APPENDIX E-4

Fluvial Geomorphology

Fluvial Geomorphological Assessment,
GEO Morphix Limited, June 28, 2020

Joshua's Creek Environmental Implementation Report (EIR) Addendum
1086 Burnhamthorpe Road East
Town of Oakville, Ontario

Fluvial Geomorphological Assessment

Prepared for:
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June 28, 2020
Project No. 17051

GEO MORPHIX
Geomorphology
Earth Science
Observations

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1 Introduction

GEO Morphix Ltd. was retained to complete a fluvial geomorphological assessment in support of a scoped Environmental Impact Report (EIR) for the property located at 1086 Burnhamthorpe Road East in the Town of Oakville, located between Trafalgar Road and Ninth Line (**Figure 1**). A tributary of Joshua's Creek flows through the northern portion of subject lands in a generally west to east orientation prior to joining the main channel approximately 1.3 km to the southeast, adjacent to the Glen Oaks Funeral Home and Cemetery.

The activities listed below were completed in support of the geomorphological assessment:

- Review available background reports and mapping (e.g., soils, physiography, geology, and topography)
- Complete a historical assessment using aerial photographs to identify changes to the system due to land use and past channel modifications
- Verify or refine meander belt widths for the tributary of Joshua's Creek determined through the North Oakville Creeks Subwatershed Study (NOCSS)
- Conduct rapid geomorphological field assessments for the tributary to document channel conditions and verify the results of our desktop assessment

Figure 1: Location of subject lands

2 Background Review

2.1 North Oakville Creeks Subwatershed Study

The North Oakville Subwatershed Study (NOCSS; TSH et al., 2006) was prepared in support of the Secondary Plan for the North Oakville Development Area in the Town of Oakville. The intent of the study was to provide a management strategy to assist with policy direction for future development within the watershed. A fluvial geomorphological study was carried out as part of NOCSS, and included reach delineation, a historical assessment, rapid geomorphological assessments, and detailed geomorphological assessments on select reaches determined to be sensitive or representative of the watershed and channel form. Meander belt widths were calculated using digital and topographic mapping. **Reach JC-7**, a portion of which is located within the subject lands, was assigned a Rapid Geomorphic Assessment (RGA; MOE, 2003) score of 0.11 (in regime) and a Rapid Stream Assessment Technique (RSAT) score of 22 (moderate or fair). A meander belt width of 20 m was delineated for **Reach JC-7**.

Reach JC-7 was assigned medium constraint ranking, meaning the reach is to be maintained as an open watercourse with a riparian corridor (meander belt width, erosion allowance and setback) but is permitted to be altered. Management options for medium constraint streams from a geomorphic perspective included do nothing (develop outside of its boundary), enhance existing conditions (maintain and enhance in-situ), or re-locate and enhance the corridor through approaches that may include the re-establishment of a meandering planform, functioning floodplain, and riffle-pool morphology. Based on the proposed development plan, this tributary will remain in situ.

2.2 Environmental Implementation Report/Functional Servicing Study (EIR/FSS) for Joshua's Creek Tributaries and the Mattamy Lands

The EIR/Functional Servicing Study for the Mattamy lands located to the immediate east was reviewed to provide additional context. This study was led by Stonybrook Consulting Inc. and was finalized in August 2019. The EIR included a historical assessment, watercourse characterization, erosion hazard delineation and an erosion mitigation assessment in support of the stormwater management strategy. The portion of **Reach JC-7** downstream of the subject lands was assigned an RGA score of 0.14 (in regime).

The portion of **Reach JC-7** within the EIR/FSS study area is to be retained with applicable buffers and setbacks. The stream corridor width was defined along a portion of **Reach JC-7** based on fluvial geomorphological requirements and a number of other environmental and geotechnical considerations. Although a number of reaches of Joshua's Creek east of the subject lands were either fully or partially confined, all reaches were treated as unconfined as it provided a conservative approach for meander belt width delineation. Meander belt widths were determined using aerial photographs and an empirical model (modified from the Williams, 1986 width method). For the portion of **Reach JC-7** downstream of the subject lands, results of the two approaches were compared, and the empirical approach was selected as this provided a more conservative value of 26 m. This meander belt width is examined further in the current study in support of delineating development constraints on the subject lands.

3 Site History

A high-level historical assessment was completed as part of the NOCSS 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, as well as the basis for understanding the potential future changes to the channel. To supplement this analysis with a more detailed assessment, aerial photographs from 1954 (scale 1:15,840) and 1978 (Scale :10,000) from the Ministry of Natural Resources and Forestry (MNRF) and recent satellite imagery from Google Earth Pro (2005 and 2018) were reviewed to complete the historical assessment. Refer to **Appendix A** for copies of the imagery.

In 1954, land use in vicinity of the subject lands consisted of predominantly agriculture and rural residences, with hedgerows and isolated woodlots. Significant lengths of channel within and upstream of the subject lands had been straightened and lacked natural riparian vegetation. This likely created channels with limited morphology and caused increased sediment inputs in the spring and during significant precipitation events. The eastern driveway crossing was present, although no ponding was apparent in the image. Construction of the offline pond within the existing homestead was underway by 1954, but did not appear to contain open water. Natural meanders were visible along the reach downstream of the subject lands.

There was limited change in land use between 1954 and 1978. An additional residence, driveway, and crossing were present west (upstream) of the subject lands in 1978. Woody vegetation had been installed around the periphery of the offline pond, which likely also provided shade to the adjacent tributary. Limited ponding was apparent downstream of the eastern driveway crossing. The tributary corridor downstream of the subject lands had begun to naturalize with several small trees/shrubs apparent in the 1978 imagery.

By 2005, the western driveway had been decommissioned. In addition, the pond feature downstream of the eastern driveway was visible. By 2009, the pond downstream of the crossing had expanded to the south. Upstream of the subject lands, the tributary was still maintained as a channelized feature. However, natural riparian vegetation had further expanded along the corridor downstream of the subject lands. This likely significantly improved instream temperatures, channel stability and aquatic and terrestrial habitat conditions downstream of the subject lands when compared to the 1954 imagery. Between 2014 and 2015, the existing western access road and tributary crossing had been constructed and the pond upstream of the eastern driveway crossing was clearly visible.

4 Watercourse Characteristics

4.1 Physiography and Geology

Channel planform and morphology are largely governed by the flow regime and by the type and availability of sediment (i.e., surficial geology) within the stream corridor. Physiography, riparian vegetation, and land use will also influence the channel. These factors provide insight to existing conditions and future potential changes as they relate to a proposed activity. The subject lands are located within the South Slope Physiographic Region, located between the Lake Iroquois Shoreline and the Peel Plain (Chapman and Putnam, 1984). Specifically, the subject lands are located within the till moraine physiographic landform, while areas north of Highway 407 are located within the bevelled till plains physiographic landform (Chapman and Putnam, 2007). The Trafalgar Moraine is located north of Burnhamthorpe Road East (TSH et al., 2006).

Bedrock geology is comprised of red shale of the Queenston Formation. The bedrock is uniform in character with a surface that is flat to gently undulating with a southeastward slope (TSH, et al., 2006). With the exception of the Sixteen Mile Creek valley corridor, no bedrock outcrops are mapped within the study area. However, field reconnaissance completed as part of NOCSS (TSH et al., 2006) observed bedrock outcrops within the Joshua's Creek Valley between Dundas Street and Burnhamthorpe Road where the watercourse had downcut through a localized bedrock high. No bedrock outcrops were observed within the subject lands by GEO Morphix Ltd.

Published mapping indicates that local surficial geology consists of Halton Till (clay to silt textured) with low permeability (OGS, 2010 and TSH et al., 2006). Sand lenses are sometimes encountered but tend to be limited in extent and thickness (TSH et al., 2006). The till ranges in thickness from less than 5 m in areas south of Burnhamthorpe Road to more than 19 m thick along the rest of the Trafalgar Moraine north of the subject lands. The upper few meters are often fractured and weathered. Areas of alluvium are mapped along tributaries of Joshua's Creek east (downstream) of the study area (OGS, 2010).

4.2 Reach Delineation

Reaches are homogeneous segments of channel used in geomorphological investigations. Reaches are studied semi-independently as each is expected to function in a manner that is at least slightly different from adjoining reaches. This method allows for a meaningful characterization of a watercourse as the aggregate of reaches, or an understanding of a reach, for example, as it relates to a proposed activity. Reaches are typically delineated based on changes in the following:

- Channel planform
- Channel gradient
- Physiography
- Land cover (land use or vegetation)
- Flow, due to tributary inputs
- Soil type and surficial geology
- Historical channel modifications

This follows scientifically-defensible methodology proposed by Montgomery and Buffington (1997), Richards et al. (1997), and the Toronto and Region Conservation Authority (2004). Reaches were delineated as part of the NOCSS (TSH et al., 2006). The reach breaks were refined within the property by GEO Morphix Ltd. during field work conducted in July 2017 (**Appendix B**). For this study, **Reach JC-7** was subdivided into two reaches (**JC-7a** and **JC-7b**), with only **Reach JC-7a** assessed within the subject lands due to private property to the west.

4.3 General Reach Observations

Field investigations were completed on July 7, 2017 and included the following:

- Habitat sketch maps based on Newson and Newson (2000) outlining channel substrate, flow patterns, geomorphological units (e.g., riffle, run, pool), and riparian vegetation for the extent of each reach assessed
- Descriptions of riparian conditions
- Estimates of bankfull channel dimensions
- Bed and bank material composition and structure
- Observations of erosion, scour or deposition
- Collection of photographs to document the watercourses, riparian areas and/or valley, surrounding land use, and channel disturbances such as crossing structures

These observations and measurements are summarized below. The descriptions are supplemented and supported with representative photographs, which are included in **Appendix C**. Field sheets, including reach summaries, habitat sketch maps and rapid assessments, are provided in **Appendix D**.

Reach JC-7 was characterized as having an intermittent flow regime and was situated within a confined valley. There was limited flow at the time of the assessment. Adjacent land uses consisted of predominantly agriculture and rural residences. The reach contained a poorly defined channel with significant vegetation encroachment. The riparian buffer was approximately 4-10 channel widths but was fragmented by manicured lawn / landscaped vegetation. Bankfull width and depth were variable, ranging from 0.5 m to 1.55 m, and 0.2 to 0.53 m, respectively. While scattered cobbles were present near the downstream extent of the reach, channel substrate consisted of clay and silt and the channel banks consisted of clay, silt, sand and gravel.

Reach JC-7a was also confined and was characterized as having an intermittent flow regime. This reach extended from the online pond near the eastern driveway crossing to approximately 50 m upstream of the subject lands. Riparian vegetation largely consisted of grasses, manicured lawn and isolated trees downstream of the eastern driveway, and landscaped trees and manicured lawn upstream of the eastern driveway. A relatively narrow, straight channel was present upstream of the online pond, and contained a series of rock weirs. An offline pond was present north of the channel, separated from the reach by an earthen berm. No direct connection between the offline pond and **Reach JC-7a** was observed during the field assessment, although an overflow pathway was apparent near the downstream extent of the pond. The culvert at the western (upstream) driveway crossing was slightly perched, with a shallow pool of standing water downstream of the crossing at the time of the assessment. Riffles and pools were absent and bankfull channel width and depth were approximately 0.6 and 0.2, respectively. Both channel substrate and bank material consisted of clay and silt.

4.4 Reconnaissance-level Assessments

Channel stability was semi-quantified through the application of the MOE (2003) 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). The RGA for **Reach JC-7** resulted in a score of 0, indicating that the portion of reach assessed was in regime. We note that this value is lower than that determined for the EIR/FSS for lands to the east (Stonybrook Consulting Inc. et al., August 2019); however, the portion of **Reach JC-7** assessed as part of that study was also evaluated as in regime based on the RGA score (0.14). The RGA score of 0 reflects conditions along the portion of **Reach JC-7** within the subject lands. The RGA for **Reach JC-7a** also resulted in a score of 0, indicating that the reach was in regime.

The Rapid Stream Assessment Technique (RSAT) is typically employed to provide a broader view of the system and considers the ecological function of the watercourse (Galli, 1996). Observations of channel stability, channel scouring or sediment deposition, instream and riparian habitats, and water quality are recorded as part of the assessment to provide an overall score that ranks the channel as maintaining a poor (<13), fair (13-24), good (25-34), or excellent (35-42) degree of stream health. The RSAT was not applied to either reach assessed within the subject lands as they displayed limited channel form (i.e. no riffle and pools present) and there was limited flow at the time of the assessment.

The portions of **Reaches JC-7** and **JC-7a** within the subject lands were classified as S- Stable according to a modified Downs (1995) Channel Evolution Model. The Downs Model 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.

5 Meander Belt Width Delineation

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 meandering channel has historically occupied and will likely occupy in the future. This assessment is therefore useful for determining the potential limit of development for proposed activities in the vicinity of a stream.

When defining the meander belt width for a creek system, the TRCA (2004) protocol treats unconfined and confined systems differently. Unconfined systems are those with poorly defined valleys or slopes well-outside where the channel could realistically migrate. In unconfined systems, the meander belt boundaries centre along the general valley orientation and are defined as parallel lines drawn tangentially to the outside bends of the most laterally extreme meanders within the reach (TRCA, 2004). Georeferenced historic aerial imagery can be used to examine past positions and configurations of the channel planform and to delineate the channel centreline, and its central tendency (i.e. meander belt axis). Confined systems are those where the watercourse is contained within a defined valley, where valley wall contact is possible. When a channel is confined, erosion of the valley wall needs to be considered. This is usually addressed with an erosion setback based on a geotechnically stable top of slope.

As noted in **Section 2.2**, a meander belt width was delineated for a portion of **Reach JC-7** as part of the EIR/FSS completed for the property immediately to the east of the subject lands (Stonybrook Consulting Inc. et al., 2019). Although several reaches within adjacent lands were characterized as confined or partially confined, all reaches in that study were treated as unconfined as this provides a more conservative estimate of the hazard. In accordance with the NOCSS (TSH et al., 2006), the meander belt widths were determined using a combination of historical aerial photographs and empirical models. The largest meander amplitude measured for Reach **JC-7** over the period of record (1954, 1978, and 2016) was 15.1 m. This measurement included the bankfull width of the channel. A 20% factor of safety was then applied.

Meander belt widths were also calculated using a modified Williams (1986) model, which is based on the largest channel bankfull measurement. The most conservative documented estimate of bankfull width (3.6 m) was used for the model based on values provided by Stonybrook Consulting Inc. et al. (2019). The empirical relation is outlined below:

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

where B_w is meander belt width (m) and W_b is bankfull channel width (m). An additional 20% buffer, or factor of safety, was applied to the computed belt width. The two approaches were compared and the largest or most conservative was chosen for the proposed meander belt width. For the portion of **Reach JC-7**, a meander belt width of 26 m was delineated.

Because **Reach JC-7** has been further divided into subreaches (**JC-7a** and **JC-7b**) as part of the current study, refinement of the meander belt width is required for Reach **JC-7a** within the subject lands. As this reach was previously modified, the empirical approach consistent with that used for lands to the east was employed. The bankfull width measured for **Reach JC-7a** was 0.6 m, resulting in a nominal meander belt width of 4 m. Therefore, as a conservative approach, the maximum bankfull width (1.55 m) measured within the subject lands along the downstream

section of Reach JC-7 was used. Following Eq.1 above, this results in a meander belt width of 10 m (**Appendix E**). It should be noted that due to the high degree of channel stability observed in the field and intermittent flow conditions, there is limited potential for channel migration and an erosion hazard along **Reach JC-7a**.

A portion of Reach **JC-8** located on adjacent lands abuts the western property boundary of the subject lands. Due to site access, **JC-8** was not assessed in the field. However, the current site plan for the subject lands accommodates the required 100 m wide linkage preserve area associated with this feature. Based on our desktop review and available reporting, **Reach JC-8** consists of a poorly defined swale flowing through an agricultural field and as such has limited migration potential. The 100 m wide linkage preserve area and currently proposed site plan for the subject lands can easily accommodate any erosion hazard associated with **Reach JC-8**. The meander belt width for Reach **JC-8** on adjacent lands to the west can be further evaluated as part of any future studies required in support of development.

6 Crossing Recommendations

The proposed development fabric includes a single crossing of **Reach JC-7a** on adjacent lands to the west, where a future access to the development is proposed from Burnhamthorpe Road East. TRCA (2015) and CVC (2015) have developed crossing guidelines to address natural hazards and the maintenance of channel form and function. The following crossing recommendations are provided from a geomorphological perspective and are subject to refinement as part of future studies and site-specific field work on adjacent lands.

TRCA recommends that crossing structures span the meander belt width, where feasible, or, at minimum, the 100-year erosion limit to avoid the migration of the channel into the crossing structure within the next 100 years. The TRCA guidelines also allow smaller crossing structures that accommodate relatively small, stable watercourses provided that they consider physical channel characteristics (e.g., alignment, width and depth) and fluvial processes (e.g., erosion and scour).

CVC (2015) highlights several recommendations from a geomorphological perspective:

- Where possible, the crossing structure design should avoid the need for channel armouring or adjustment
- Where feasible, the crossing structure should have a span that accommodates the channel's 100-year erosion limit or a lesser planning horizon determined through consultation with CVC
- The crossing should be at minimum three times the bankfull channel width for channels less than 4 m wide.
- The crossing should ensure that sediment transport processes and flow velocities are not impacted during frequent storm events

A crossing structure that spans the meander belt width is not warranted due to the lack of channel erosion or migration observed in the field. Following CVC guidelines, a culvert span of 1.8 m is recommended to address the minimum requirement of three times the bankfull channel width (0.6 m; CVC, 2015). However, a smaller opening may be appropriate given the stability of the channel and proper stabilization at the inlet and outlet.

The following additional recommendations are provided based on existing conditions, TRCA (2015) and CVC (2015) crossing guidelines, and standard best management practices:

- The inclusion of a low-flow channel is recommended to maintain or enhance flow characteristics and sediment conveyance through the culvert
- The proposed crossing structure design should minimize the degree and duration of inwater works to the extent possible
- The crossing structure should be an open-bottom culvert or embedded a minimum of 0.3 m, as appropriate; however, in this case, a closed bottom culvert would be acceptable provided there is no impact on channel form or function
- Natural substrate (e.g., riverstone) should be used to reconstruct the bed, where feasible
- Any inwater works should be conducted in the dry during the appropriate inwater timing window

The above recommendations do not consider minimum culvert flow conveyance requirements to address upstream flooding or road overtopping concerns.

7 Summary

A fluvial geomorphological was completed for Joshua's Creek within the subject lands, located at 1086 Burnhamthorpe Road East in the Town of Oakville. This investigation included a review of previously completed reports and secondary source information, a review of site history, refinement of previously defined reach breaks, meander belt width delineation, rapid field reconnaissance, and crossing recommendations to be considered during future design stages. **Reach JC-7**, delineated as part of the NOCSS (TSH et al., 2006), was subdivided into Reaches **JC-7**, **JC-7a** and **JC-7b** for the purposes of this study due to historical channel modifications and adjacent land uses. The portions of Reaches **JC-7** and **JC-7a** within the subject lands were evaluated to be stable, with both reaches having RGA scores of 0 (in regime).

A conservative meander belt width of 26 m was delineated for a portion of **Reach JC-7** as part of the EIR/FSS completed for the property east of the subject lands (Stonybrook Consulting Inc. et al., 2019). As **Reach JC-7** was divided into subreaches as part of the current study, the meander belt width for Reach **JC-7a** was refined. To maintain consistency with previous work an empirical approach was employed, whereby the maximum bankfull width (1.55 m) within the subject lands along **Reach JC-7** was used, resulting in a meander belt width of 10 m. Due to the high degree channel stability observed in the field and intermittent flow conditions, there is limited potential for channel migration and an erosion hazard along **Reach JC-7a**. This meander belt width is fully accommodated within the 100 m wide Linkage Preserve Area (LPA) associated with this corridor.

A portion of Reach **JC-8,** located on adjacent property, abuts the western boundary of the subject lands. This reach was not assessed in the field due to site access limitations. Importantly, the current site plan for the subject lands accommodates the required 100 m wide LPA associated with **Reach JC-8**. Based on our desktop review and available reporting, this reach consists of a poorly defined swale flowing through an agricultural field and as such, has limited migration potential. The 100 m wide linkage preserve area and currently proposed site plan for the subject lands can easily accommodate any erosion hazard associated with **Reach JC-8**. The meander belt width for Reach **JC-8** on adjacent lands to the west can be further evaluated as part of any future studies required in support of development.

The proposed development fabric includes a single crossing of **Reach JC-7a** on adjacent lands to the west, where a future access to the development is proposed from Burnhamthorpe Road East. Following CVC (2015) guidelines, a culvert span of 1.8 m is recommended from a fluvial

geomorphological perspective to address the minimum requirement of three times the bankfull channel width (0.6 m; CVC, 2015). However, a smaller opening may be appropriate given the stability of the channel and proper stabilization at the inlet and outlet. The recommended crossing span should be verified and/or refined, as required, as part of future studies and site-specific field work on adjacent lands.

Should you have any questions please contact the undersigned.

Respectfully submitted,

Paul Villard Ph.D., P.Geo., CAN-CISEC, EP, CERP
Director, Principal Geomorphologist

Suzanne St. Onge, M.Sc.
Senior Environmental Scientist

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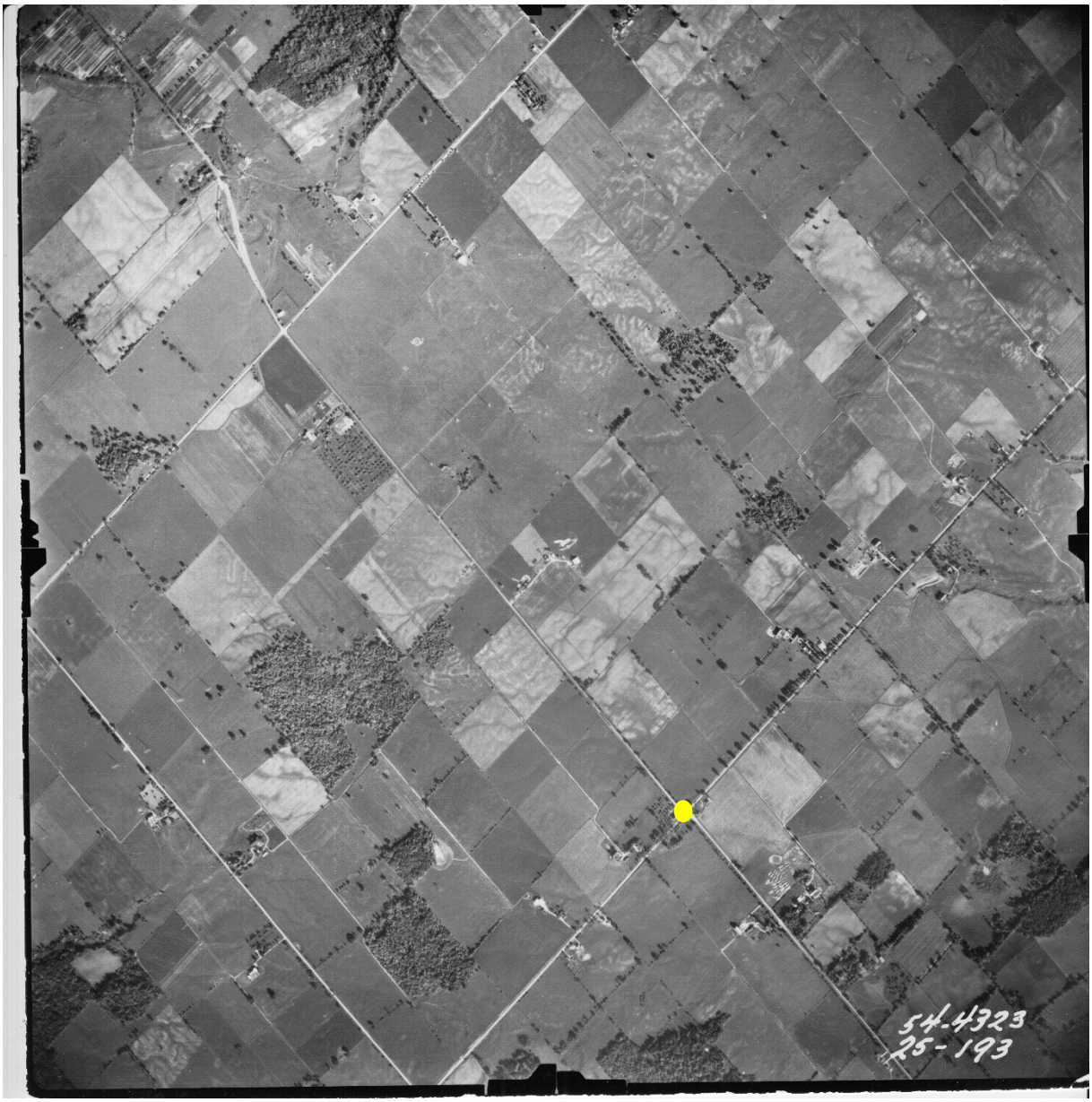
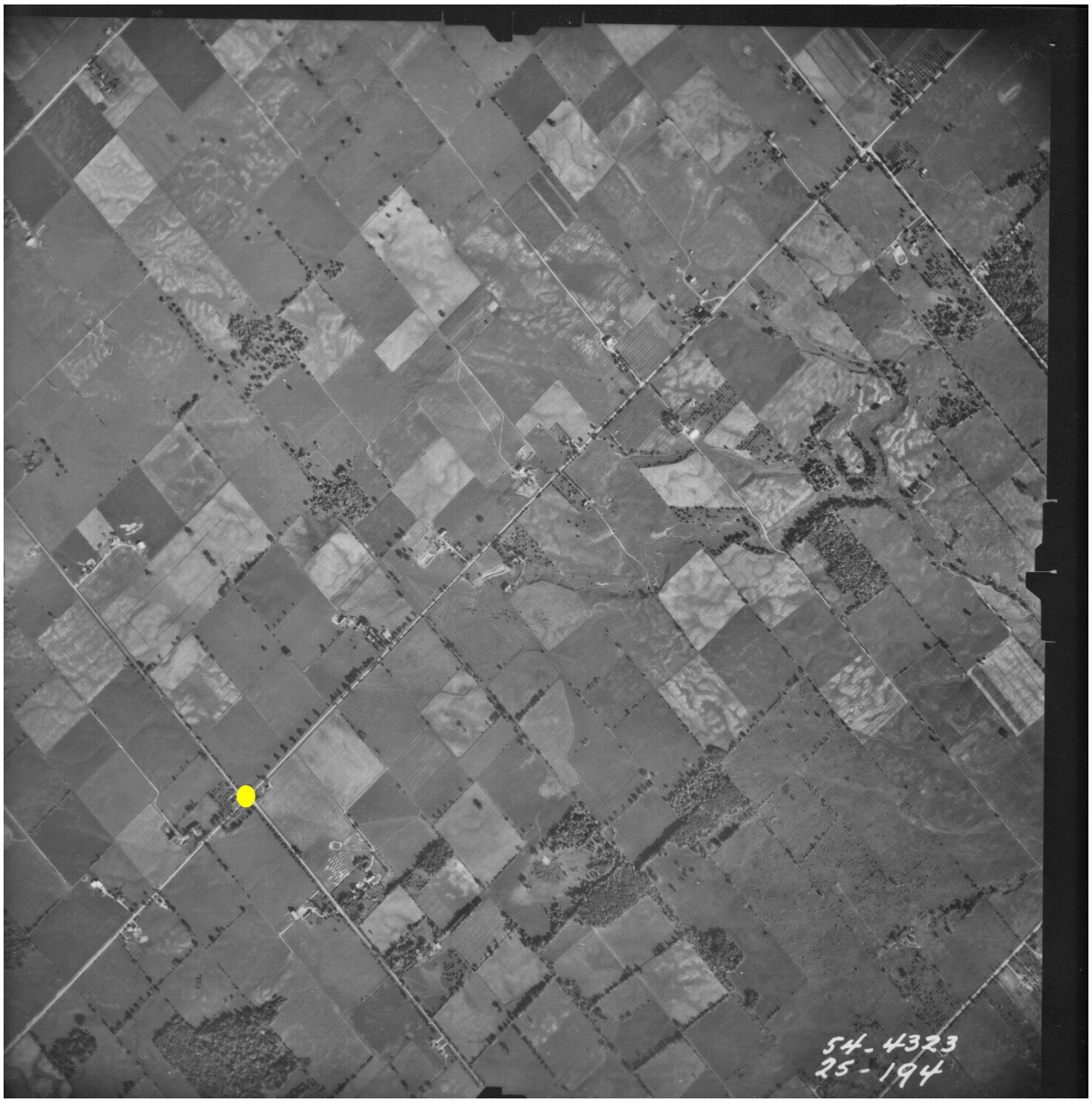
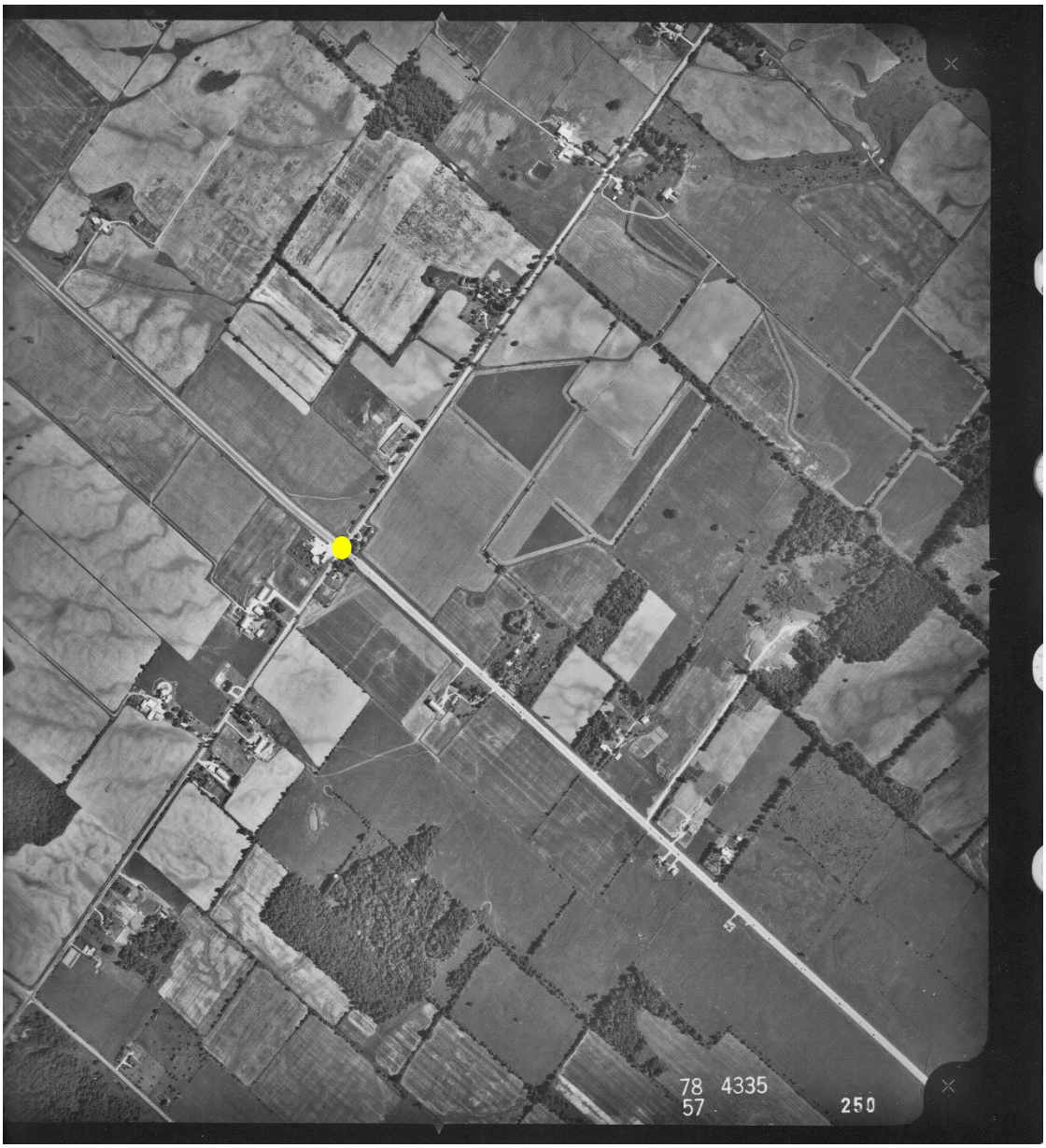
Appendix A
Historical Aerial Imagery



Location: Burnhamthorpe Road East and Trafalgar Road, Oakville (yellow dot)
Year: 1954
Scale: 1:15,840
Source: Ministry of Natural Resources and Forestry



Location: Burnhamthorpe Road East and Trafalgar Road, Oakville (yellow dot)
Year: 1954
Scale: 1:15,840
Source: Ministry of Natural Resources and Forestry

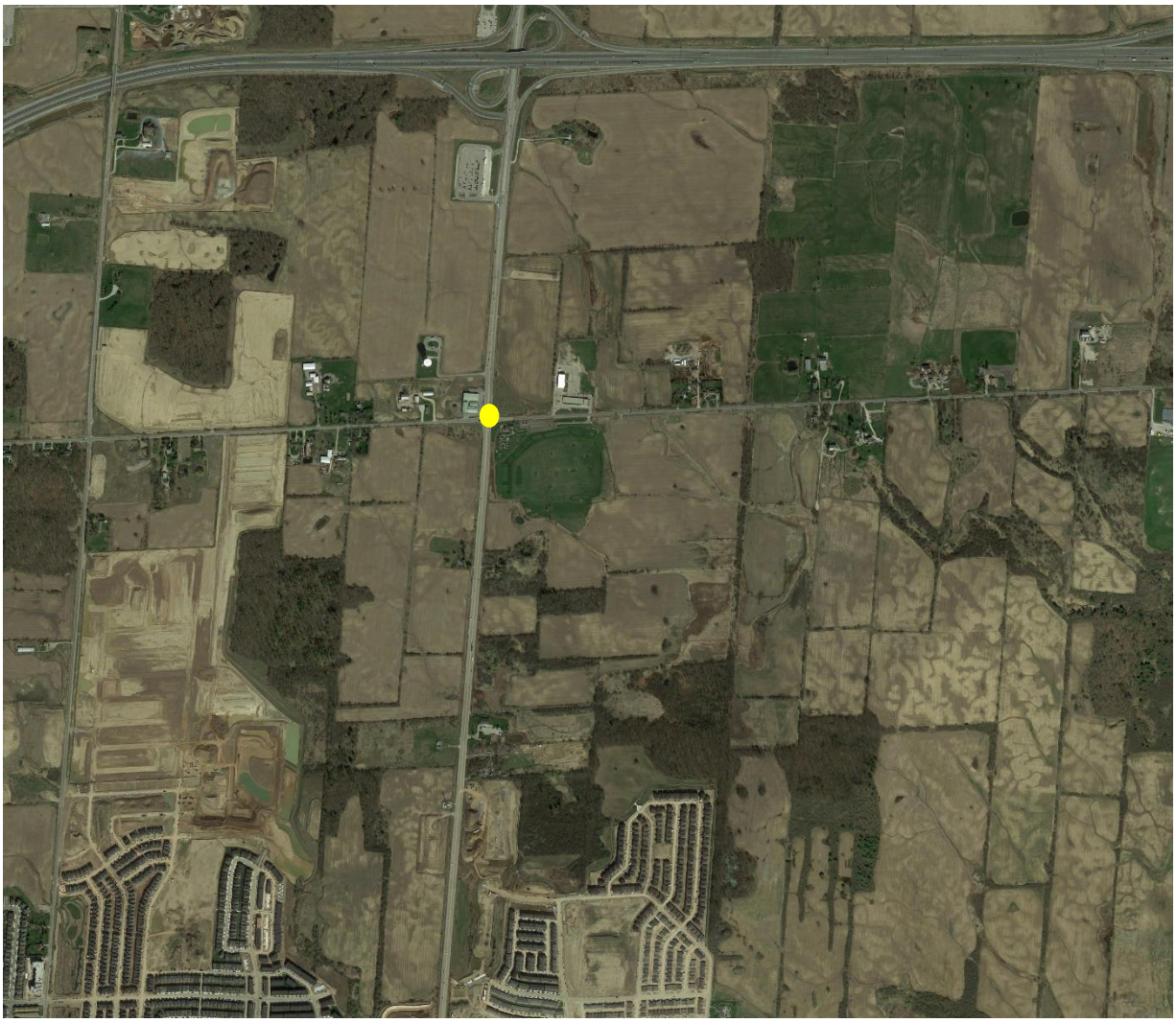


Location: Burnhamthorpe Road East and Trafalgar Road, Oakville (yellow dot)
Year: 1978
Scale: 1:10,000
Source: Ministry of Natural Resources and Forestry

Location: Burnhamthorpe Road East and Trafalgar Road, Oakville
Year: 1978
Scale: 1:10,000
Source: Ministry of Natural Resources and Forestry

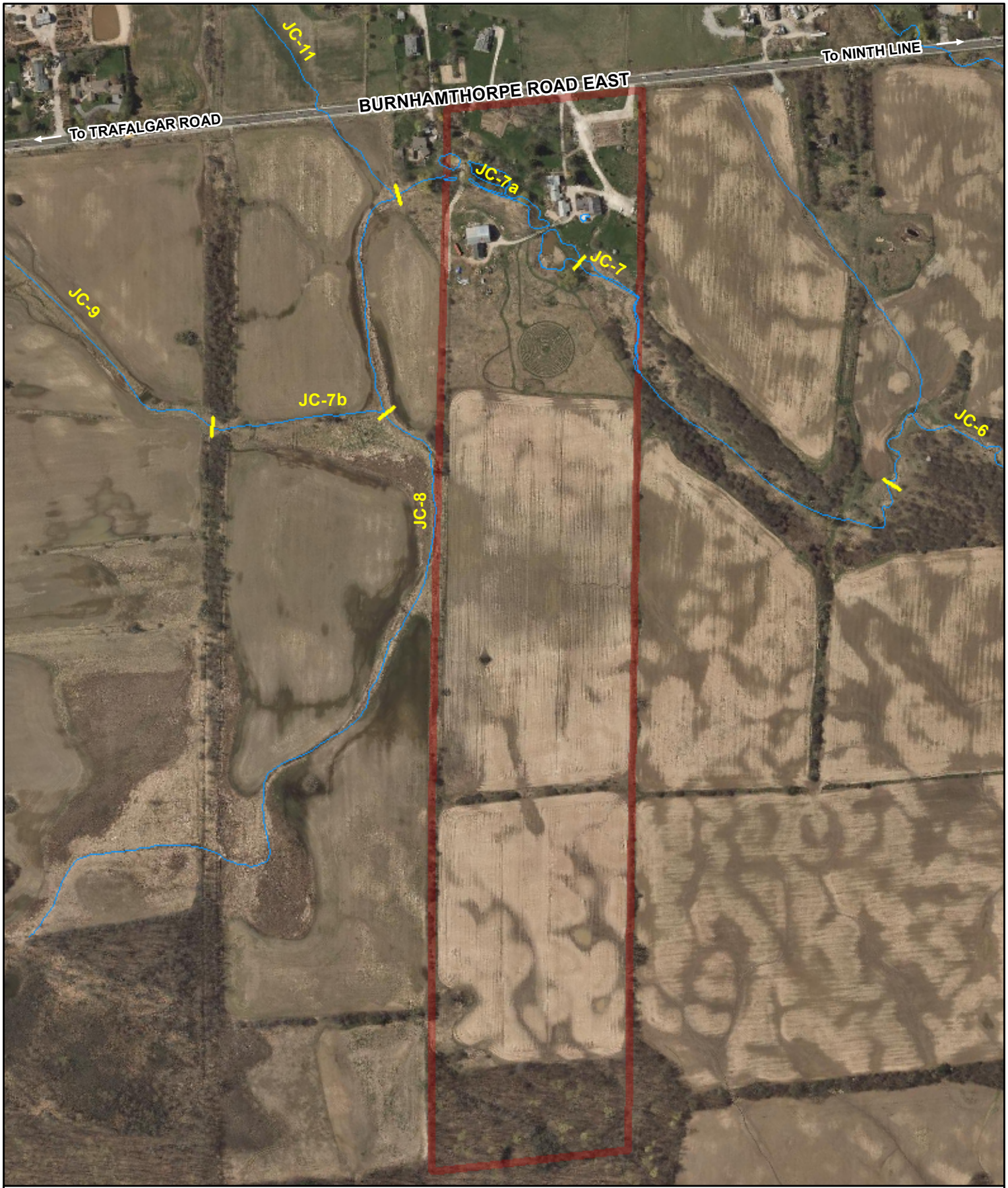
Location: Burnhamthorpe Road East and Trafalgar Road, Oakville
Year: 1978
Scale: 1:10,000
Source: Ministry of Natural Resources and Forestry

Location: Burnhamthorpe Road East and Trafalgar Road, Oakville
Year: 2005
Scale: N/A
Source: Google Earth Pro



Location: Burnhamthorpe Road East and Trafalgar Road, Oakville
Year: 2018
Scale: N/A
Source: Google Earth Pro

Appendix B
Reach Delineation



Legend

- JC-7 Reach Break and ID
- Watercourse
- Property Boundary

Sixteen Mile Creek

Reach Delineation

1086 Burnhamthorpe Road East
Oakville

0 100
Metres

GEO MORPHIX

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community Imagery Date: May, 2018.
Reach Break and ID: GEO Morphix Ltd., 2017. Property Boundary: GEO Morphix Ltd., 2017.
Watercourse: GEO Morphix Ltd., 2017; MNRF, 2019, Gelbloom Surveying Limited, 2019.
Print Date: October, 2019. PN17051. Drawn By: W.B., S.S.

Appendix C
Photographic Record

Photo 1 **Reach JC-7**	
	Downstream view of Reach JC-7, which was confined and surrounded by agricultural and residential land uses.
Photo 2 **Reach JC-7**	
	Within the downstream portion of the reach the channel was narrow with extensive vegetation encroachment. The riparian vegetation was dominated by grasses.

Reach JC-7 **Photo 3**	
	Within the upstream section of the reach, riparian areas consisted of manicured lawn. Iron staining was indicative of groundwater contributions.
Reach JC-7a **Photo 4**	
	The reach contained online ponds and manicured areas in vicinity of the rural residence. This pond was located downstream of the southern internal driveway crossing.

Photo 5 **Reach JC-7a**	
	Upstream of the crossing, the pond transitioned to a relatively narrow watercourse with limited flow at the time of the assessment.
Photo 6 **Reach JC-7a**	
	View of the earthen berm seperating the offline pond located north of the channel.

Photo 7 **Reach JC-7a**	
	Upstream view of the watercourse prior to the culvert at the upstream driveway. Note the earthen berm (right of image) separating the offline pond from the channel.
Photo 8 **Reach JC-7a**	
	Photograph taken facing upstream towards a driveway crossing. Rip rap was placed at 3 locations across the channel as weir structures.

Appendix D
Field Sheets

GEO MORPHIX
Geomorphology Earth Science Observations

General Site Characteristics

Project Code: PN170511

Date:	July 7, 2017	**Stream/Reach:**	JC-7
Weather:	Sun & 25C	**Location:**	Oakville, ON
Field Staff:	CH + JM	**Watershed/Subwatershed:**	Joshua Crk

Features

- Reach break
- Cross-section
- Flow direction
- Riffle
- Pool
- Medial bar
- Eroded bank
- Undercut bank
- Rip rap/stabilization/gabion
- Leaning tree
- Fence
- Culvert/outfall
- Swamp/wetland
- Grasses
- Tree
- Instream log/tree
- Woody debris
- Station location
- Vegetated island

pg2

• piezometer

Flow Type

H1	Standing water
H2	Scarcely perceptible flow
H3	Smooth surface flow
H4	Upwelling
H5	Rippled
H6	Unbroken standing wave
H7	Broken standing wave
H8	Chute
H9	Free fall

Substrate

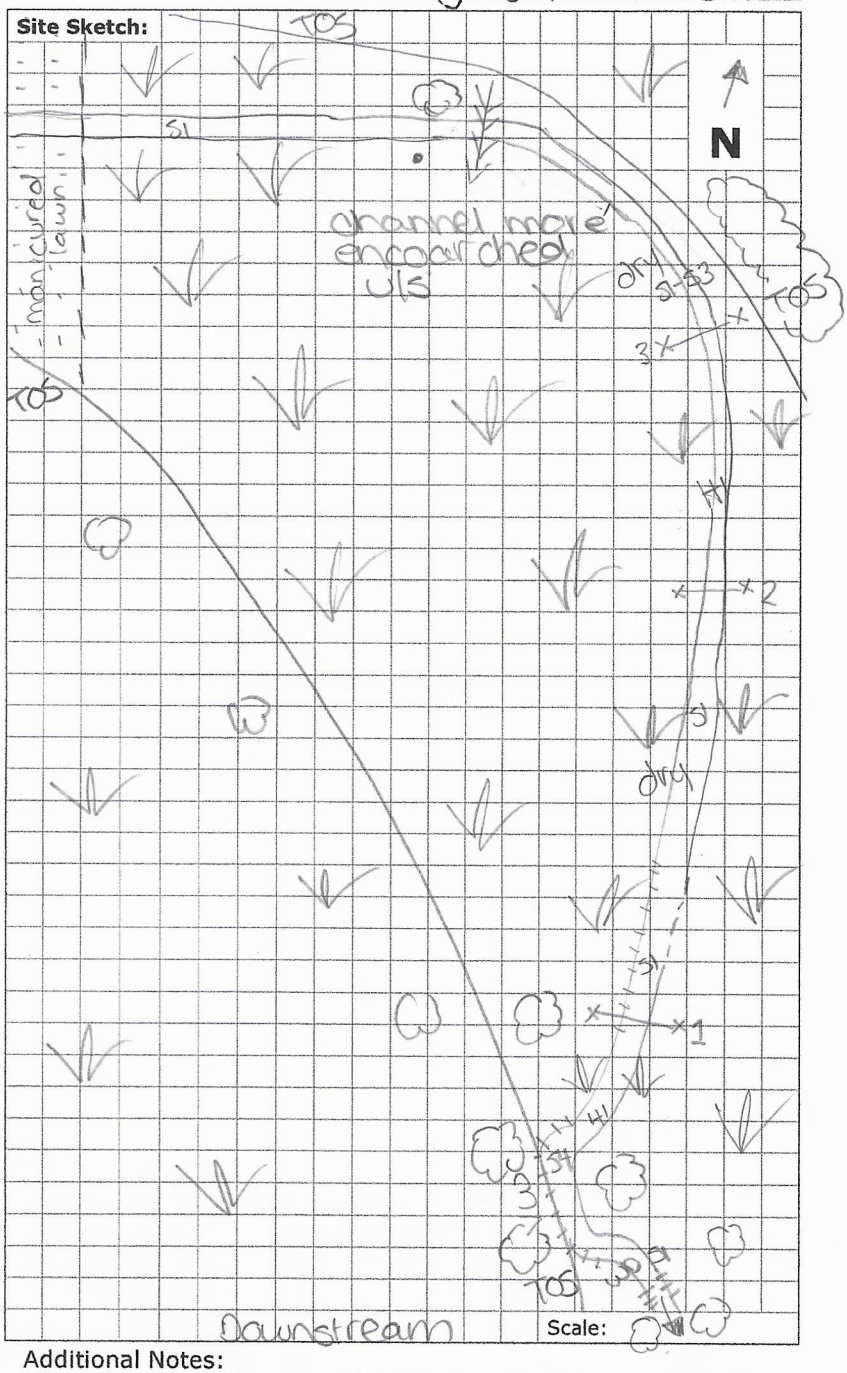
S1	Silt	**S6**	Small boulder
S2	Sand	**S7**	Large boulder
S3	Gravel	**S8**	Bimodal
S4	Small cobble	**S9**	Bedrock/till
S5	Large cobble		

Other

BM	Benchmark	**EP**	Erosion pin
BS	Backsight	**RB**	Rebar
DS	Downstream	**US**	Upstream
WDJ	Woody debris jam	**TR**	Terrace
VWC	Valley wall contact	**FC**	Flood chute
BOS	Bottom of slope	**FP**	Flood plain
TOS	Top of slope	**KP**	Knick point

WD woody debris

Site Sketch:



Additional Notes:

VWC @ DS N 10m long and 3m high

pg 1 of 3

Completed by: CH Checked by: _____

GEO MORPHIX
Geomorphology Earth Science Observations

General Site Characteristics

Project Code: PN170511

Date:	July 7, 2017	**Stream/Reach:**	JC-7 / JC-7a
Weather:	Sun & 25C	**Location:**	Oakville, ON
Field Staff:	CH + JM	**Watershed/Subwatershed:**	Joshua Crk

Features
- Reach break
- Cross-section
- Flow direction
- Riffle
- Pool
- Medial bar
- Eroded bank
- Undercut bank
- Rip rap/stabilization/gabion
- Leaning tree
- Fence
- Culvert/outfall
- Swamp/wetland
- Grasses
- Tree
- Instream log/tree
- Woody debris
- Station location
- Vegetated island

Flow Type

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H2	Scarcely perceptible flow
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H6	Unbroken standing wave
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H9	Free fall

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S2	Sand	**S7**	Large boulder
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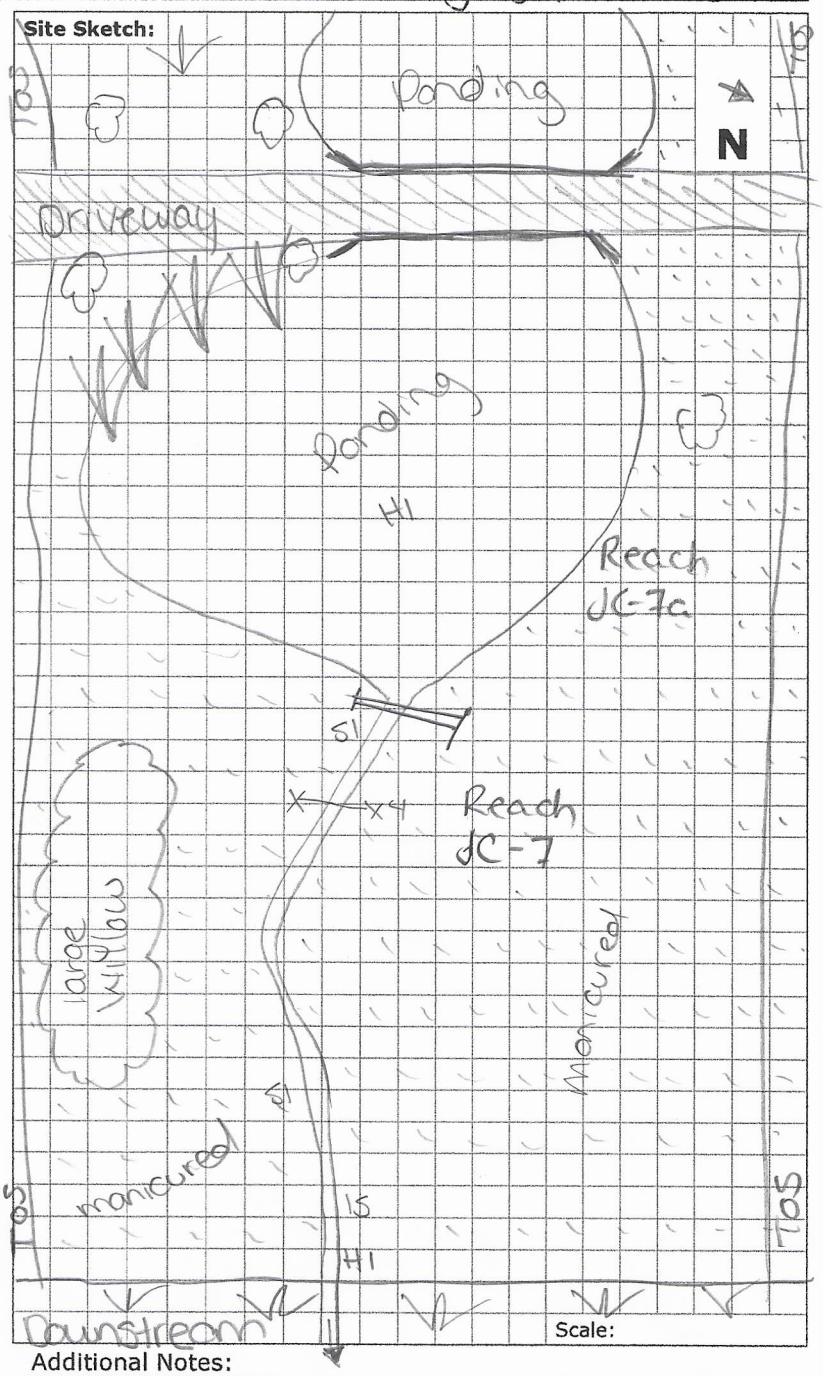
S4	Small cobble	**S9**	Bedrock/till
S5	Large cobble		

Other

BM	Benchmark	**EP**	Erosion pin
BS	Backsight	**RB**	Rebar
DS	Downstream	**US**	Upstream
WDJ	Woody debris jam	**TR**	Terrace
VWC	Valley wall contact	**FC**	Flood chute
BOS	Bottom of slope	**FP**	Flood plain
TOS	Top of slope	**KP**	Knick point

Site Sketch:



pg 3

pg 1

Additional Notes:

IS iron staining

pg 2 of 3

Completed by: CH Checked by: _____

GEO | MORPHIX
Geomorphology Earth Science Observations

General Site Characteristics

Project Code: PM170511

Date:	July 7, 2017	**Stream/Reach:**	JC-7a
Weather:	Sun & 25C	**Location:**	Oakville, ON
Field Staff:	CH + JM	**Watershed/Subwatershed:**	Joshua Crk

Features

- Reach break
- Cross-section
- Flow direction
- Riffle
- Pool
- Medial bar
- Eroded bank
- Undercut bank
- Rip rap/stabilization/gabion
- Leaning tree
- Fence
- Culvert/outfall
- Swamp/wetland
- Grasses
- Tree
- Instream log/tree
- Woody debris
- Station location
- Vegetated island

Flow Type

H1	Standing water
H2	Scarcely perceptible flow
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H6	Unbroken standing wave
H7	Broken standing wave
H8	Chute
H9	Free fall

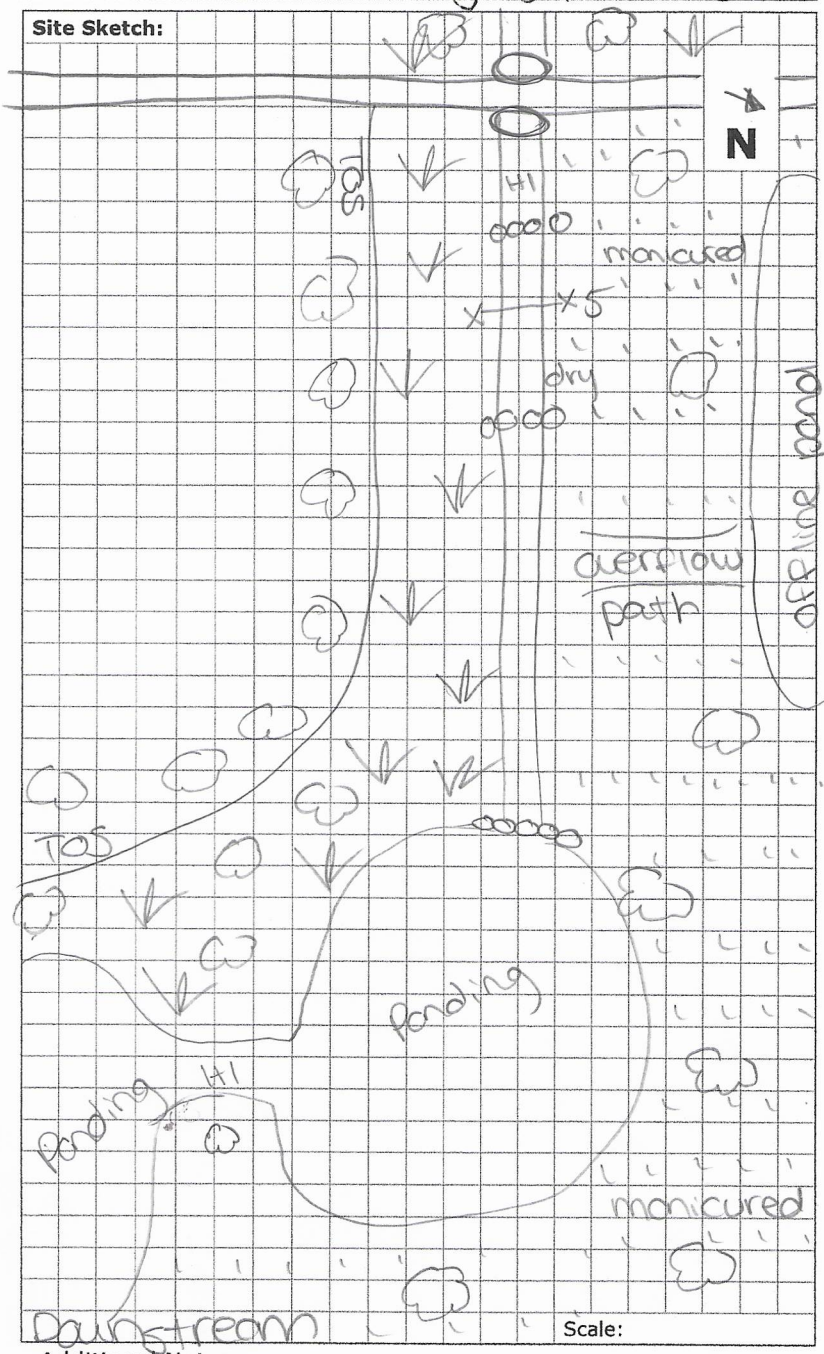
Substrate

S1	Silt	**S6**	Small boulder
S2	Sand	**S7**	Large boulder
S3	Gravel	**S8**	Bimodal
S4	Small cobble	**S9**	Bedrock/till
S5	Large cobble		

Other

BM	Benchmark	**EP**	Erosion pin
BS	Backsight	**RB**	Rebar
DS	Downstream	**US**	Upstream
WDJ	Woody debris jam	**TR**	Terrace
VWC	Valley wall contact	**FC**	Flood chute
BOS	Bottom of slope	**FP**	Flood plain
TOS	Top of slope	**KP**	Knick point

Site Sketch:



Additional Notes:

pg 2

pg 3 of 3

Completed by: CH Checked by: _____

GEO Morphix Ltd.
348 Bronte Street South, Unit 2
Milton, Ontario L9T 5B6
T 416.920.0926
e balance@geomorphix.com

Project Number: PN17051

Reach Characteristics

Date:	2017-07-06	Reach:	JC-7
Field Staff:	CH and JM	Watercourse:	Joshua's Creek
Weather:	Sunny, 25°C	Watershed:	Joshua's Creek

Location

lat=43.508715414037006, long=-79.72682886684986, alt=139.45703263198635, accuracy=8.0

General Characteristics

Land Use:	Agricultural, Residential
Valley Type:	Confined
Channel Type:	12 - Sinuous suspended load
Flow Type:	Intermittent
Groundwater:	yes Iron staining present
Notes:	

Riparian Vegetation

Dominant Vegetation Type:	Grasses
Dominant Species:	
Riparian Coverage:	Fragmented
Width of Riparian Zone:	4 - 10 Channel Widths
Riparian Age Class:	Immature (<5 years)
Extent of Encroachment into channel:	Moderate
Notes:	Manicured lawns at downstream extent

Aquatic/Instream Vegetation

Type of Instream Vegetation:	Rooted Emergent
Coverage of Reach (%):	40
Presence of Woody Debris:	Present in Channel
Density of Woody Debris:	Low
Number of WDJs per 50 m:	0
Notes:	

Channel Characteristics

Type of Sinuosity:	Sinuous
Degree of Sinuosity:	Low sinuosity (1.06 - 1.30)
Gradient:	Low
Number of Channels:	Single
Entrenchment:	Low (>2.2)
Bank Failures (Brierley and Fryirs, 2005):	Fluvial Entrainment (Hydraulic Action)
Downs Model of Channel Evolution (1995):	S - Stable - no observable morphological change
Riffle Substrate:	Clay, Silt
Pool Substrate:	Clay, Silt
Bank Material:	Clay, Silt, Sand, Gravel
Bank Angle:	30° - 60°, 60° - 90°
Extent of Bank Erosion:	5 - 30%

Notes:	No riffle - pool features, scattered cobbles present at downstream extent

Channel Measurements

Cross Section #1: Run

Bankfull Width (m):	1.55	**Wetted Width (m):**	1.45
Bankfull Depth (m):	0.53	**Wetted Depth (m):**	0.236
Velocity (m/s):	0	**Measurement Type:**	No flow

Cross Section #2: Run

Bankfull Width (m):	1	**Wetted Width (m):**	0
Bankfull Depth (m):	0.2	**Wetted Depth (m):**	0
Velocity (m/s):	0	**Measurement Type:**	Dry Channel

Cross Section #3: Run

Bankfull Width (m):	0.5	**Wetted Width (m):**	0
Bankfull Depth (m):	0.25	**Wetted Depth (m):**	0
Velocity (m/s):	0	**Measurement Type:**	Dry Channel

Cross Section #4: Run

Bankfull Width (m):	0.8	**Wetted Width (m):**	0.4
Bankfull Depth (m):	0.2	**Wetted Depth (m):**	0.1
Velocity (m/s):	0	**Measurement Type:**	No flow

Additional Measurements

Is riffle-pool development absent?	yes
Riffle-pool Spacing (m):	NA
% Riffles:	0
% Pools:	0
Meander Amplitude (m):	NA
Pool Depth (m):	NA
Riffle Length (m):	NA
Undercuts (m):	0.15
Notes:	

Water Quality

Odour:	None
Turbidity:	Clear
Notes:	Standing water.

GEO | MORPHIX

Rapid Geomorphic Assessment **Project Code:** PN170501

Date:	July 7, 2017	**Stream/Reach:**	JC-7
Weather:	sun + 25 °C	**Watershed/Subwatershed:**	Joshua Crk
Field Staff:	CH + JM	**Location:**	Oakville, ON

Process	No.	Geomorphological Indicator: Description	Present? Yes	Present? No	Factor Value
Evidence of Aggradation (AI)	1	Lobate bar		✓	0/5
	2	Coarse materials in riffles embedded	NA		
	3	Siltation in pools	NA		
	4	Medial bars		✓	
	5	Accretion on point bars		✓	
	6	Poor longitudinal sorting of bed materials		✓	
	7	Deposition in the overbank zone		✓	
		Sum of indices =	0	5	0.0
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	NA		0/5
	2	Exposed sanitary / storm sewer / pipeline / etc.	NA		
	3	Elevated storm sewer outfall(s)	NA		
	4	Undermined gabion baskets / concrete aprons / etc.	NA		
	5	Scour pools downstream of culverts / storm sewer outlets	NA		
	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 =	0	5	0.0
Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.		✓	0/6
	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	NA		
	6	Outflanked gabion baskets / concrete walls / etc.	NA		
	7	Length of basal scour >50% through subject reach		✓	
	8	Exposed length of previously buried pipe / cable / etc.	NA		
	9	Fracture lines along top of bank		✓	
	10	Exposed building foundation	NA		
		Sum of indices =	0	6	0.0
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)		✓	0/7
	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 =	0	7	0.0

Additional notes:

Stability Index (SI) = (AI+DI+WI+PI)/4 = 0.0

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

Completed by: CH Checked by: _____

GEO Morphix Ltd.
348 Bronte Street South, Unit 2
Milton, Ontario L9T 5B6
T 416.920.0926
e balance@geomorphix.com

Project Number: PN17051

Reach Characteristics

Date:	2017-07-06	Reach:	JC-7a
Field Staff:	CH and JM	Watercourse:	Joshua's Creek
Weather:	Sunny, 25°C	Watershed:	Joshua's Creek

Location

lat=43.508715414037006, long=-79.72682886684986, alt=139.45703263198635, accuracy=8.0

General Characteristics

Land Use:	Agricultural, Residential
Valley Type:	Confined
Channel Type:	12 - Sinuous suspended load
Flow Type:	Intermittent
Groundwater:	yes Iron staining present
Notes:	

Riparian Vegetation

Dominant Vegetation Type:	Grasses and scattered trees
Dominant Species:	
Riparian Coverage:	Fragmented
Width of Riparian Zone:	4 - 10 Channel Widths
Riparian Age Class:	Immature (<5 years)
Extent of Encroachment into channel:	Moderate
Notes:	Manicured lawns

Aquatic/Instream Vegetation

Type of Instream Vegetation:	Rooted Emergent
Coverage of Reach (%):	60
Presence of Woody Debris:	Present in Channel
Density of Woody Debris:	Low
Number of WDJs per 50 m:	0
Notes:	

Channel Characteristics

Type of Sinuosity:	Sinuous
Degree of Sinuosity:	Straight (1 - 1.05)
Gradient:	Low
Number of Channels:	Single
Entrenchment:	Low (>2.2)
Bank Failures (Brierley and Fryirs, 2005):	Fluvial Entrainment (Hydraulic Action)
Downs Model of Channel Evolution (1995):	S - Stable - no observable morphological change
Riffle Substrate:	Clay, Silt
Pool Substrate:	Clay, Silt
Bank Material:	Clay, Silt,
Bank Angle:	30° - 60°
Extent of Bank Erosion:	5 - 30%

Notes:	No riffle - pool features, plain bed throughout. Online pond at downstream extent. Offline pond adjacent to straightened channel at upstream extent.

Channel Measurements

Cross Section #5: Run

Bankfull Width (m):	0.6	**Wetted Width (m):**	Dry
Bankfull Depth (m):	0.2	**Wetted Depth (m):**	N/A
Velocity (m/s):	N/A	**Measurement Type:**	N/A

Additional Measurements

Is riffle-pool development absent?	Yes
Riffle-pool Spacing (m):	N/A
% Riffles:	0
% Pools:	0
Meander Amplitude (m):	N/A
Pool Depth (m):	N/A
Riffle Length (m):	N/A
Undercuts (m):	None
Notes:	

Water Quality

Odour:	None
Turbidity:	Clear
Notes:	Standing water

GEO | MORPHIX

Rapid Geomorphic Assessment **Project Code:** PN170511

Date:	July 7, 2017	**Stream/Reach:**	JC-7a
Weather:	sunny + 25°C	**Watershed/Subwatershed:**	Joshua Crk
Field Staff:	CH + JM	**Location:**	Oakville, ON

Process	Geomorphological Indicator		Present?		Factor Value
	No.	Description	Yes	No	
Evidence of Aggradation (AI)	1	Lobate bar		✓	0/5
	2	Coarse materials in riffles embedded	NA		
	3	Siltation in pools	NA		
	4	Medial bars		✓	
	5	Accretion on point bars		✓	
	6	Poor longitudinal sorting of bed materials		✓	
	7	Deposition in the overbank zone		✓	
		Sum of indices =	0	5	0.0
Evidence of Degradation (DI)	1	Exposed bridge footing(s)		✓	0/7
	2	Exposed sanitary / storm sewer / pipeline / etc.	NA		
	3	Elevated storm sewer outfall(s)	NA		
	4	Undermined gabion baskets / concrete aprons / etc.	NA		
	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 =	0	7	0.0
Evidence of Widening (WI)	1	Fallen / leaning trees / fence posts / etc.		✓	0/6
	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	NA		
	6	Outflanked gabion baskets / concrete walls / etc.	NA		
	7	Length of basal scour >50% through subject reach		✓	
	8	Exposed length of previously buried pipe / cable / etc.	NA		
	9	Fracture lines along top of bank		✓	
	10	Exposed building foundation	NA		
		Sum of indices =	0	6	0.0
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)		✓	0/7
	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 =	0	7	0.0

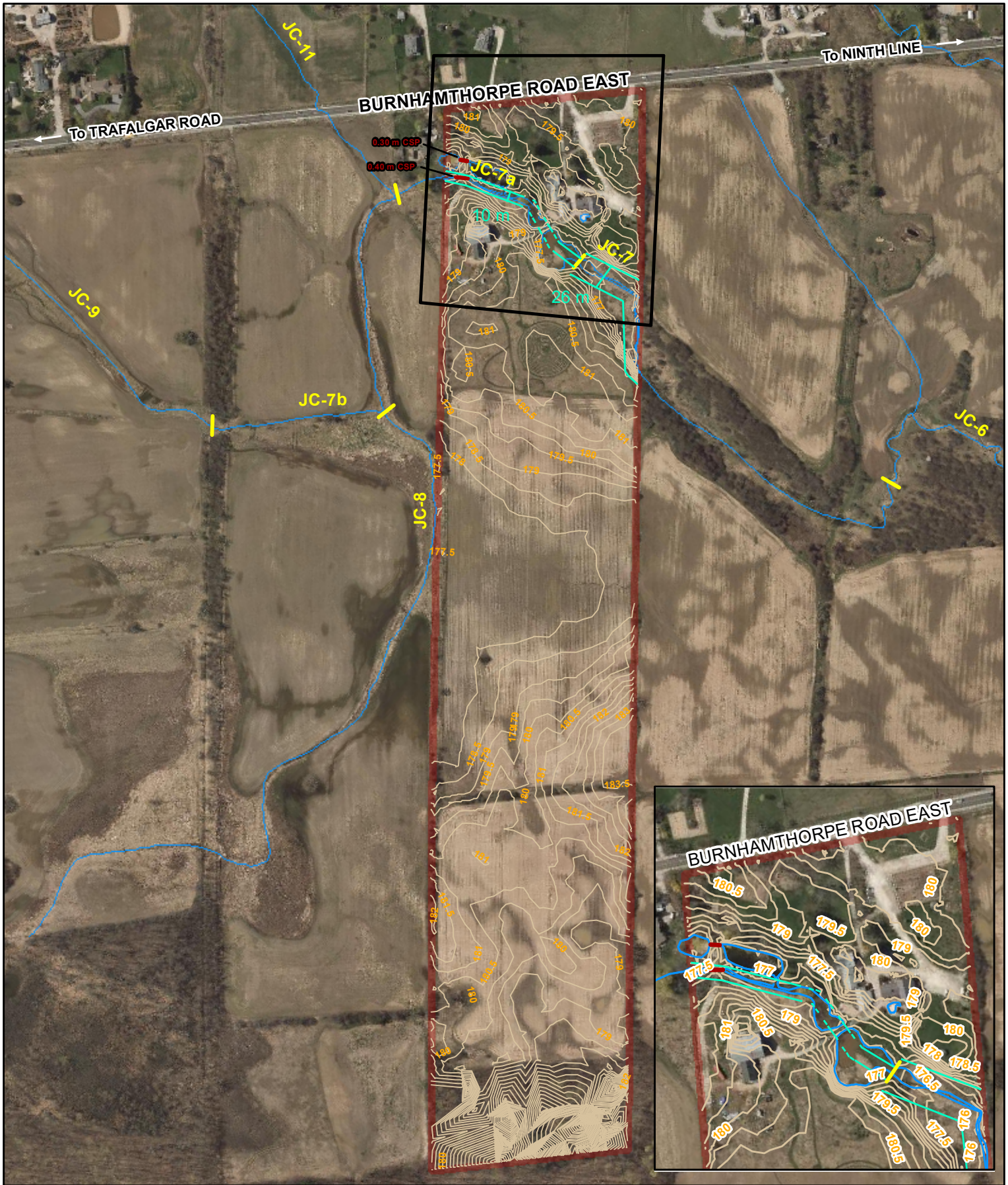
Additional notes:

Stability Index (SI) = (AI+DI+WI+PI)/4 = 0.0

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

Completed by: CH Checked by: _____

Appendix E
Meander Belt Width Assessment



Legend

- JC-7 Reach Break and ID
- Watercourse
- Contour (0.5 m)
- Meander Belt Width
- Property Boundary

Sixteen Mile Creek

Meander Belt Width Delineation

1086 Burnhamthorpe Road East
Oakville

0 100
Metres

GEO MORPHIX

Service Layer Credits: Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community Imagery Date: May, 2018.
Reach Break and ID and Meander Belt Width: GEO Morphix Ltd., 2017.
Property Boundary: GEO Morphix Ltd., 2017.
Watercourse: GEO Morphix Ltd., 2017; MNRF, 2019; Gelbloom Surveying Limited, 2019. Contours and Culverts: Gelbloom Surveying Limited, 2019.
Print Date: October, 2019. PN17051. Drawn By: W.B., S.S.