TECHNICAL MEMORANDUM

DATE August 26, 2019 **Project No.** 1648031

TO Stephen Keen
CIMA +

CC Project File

FROM Andrew Forbes and Justin Lim **EMAIL aforbes@golder.com; jlim@golder.com**

FLUVIAL GEOMORPHIC ASSESSMENT IN SUPPORT OF THE NINTH LINE MUNICIPAL CLASS ENVIRONMENTAL ASSESSMENT, HALTON REGION

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by the Regional Municipality of Halton (Halton Region) to complete a fluvial geomorphic assessment in support of the Schedule C Municipal Class Environmental Assessment (EA) for the proposed roadway improvements at Ninth Line from approximately Highway 407 to Dundas Street East in Halton Region, Ontario. This technical memorandum outlines the methods and results of the fluvial geomorphic assessment.

1.1 Background

As shown on Figure 1, Ninth Line between Highway 407 and Dundas Street East is currently characterized by a two-lane rural road that is serviced by roadside ditches and culvert crossings. Agriculture is the prominent land use adjacent to the road; however, there are several notable developments in the local area, including the Fern Hill School (private elementary school), the Glen Oaks Funeral Home & Cemetery, and the Ninth Line Sports Park and Tennis School. Ninth Line between Highway 407 and Dundas Street East has been identified for improvements based on the Halton Region Transportation Master Plan (Halton Region, 2011). The roadway improvements will include widening of the road to four-lanes with the associated installation of new or modified culvert crossings and other stormwater management works.

The headwaters of Joshua's Creek originate in the area north of William Halton Parkway (or immediately south of Highway 407). This portion of the watercourse system combines a series of first and second order streams that flow in a mostly southeastern direction and drain beneath Ninth Line at the following four crossing locations between Highway 407 and Dundas Street East:

- 150 m west of the intersection of Ninth Line and William Halton Parkway via a 700 mm diameter CSP;
- 700 m southeast of the intersection of Ninth Line and William Halton Parkway by way of a 600 mm diameter CSP, noting that this portion of the watercourse system is centered over a Provincially Significant Wetland (PSW);
- 1,100 m southeast of the intersection of Ninth Line and William Halton Parkway by way of a 500 mm CSP; and,

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- 1,400 m southeast of the intersection of Ninth Line and William Halton Parkway (or 740 m northwest of the intersection of Ninth Line and Dundas Street East) via a closed-bottom concrete box culvert with a respective width and height of 1.9 m and 1.3 m.

Joshua's Creek ultimately discharges to Lake Ontario at a location approximately 10.5 km downstream of the study area. The watershed of Joshua's Creek is largely urbanized (residential), although agricultural land use remains dominant in the headwater areas.

1.2 Purpose and Scope

Modifications to the roadway at Ninth Line have the potential to influence channel conditions at Joshua's Creek. To that end, a fluvial geomorphic assessment was completed along defined 'reach lengths' (i.e., sections of the watercourse that include similar geomorphic characteristics and controls) to assess meander potential and channel stability. The results of the fluvial geomorphic assessments will be used to support the Class EA process, as well as to assist with the preliminary design of any modifications to the watercourse crossings.

The specific work scope involved the following tasks:

- Background review and field inspections at all reach lengths to characterize channel morphology and assess bed and bank stability (assuming that well defined channel conditions are applicable);
- Meander belt width assessment at select reach lengths to determine the meander potential of the stream in the vicinity of the roadway improvements; and,
- 100-year erosion evaluation at select reach lengths to determine the long-term erosion potential of the stream in the vicinity of the roadway improvements.

Each of these tasks is described in Section 2.0.

2.0 METHODOLOGY

2.1 Background Review and Field Inspections

The following background information was reviewed to assist with the fluvial geomorphic assessment at Ninth Line:

- The North Oakville Creeks Subwatershed Study (NOCSS) (Town of Oakville, 2006) that was obtained from the Town of Oakville website;
- Aerial photography from 1960 and 1980 that was retrieved from the National Air Photo Library, as well as 2015 orthoimagery that was obtained from First Based Solutions;
- HEC-RAS hydraulic modelling for Joshua's Creek (main branch) that was provided by the Halton Conservation Authority (HCA) (via email on August 2, 2016), noting that this modelling information included regional flood estimates for all reaches in the model; and,
- Topographic survey information that was obtained from a December 21, 2015 survey conducted by Cunningham McDonnell Limited.

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In addition to the background review, a site visit was completed on September 21, 2016. The site reconnaissance included a walk-over at all relevant reach lengths to assess channel morphology and to identify any areas of instability. Further to these general inspections, field activities at reach lengths with a defined bed and bank involved substrate sampling, Rapid Geomorphic Assessments (RGAs), and topographic channel surveys.

The field data was used to inform the meander belt width and 100-year erosion assessments (Sections 2.2 and 2.3), as well as the hydraulic analyses (captured under a separate cover).

2.2 Meander Belt Assessment

A belt width assessment was conducted at select reach lengths based on protocols developed by Toronto and Region Conservation Authority (TRCA, 2004). The belt width assessment included the following activities:

- Background preparation, comprising a detailed analysis of maps and historical aerial photographs, in order to delineate the reach lengths and examine historical land use and channel patterns;
- Field reconnaissance at the identified reach lengths (described in Section 2.1) to evaluate current conditions and obtain measurements of channel geometry; and,
- Delineation/quantification of the preliminary, existing and final meander belt widths at select reach lengths to infer the stream corridor that the channel encompassed in the past and could potentially occupy in the future.

2.3 100-Year Erosion Assessment

A 100-year erosion assessment was conducted at select reach lengths in accordance with procedures outlined by Toronto and Region Conservation Authority (TRCA, 2007). The development of the 100-year erosion limit considered the average rate of channel migration in the vicinity of the relevant culvert crossings and was based on similar activities described for the meander belt width assessment (Section 2.2), namely an analysis of historical aerial photographs and a field reconnaissance.

3.0 RESULTS

3.1 Background Review and Field Inspections

To account for changes in fluvial geomorphologic characteristics along a channel, watercourses are typically separated into reaches that display similar physical characteristics and controls on channel morphology. With reference to Figure 1, field observations, in combination with a review of available base mapping and air photographs, identified a total of five (5) potentially relevant reach lengths at Ninth Line between Highway 407 and Dundas Street East. These reach lengths are described herein as RL-01 through RL-05. Key observations at each of the reach lengths are summarized in Table 1. Photographs of the reach lengths are presented in Attachment A.

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Table 1: Key Results from Background Review and Field Inspections at RL-01 through RL-05

Reach Length	General Description of Channel Morphology and/or Water Feature Conditions	Bankfull Width	Channel Substrate	Riparian Conditions	Additional Remarks from Background Review
RL-01	Small intermittent watercourse with well-defined channel (i.e., incised with visible bed and bank) that includes a meandering pattern and numerous instances of instability (e.g., marked erosion at the bed and banks, presence of overflow chutes and cut-off channels, etc.). The channel reach is located immediately downstream of a concrete box culvert that under-crosses Ninth Line.	~ 0.5 to 1 m	Fine sandy silt at the bed and banks (D50 = 1.5 to 1.6 mm)	Mostly low lying vegetation at channel margins (i.e., manicured grass cover)	A review of Town of Oakville's NOCSS (2006) showed that RL-01 overlaps with stream reach JC-22 (from the Oakville study). The results of this previous assessment at JC-22 concluded that the channel requires remediation (specifically bank revetment to address erosion issues) and includes an estimated meander belt width of 40m.

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Table 1: Key Results from Background Review and Field Inspections at RL-01 through RL-05

Reach Length	General Description of Channel Morphology and/or Water Feature Conditions	Bankfull Width	Channel Substrate	Riparian Conditions	Additional Remarks from Background Review
RL-02	Small intermittent watercourse with instances of well-defined channel, noting that there is no defined bed and bank in the area immediately upstream of the box culvert (it represents a broad valley feature or depression), but an incised channel feature becomes apparent on an intermittent basis further upstream (e.g., between approximately 50 m and 100 m upstream of the culvert). The sections of defined channel include a meandering pattern and relatively stable conditions (i.e., well vegetated bank and/or riparian areas with limited evidence of erosion and sedimentation).	~ 1 to 2 m (where defined channel conditions were observed)	Fine sandy silt at the bed (D50 = 0.03)	Dense cover of shrubs, grasses and small trees at the riparian area	Available mapping confirmed that RL-02 receives surface water flows from the reach length at RL-03, as well as a ditch that collects agricultural runoff and highway runoff from Highway 403.

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Table 1: Key Results from Background Review and Field Inspections at RL-01 through RL-05

Reach Length	General Description of Channel Morphology and/or Water Feature Conditions	Bankfull Width	Channel Substrate	Riparian Conditions	Additional Remarks from Background Review
RL-03	Roadside ditch at upstream portion of the reach, and agricultural swale or drain at the downstream end. The ditch/swale holds a discernible shape and alignment but represents an engineered feature with no natural channel form.	n/a	Not assessed	Road and cropland (agricultural field)	--
RL-04	No defined channel – the reach	n/a	Not	Wetland	--
RL-05	Small agricultural swale or drain, recognizing that the feature holds a discernible shape and alignment but represents an engineered feature	n/a	Not assessed	Road and cropland (agricultural field)	--

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Based on the above, defined channel conditions were limited to RL-01 and RL-02 (separated/bounded by the concrete box culvert that under-crosses Ninth Line). For this reason, detailed field activities, coupled with meander belt width and 100-year erosion assessments, were targeted at these two reaches alone.

The completed RGA forms at RL-01 and RL-02 are presented in Attachment B. Grain size results for these reaches are presented in Attachment C. The results of the RGAs suggest that RL-01 is in adjustment (undergoing widening and planform changes), while RL-02 is comparatively stable.

3.2 Meander Belt Assessment

3.2.1 Aerial Photography Analysis

A historical air photograph analysis was completed in support of the meander belt assessment, and relied on aerial photography from 1960 and 1980, as well as orthoimagery from 2015. These images/photos were used to evaluate changes in channel patterns and surrounding land use over time at RL-01 and RL-02. The key results of the historical air photo analysis are summarized in Table 2, noting that channel and riparian conditions were largely discernible in each of the available photos/images. The observed changes in the channel planform are illustrated on Figure 2.

Table 2: Key Results of Historical Air Photo Analysis at RL-01 and RL-02

	Land Use	Channel Planform and Riparian Setting
1960	- Land use in the surrounding areas at RL-01 and RL-02 were dominated by agriculture in 1960.	- Channel conditions at RL-01 and RL-02 in 1960 were characterized by defined bed and bank and moderate to high sinuosity. These conditions were observed along the full extent of each reach length, noting several particularly prominent meander bends immediately upstream and downstream of the concrete box culvert at Ninth Line. - Riparian conditions at RL-01 and RL-02 were comprised of a dense cover of vegetation (mix of grasses, shrubs and small trees).
1980	- Agriculture remained the dominant land use in 1980; however, some of the agricultural fields that were present in 1960 had been subsequently converted (or appeared to be in the process of being converted) to transportation infrastructure. This included the development of several rural side roads in the immediate surrounding area, as well	- Channel and riparian conditions at RL-01 and RL-02 in 1980 remained relatively consistent with the associated observations from 1960, noting a few instances at RL-01 where meander bends have slightly shifted (i.e., lateral adjustment of the channel) relative to 1960.

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	Land Use	Channel Planform and Riparian Setting

2015	- Agricultural land use remains most prominent under current conditions (2015), noting, however, that more of the agricultural fields have been converted to alternate land uses. This includes the Highway 403 corridor, as well the emergence of several pockets of commercial and institutional properties (i.e., private school, funeral home and cemetery, and sports park).	- Channel and riparian conditions at RL-01 and RL-02 under current conditions remain generally consistent with associated observations from 1960 and 1980, with the exception of the following:
		  - The channel at RL-01 includes several marked examples of lateral migration. In particular, a number of the meander bends on the eastern side of the valley were shown to be noticeably elongated relative to the conditions in 1960/1980.
		  - Riparian vegetation at RL-01 has been converted to mostly low lying vegetation (i.e., manicured grass). These observed conditions reflect lawn maintenance activities at the cemetery in this area.
		  - The channel at RL-02 is no longer apparent in some sections (i.e., no defined bed and bank), including the area immediately upstream of the culvert that had previously supported a prominent meandering pattern in 1960/1980. It is assumed that the channel has aggraded (i.e., filled in through sediment deposition) in this area.
		- The channel that extends between Highway 403 and the upstream end of RL-02 has been re-aligned (i.e., straightened) relative to 1960/1980. This channel adjustment was likely completed to support the construction of Highway 403 and/or the capture and diversion of runoff from the highway corridor.

Overall, land use in the surrounding areas at RL-01 and RL-02 has been dominated by agriculture for the duration of the historical air photo record, recognizing that the conversion of agricultural fields to transportation infrastructure (specifically the Highway 403 corridor) and other land uses have occurred over the past 35 years. Channel planform at RL-01 and RL-02 remained largely unchanged for the initial 20 years of the air photo record (between 1960 and 1980); however, channel conditions at RL-01 has showed marked evidence of lateral instability (i.e., adjustment and migration of several meander bends) during the most recent period of record.

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3.2.2 Belt Width Calculations

The meander belt width estimates at RL-01 and RL-02 are described below, recognizing that the assessment assumed no major long term changes in the hydrologic regime (i.e., flow duration and frequency) and considered a single belt width for the two adjoining reach lengths:

- A preliminary meander belt width was measured to be approximately 20 m. This preliminary meander belt represents the measured width between the outer-most meander bends at RL-01 and RL-02 (i.e., perpendicular to the established meander belt boundaries).
- The existing meander belt width was estimated to be approximately 21 m. The calculation of the existing belt width combines the preliminary meander belt width with the average bankfull width of the channel (~1.0 m), as estimated in the field (20 m + 1 m = 21 m).
- The final meander belt width was estimated to be approximately 30 m. This final belt width combines the estimated existing belt width with the average 100-year migration distance of 10 m (21 m +10 m = 30 m).

The final meander belt width of approximately 30 m was plotted on the 2015 aerial image (Figure 3); divided over the meander belt width axis to allow equal channel buffer on either side of the axis.

3.3 100-Year Erosion Limit

The 100-year erosion limit at RL-01 and RL-02 was assessed based on the rates of channel migration at the following major meander bends, with consideration for the air photo record between 1960 and 2015:

- Meander Bend #1 (located approximately 50 m upstream of Ninth Line) – average migration rate of 7 cm/yr.
- Meander Bend #2 (located approximately 35 m downstream of Ninth Line) – average migration rate of 13 cm/yr.
- Meander Bend #3 (located approximately 60 m downstream of Ninth Line) – average migration rate of 10 cm/yr.

The average 100-year migration distance was estimated to be 10 m based on the average of all three meander bend migration rates. This 100-year erosion limit was determined by extending the rate of migration at the most active meander bend (Meander Bend #3) over a 100-year time span (0.13 m/yr * 100 = 13 m), and then applying this distance to either side of the average width of the bankfull channel (13 m * 2 + 1 m = 27 m). Thus, the 100-year erosion limit was estimated to be 27 m.

4.0 SUMMARY AND CONCLUSIONS

A fluvial geomorphic assessment was completed to support the Schedule C Municipal Class EA for the proposed roadway improvements at Ninth Line from approximately Highway 407 to Dundas Street East in Halton Region.

The key findings of the assessment are summarized below:

- The results of the field reconnaissance and air photo analysis at the study area confirmed that defined channel conditions (i.e., incised channel with a visible bed and bank) are limited to the stream reach downstream of the concrete box culvert (described in the assessment as RL-01) and, to a lesser extent, at

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the stream reach upstream of the concrete box culvert (RL-02), noting that there is no defined bed and bank in the area immediately upstream of the culvert (it represents a broad valley feature or depression), but an incised channel feature becomes apparent on an intermittent basis further upstream. The channel at RL-01 follows a meandering pattern and includes numerous instances of instability (e.g., notable erosion at the bed and banks, presence of overflow chutes and cut-off channels, marked evidence of lateral channel migration at several meander bends, etc.). Channel conditions at RL-02 (where applicable) are comparatively stable, recognizing that the channel in the area immediately upstream of the culvert appears to have aggraded (i.e., filled in through sediment deposition) during the most recent portion of the historical air photo record. The area further upstream in the local drainage system (including three other watercourse crossings at RL-03 through RL-05) is characterized by either wetland or roadside ditch/swale, meaning that natural channel form is largely absent and any fluvial geomorphic function would be limited to mostly flow conveyance alone.

- The identified channel instability at RL-01 is consistent with the results of previous studies at this stream reach (i.e., North Oakville Creeks Subwatershed Study). The observed conditions may reflect one or more of the following factors: channel alterations (i.e., straightening) in the upstream catchment, particularly the section of channel located immediately downstream of the Highway 403 crossing, coupled with potential changes to the local flow regime to accommodate drainage/runoff from the highway corridor; sediment aggradation or trapping at RL-02 (and hence reduced sediment conveyance to RL-01); and land management practices in the immediate riparian areas at RL-01 (i.e., manicured grass cover at the funeral home and cemetery) resulting in increased runoff to the channel and reduced stability in the overbank zone (relative to natural riparian vegetation).
- The results of the desktop analysis at RL-01 and RL-02 suggest a meander belt width and an associated 100-year erosion limit of approximately 30 m and 27 m, respectively, noting that the estimated meander belt width is relatively consistent with the associated belt width boundaries from the North Oakville Creeks Subwatershed Study (for the portion of stream reach where this overlap between both assessments). Based on TRCA protocols, crossing structures should be constructed outside of the meander belt width of a watercourse to the extent possible, or, alternatively, the features should be designed to match or exceed the 100-year erosion limit of the channel. However, for this particular study, Golder is of the opinion that a crossing span less than the estimated dimensions of the meander belt width and 100-year erosion limit at RL-01 and RL-02 would be appropriate with consideration of the following:
  - The existing concrete box culvert that separates RL-01 and RL-02 is located within the boundaries of the estimated belt width and 100- year erosion limit of the channel;
  - Spanning a new crossing structure the length of the estimated belt width or 100-year erosion limit of the channel at RL-01/RL-02 would be impractical and cost prohibitive (and unwarranted from a fluvial geomorphic standpoint, given that there is little to no channel morphology to accommodate in the area immediately upstream of the crossing at RL-02); and
  - The existing concrete box culvert that separates RL-01 and RL-02 is designed to convey up to and including the Regional flow event; hence, major flows will be directed through the culvert, with limited opportunities to outflank the crossing feature and erode a separate flow path.

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For the reasons identified above and from the perspective of fluvial geomorphology, it is suggested that upgrade or replacement of the existing crossing structure at RL-01 and RL-02 include a width of approximately two (2) to three (3) times the average bankfull width of the channel, recognizing that the preliminary design of Culvert #9 (located at the crossing that separates RL-01 and RL-02) includes a span that is approximately three (3) times the bankfull width of the downstream channel. This suggested crossing span is expected to accommodate the identified fluvial geomorphic processes and hazards at the subject reaches. The preliminary recommendations described here are based on the results of the fluvial geomorphology assessment alone. Any modification to the crossing structure span will also need to consider the required hydraulic conditions (e.g., flood conveyance for the design event) and the relevant ecological functions (e.g., wildlife passage in the riparian zone).

- Any proposed modifications to the existing concrete box culvert should be designed to maintain or enhance flow and sediment conveyance between RL-01 and RL-02. Related to this point, the incorporation of bank and/or bed treatments (e.g., flow dissipation pool, bank revetments, bed armouring, etc.) should be considered at the inlet and outlet of the culvert to mitigate any increased opportunity for scour and erosion in the local area or further downstream. It is understood that all of the channel and culvert works will be implemented and maintained outside of private lands.

As part of the ongoing design efforts for the project, the fluvial geomorphic specialist will carry out regular communications with the design engineers to refine the specific layout and configuration of the watercourse crossing at Culvert #9. This will involve specific advice on suitable crossing conditions and associated mitigation strategies to maintain or enhance sediment conveyance, fish/terrestrial passage, and overall channel stability.

5.0 CLOSURE

We trust that this technical memorandum meets your needs at this time. If you have any questions, please do not hesitate to contact the undersigned.

Yours truly,

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Justin Lim, MSc
Water Resources Specialist

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Andrew Forbes, MSc, PGeo
Associate, Senior Geoscientist

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ATTACHMENTS:

Figure 1 – Site Plan and Reach Lengths for Study Area at Ninth Line
Figure 2 – Historical Channel Patterns for Study Area at Ninth Line
Figure 3 – Estimated Meander Belt Width for Study Area at Ninth Line
Attachment A – Photographs
Attachment B – Results of Rapid Geomorphic Assessments
Attachment C – Grain Size Distribution Curves

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REFERENCES

Halton Region. September 2011. Transportation Master Plan (2031) – The Road to Change. Ministry of Transportation Ontario. October 1997. MTO Drainage Management Manual.

Town of Oakville. August 2006. North Oakville Creeks Subwatershed Study.

TRCA [Toronto and Region Conservation Authority]. September 2007. Watercourse Crossing Design and Submission Requirements.

TRCA [Toronto and Region Conservation Authority]. 2004. Belt Width Delineation Procedures. Developed by Parish Geomorphic Ltd. for the Toronto and Region Conservation Authority.

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FIGURES

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LEGEND

- Culvert Crossing
- Reach Break
- Reach Length (RL) with Well Defined Channel
- Reach Length (RL) with Poorly Defined Channel
- Provincially Significant Wetland (RL-04)

0 100 200

1:5,000 METRES

REFERENCE(S)

1. IMAGERY OBTAINED FROM FIRST BASE SOLUTIONS (SPRING 2015)
2. PROJECTION: TRANSVERSE MERCATOR DATUM: NAD83 COORDINATE SYSTEM: UTM ZONE 17

CLIENT
CIMA+

PROJECT
JOSHUA CREEK
NINTH LINE, OAKVILLE ONTARIO

TITLE
REACH LENGTHS FOR STUDY AREA AT NINTH LINE

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-09-11
DESIGNED	SO
PREPARED	SO
REVIEWED	JL
APPROVED	AF

PROJECT NO.	CONTROL	REV.	FIGURE
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LEGEND

- Observed Channel Alignment in 1960
- Observed Channel Alignment in 1980
- Observed Channel Alignment in 2015 (Well Defined Bed and Banks)
- Inferred Channel Alignment in 2015 (No Defined Bed and Banks)
- Reach Break

0 25 50

1:1,000 METRES

REFERENCE(S)

1. IMAGERY OBTAINED FROM FIRST BASE SOLUTIONS (SPRING 2015)
2. PROJECTION: TRANSVERSE MERCATOR DATUM: NAD83 COORDINATE SYSTEM: UTM ZONE 17

CLIENT
CIMA+

PROJECT
JOSHUA CREEK
NINTH LINE, OAKVILLE ONTARIO

TITLE
HISTORICAL CHANNEL FOR STUDY AREA AT NINTH LINE

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-09-11
DESIGNED	SO
PREPARED	SO
REVIEWED	JL
APPROVED	AF

PROJECT NO.	CONTROL	REV.	FIGURE
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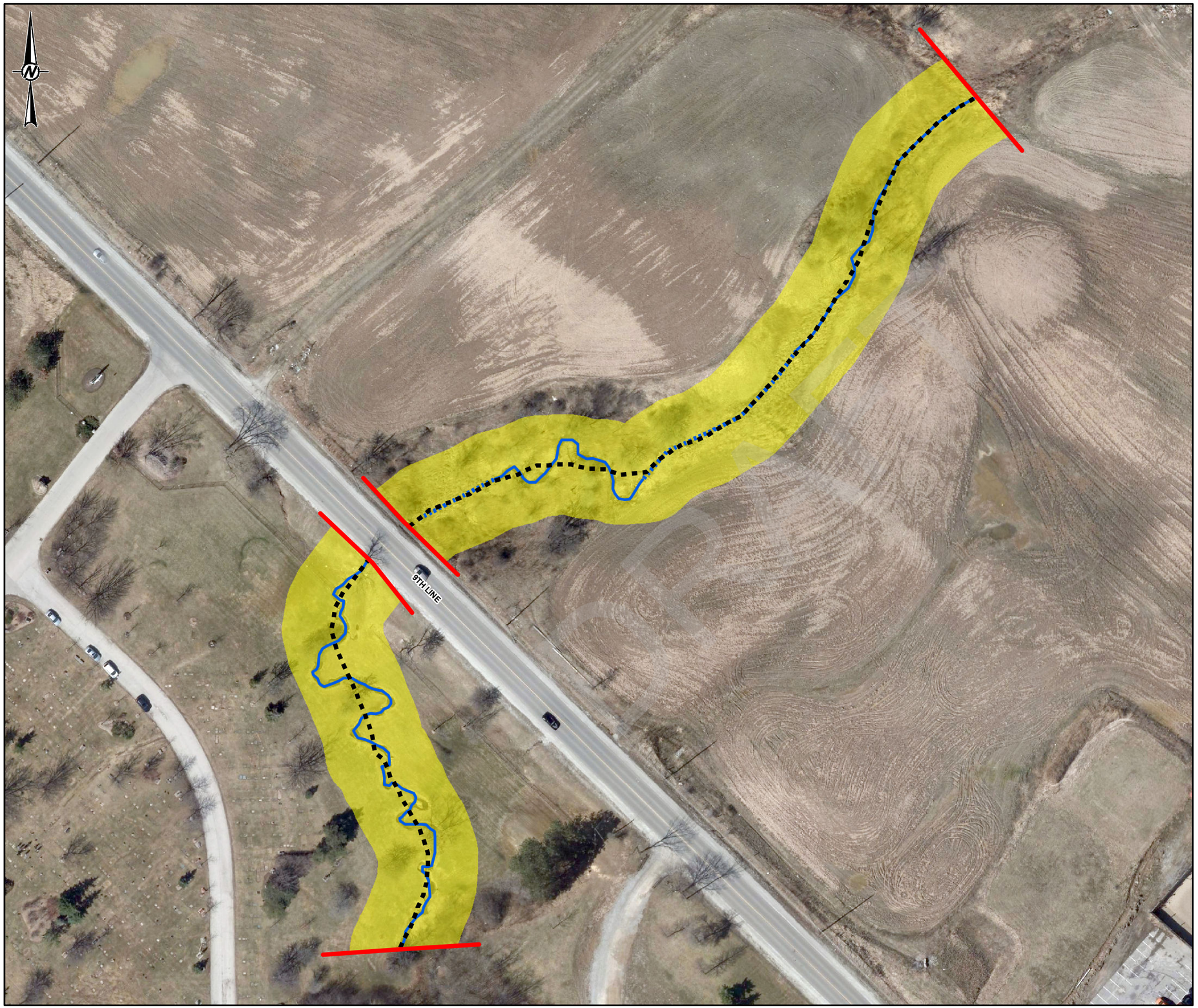

LEGEND

- Observed Channel Alignment in 2015 (Well Defined Bed and Banks)
- Inferred Channel Alignment in 2015 (No Defined Bed and Banks)
- Meander Belt Axis
- Reach Break
- Final Meander Belth Width

0 25 50

1:1,000 METRES

REFERENCE(S)

1. IMAGERY OBTAINED FROM FIRST BASE SOLUTIONS (SPRING 2015)
2. PROJECTION: TRANSVERSE MERCATOR DATUM: NAD83 COORDINATE SYSTEM: UTM ZONE 17

CLIENT
CIMA+

PROJECT
JOSHUA CREEK
NINTH LINE, OAKVILLE ONTARIO

TITLE
ESTIMATED MEANDER BELT WIDTH FOR STUDY AREA AT NINTH LINE

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-09-11
DESIGNED	SO
PREPARED	SO
REVIEWED	JL
APPROVED	AF

PROJECT NO.	CONTROL	REV.	FIGURE
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ATTACHMENT A

Photographs

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Photograph 1: RL-02; view looking upstream from the concrete box culvert on September 16, 2016.

Photograph 2: RL-01; view looking upstream at a location immediately downstream of the concrete box culvert on September 16, 2016.

Photograph 3: RL-01; view looking downstream from the concrete box culvert on September 16, 2016.

Photograph 4: RL-01; observed bank erosion at a mid-reach location on September 16, 2016.

Photograph 5: RL-03; view looking upstream on September 21, 2016.

Photograph 6: PSW (RL-04); view looking west from Ninth Line on September 21, 2016.

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ATTACHMENT B

Results of Rapid Geomorphic Assessments

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RAPID GEOMORPHIC ASSESSMENT (RGA)

Date: 21-Sep-16 Location: RL-01

Field Staff: MLE/DL Project #: 1648031

FORM/ PROCESS	GEOMORPHIC INDICATOR #	DESCRIPTION	PRESENT (YES) OR ABSENT (NO)	
Evidence of Aggradation (AI)	1	Lobate bar		No
	2	Coarse material in riffles embedded		No
	3	Siltation in pools	Yes	
	4	Medial bars		No
	5	Accretion on point bars		No
	6	Poor longitudinal sorting of bed materials	Yes	
	7	Deposition in the overbank zone		No
		RATIO OF INDICES [(1)]	2/7 = 0.29	
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	N/A	
	2	Exposed sanitary/storm sewer/pipeline/etc.		No
	3	Elevated storm sewer outfall(s)	Yes	
	4	Undermined gabion baskets/concrete aprons/etc.	N/A	
	5	Scour pools d/s of culverts/stormsewer outlets	Yes	
	6	Cut face on bar forms	Yes	
	7	Head cutting due to knick point migration		No
	8	Terrace cut through older bar material		No
	9	Suspended armor layer visible in bank		No
	10	Channel worn into undisturbed overburden/bedrock		No
		RATIO OF INDICES [(1)]	3/8 = 0.38	
Evidence of Widening (WI)	1	Fallen/leaning trees/fence posts/etc.	Yes	
	2	Occurrence of large organic debris	Yes	
	3	Exposed tree roots	Yes	
	4	Basal scour on inside meander bends	Yes	
	5	Basal scour on both sides of channel through riffle	N/A	
	6	Gabion baskets/concrete walls/etc. out flanked	N/A	
	7	Length of basal scour > 50% through subject reach	Yes	
	8	Exposed length of previously buried pipe/cable/etc.	N/A	
	9	Fracture lines along top of bank		No
	10	Exposed building foundation	N/A	
		RATIO OF INDICES [(1)]	5/6 = 0.83	
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)	Yes	
	2	Single thread channel to multiple channel	Yes	
	3	Evolution of pool-riffle form to low bed relief form		No
	4	Cutoff channel(s)	Yes	
	5	Formation of island(s)	Yes	
	6	Thalweg alignment out of phase meander form	Yes	
	7	Bar forms poorly formed/reworked/removed	Yes	
		RATIO OF INDICES [(1)]	6/7 = 0.86	
STABILITY INDEX (SI) = (AI + DI + WI + PI) / 4 [(2)]			0.59	

Notes:

[1] Ratio of Indices or Factor = Number of Indices Present / Total Number of Indice.s

[2] Stability Index or SI values inferred as follows: 0.20 or lower = In Regime; 0.21 to 0.40 = Transitional or Stressed; and 0.41 or higher = In Adjustment.

Sourced and adapted from: *Ontario Ministry of the Enviroment, 2003. Stormwater Management Planning and Design Manual.*

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RAPID GEOMORPHIC ASSESSMENT (RGA)

Date: 21-Sep-16 Location: RL-02

Field Staff: MLE/DL Project #: 1648031

FORM/ PROCESS	GEOMORPHIC INDICATOR #	DESCRIPTION	PRESENT (YES) OR ABSENT (NO)	
Evidence of Aggradation (AI)	1	Lobate bar		No
	2	Coarse material in riffles embedded		No
	3	Siltation in pools	Yes	
	4	Medial bars		No
	5	Accretion on point bars		No
	6	Poor longitudinal sorting of bed materials		No
	7	Deposition in the overbank zone	Yes	
		RATIO OF INDICES (1)	2/7 = 0.29	
Evidence of Degradation (DI)	1	Exposed bridge footing(s)	N/A	
	2	Exposed sanitary/storm sewer/pipeline/etc.		No (Buried)
	3	Elevated storm sewer outfall(s)		No
	4	Undermined gabion baskets/concrete aprons/etc.	N/A	
	5	Scour pools d/s of culverts/stormsewer outlets	N/A	
	6	Cut face on bar forms		No
	7	Head cutting due to knick point migration		No
	8	Terrace cut through older bar material		No
	9	Suspended armor layer visible in bank		No
	10	Channel worn into undisturbed overburden/bedrock		No
		RATIO OF INDICES (1)	0/7 = 0.00	
Evidence of Widening (WI)	1	Fallen/leaning trees/fence posts/etc.		No
	2	Occurrence of large organic debris	Yes	
	3	Exposed tree roots		No
	4	Basal scour on inside meander bends		No
	5	Basal scour on both sides of channel through riffle	N/A	
	6	Gabion baskets/concrete walls/etc. out flanked	N/A	
	7	Length of basal scour > 50% through subject reach		No
	8	Exposed length of previously buried pipe/cable/etc.		No
	9	Fracture lines along top of bank		No
	10	Exposed building foundation	N/A	
		RATIO OF INDICES (1)	1/7 = 0.14	
Evidence of Planimetric Form Adjustment (PI)	1	Formation of chute(s)		No
	2	Single thread channel to multiple channel		No
	3	Evolution of pool-riffle form to low bed relief form		No
	4	Cutoff channel(s)		No
	5	Formation of island(s)		No
	6	Thalweg alignment out of phase meander form		No
	7	Bar forms poorly formed/reworked/removed		No
		RATIO OF INDICES (1)	0/7 = 0.00	
STABILITY INDEX (SI) = (AI + DI + WI + PI) / 4 (2)			0.11	

Notes:

[1] Ratio of Indices or Factor = Number of Indices Present / Total Number of Indice.s

[2] Stability Index or SI values inferred as follows: 0.20 or lower = In Regime; 0.21 to 0.40 = Transitional or Stressed; and 0.41 or higher = In Adjustment.

Sourced and adapted from: *Ontario Ministry of the Enviroment, 2003. Stormwater Management Planning and Design Manual.*

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ATTACHMENT C

Grain Size Distribution Curves

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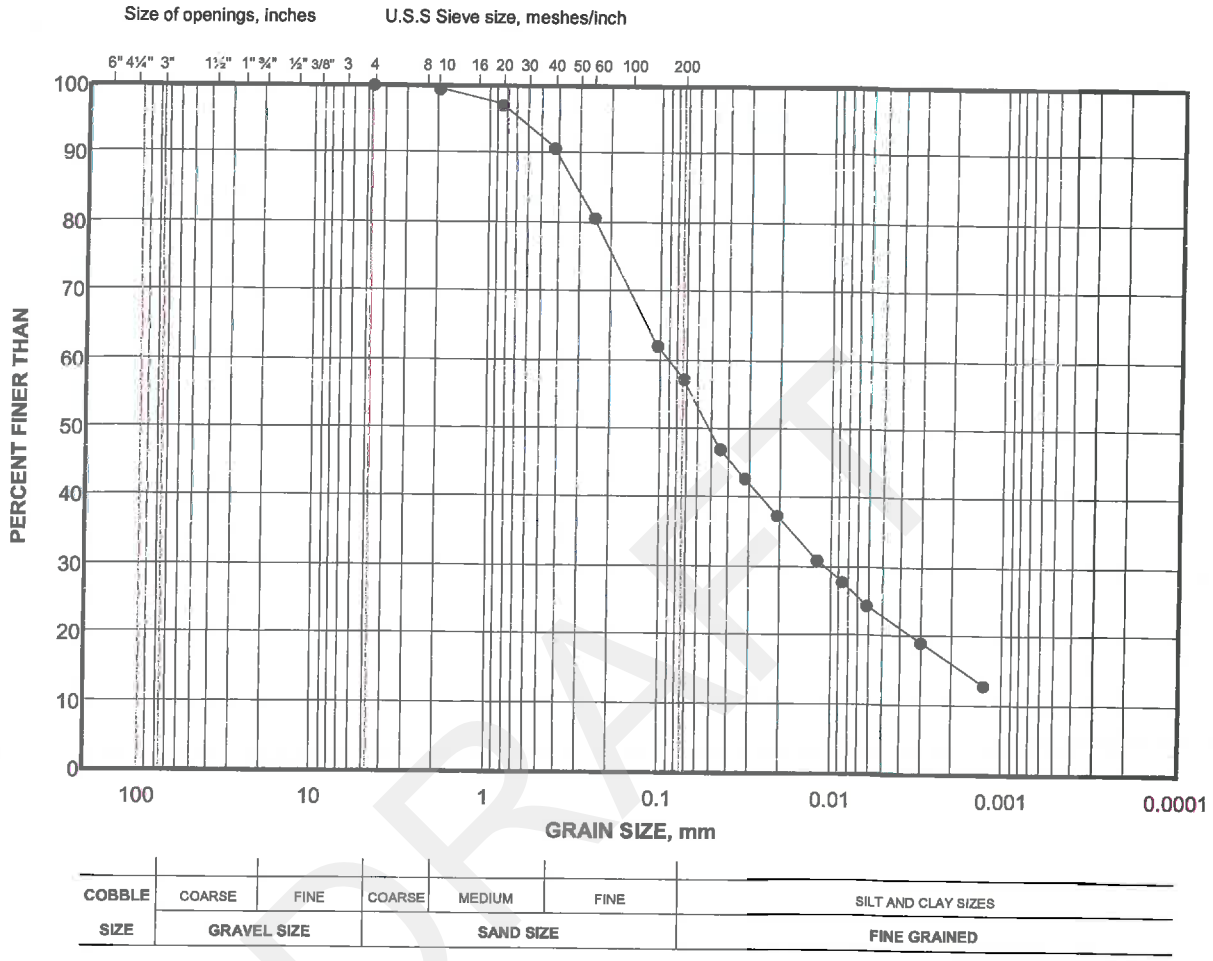
GRAIN SIZE DISTRIBUTION

FIGURE



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LEGEND

SYMBOL	SAMPLE
●	D/5 BANK

REMARKS
5.44g of wood chips retained on 4.75 mm sieve

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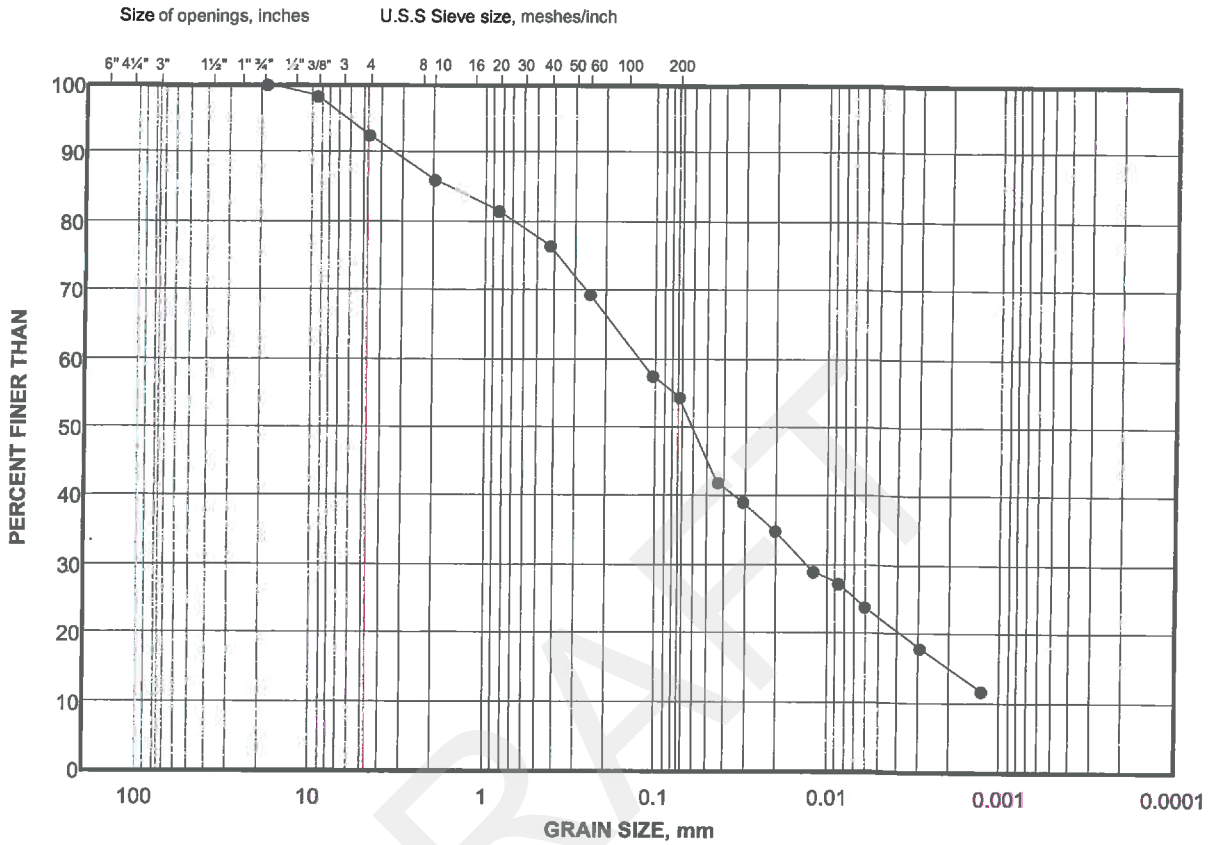
Checked By: _____

Golder Associates

Date: 08-Nov-16

GRAIN SIZE DISTRIBUTION

FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

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LEGEND

SYMBOL	SAMPLE
●	D/5 BED

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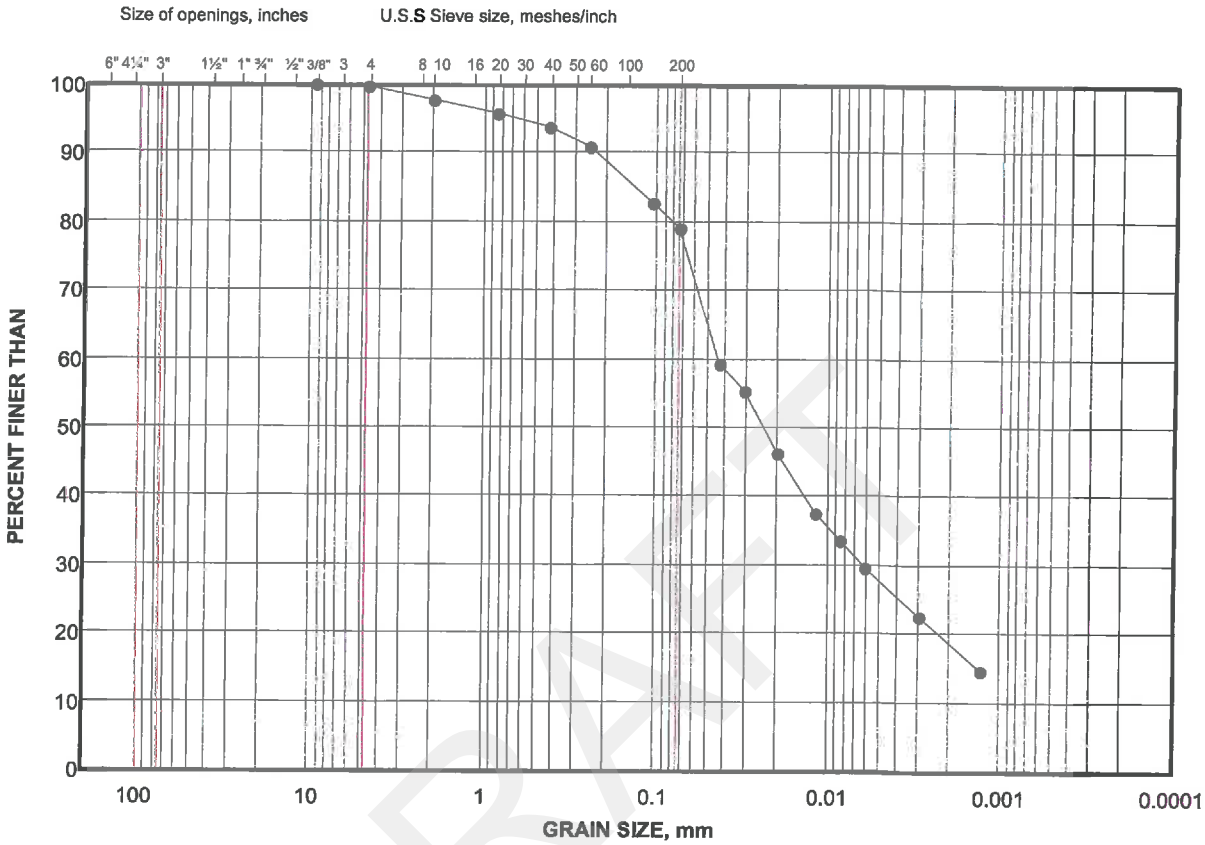
GRAIN SIZE DISTRIBUTION

FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

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LEGEND

SYMBOL	SAMPLE
●	U/5 BED

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