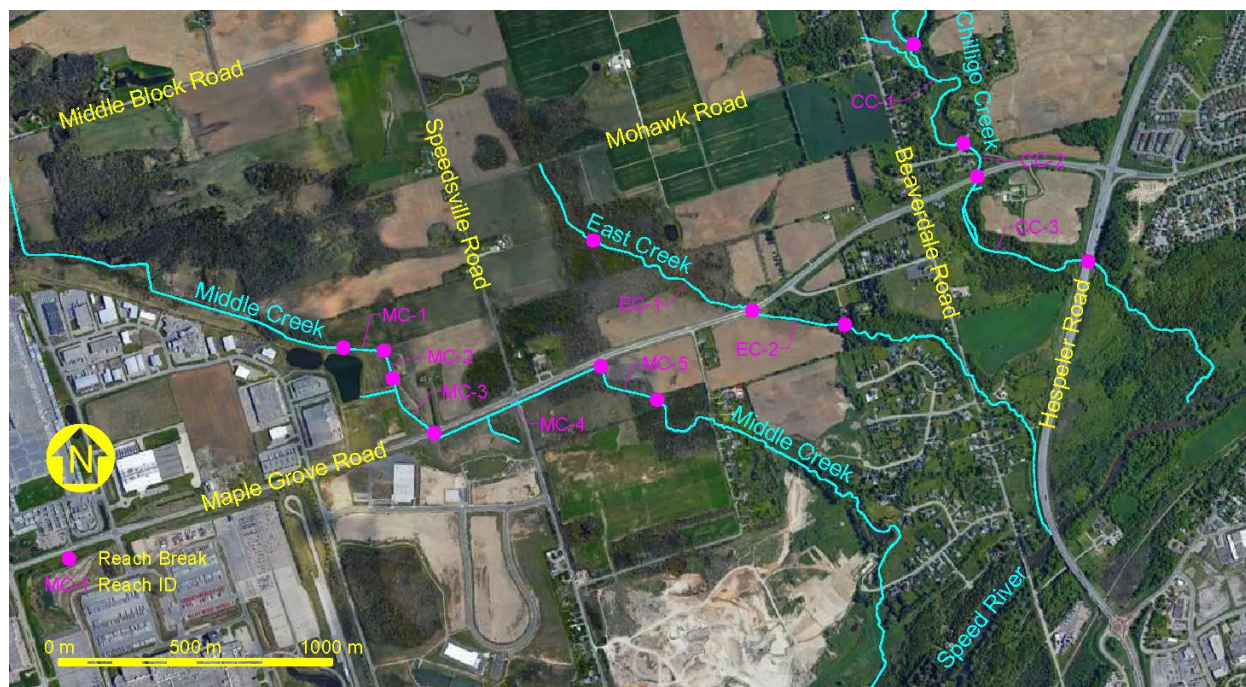
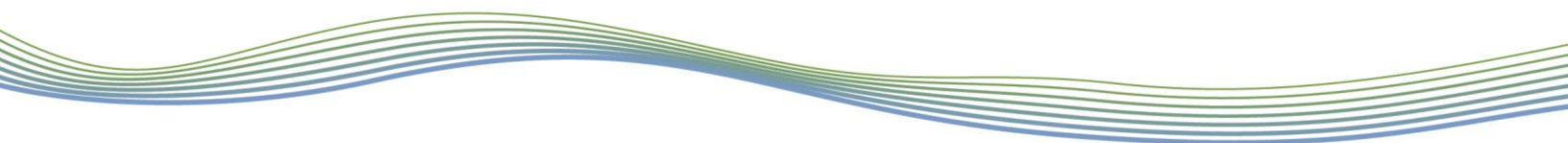


Figure 2: Reaches of Middle, East and Chilligo Creeks

Table 2: General reach characteristics of Middle, East and Chilligo Creeks

Reach	Start & End Locations	Length	Characteristics
Middle Creek			
MC-1	Woodlot northwest of the SWM pond and emergency spillway of SWM pond to the north-south-aligned channel east of the SWM pond	150	Semi-confined system with embankment along south side of channel and agricultural land on north side; straight, grass-lined channel; rooted emergent vegetation; poor channel definition; glaciofluvial deposits (surficial geology)
MC-2	East end of the west-east-aligned channel to the confluence with an east drainage feature (~40 m upstream of SWM pond outlet channel)	120	Straight and defined channel; narrow, woody riparian zone; berms along channel; glaciofluvial deposits (surficial geology)
MC-3	Confluence with an east drainage feature (~40 m upstream of SWM pond outlet channel) to Maple Grove Road	240	Grass-lined channel; rooted emergent vegetation; poor channel definition; low channel sinuosity; till (surficial geology)



MC-4	Full length of channel along south side of Maple Grove Road	650	Roadside ditch confined by road embankment and berm; straight channel; rooted emergent vegetation and sand bed; fragmented woody riparian buffer; till (surficial geology)
MC-5	Maple Grove Road to north end of woodlot on west side of Briardean Road	260	Straightened channel with woody riparian vegetation; till (surficial geology)
East Creek			
EC-1	South end of channelized section (~300 m south of Mohawk Road) to Maple Grove Road	600	Swamp with poorly defined watercourse; low gradient; forested riparian cover; glaciofluvial deposits (surficial geology)
EC-2	Maple Grove Road to woodlot (~300 m south of Mohawk Road)	300	Straight channel; in-channel woody debris; woody riparian cover primarily on north side of channel; glaciofluvial deposits (surficial geology)
Chilligo Creek			
CC-1	Confluence with Klassen Drain to Chilligo Road	630	High sinuosity channel; grass and herbaceous riparian zone; valley confinement/setting; evidence of bed adjustments (knickpoints); sand and gravel/cobble bed; glaciofluvial deposits (surficial geology)
CC-2	Chilligo Road to Maple Grove Road	150	Generally straight channel; mature, wooded riparian buffer; bed and bank armouring; bed grade controls; cobble bed; valley confinement/setting; glaciofluvial deposits (surficial geology)
CC-3	Maple Grove Road to Hespeler Road	660	Moderate channel sinuosity; forested riparian buffer; partially valley confinement/setting; cobble bed; instream woody debris; evidence of planform adjustments (island formation); modern alluvial deposits (surficial geology)

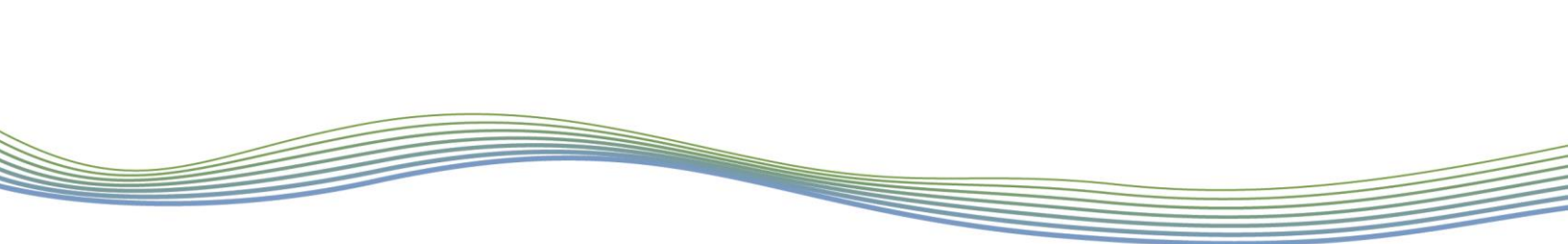
4.2 Reach Observations

A field investigation was completed on collected on December 4, 2018 to verify the reaches that were delineated as part of the desktop assessment and to characterize each reach. A photographic record is included in **Appendix A**.

4.2.1 Middle Creek

Reach MC-1 is a semi-confined system with an embankment of a stormwater management pond along the south side of the channel and an agricultural field on the north side. The reach is not naturally semi-confined as the embankment is a constructed feature. Riparian vegetation consists of herbaceous plants with shrubs only along the embankment.

Flow is conveyed through a grass-lined channel, which may have developed due to persistently low flows and/or low energy. There is no defined channel, but a flow path through the vegetation. Where the bed is exposed, substrate consists of primarily silt and clay, suggesting that this is a low-energy reach.



Reach MC-2 has a straight channel confined between berms approximately 6 to 7 m apart. Riparian vegetation consists of narrow strips of trees along the banks and mostly herbaceous plants beyond the trees. The creek was previously channelized and has a rectangular cross section with an average bankfull width of 3.8 m and an average mean bankfull depth of 0.41 m. There was a lack of ripples on the water surface on the day of observation, which indicated that the flow velocity and stream energy were low. This assessment is supported by the plane bed and leaf litter on the bed. There is also limited bank erosion due to woody vegetation establishment as well as the low energy.

Reach MC-3 is located immediately north (upstream) of Maple Grove Road and is similar to Reach MC-1 with respect to form and function, with the exception of the lack of confinement by an embankment. The channel is straight and has a continuous riparian buffer consisting of herbaceous vegetation. Grasses have heavily encroached into most of the channel resulting in a flow path through vegetation rather than a well-defined channel. Where there is a channel, average bankfull width and mean depth is 4.1 m and 0.42 m.

At the downstream end of the reach at Maple Grove Road, flow is conveyed through a twin corrugated steel pipe (CSP) culvert. The CSPs have a diameter of 1.4 m and are partially embedded.

Reach MC-4 is essentially a ditch along the south side of Maple Grove Road. The channel, also known as Hunsperger Drain, is linear and confined by the road embankment to the north and a berm to the south. Riparian vegetation is comprised of herbaceous plants as well as trees and shrubs along the south side. The channel substrate generally consists of gravel and cobble, and banks are lined with riverstone to inhibit erosion, although there were observations of localized bank erosion. The average bankfull channel width is 2.8 m and the average maximum bankfull depth is 0.44 m.

At the downstream end of the reach, the channel turns away from the road to the south. A CSP culvert also augments flow by conveying water from the north side of Maple Grove Road.

Reach MC-5 has a linear channel with woody riparian vegetation. The upstream end of the reach is at Maple Grove Road where the channel turns to travel south. There is also a CSP culvert that conveys flow from the north side of the road. The channel has tree cover and therefore shade during the growing season.

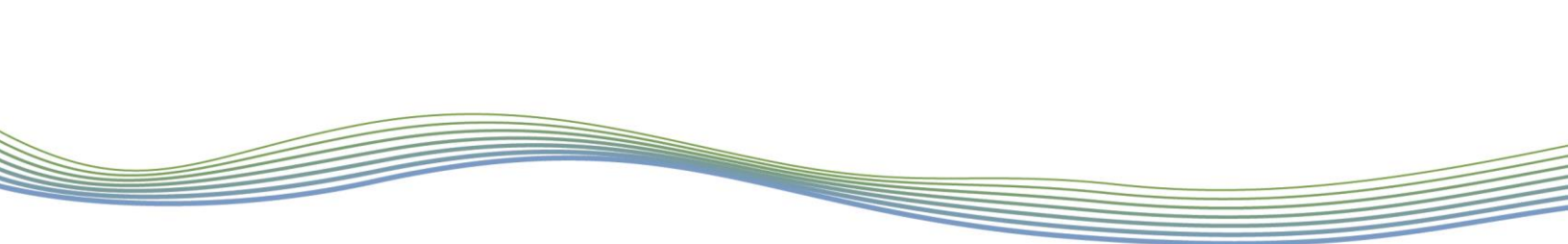
4.2.2 East Creek

Reach EC-1 may be a swamp, although this would need to be confirmed during other seasons to determine if the water table is frequently above-ground. The corridor is vegetated with deciduous trees, and the watercourse is frequently poorly defined and recognizable only as a depressional feature on the ground, particularly where water is ponded. Woody debris was frequently found in the channel. At the downstream end of the reach at Maple Grove Road, flow is conveyed through a 1.25 m diameter, partially embedded CSP culvert.

Reach EC-2 has an unconfined channel that travels along the margin of an agricultural field. Along the north side of the channel, the riparian zone is vegetated with mature trees, while the south side has a narrow buffer of herbaceous plants between the channel and agricultural land. The channel is shallow (0.20 m), approximately 1.4 m wide and has low angle banks. The substrate is comprised of fines with an overlying layer of leaf litter, which indicates a low-energy system. The barely perceptible flow is further evidence of low energy. Fallen trees are frequently found, but channel widening or migration is not the causal mechanism.

4.2.3 Chilligo Creek

Reach CC-1 is a confined channel system between the confluence with a significant tributary from the west (upstream end) and Chilligo Road. The reach includes a meandering channel and two offline ponds,



which appear to have been constructed following the failure and subsequent removal of the Fisher Mills Dam. The valley floor is dominated by herbaceous vegetation including moisture-tolerant plants.

Following dam removal, the channel was apparently allowed to self-establish resulting in a sinuous planform through the impounded sediments. It is evident that the channel is continuing to adjust laterally as indicated by the eroding and failing banks. The channel has a riffle and pool morphology. Riffles are comprised of gravel, cobble and boulder, while pools have primarily sand and gravel. The average bankfull channel width is 8.5 m, and the average maximum bankfull depth is 0.81 m.

At the downstream end of the reach, flows cross Chilligo Road through a ~15 m span bridge with rocks that define the channel banks, which suggest that the channel may have been constructed. There is a low-level weir immediately upstream of the bridge, which may have been constructed or may possibly be a remnant of the dam. In either case, it provides a grade control for the upstream channel bed.

Reach CC-2 is located between Chilligo and Maple Grove Roads and bisected by Fisher Mills Road. Riparian vegetation changes between trees and herbaceous plants in the longitudinal direction. In contrast to the adjoining reaches, the channel in this reach has been evidently modified, presumably due to the close spacing of crossing structures over a short distance of 150 m. Modifications include the construction of channel-spanning weirs and bank armouring with armourstone.

The channel has a relatively high gradient with riffles and poorly developed (shallow) pools. The bed substrate is generally comprised of cobble and boulders with little distinction between riffles and pools. The average bankfull channel width is 8.1 m and the average maximum bankfull depth is 0.48 m.

The Fisher Mills Road bridge has a similar structure to the Chilligo Road bridge and also spans 15 m. The channel, however, occupies a larger proportion of the crossing offering less opportunity for terrestrial passage. The Maple Grove Road bridge is also similar, but has a 25 m span.

Reach CC-3 is between Maple Grove and Hespeler Roads and has a meandering channel in a well-forested valley comprised of coniferous and deciduous species. The channel has a riffle and pool bed morphology spaced approximately 40 m apart. Riffle substrate is comprised of sand, gravel, cobbles and boulders, while pools have clay, sand, gravel and few cobbles. Bankfull channel width averages 8.4 m and the maximum depth is 0.79 m.

The channel has a high width-to-depth ratio, which is symptomatic of a widening channel. Evidence of widening includes falling and fallen trees along the banks and exposed tree roots. The channel is also experiencing adjustments to its planform as indicated by the formation of islands, cutoff channels and poorly formed bars.

4.3 Reconnaissance-level Assessments

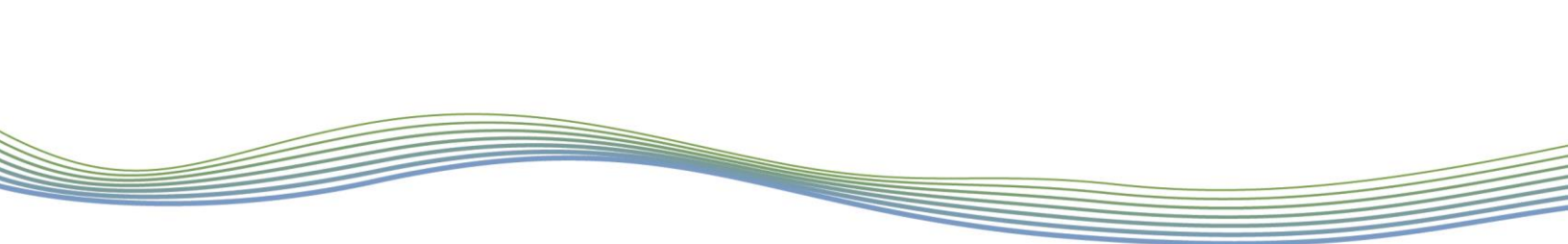
Channel instability was semi-quantified through the application of the Ontario Ministry of the Environment's (2003) Rapid Geomorphic Assessment (RGA). Observations were quantified using an index that identifies channel sensitivity based on evidence of aggradation, degradation, channel widening, and planimetric form adjustment. The index produces values that indicate whether the channel is stable/in regime (score <0.20), stressed/transitional (score 0.21-0.40) or adjusting (score >0.41). Completed field sheets are provided in **Appendix B**.

The Rapid Stream Assessment Technique (RSAT) was also employed to provide a broader view of the system with respect to the ecological function of the watercourse (Galli, 1996). Observations were made of channel stability, channel scouring or sediment deposition, instream and riparian habitats, and water quality. The RSAT score ranks the channel as maintaining a poor (<13), fair (13-24), good (25-34), or excellent (35-42) degree of stream health.

Finally, the reaches were classified according to a modified Downs (1995) Channel Evolution Model (CEM) and the River Styles Framework (Brierley and Fryirs, 2005). The CEM describes successional stages of a channel as a result of a perturbation, namely hydromodification. Understanding the current stage of the system is beneficial as this allows one to predict how the channel will continue to evolve or respond to an alteration to the system. The River Styles Framework provides a geomorphological approach to examining river character, behaviour, condition, and recovery potential. The results of these reconnaissance-level assessments are summarized in **Table 3**.

Table 3: Reconnaissance-level stream assessment results

Reach	RGA (MOE, 2003)			RSAT (Galli, 1996)			Channel Evolution Model (Downs, 1995)	River Style (Brierley and Fryirs, 2005)
	Score	Condition	Dominant Systematic Adjustment	Score	Condition	Limiting Factor		
Middle Creek								
MC-1	Not applicable – vegetation-controlled channel			Not applicable – vegetation-controlled channel, small watercourse			S – stable	Straight, suspended load
MC-2	Not applicable – channelized watercourse			Not applicable – channelized, small watercourse			S – stable	Straight, suspended load
MC-3	Not applicable – vegetation-controlled channel			Not applicable – vegetation-controlled channel, small watercourse			S – stable	Straight, suspended load
MC-4	Not applicable – roadside ditch			Not applicable – roadside ditch, small watercourse			S – stable	Straight, suspended load
MC-5	Not applicable – channelized watercourse			Not applicable – channelized, small watercourse			S – stable	Straight, suspended load
East Creek								
EC-1	Not applicable – marsh, poor channel definition			Not applicable – marsh, poor channel definition, small watercourse			S – stable	Meandering, suspended load
EC-2	Not applicable – channelized watercourse			Not applicable – channelized, small watercourse			S – stable	Straight, suspended load
Chilligo Creek								
CC-1	0.29	In transition	Widening	18	Fair	Channel instability, poor riparian habitat	E – enlarging	Meandering, mixed load
CC-2	Not applicable – armoured banks			Not applicable – armoured banks			S – stable	Straight, mixed load
CC-3	0.40	In transition	Planform adjustment	23	Fair	Channel instability	E – enlarging	Meandering, mixed load



RGA and RSAT are intended for fully alluvial, meandering channels and therefore can only be applied to two reaches of Chilligo Creek. In both cases, the reaches are 'in transition' although the primary mode of adjustment differs. These two reaches are also in 'fair' stream health, as indicated by the RSAT.

All reaches of Middle and East Creeks are 'stable' according to the CEM. Both creeks are first order streams and, although previously channelized, would have low potential for adjustments, in large part due to the establishment of instream vegetation.

5 Erosion Hazard Assessment

5.1 Meander Belt and Erosion Limits

Most watercourses in southern Ontario have a natural tendency to develop and maintain a meandering planform, provided there are no spatial constraints. A meander belt width assessment estimates the lateral extent that a sinuous channel has historically occupied and will likely occupy in the future due to lateral and downstream meander bend migration. This assessment is therefore useful for determining the potential hazard to the proposed Maple Grove Road as well as the crossing structures associated with each watercourse.

When defining the potential erosion hazard limits for a creek system, however, unconfined and confined systems are assessed differently (TRCA, 2004). Unconfined systems are those with poorly defined valleys or those with valley walls positioned where a sinuous channel would not realistically contact. Confined systems are those where a watercourse is contained within a defined valley, where meander bend development may be constrained by valley walls.

In unconfined systems, the meander belt width can be graphically defined using orthorectified aerial imagery. The channel's meander belt axis is initially determined for each reach, and the lateral limits of the meander belt, as defined by the channel's maximum meander amplitude, is then used to measure the meander belt width.

A modelling approach can be used where the channel has been previously modified or its position cannot be determined in the imagery due to tree cover or poor photograph resolution, for example. These models are scientifically defensible and have been verified in past projects as suitable for use in southern Ontario. Empirical relations from Williams (1986) are applied using bankfull channel dimensions measured in the field to estimate the meander belt width (m), B_w :

$$B_w = 4.3W_b^{1.12} + W_b \quad [\text{Eq. 1}]$$

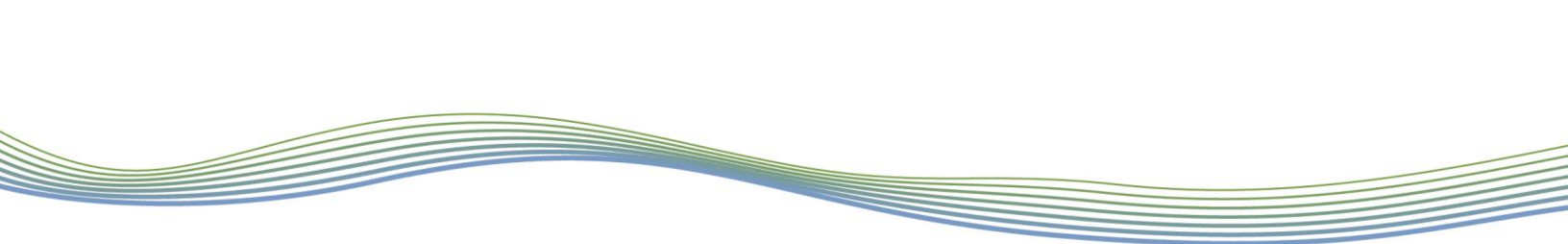
where A is bankfull cross-sectional area (m^2) and W_b is bankfull channel width (m). An additional 20% buffer, or factor of safety, is applied to the computed results to address issues of under prediction.

The Ward et al. (2002) model can also be used to estimate the meander belt width (ft), B_w :

$$B_w = 6W_b^{1.12} \quad [\text{Eq. 2}]$$

Again, an additional 20% buffer, or factor of safety, is applied to the results.

When watercourses are partially or fully confined within a valley, the methods outlined above cannot be sole means of determining the erosion hazard, as an erosion setback must also be applied (OMNR, 2001). Initially, a confined channel is treated as an unconfined system (without the factor of safety) and the meander belt is measured or modelled, as appropriate. The effect of the valley wall is then considered by applying a 5 to 8 m toe erosion allowance from the toe of valley slope, if the channel is within 15 m from the toe of slope (OMNR, 2001). A combination of these procedures provides the ultimate meander belt width. This approach is physically based and conservative, while providing a



result similar to that produced by the TRCA (2004) method, which places the meander belt limit at the midpoint between the toe and top of the valley slope (viewed orthogonally). It should be noted that the 5 to 8 m toe erosion allowance assumes that the valley wall is composed of clay, clay-silt or gravel, and that the toe erosion allowance can be greater or less depending on the type of material (OMNR, 2001).

For this study, the potential erosion hazard associated with the reaches immediately upstream of and along Maple Grove Road are of interest as only these have the ability to adjust and become problematic. However, the reaches of East and Chilligo Creeks upstream of the road (Reaches EC-1 and CC-2, respectively) can be removed from further analysis as the former is a marsh, which does not function in a similar manner as an alluvial watercourse, and the latter is armoured. The reaches remaining that qualify for erosion hazard assessment are Middle Creek Reaches MC-3 and MC-4.

Middle Creek Reach MC-3 is an unconfined system and therefore a meander belt width applies. A modelling approach is necessary due to the channel straightening before 1945 (the earliest aerial photograph available) and the resultant lack of evidence of a sinuous planform. The Williams (1986) and Ward (2002) relations produce meander belt widths of 29.6 m and 39.8 m, respectively. Based on past studies and experience and an understanding of the dynamics of low-order streams, the Williams (1986) relation provides a more realistic result.

Middle Creek Reach MC-4, along the south side of Maple Grove Road, is considered a confined system due to the road embankment on the north side of the channel and the berm along the south side. As such, a toe erosion allowance is applied as an offset to the channel banks. For this study, an 8 m toe erosion allowance is employed to provide a more conservative result. This results in a total theoretical lateral channel erosion limit of 19 m (3 m wide channel, rounded up from 2.8 m, plus 8 m on each side).

It must be stressed that the erosion hazard assessment applied to Reach MC-4 does not consider the fact that it extends into the existing paved road, nor does it include a stable slope allowance, which is a setback that ensures safety in the event of a slope failure associated with the berm along the south side of the channel. The stable slope allowance is determined as the horizontal distance measured into a slope from the toe erosion allowance (8 m assumed in this case) equivalent to three times the height of the slope. In other words, the stable top of slope is considered to be where a 3:1 line extending from the toe erosion allowance, in cross section, intersects the existing ground. The stable slope allowance can alternatively be determined through a slope stability study (OMNR, 2001).

The modelled meander belt width for Reach MC-3 and the erosion allowance for Reach MC-4 are graphically depicted in a figure provided in **Appendix C**.

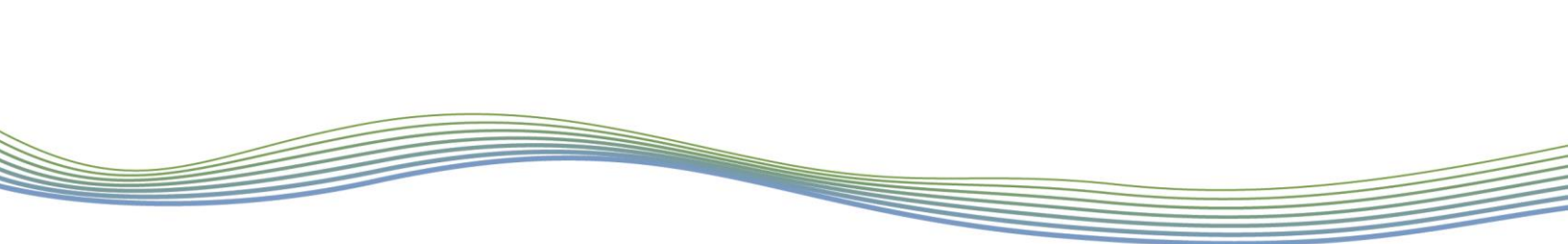
5.2 Channel Migration

By overlaying historical aerial imagery (orthorectified and georeferenced), individual meander bends can potentially be tracked in the lateral and downstream directions over time to determine the 100-year migration rate and erosion limit. In this study, however, the 100-year erosion limits could not be determined due to the degree and extent of historical channel modifications (e.g., straightening and armouring).

6 Summary and Recommendations

6.1 Summary

Historically, Middle, East and Chilligo Creeks have been directly affected to varying degrees by changes in land used and development. Surrounded by agricultural land, Middle Creek was perhaps the most heavily impacted as it was channelized presumably to rapidly convey runoff off the fields and to maximize cultivable area. Although Chilligo Creek was largely spared from channelization, it was



dammed at Chilligo Road to initially support a sawmill. The dam created a pond that trapped sediment resulting in a loss of sediment supply to downstream reaches. The dam has since been removed, allowing a channel to naturally re-establish and the impounded sediment to be conveyed downstream. East Creek, in contrast, has experienced relatively little change, possibly due in part to the swamp conditions on the north side of Maple Grove Road.

With respect to the physical setting, the three subwatersheds gently slope towards Speed River. All three also have a geology composed of relatively high proportions of sand, which not only promote infiltration and baseflow maintenance, but also result in channels that have the potential to readily adjust. This potential is, however, countered by the low-gradient landscape and the frequent riparian wetlands that act to attenuate instream flows.

Middle and East Creeks are therefore generally stable and exhibit other characteristics similar headwater drainage features such as the lack of morphological bed variability (e.g., no riffle and pool development). Chilligo Creek, being a much larger system, has relatively well-developed riffles and pools in the vicinity of Maple Grove Road.

The erosion hazard potential of the creeks is generally low as evidenced by the limited site observations of erosion and channel instability in Middle Creek, the East Creek marsh upstream of Maple Grove Road, and the Chilligo Creek bank armouring also upstream of the road. The potential for erosion is greatest along Middle Creek, immediately upstream of Maple Grove Road and along the south side of the road. For these two reaches, MC-3 and MC-4, the meander belt was modelled and a toe erosion allowance was applied, respectively, resulting theoretical erosion hazard corridor widths of 29.6 m and 19 m.

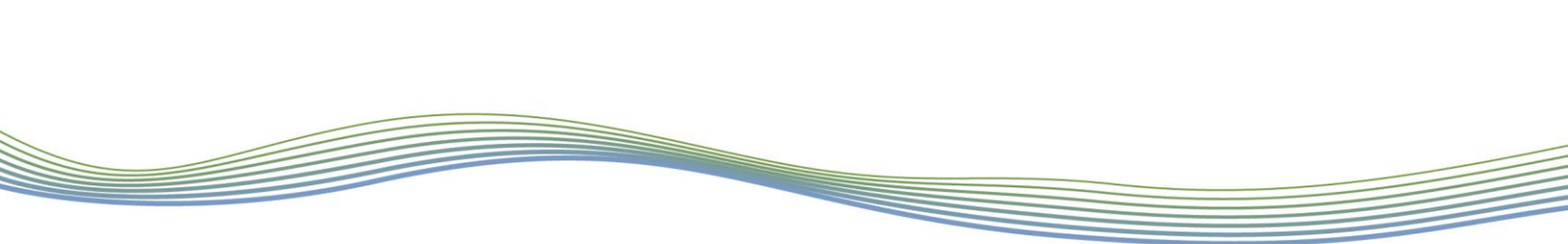
6.2 Recommendations

The need for improvements to Maple Grove Road provides an opportunity to enhance or restore the function and possibly form of the watercourses in the vicinity of the road if there are any anticipated direct impacts. Recommendations associated with each creek are provided below; however, the final recommendations will ultimately depend on the preferred alternative with consideration to all evaluation criteria.

6.2.1 Middle Creek

Should the twin CSP culvert at Maple Grove Road need to be replaced, an open-bottom crossing structure should be considered as this would not only locally restore connectivity between the surface water and groundwater. Natural substrate, hydraulically sized to resist entrainment, could also then be placed throughout the length of the replacement culvert to enhance conditions for fish passage. The culvert would ideally have a span equivalent to three times the bankfull channel width, 12.3 m (3 x 4.1 m). Understanding that this may not be possible for various reasons, a 5 m span culvert would be acceptable as a ~4 m wide low flow channel, consistent with that in Reach MC-3, could be constructed through the culvert. A lower span culvert is also an option, but at the cost of establishing a low flow channel.

With respect to Reach MC-4 along the south side of Maple Grove Road, the Hespeler West Subwatersheds Study Working Committee (HWSSWC, 2004) recommended the restoration of the channel with a natural meandering pattern. While this may be worthy from a fluvial geomorphological perspective as well as for fish habitat improvements, it may not be feasible due to the need to acquire lands in order to accommodate the naturalized channel. A more feasible solution, assuming that the existing channel will be impacted by the works associated with the preferred solution, would be to reconstruct the channel set back farther from the road as a linear feature with greater complexity and riparian buffer/cover. Greater complexity could be provided through the construction of natural bedforms such as riffles, boulder clusters and pools. While this option may still require land acquisition, it could significantly improve channel conditions for fish.



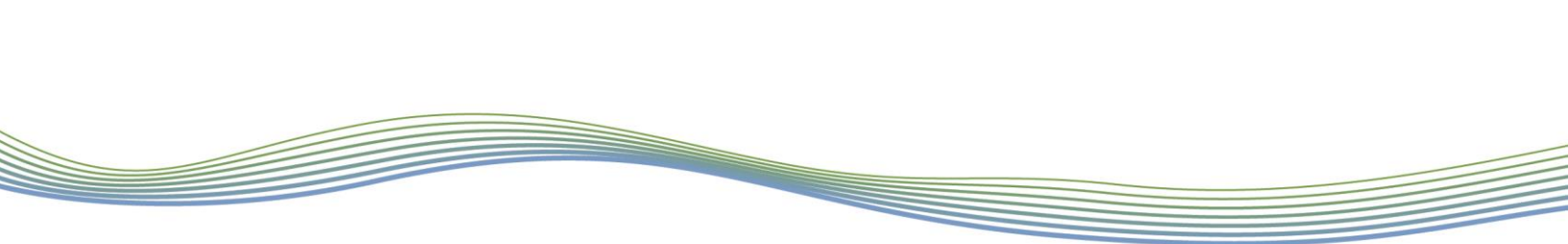
6.2.2 East Creek

If a replacement culvert is required for East Creek, similar recommended improvements associated with the Middle Creek culvert could also be employed. Here, however, the upstream reach, Reach EC-1, is a marsh with a poorly defined channel and therefore the bankfull channel dimension through the culvert would need to be approximated based on the hydraulic model output assuming that the bankfull discharge is roughly equivalent to the storm flows associated with the 1.5 or 2 year recurrence interval.

Among other suggested management activities for East Creek elsewhere in the system, the HWSSWC (2004) also recommended the rehabilitation of the channel downstream of Maple Grove Road adjacent to a sod farm. This is referring to the Reach EC-2 channel, which was previously straightened and removed of riparian vegetation along the south side of the channel.

6.2.3 Chilligo Creek

The Chilligo Creek bridge was constructed in the early 2000s with four lanes and wide shoulders, which may accommodate an additional lane if necessary. It is therefore assumed that the bridge would not need to be modified and, consequently, there would be no channel disturbance. If there is a need for offsetting or compensation, an effective yet simple strategy to improve fish habitat would be to install riparian plantings. The channel currently lacks woody riparian vegetation immediately upstream and downstream of the bridge.



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Appendix A: Reach Photographs

Photo 1
Middle Creek Reach MC-1



Poorly-defined channel along embankment on north side of stormwater management pond.

Photo 2
Middle Creek Reach MC-1



Flow path through herbaceous vegetation with an agricultural field on the left (north).

Photo 3
Middle Creek Reach MC-2



Straight channel with trees along the banks. The channel has a rectangular cross section with limited evidence of bank erosion.

Photo 4
Middle Creek Reach MC-2



General plane bed comprised of most sand with submergent vegetation and leaf litter. The leaf litter suggests that the channel has low energy.

Photo 5
Middle Creek Reach MC-3



Straight channel through a wide corridor lined with herbaceous vegetation.

Photo 6
Middle Creek Reach MC-3



For most of the reach, there is a flow path through vegetation and no defined channel.

Photo 7
Middle Creek Reach MC-3



Twin corrugated steel pipe culvert inlet at Maple Grove Road. The pipes are partially embedded.

Photo 8
Middle Creek Reach MC-3



Reach viewed upstream from Maple Grove Road at downstream end of reach.

Photo 9
Middle Creek Reach MC-4



Culvert outlet at upstream end of reach at Maple Grove Road.

Photo 10
Middle Creek Reach MC-4



Linear channel along the south side of Maple Grove Road with some riverstone armouring along south bank. The channel along the road is also known as Hunsperger Drain.

Photo 11
Middle Creek Reach MC-4



Channel with limited morphological variability due to function as roadside ditch.

Photo 12
Middle Creek Reach MC-4



Culvert inlet at Speedville Road. On the right is a riverstone-lined channel associated with an outlet for a stormwater management pond.

Photo 13
Middle Creek Reach MC-4



Speedville Road culvert outlet.

Photo 14
Middle Creek Reach MC-4



Plane bed with riverstone bank armouring along channel.

Photo 15
Middle Creek Reach MC-4



Downstream end of reach where the channel turns away from the road.

Photo 16
Middle Creek Reach MC-5



Upstream end of reach viewed downstream from Maple Grove Road. A CSP culvert conveys flow from the north side of Maple Grove Road into the reach.

Photo 17
Middle Creek Reach MC-5



Generally straight channel with a narrow woody riparian zone.

Photo 18
East Creek Reach EC-1



Watercourse with poorly-fined channel through a swamp.

Photo 19
East Creek Reach EC-1



The depth of flow is close to matching surrounding grades during dry periods, which suggests that the area is frequently inundated.

Photo 20
East Creek Reach EC-1



CSP culvert inlet at downstream end of reach (Maple Grove Road).

Photo 21
East Creek Reach EC-2



Reach viewed downstream from Maple Grove Road.

Photo 22
East Creek Reach EC-2



CSP culvert outlet at Maple Grove Road.

Photo 23
East Creek Reach EC-2



Low-flow channel near Maple Grove Road with herbaceous vegetation.

Photo 24
East Creek Reach EC-2



Typical channel in reach with limited morphological bed variability, barely perceptible flow, fallen trees and riparian trees along left bank.

Photo 25
Chilligo Creek Reach CC-1



Beaver dam with overtopping flow.

Photo 26
Chilligo Creek Reach CC-1



Offline pond on the east side of channel at the upstream end of reach.

Photo 27
Chilligo Creek Reach CC-1



Herbaceous riparian vegetation including abundant moisture-tolerant plants.

Photo 28
Chilligo Creek Reach CC-1



Photo 29
Chilligo Creek Reach CC-1



Offline pond on the east side of channel at the downstream end of reach.

Photo 30
Chilligo Creek Reach CC-1



Chilligo Road bridge at the downstream end of reach. A weir is positioned just upstream of the bridge and provides upstream channel bed grade control.

Photo 31
Chilligo Creek Reach CC-1



Rock-lined channel through the Chilligo Road bridge. The rock may have been placed to not only protect the bridge, but to also form the channel.

Photo 32
Chilligo Creek Reach CC-1



Reach viewed upstream from Chilligo Road bridge. Note the valley wall contact to the left.

Photo 33
Chilligo Creek Reach CC-2



Reach viewed downstream from Chilligo Road bridge towards the Fisher Mills Road bridge.

Photo 34
Chilligo Creek Reach CC-2



Rock weirs constructed across channel to control bed grade and concentrate flow through centre of channel.

Photo 35
Chilligo Creek Reach CC-2



Channel approach to Fisher Mills Road. The channel has a relatively high gradient and energy and therefore larger substrate in the cobble and boulder range.

Photo 36
Chilligo Creek Reach CC-2



Reach viewed upstream from Fisher Mills Road bridge.

Photo 37
Chilligo Creek Reach CC-2



Photo 38
Chilligo Creek Reach CC-2



Armourstone along the outside bank of a bend, downstream of Fisher Mills Road.

Photo 39
Chilligo Creek Reach CC-2



Riffle section with rapid flow upstream of Maple Grove Road.

Photo 40
Chilligo Creek Reach CC-2



Channel and overbank area under the Maple Grove Road bridge.

Photo 41
Chilligo Creek Reach CC-3



Photo 42
Chilligo Creek Reach CC-3



Photo 43
Chilligo Creek Reach CC-3



Photo 44
Chilligo Creek Reach CC-3



Photo 45
Chilligo Creek Reach CC-3



Photo 46
Chilligo Creek Reach CC-3



Photo 47
Chilligo Creek Reach CC-3



Straight riffle section upstream of Hespeler Road. Erosion of bank on left and leaning tree on right suggest channel widening.

Photo 48
Chilligo Creek Reach CC-3



Hespeler Road bridge with rock protection along abutments.



Appendix B: RGA and RSAT Field Sheets

Rapid Geomorphic Assessment

Project Code: 18116

Date:	Dec 4, 2018	Stream/Reach:	CHILLIGO CREEK REACH CC-1
Weather:	0°C	Watershed/Subwatershed:	SPEED RIVER
Field Staff:	BM JT	Location:	CAMBRIDGE

Process	Geomorphological Indicator		Present?		Factor Value
	No.	Description	Yes	No	
Evidence of Aggradation (AI)	1	Lobate bar		✓	2/7
	2	Coarse materials in riffles embedded		✓	
	3	Siltation in pools	✓		
	4	Medial bars	✓		
	5	Accretion on point bars		✓	
	6	Poor longitudinal sorting of bed materials		✓	
	7	Deposition in the overbank zone		✓	
Sum of indices =			2	5	0.286

Evidence of Degradation (DI)	1	Exposed bridge footing(s)		✓	1/6
	2	Exposed sanitary / storm sewer / pipeline / etc.			
	3	Elevated storm sewer outfall(s)			
	4	Undermined gabion baskets / concrete aprons / etc.			
	5	Scour pools downstream of culverts / storm sewer outlets			
	6	Cut face on bar forms		✓	
	7	Head cutting due to knickpoint migration		✓	
	8	Terrace cut through older bar material		✓	
	9	Suspended armour layer visible in bank	✓		
	10	Channel worn into undisturbed overburden / bedrock		✓	
Sum of indices =			1	5	0.167

Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	✓		3/7
	2	Occurrence of large organic debris	✓		
	3	Exposed tree roots	✓		
	4	Basal scour on inside meander bends		✓	
	5	Basal scour on both sides of channel through riffle		✓	
	6	Outflanked gabion baskets / concrete walls / etc.			
	7	Length of basal scour >50% through subject reach		✓	
	8	Exposed length of previously buried pipe / cable / etc.			
	9	Fracture lines along top of bank		✓	
	10	Exposed building foundation			
Sum of indices =			3	4	0.429

Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)		✓	1/7
	2	Single thread channel to multiple channel		✓	
	3	Evolution of pool-riffle form to low bed relief form	✓		
	4	Cut-off channel(s)		✓	
	5	Formation of island(s)		✓	
	6	Thalweg alignment out of phase with meander form		✓	
	7	Bar forms poorly formed / reworked / removed		✓	
Sum of indices =			1	6	0.143

Additional notes:

Stability Index (SI) = (AI+DI+WI+PI)/4 = 0.29

Condition	In Regime	In Transition/Stress	In Adjustment
SI score =	☐ 0.00 - 0.20	☒ 0.21 - 0.40	☐ 0.41

Completed by: BM Checked by: KT

Rapid Stream Assessment Technique

Project Code: 18116

Date:	DEC 4, 2018	Stream/Reach:	CHILLIGO CREEK REACH CC-1
Weather:	0°C	Location:	SPEED RIVER
Field Staff:	BM JT	Watershed/Subwatershed:	CAMBRIDGE

Evaluation Category	Poor	Fair	Good	Excellent
Channel Stability	< 50% of bank network stable - Recent bank sloughing, slumping or failure frequently observed	50-70% of bank network stable - Recent signs of bank sloughing, slumping or failure fairly common	71-80% of bank network stable - Infrequent signs of bank sloughing, slumping or failure	> 80% of bank network stable - No evidence of bank sloughing, slumping or failure
	- Stream bend areas highly unstable - Outer bank height 1.2 m above stream bank (2.1 m above stream bank for large mainstem areas) - Bank overhang > 0.8-1.0 m	- Stream bend areas unstable - Outer bank height 0.9-1.2 m above stream bank (1.5-2.1 m above stream bank for large mainstem areas) - Bank overhang 0.8-0.9m	- Stream bend areas stable - Outer bank height 0.6-0.9 m above stream bank (1.2-1.5 m above stream bank for large mainstem areas) - Bank overhang 0.6-0.8 m	- Stream bend areas very stable - Height < 0.6 m above stream (< 1.2 m above stream bank for large mainstem areas) - Bank overhang < 0.6 m
	- Young exposed tree roots abundant > 6 recent large tree falls per stream mile	- Young exposed tree roots common 4-5 recent large tree falls per stream mile	- Exposed tree roots predominantly old and large, smaller young roots scarce 2-3 recent large tree falls per stream mile	- Exposed tree roots old, large and woody - Generally 0-1 recent large tree falls per stream mile
	- Bottom 1/3 of bank is highly erodible material - Plant/soil matrix severely compromised	- Bottom 1/3 of bank is generally highly erodible material - Plant/soil matrix compromised	Bottom 1/3 of bank is generally highly resistant plant/soil matrix or material	Bottom 1/3 of bank is generally highly resistant plant/soil matrix or material
	Channel cross-section is generally trapezoidally-shaped	Channel cross-section is generally trapezoidally-shaped	Channel cross-section is generally V- or U-shaped	Channel cross-section is generally V- or U-shaped
Point range	☐ 0 ☐ 1 ☒ 2	☐ 3 ☐ 4 ☐ 5	☐ 6 ☐ 7 ☐ 8	☐ 9 ☐ 10 ☐ 11

Channel Scouring/ Sediment Deposition	> 75% embedded (> 85% embedded for large mainstem areas)	50-75% embedded (60-85% embedded for large mainstem areas)	25-49% embedded (35-59% embedded for large mainstem areas)	Riffle embeddedness < 25% sand-silt (< 35% embedded for large mainstem areas)
	- Few, if any, deep pools - Pool substrate composition >81% sand-silt	- Low to moderate number of deep pools - Pool substrate composition 60-80% sand-silt	- Moderate number of deep pools - Pool substrate composition 30-59% sand-silt	- High number of deep pools (> 61 cm deep) (> 122 cm deep for large mainstem areas) - Pool substrate composition <30% sand-silt
	Streambed streak marks and/or "banana"-shaped sediment deposits common	Streambed streak marks and/or "banana"-shaped sediment deposits common	Streambed streak marks and/or "banana"-shaped sediment deposits uncommon	Streambed streak marks and/or "banana"-shaped sediment deposits absent
	- Fresh, large sand deposits very common in channel - Moderate to heavy sand deposition along major portion of overbank area	- Fresh, large sand deposits common in channel - Small localized areas of fresh sand deposits along top of low banks	- Fresh, large sand deposits uncommon in channel - Small localized areas of fresh sand deposits along top of low banks	- Fresh, large sand deposits rare or absent from channel - No evidence of fresh sediment deposition on overbank
	Point bars present at most stream bends, moderate to large and unstable with high amount of fresh sand	Point bars common, moderate to large and unstable with high amount of fresh sand	Point bars small and stable, well-vegetated and/or armoured with little or no fresh sand	Point bars few, small and stable, well-vegetated and/or armoured with little or no fresh sand
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☒ 4	☐ 5 ☐ 6	☐ 7 ☐ 8

Date:	Dec 4, 2018		Reach:	CC-1		Project Code:	18116	
Evaluation Category	Poor	Fair	Good	Excellent				
Physical Instream Habitat	Wetted perimeter < 40% of bottom channel width (< 45% for large mainstem areas)	Wetted perimeter 40-60% of bottom channel width (45-65% for large mainstem areas)	Wetted perimeter 61-85% of bottom channel width (66-90% for large mainstem areas)	Wetted perimeter > 85% of bottom channel width (> 90% for large mainstem areas)				
	Dominated by one habitat type (usually runs) and by one velocity and depth condition (slow and shallow) (for large mainstem areas, few riffles present, runs and pools dominant, velocity and depth diversity low)	- Few pools present, riffles and runs dominant. - Velocity and depth generally slow and shallow (for large mainstem areas, runs and pools dominant, velocity and depth diversity intermediate)	- Good mix between riffles, runs and pools - Relatively diverse velocity and depth of flow	- Riffles, runs and pool habitat present - Diverse velocity and depth of flow present (i.e., slow, fast, shallow and deep water)				
	- Riffle substrate composition: predominantly gravel with high amount of sand < 5% cobble	- Riffle substrate composition: predominantly small cobble, gravel and sand 5-24% cobble	- Riffle substrate composition: good mix of gravel, cobble, and rubble material 25-49% cobble	- Riffle substrate composition: cobble, gravel, rubble, boulder mix with little sand > 50% cobble				
	Riffle depth < 10 cm for large mainstem areas	Riffle depth 10-15 cm for large mainstem areas	Riffle depth 15-20 cm for large mainstem areas	Riffle depth > 20 cm for large mainstem areas				
	Large pools generally < 30 cm deep (< 61 cm for large mainstem areas) and devoid of overhead cover/structure	Large pools generally 30-46 cm deep (61-91 cm for large mainstem areas) with little or no overhead cover/structure	Large pools generally 46-61 cm deep (91-122 cm for large mainstem areas) with some overhead cover/structure	Large pools generally > 61 cm deep (> 122 cm for large mainstem areas) with good overhead cover/structure				
	Extensive channel alteration and/or point bar formation/enlargement	Moderate amount of channel alteration and/or moderate increase in point bar formation/enlargement	Slight amount of channel alteration and/or slight increase in point bar formation/enlargement	No channel alteration or significant point bar formation/enlargement				
	Riffle/Pool ratio 0.49:1 ; $\geq 1.51:1$	Riffle/Pool ratio 0.5-0.69:1 ; 1.31-1.5:1	Riffle/Pool ratio 0.7-0.89:1 ; 1.11-1.3:1	Riffle/Pool ratio 0.9-1.1:1				
	Summer afternoon water temperature > 27°C	Summer afternoon water temperature 24-27°C	Summer afternoon water temperature 20-24°C	Summer afternoon water temperature < 20°C				
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☐ 4	☒ 5 ☐ 6	☐ 7 ☐ 8				
Water Quality	Substrate fouling level: High (> 50%)	Substrate fouling level: Moderate (21-50%)	Substrate fouling level: Very light (11-20%)	Substrate fouling level: Rock underside (0-10%)				
	- Brown colour - TDS: > 150 mg/L	- Grey colour - TDS: 101-150 mg/L	- Slightly grey colour - TDS: 50-100 mg/L	- Clear flow - TDS: < 50 mg/L				
	Objects visible to depth < 0.15m below surface	Objects visible to depth 0.15-0.5m below surface	Objects visible to depth 0.5-1.0m below surface	Objects visible to depth > 1.0m below surface				
	Moderate to strong organic odour	Slight to moderate organic odour	Slight organic odour	No odour				
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☐ 4	☒ 5 ☐ 6	☐ 7 ☐ 8				
Riparian Habitat Conditions	Narrow riparian area of mostly non-woody vegetation	Riparian area predominantly wooded but with major localized gaps	Forested buffer generally > 31 m wide along major portion of both banks	Wide (> 60 m) mature forested buffer along both banks				
	Canopy coverage: < 50% shading (30% for large mainstem areas)	Canopy coverage: 50-60% shading (30-44% for large mainstem areas)	Canopy coverage: 60-79% shading (45-59% for large mainstem areas)	Canopy coverage: > 80% shading (> 60% for large mainstem areas)				
Point range	☐ 0 ☐ 1	☒ 2 ☐ 3	☐ 4 ☐ 5	☐ 6 ☐ 7				
Total overall score (0-42) = 18		Poor (<13)	Fair (13-24)	Good (25-34)		Excellent (>35)		

Completed by: BM Checked by: KA

Rapid Geomorphic Assessment

Project Code:

Date:	DEC 4, 2018	Stream/Reach:	CHILWIGO CREEK REACH CC-3
Weather:	0°C	Watershed/Subwatershed:	SPEED RIVER
Field Staff:	BM JT	Location:	CAMBRIDGE

Process	Geomorphological Indicator		Present?		Factor Value
	No.	Description	Yes	No	
Evidence of Aggradation (AI)	1	Lobate bar		✓	1/7
	2	Coarse materials in riffles embedded		✓	
	3	Siltation in pools		✓	
	4	Medial bars	✓		
	5	Accretion on point bars		✓	
	6	Poor longitudinal sorting of bed materials		✓	
	7	Deposition in the overbank zone		✓	
Sum of indices =			1	6	0.143

Evidence of Degradation (DI)	1	Exposed bridge footing(s)	✓		2/6
	2	Exposed sanitary / storm sewer / pipeline / etc.	—		
	3	Elevated storm sewer outfall(s)	—		
	4	Undermined gabion baskets / concrete aprons / etc.	—		
	5	Scour pools downstream of culverts / storm sewer outlets	—		
	6	Cut face on bar forms		✓	
	7	Head cutting due to knickpoint migration		✓	
	8	Terrace cut through older bar material		✓	
	9	Suspended armour layer visible in bank	✓		
	10	Channel worn into undisturbed overburden / bedrock		✓	
Sum of indices =			2	4	0.333

Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.	✓		3/7
	2	Occurrence of large organic debris	✓		
	3	Exposed tree roots	✓		
	4	Basal scour on inside meander bends		✓	
	5	Basal scour on both sides of channel through riffle		✓	
	6	Outflanked gabion baskets / concrete walls / etc.	—		
	7	Length of basal scour >50% through subject reach		✓	
	8	Exposed length of previously buried pipe / cable / etc.	—		
	9	Fracture lines along top of bank		✓	
	10	Exposed building foundation	—		
Sum of indices =			3	4	0.429

Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)	✓		5/7
	2	Single thread channel to multiple channel	✓		
	3	Evolution of pool-riffle form to low bed relief form		✓	
	4	Cut-off channel(s)	✓		
	5	Formation of island(s)	✓		
	6	Thalweg alignment out of phase with meander form		✓	
	7	Bar forms poorly formed / reworked / removed	✓		
Sum of indices =			5	2	0.714

Additional notes:		Stability Index (SI) = (AI+DI+WI+PI)/4 =			0.40
	Condition	In Regime	In Transition/Stress	In Adjustment	
SI score =		☐ 0.00 - 0.20	☒ 0.21 - 0.40	☐ 0.41	

Completed by: BM Checked by: KT

Rapid Stream Assessment Technique

Project Code: 18116

Date:	DEC 4, 2018	Stream/Reach:	CHILLIGO CREEK REACH CC-3
Weather:	0°C SUNNY	Location:	SPEED RIVER
Field Staff:	BM JT	Watershed/Subwatershed:	CAMBRIDGE

Evaluation Category	Poor	Fair	Good	Excellent
Channel Stability	< 50% of bank network stable - Recent bank sloughing, slumping or failure frequently observed	50-70% of bank network stable - Recent signs of bank sloughing, slumping or failure fairly common	71-80% of bank network stable - Infrequent signs of bank sloughing, slumping or failure	> 80% of bank network stable - No evidence of bank sloughing, slumping or failure
	- Stream bend areas highly unstable - Outer bank height 1.2 m above stream bank (2.1 m above stream bank for large mainstem areas) - Bank overhang > 0.8-1.0 m	- Stream bend areas stable - Outer bank height 0.9-1.2 m above stream bank (1.5-2.1 m above stream bank for large mainstem areas) - Bank overhang 0.8-0.9m	- Stream bend areas stable - Outer bank height 0.6-0.9 m above stream bank (1.2-1.5 m above stream bank for large mainstem areas) - Bank overhang 0.6-0.8 m	- Stream bend areas very stable - Height < 0.6 m above stream (< 1.2 m above stream bank for large mainstem areas) - Bank overhang < 0.6 m
	- Young exposed tree roots abundant > 6 recent large tree falls per stream mile	- Young exposed tree roots common 4-5 recent large tree falls per stream mile	- Exposed tree roots predominantly old and large, smaller young roots scarce 2-3 recent large tree falls per stream mile	- Exposed tree roots old, large and woody - Generally 0-1 recent large tree falls per stream mile
	- Bottom 1/3 of bank is highly erodible material - Plant/soil matrix severely compromised	- Bottom 1/3 of bank is generally highly erodible material - Plant/soil matrix compromised	Bottom 1/3 of bank is generally highly resistant plant/soil matrix or material	Bottom 1/3 of bank is generally highly resistant plant/soil matrix or material
	Channel cross-section is generally trapezoidally-shaped	Channel cross-section is generally trapezoidally-shaped	Channel cross-section is generally V- or U-shaped	Channel cross-section is generally V- or U-shaped
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☒ 4 ☐ 5	☐ 6 ☐ 7 ☐ 8	☐ 9 ☐ 10 ☐ 11

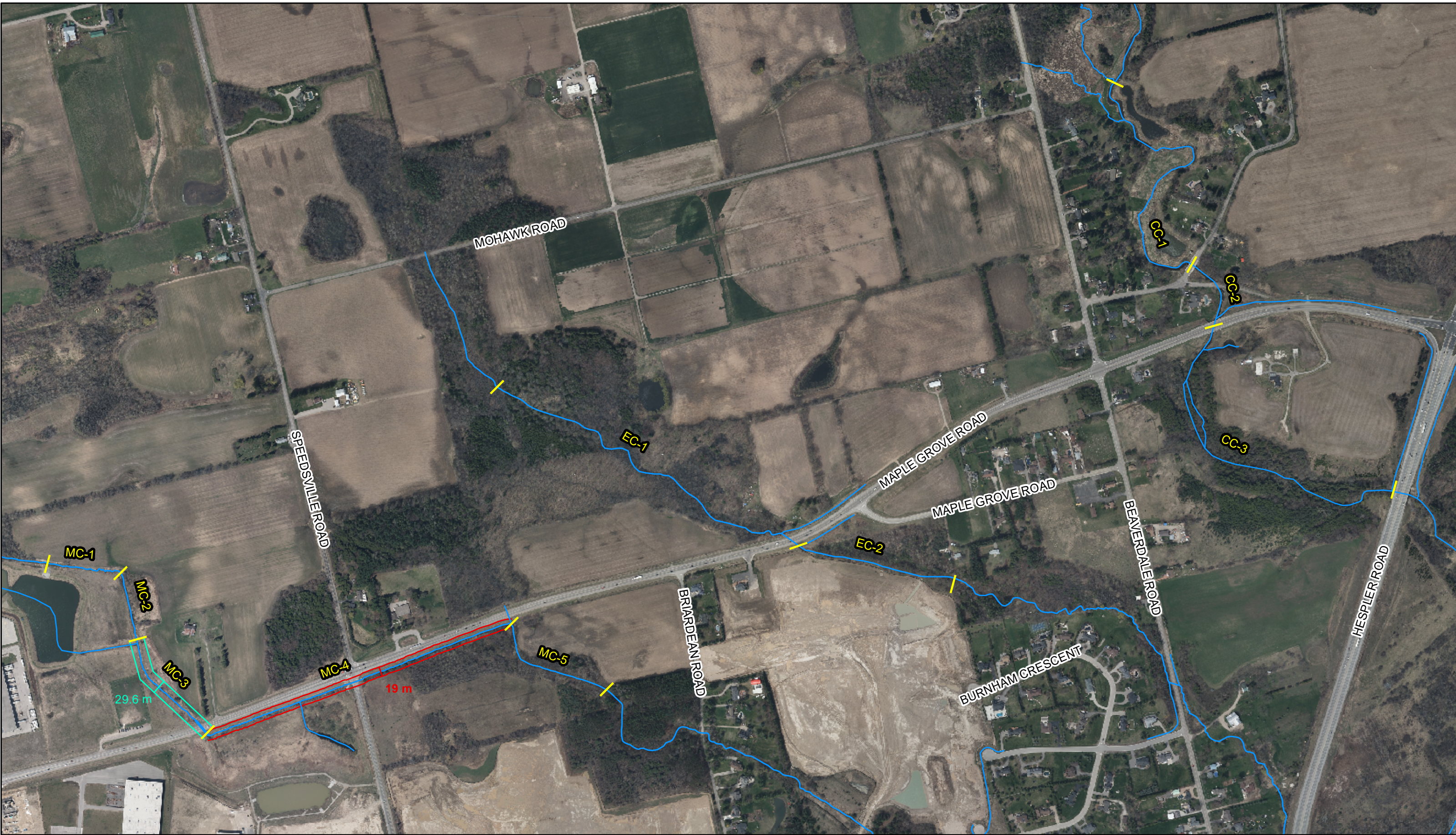
Channel Scouring/ Sediment Deposition	> 75% embedded (> 85% embedded for large mainstem areas)	50-75% embedded (60-85% embedded for large mainstem areas)	25-49% embedded (35-59% embedded for large mainstem areas)	Riffle embeddedness < 25% sand-silt (< 35% embedded for large mainstem areas)
	- Few, if any, deep pools - Pool substrate composition >81% sand-silt	- Low to moderate number of deep pools - Pool substrate composition 60-80% sand-silt	- Moderate number of deep pools - Pool substrate composition 30-59% sand-silt	- High number of deep pools (> 61 cm deep) (> 122 cm deep for large mainstem areas) - Pool substrate composition <30% sand-silt
	Streambed streak marks and/or "banana"-shaped sediment deposits common	Streambed streak marks and/or "banana"-shaped sediment deposits common	Streambed streak marks and/or "banana"-shaped sediment deposits uncommon	Streambed streak marks and/or "banana"-shaped sediment deposits absent
	- Fresh, large sand deposits very common in channel - Moderate to heavy sand deposition along major portion of overbank area	- Fresh, large sand deposits common in channel - Small localized areas of fresh sand deposits along top of low banks	- Fresh, large sand deposits uncommon in channel - Small localized areas of fresh sand deposits along top of low banks	- Fresh, large sand deposits rare or absent from channel - No evidence of fresh sediment deposition on overbank
	Point bars present at most stream bends, moderate to large and unstable with high amount of fresh sand	Point bars common, moderate to large and unstable with high amount of fresh sand	Point bars small and stable, well-vegetated and/or armoured with little or no fresh sand	Point bars few, small and stable, well-vegetated and/or armoured with little or no fresh sand
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☒ 4	☐ 5 ☐ 6	☐ 7 ☐ 8

Date:	DEC. 4, 2018		Reach:	CC-3		Project Code:	18116	
Evaluation Category	Poor	Fair	Good	Excellent				
Physical Instream Habitat	Wetted perimeter < 40% of bottom channel width (< 45% for large mainstem areas)	Wetted perimeter 40-60% of bottom channel width (45-65% for large mainstem areas)	Wetted perimeter 61-85% of bottom channel width (66-90% for large mainstem areas)	Wetted perimeter > 85% of bottom channel width (> 90% for large mainstem areas)				
	Dominated by one habitat type (usually runs) and by one velocity and depth condition (slow and shallow) (for large mainstem areas, few riffles present, runs and pools dominant, velocity and depth diversity low)	- Few pools present, riffles and runs dominant - Velocity and depth generally slow and shallow (for large mainstem areas, runs and pools dominant, velocity and depth diversity intermediate)	- Good mix between riffles, runs and pools - Relatively diverse velocity and depth of flow	- Riffles, runs and pool habitat present - Diverse velocity and depth of flow present (i.e., slow, fast, shallow and deep water)				
	- Riffle substrate composition: predominantly gravel with high amount of sand < 5% cobble	- Riffle substrate composition: predominantly small cobble, gravel and sand 5-24% cobble	- Riffle substrate composition: good mix of gravel, cobble, and rubble material 25-49% cobble	- Riffle substrate composition: cobble, gravel, rubble, boulder mix with little sand > 50% cobble				
	Riffle depth < 10 cm for large mainstem areas	Riffle depth 10-15 cm for large mainstem areas	Riffle depth 15-20 cm for large mainstem areas	Riffle depth > 20 cm for large mainstem areas				
	Large pools generally < 30 cm deep (< 61 cm for large mainstem areas) and devoid of overhead cover/structure	Large pools generally 30-46 cm deep (61-91 cm for large mainstem areas) with little or no overhead cover/structure	Large pools generally 46-61 cm deep (91-122 cm for large mainstem areas) with some overhead cover/structure	Large pools generally > 61 cm deep (> 122 cm for large mainstem areas) with good overhead cover/structure				
	Extensive channel alteration and/or point bar formation/enlargement	Moderate amount of channel alteration and/or moderate increase in point bar formation/enlargement	Slight amount of channel alteration and/or slight increase in point bar formation/enlargement	No channel alteration or significant point bar formation/enlargement				
	Riffle/Pool ratio 0.49:1 ; $\geq 1.51:1$	Riffle/Pool ratio 0.5-0.69:1 ; 1.31-1.5:1	Riffle/Pool ratio 0.7-0.89:1 ; 1.11-1.3:1	Riffle/Pool ratio 0.9-1.1:1				
	Summer afternoon water temperature > 27°C	Summer afternoon water temperature 24-27°C	Summer afternoon water temperature 20-24°C	Summer afternoon water temperature < 20°C				
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☐ 4	☒ 5 ☐ 6	☐ 7 ☐ 8				
Water Quality	Substrate fouling level: High (> 50%)	Substrate fouling level: Moderate (21-50%)	Substrate fouling level: Very light (11-20%)	Substrate fouling level: Rock underside (0-10%)				
	- Brown colour - TDS: > 150 mg/L	- Grey colour - TDS: 101-150 mg/L	- Slightly grey colour - TDS: 50-100 mg/L	- Clear flow - TDS: < 50 mg/L				
	Objects visible to depth < 0.15m below surface	Objects visible to depth 0.15-0.5m below surface	Objects visible to depth 0.5-1.0m below surface	Objects visible to depth > 1.0m below surface				
	Moderate to strong organic odour	Slight to moderate organic odour	Slight organic odour	No odour				
Point range	☐ 0 ☐ 1 ☐ 2	☐ 3 ☐ 4	☒ 5 ☐ 6	☐ 7 ☐ 8				
Riparian Habitat Conditions	Narrow riparian area of mostly non-woody vegetation	Riparian area predominantly wooded but with major localized gaps	Forested buffer generally > 31 m wide along major portion of both banks	Wide (> 60 m) mature forested buffer along both banks				
	Canopy coverage: < 50% shading (30% for large mainstem areas)	Canopy coverage: 50-60% shading (30-44% for large mainstem areas)	Canopy coverage: 60-79% shading (45-59% for large mainstem areas)	Canopy coverage: > 80% shading (> 60% for large mainstem areas)				
Point range	☐ 0 ☐ 1	☐ 2 ☐ 3	☐ 4 ☒ 5	☐ 6 ☐ 7				
Total overall score (0-42) = 23		Poor (<13)	Fair (13-24)	Good (25-34)		Excellent (>35)		

Completed by: BM Checked by: KT



Appendix C: Meander Belt Width and Toe Erosion Allowance



Legend

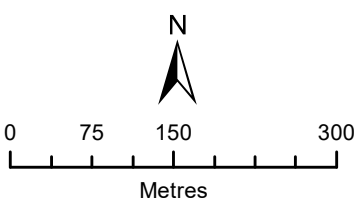
Reach Break and ID

Toe Erosion Allowance

Watercourse

Meander Belt Width

Middle Creek, East Creek, and Chilligo Creek
Meander Belt Width and Toe Erosion Allowance
Cambridge, Ontario



GEO

MORPHIX

Orthoimagery: City of Cambridge, 2017.
Reach Break and ID and Meander Belt Width and
Toe Erosion Allowance: GEO Morphix Ltd., 2019.
Watercourse: City of Cambridge, 2018.
Print Date: September 2019. PN18116. Drawn By: W.B., K.T.