Appendix C
Fluvial Geomorphology Assessment
June 16, 2015
WE 14046

Tom Mahood, P.Eng.
Project Manager
CH2M
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Kitchener, ON N2G 4Y9

Dear Mr Mahood:

RE: Mud Creek Environmental Assessment – City Of London
Fluvial Geomorphological Component – Draft Report

1. INTRODUCTION
In anticipation of development in the Mud Creek Subwatershed, the City of London (City) has requested consulting services to support a Municipal Class Schedule B Environmental Assessment (EA). An original Subwatershed Study was completed in 1995, with recent studies completed in 2009 and 2014. The most recent update addressed water resources components, and included some preliminary mitigation strategies to address existing issues within the watershed, with specific direction to improve flooding, erosion, and sedimentation issues. Within the EA, the City requires that the mitigation strategies from the Subwatershed Study Update (2014) be considered in developing sound environmental design alternatives that consider the current and future conditions of the subwatershed as they relate to development.

Water’s Edge was authorized by CH2M to undertake a fluvial geomorphological assessment for Mud Creek which confirms and updates previous findings/issues through a desktop and field assessment. The results of the assessment will be used develop and assess design alternatives, ultimately contributing to the selection of a preferred. Functional concept designs for the preferred alternative are required to fulfill the requirements of the EA that enhance the conveyance of flood events, while creating a dynamically stable river channel.

Issues identified through the background review and those explicitly stated by the City in their RFP will be used to guide this study, particularly when updating the existing conditions and reviewing prior mitigation recommendations. Furthermore, the EA process requires that insight, concerns, and feedback from local stakeholders be considered in the selection and design of the preferred alternative. Emphasis in this study will be placed on developing functional, concept designs that consider the existing issues and future impacts, and stakeholder feedback which may then be used to advise the detailed design of Mud Creek prior to and during development.

The entire Mud Creek subwatershed has a drainage area of 7.59km², but the focus of this study is placed on the remaining open watercourses of East Mud Creek that has a drainage area of 3.58km² (Figure 1.1) The primary goal for the remediation of streams in this area is to reduce overland flooding along Oxford Street in the central portion of the catchment. Coincidentally, flood mitigation requires channel design updates that enhance both the ecological and physical condition and function of the system to convey, and store, water and sediment, while improving the quality of the stream and riparian habitat zones.
2. BACKGROUND REVIEW

A number of data sources including the latest Subwatershed Update and provide pertinent information on the existing and future conditions including: watershed and channel characteristics, hydrology and hydraulics, geology, specific issues related to erosion and deposition, and potential alternatives to manage future conditions. The following data sources were used to review background information and gather an understanding of existing and future conditions for the study area:

- East Mud Creek Tributary Storm Drainage and Stormwater Management (SWM) Servicing Study – Class EA – Draft Report (Development Engineering Ltd. 2009). Supporting Documentation:
  - Geomorphic Existing Conditions Mud Creek (Geomorphic Solutions, 2008).
  - Supporting Technical Memoranda (Geomorphic Solutions, 2008)
- Mud Creek Subwatershed Study – Update of the Water Resources Components (Delcan, 2014). Supporting Documentation:
The following sections summarize general and specific points relating to or influencing stream channel morphology for Mud Creek:

**Physiography and Surficial Geology**

Reviewing the site area’s surficial materials is important to evaluate active channel processes. Stream channel form and sediment supply are controlled by the region’s physiography and underlying surficial geology.

The Mud Creek drainage basin is located entirely within the Stratford Till Plain physiographic region (Chapman and Putnam 2007). The Thames River valley was a glacial spillway, and much of Mud Creek passes over fluvial sands and gravels associated with glacial outwash. Borehole data suggest that much of the area is underlain by silty Tills with occurrences of loose sands and gravels. The upper portions of Mud Creek flow over glacial tills that have a low stone content and are less consolidated than other Ontario Tills (e.g. Newmarket Till). Overburden thickness is ~30m to around ~70m, through which Mud Creek has cut some distinctive valley features, creating some confined reaches. Ravine features vary along the system and likely relate to a transition between different stratigraphic units (e.g. tills to sands).

**Land Use/Cover**

Within the floodplain of Mud Creek, land is primarily forested, with agricultural land and open space running adjacent to the upper reaches, north of Oxford Street. Land use is primarily urban beyond the floodplain, with mixed low and high density residential, commercial, roads, and open space (cemetery and golf course). A CP rail corridor acts as the northern limit of the study area, while another CN Rail Corridor crosses the main channel with a concrete-pipe culvert beneath. Oxford Street West and Proudfoot Lane cross the open watercourse with concrete box culverts.

Historical air photo assessment from previous work determined that land-cover transitioned from being primarily agricultural to urban through the 1960s and 1970s.

**Channel Characteristics**

The historical assessment in earlier studies also characterized channel adjustments and inferred the mode of adjustment. Development directly altered the channel configuration and drainage pattern of Mud Creek. Early modifications (pre-1945) included channel straightening to maximize the land available for agricultural activity. As the urbanization of London expanded into Mud Creek’s catchment, many tributaries were piped to accommodate development.

Most of the piping occurred upstream of the CP Rail embankment, while downstream was left natural or straightened to accommodate agricultural practices. From the CN Railway to upstream of Oxford Street, the creek was straightened and widened. Evidence was found to indicate significant backwatering upstream of the CN Culvert historically and within contemporary photography. The channel was realigned, causing some length increase at the Proudfoot Lane culvert between 1972 and 1982 (Figure 2.1).

Using surficial geology, topographic data, and colour aerial photography, Geomorphic Solutions delineated reaches to allow for a systematic review of channels in the watershed. Parish Geomorphic Ltd used the same general reach segments in their analysis, and updated work that included Rapid Geomorphic Assessments (RGAs), the Rapid Stream Assessment Technique (RSAT), to characterize the stability and ecological health of each reach, respectively. During these rapid assessments, general channel characteristics were recorded and summarized.
RGA and RSAT results varied between each study, and will be revisited later in this report. But, RGA (stability) scores ranged from in regime (stable), to in adjustment (unstable), and RSAT scores revealed primarily low stream health with some moderately healthy reaches.

Some general fluvial characteristics were observed along the system:

- Upstream sections that were previously straightened were actively recovering by eroding the channel boundaries. Coarse gravels and cobbles made up some bedforms (bars and riffles), and were likely supplied from the eroding banks and bed.
- Closer to Oxford Street, bank definition became more poorly defined as aggradation and in channel vegetation (cattails) encroached upon the channel. These sediments formed a soft bed and were likely supplied from upper reaches. Water was slow moving, exhibiting a backwater effect.
- This backwater effect, soft bed, and aggradation continued down towards the CN Culvert which was identified as the major cause for this issue. Banks downstream of Oxford were better defined through these forested reaches. Immediately upstream of the CN Culvert, a large ponded section exists with no defined channel. These sections were entirely straightened similar to those upstream.
- Downstream of the CN Culvert, Mud Creek was straightened, and flows between the CN Culvert and a large concrete aquaduct that drains the system to the Thames River. This section had high steep banks, with exposed tree roots, and wood debris, which are indicative of the channel's tendency to widen. Well developed pools and riffles of sorted gravels and cobbles were observed, as were a number of artificial weirs and one private foot bridge. This section flows through private property at the rear of detached residential parcels.

The Subwatershed Study (2014) included an erosion threshold analysis that determined the hydraulics such as discharge, flow depth, and average velocity, at which the enough shear stress is produced to mobilize an index grainsize characteristic of a selected reach.
**Existing Channel Issues**

Each study dating back to 1995 identified the significant backwatering impact that the CN Rail culvert. Compared to the culverts at Proudfoot Land and Oxford Street, the invert of the CN Culvert sits approximately 1.38m higher than the Proudfoot Invert located 485m upstream. This culvert impedes the conveyance of water and sediment under a range of flow conditions, and prolongs the erosive effects of flood events downstream. The low gradient and backwater effect extend upstream of Oxford Street, resulting in excessive sedimentation in the channel, and a lack of variation in bedforms and material, limiting the amount of available low flow habitat through these middle reaches. The storage of excess sediment upstream of the CN rail can also enhance the erosive effect downstream as the channel erodes its boundary to expend energy.

Sediment buildup in the Proudfoot and Oxford culverts has severely reduce the capacity, and gradient through the middle reaches.

**Recommended Stream Remediation**

To address the primary issues resulting from the existing CN Culvert an important recommendation was made to enlarge and/or lower the culvert to improve upstream slopes and enhance flow and sediment conveyance. Recognizing the potential complications of such a construction project, recommendations were also made to enhance the backwatered sections upstream of the CN Rail corridor under existing conditions by managing stormwater and reconstructing the channel and floodplain to convey predicted flows. The control of flows would reduce the amount of sediment delivered to the middle reaches, and the reconstruction or “cleaning and lowering” of the channel and floodplain would help reduce downstream flow energy during floods and store some fine sediment in the system. The reach downstream of the CN
Culvert could be designed with a channel cross-section, floodplain connectivity, profile, and substrates that create a more natural habitat where peak flows of around a 1.5 to 2-year recurrence interval will move the sediment and support the riparian zone and floodplain.

Final alternatives out of the Delcan (2014) Subwatershed Study Update included the aforementioned recommendations with the following actions:

- On-site water quality/quantity (SWM) controls;
- Cleaning out the Proudfoot and Oxford Culverts
- Cleaning stormwater pipes affected by the reduced culvert capacity;
- Line the CN culvert to address structural stability;
- Bank treatments to reduce erosion downstream of the CN Culvert;
- Channel “cleaning” and “deepening” from the CN Culvert to upstream of Oxford Street, and;
- Channel stabilization further upstream.

These recommendations and the background review in general have been considered in the development and assessment of additional alternatives presented as a part of this study.

3. REACH DELINEATION

Channel morphology and substrate characteristics tend to change along a watercourse. Hence, it becomes imperative to account for this variation by delineating lengths of a watercourse that exhibit similar planform, sediment substrate, land use, local geology, valley confinement, hydrology and gradient. Typically reaches are comprised of at least two meander bends and range in length from 200m to a few thousand metres. Since reaches were already previously delineated by Geomorphic Solutions (GS) in 2008, and adapted by Parish Geomorphic Limited (PGL) in 2013, this assessment also adopted the existing reach delineation to allow for comparison between studies. PGL subdivided reach 7C into two reaches due to an obvious change in sinuosity, creating 15 reaches. Based on updated aerial photography and an initial site visit, Water’s Edge reverted back to the original reach breaks delineated by GS in 2008. Each of these 14 reaches was walked, but rapid field assessments were only performed upon 11 reaches in total due to lack of channel definition. Table 3.1 contains some general descriptions of each reach assessed. Descriptions and discussions throughout the rest of this document refer to left and right banks as viewed in a downstream direction.
Figure 3.1: Reach map.
### Table 3.1: General Reach Characteristics

<table>
<thead>
<tr>
<th>Reach</th>
<th>Characteristics</th>
</tr>
</thead>
</table>
| MC-1  | Straightened channel with bank scour. Primarily run features with few pools and riffles.  
The channel flows through a woodlot/residentially property, with manicured lawns and some fencing along the top of bank.  
The lower 30m is a confined rip-rap channel that flows into the Riverside Drive culvert which discharges directly to the Thames River. |
| MC-2  | Entirely backwatered by CN Culvert, no identifiable channel. |
| MC-3  | Previously straightened and realigned to accommodate the commercial development along the right bank.  
Flows through forested section of floodplain.  
Right bank is confined downstream of a 90° bend, with a narrow floodplain bench for some of this confined stretch.  
The woodlot provides channel cover and wood debris.  
No defined low-flow channel, bed is soft and fine. |
| MC-4  | Similar to MC-3, but with a narrower wooded riparian buffer.  
Minor bank erosion noted within closer proximity to Proudfoot Lane. |
| MC-5  | Designed channel running parallel to Oxford St W.  
Backwater effect still present, causing siltation. Riparian zone and channel margins dominated by cattails.  
Riparian width confined to channelized section. Mowed lawn beyond riparian zone.  
Bank erosion and widening downstream of twin driveway culverts. |
| MC-6  | Backwater effect ends around the upstream limit of this reach where the outfall reach 6b joins.  
Similar to MC-3&4 with heavy siltation.  
Channel migration evident.  
Fallen trees provide wood debris.  
Large forest canopy and riparian habitat |
| MC-7  | Flowing channel, previously straightened but lateral bars indicate a meandering tendency.  
Gravels and cobbles comprise bedforms (riffles, and bars).  
Large forest canopy and riparian habitat |
| MC-7a | Heavy silt/sand content – possibly from adjacent farm runoff.  
Straight channel with minor undulations in the planform. In channel vegetation present near the confluence with MC-7.  
Bank erosion and widening occurring around failing bridge footings of former farm crossing.  
Bedforms present, but irregularly between areas of siltation. |
| MC-7b | Sinuous, narrow single-thread channel with gravel riffles and some deep pools.  
Banks are overhanging along the outer side of bends. |
| MC-7c | Bed materials dominated by cobbles, and boulders.  
Flows through a defined valley, with forested banks. Channel appears to be widening, causing trees to fail.  
A series of step-pools through glacial till occurs nearer the top end of the reach.  
Channel originates at the upstream end from an outfall structure. |
| MC-8  | Originates at stormwater outfall, with deep/wide scour pool into glacial till.  
Gravel/cobble substrates throughout.  
Bedforms include riffles and bars, pools are generally shallow.  
Steep. High (3m) bank comprised of sands and gravels actively eroding.  
Some sections of the channel highly confined to the channelized geometry imposed during straightening.  
Bank scour is contributing wood debris from the vegetated banks. |
4. FIELD ASSESSMENTS

Staff visited East Mud Creek in early December of 2014 to gather a synoptic level understanding of the trends and channel condition through the application of rapid assessments (check sheets). Rapid field assessments provide an indication of the channel stability and ecological health and impacts, while also identifying primary processes in action (e.g. widening). Staff then returned on two occasions in April of 2015 to complete a geomorphic survey of channel dimensions and composition to provide a detailed characterization to support an erosion thresholds assessment and the development of concept designs.

4.1. Rapid Assessments

Rapid Geomorphic Assessment (RGA)

Creek stability was assessed using a Rapid Geomorphic Assessment (MOE, 2003). The RGA assessment focuses entirely on the geomorphic component of a river system. The RGA method consists of four factors that summarize various components of channel adjustment, specifically: aggradation, degradation, channel widening and plan form adjustment. Each factor is assessed separately and the total score indicates the overall stability of the system. This methodology has been applied to numerous streams and rivers and the following table details the ranking criteria (see Table 4.1).

<table>
<thead>
<tr>
<th>Stability Index (SI) Value</th>
<th>Classification</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI ≤ 0.20</td>
<td>In Regime</td>
<td>The channel morphology is within a range of variance for rivers of similar hydrographic characteristics and evidence of instability is isolated or associated with normal river meander processes.</td>
</tr>
<tr>
<td>0.21 ≤ SI ≤0.40</td>
<td>Transitional/Stressed</td>
<td>Channel morphology is within a range of variance for rivers of similar hydrographic characteristics but the evidence of instability is frequent.</td>
</tr>
<tr>
<td>SI ≥ 0.40</td>
<td>In Adjustment</td>
<td>Channel morphology is not within the range of variance and evidence of instability is widespread.</td>
</tr>
</tbody>
</table>

Rapid Stream Assessment Technique (RSAT)

Rapid Stream Assessment Technique was developed by John Galli and other staff of the Metropolitan Washington (DC) Council of Governments (Galli et al, 1996). The RSAT systematically focuses on conditions reflecting aquatic-system response to watershed urbanization. It groups responses into six categories, presumed to adequately evaluate the conditions of the river system at the time of measurement on a reach-by-reach basis. The six categories are:

1. Channel stability;
2. Channel scouring and sediment deposition;
3. Physical in-stream habitat;
4. Water quality;
5. Riparian habitat conditions; and
6. Biological conditions.

River channel stability and cross-sectional characterization is a critical component of RSAT. The entire channel was inspected for signs of instability (such as bank sloughing, recently exposed non-woody tree roots, general absence of vegetation within bottom third of the bank, recent tree
falls, etc.) and channel degradation or downcutting (such as high banks in small headwater streams and erosion around man-made structures).

A rapid assessment of soil conditions along the river banks is also conducted to determine soil texture and potential erodibility of the watercourse bank. Qualitative water quality measurements were also made (temperature, turbidity, colour and odour) along with an indication of substrate fouling (i.e., the unwanted accumulation of sediment).

RSAT also typically involves a quantitative sampling and evaluation of benthic organisms. As no benthic sampling was undertaken, the score was based on site conditions and general observations of water quality.

<table>
<thead>
<tr>
<th>RSAT Score</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>41-50</td>
<td>Excellent</td>
</tr>
<tr>
<td>31-40</td>
<td>Good</td>
</tr>
<tr>
<td>21-30</td>
<td>Fair</td>
</tr>
<tr>
<td>11-20</td>
<td>Poor</td>
</tr>
<tr>
<td>0-10</td>
<td>Degraded</td>
</tr>
</tbody>
</table>

**Qualitative Habitat Evaluation Index (QHEI)**

Another rapid evaluation of the creek characteristics was carried out in order to rate the ecological impacts in the creek system by using the Qualitative Habitat Evaluation Index (QHEI). This evaluation system details the creek characteristics and relates them to the habitat of the system, ultimately rating the environmental and ecosystem considerations. This differs from the RSAT scoring by using a check-sheet of physical features and attributes, each with an assigned value based on the ecological significance, rather than assigning a score from a range based on the observed stream quality.

The Qualitative Habitat Evaluation Index (QHEI) is a physical habitat index designed to provide an empirical, quantified evaluation of the general lotic macrohabitat characteristics that are important to fish communities. A detailed analysis of the development and use of the QHEI is available in Rankin (1989) and Rankin (1995). The QHEI is composed of six principal metrics each of which are described below. The maximum possible QHEI site score is 100. Each of the metrics are scored individually and then summed to provide the total QHEI site score. This is completed at least once for each sampling site during each year of sampling. An exception to this convention would be when substantial changes to the macrohabitat have occurred between sampling passes. Standardized definitions for pool, run, and riffle habitats, for which a variety of existing definitions and perceptions exist, are essential for accurately using the QHEI. For consistency the following definitions are taken from Platts et al. (1983).

**Metric 1**, Substrate includes two components, substrate type and substrate quality. The Substrate origin refers to the “parent” material that the stream substrate is derived from. The Embeddedness is the degree that cobble, gravel, and boulder substrates are surrounded, impacted in, or covered by fine materials (sand and silt). Silt cover is the extent that substrates are covered by a silt layer (i.e., a 1 inch thick or that is obviously affecting aquatic habitats). Silt cover differs from the embeddedness metric in that it only considers the fine silt size particles whereas fine gravels, sands, and other fines are considered in assessing embedded conditions.

**Metric 2**, Instream Cover, scores presence of instream cover types and amount of overall instream cover. Each cover type that is present in an amount occurs in sufficient quantity to support species that may commonly be associated with the habitat type should be scored. Cover should not be counted when it is in areas of the stream with insufficient depth (usually < 20 cm) to make it useful. For example a logjam in 5 cm of water contributes very little, if any, cover, and at
low flow may be dry. Other cover types with limited function in shallow water include undercut banks and overhanging vegetation, boulders, and root wads.

**Metric 3.** Channel Morphology, emphasizes the quality of the stream channel that relates to the creation and stability of macrohabitat. It includes channel sinuosity (i.e. the degree to which the stream meanders), channel development, channelization, and channel stability.

**Metric 4.** Riparian Zone and Bank Erosion, emphasizes the quality of the riparian buffer zone and quality of the floodplain vegetation. This includes riparian zone width, floodplain quality, and extent of bank erosion.

**Metric 5.** Pool, glide and riffle-run quality emphasizes the quality of the pool, glide and/or riffle-run habitats. This includes pool depth, overall diversity of current velocities (in pools and riffles), pool morphology, riffle-run depth, riffle-run substrate, and riffle-run substrate quality.

**Metric 6.** Local or map gradient is calculated from topographic maps by measuring the elevation drop through the sampling area. This is done by measuring the stream length between the first contour line upstream and the first contour line downstream of the sampling site, and dividing the distance by the contour interval. If the contour lines are closely "packed" a minimum distance of at least 1.6 km (one mile) should be used.

The final QHEI scores can be qualitatively compared to other scores by the use of **Table 4.3** which provides narrative equivalents to QHEI ranges.

<table>
<thead>
<tr>
<th>QHEI Range</th>
<th>QHEI Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;70</td>
<td>Excellent</td>
</tr>
<tr>
<td>55-70</td>
<td>Good</td>
</tr>
<tr>
<td>43-54</td>
<td>Fair</td>
</tr>
<tr>
<td>30-42</td>
<td>Poor</td>
</tr>
<tr>
<td>&lt;30</td>
<td>Very Poor</td>
</tr>
</tbody>
</table>

**4.2. Rapid Assessment Results**

Similar to previous studies, the reaches of East Mud Creek exhibit a tendency to adjust, either in a transitional state or in a state of adjustment, with the exception of MC 7-a which was "in regime" in both the PGL and GS reports (**Table 4.3**). It is possible that the observed failure around the former farm crossing abutments occurred subsequently. The primary modes of adjustment are aggradation (MC-3,4,5,6,7a), and widening elsewhere. Overall, Reaches MC-7&8 are the most unstable, showing general enlargement trends, and attempts to recover from channelization and the urbanized flow regime.

RSAT results vary from upstream to downstream, with “Poor” to “Good” conditions. Some general trends can be identified, for example, the backwatered and aggrading reaches scored “fair” and “poor” in terms of stream health, while the more active channels with variation in bed form, material, and in-channel cover upstream of reach MC-6, and downstream of the CN Culvert exhibit better stream function from an ecological perspective.

QHEI values also indicate trends of poor channel characteristics for ecological function for those backwatered and aggrading reaches. Compared to other reaches, these sections lacked quality substrates, channel morphology, well developed bedforms (pools-riffles-runs) and hence any functionality, and were of a relatively low gradient.
### Table 4.3: RGA Results

<table>
<thead>
<tr>
<th>Reach</th>
<th>Aggradation</th>
<th>Degradation</th>
<th>Widening</th>
<th>Planform Adjustment</th>
<th>Stability Index</th>
<th>Condition</th>
<th>PGL 2013</th>
<th>GS 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC-1</td>
<td>0.00</td>
<td>0.40</td>
<td>0.78</td>
<td>0.00</td>
<td>0.29</td>
<td>Transitional</td>
<td>0.25</td>
<td>0.17</td>
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<tr>
<td>MC-3</td>
<td>0.71</td>
<td>0.00</td>
<td>0.33</td>
<td>0.14</td>
<td>0.30</td>
<td>Transitional</td>
<td>0.30</td>
<td>0.47</td>
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<tr>
<td>MC-4</td>
<td>0.86</td>
<td>0.00</td>
<td>0.56</td>
<td>0.00</td>
<td>0.35</td>
<td>Transitional</td>
<td>0.30</td>
<td>0.37</td>
</tr>
<tr>
<td>MC-5</td>
<td>0.86</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.21</td>
<td>Transitional</td>
<td>n/a</td>
<td>0.18</td>
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<tr>
<td>MC-6</td>
<td>0.86</td>
<td>0.00</td>
<td>0.22</td>
<td>0.00</td>
<td>0.27</td>
<td>Transitional</td>
<td>0.25</td>
<td>0.36</td>
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<tr>
<td>MC-7</td>
<td>0.43</td>
<td>0.00</td>
<td>0.44</td>
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<td>0.29</td>
<td>0.31</td>
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<tr>
<td>MC-7a</td>
<td>0.86</td>
<td>0.10</td>
<td>0.33</td>
<td>0.00</td>
<td>0.32</td>
<td>Transitional</td>
<td>0.19</td>
<td>0.18</td>
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<tr>
<td>MC-7b</td>
<td>0.57</td>
<td>0.00</td>
<td>0.25</td>
<td>0.29</td>
<td>0.28</td>
<td>Transitional</td>
<td>0.36</td>
<td>0.30</td>
</tr>
<tr>
<td>MC-7c</td>
<td>0.29</td>
<td>0.22</td>
<td>0.88</td>
<td>0.29</td>
<td>0.42</td>
<td>In Adjustment</td>
<td>0.39</td>
<td>0.35</td>
</tr>
<tr>
<td>MC-8</td>
<td>0.43</td>
<td>0.50</td>
<td>0.67</td>
<td>0.00</td>
<td>0.40</td>
<td>Transitional</td>
<td>0.32</td>
<td>0.24</td>
</tr>
</tbody>
</table>

### Table 4.4: RSAT Scores

<table>
<thead>
<tr>
<th>Reach</th>
<th>Channel Stability/11</th>
<th>Scour and Deposition/8</th>
<th>In-Stream Habitat/8</th>
<th>Water Quality/8</th>
<th>Riparian Condition/7</th>
<th>Biological Indicators/8</th>
<th>Total Score/50</th>
<th>Condition</th>
<th>PGL 2013</th>
<th>GS 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC-1</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>33</td>
<td>Good</td>
<td>28.5</td>
<td>26.5</td>
</tr>
<tr>
<td>MC-3</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>21</td>
<td>Fair</td>
<td>24.5</td>
<td>14.5</td>
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<td>MC-4</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>20</td>
<td>Poor</td>
<td>24.5</td>
<td>14.5</td>
</tr>
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<td>MC-5</td>
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<td>2</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>16</td>
<td>Poor</td>
<td>n/a</td>
<td>11</td>
</tr>
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<td>MC-6</td>
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<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>21</td>
<td>Fair</td>
<td>23.5</td>
<td>13.5</td>
</tr>
<tr>
<td>MC-7</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>31</td>
<td>Good</td>
<td>31</td>
<td>16</td>
</tr>
<tr>
<td>MC-7a</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>25</td>
<td>Fair</td>
<td>24.5</td>
<td>18.5</td>
</tr>
<tr>
<td>MC-7b</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>31</td>
<td>Good</td>
<td>26.5</td>
<td>21.5</td>
</tr>
<tr>
<td>MC-7c</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>33</td>
<td>Good</td>
<td>27</td>
<td>16.5</td>
</tr>
<tr>
<td>MC-8</td>
<td>3</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>3</td>
<td>5</td>
<td>28</td>
<td>Fair</td>
<td>27</td>
<td>13.5</td>
</tr>
</tbody>
</table>

### Table 4.5: QHEI Scores
4.3. Detailed Field Surveys

In addition to rapid field assessments, detailed surveys were completed using a survey grade GPS and/or total station in April of 2015. This detailed work included cross-section and profile surveys, and Wolman pebble counts to quantify bed material size. Bank materials were also noted at each cross-section. Reaches MC-1, MC-7 and MC-8 were selected for detailed analysis in anticipation of the conceptual channel design having to tie into a location upstream of the backwater effect, and similarly downstream of the CN Culvert as it is relocated to a lower elevation.

This detailed assessment focused on surveying the bankfull channel dimensions at each cross-section using known indicators such as inflection points and vegetation patterns. The “bankfull” channel represents the maximum capacity of the channel to contain flows before water inundates the floodplain. This channel form is generally thought to respond to prevailing flow and sediment regimes, with some influence of valley confinement, bedrock/cohesive horizons, and artificial channel hardening. The prevailing flow that shapes the channel is often referred to as the “channel forming” or “prevailing” discharge, and has a recurrence of 1.5 to 2-years. The bankfull channel survey of cross-section and gradient (energy slope), and material roughness can be utilized to estimate bankfull discharge, and other hydraulic characteristics including shear stress. Table 4.6 presents the results of the detailed bankfull surveys, and Table 4.7 contains the estimated hydraulics for each reach.

Bankfull dimensions generally enlarge in the downstream direction with areas increasing from Reaches MC-7 and 8 down to MC-1, which is typical of alluvial systems. Slopes are moderate through the surveyed reaches, with the exception of the upmost section of Reach MC-8 that is slightly higher. Bed materials in both surveys are in the gravel to cobble range, with sands located in the interstitial spaces.

Two parameters of particular importance with respect to channel stability are the width-to-depth and entrenchment ratios. The former indicates a tendency for a channel to widen and aggrade as this value increases, and incise and narrow as it decreases. Values above 15 and below 8 are indicative of a channel becoming unstable. The entrenchment ratio is similar in that it provides a direct measure of channel incision. Low entrenchment ratios (<1.4) indicate that the bankfull
channel has little access to the floodplain, and larger floods are conveyed within a greater cross-section area above the bankfull elevation before spilling onto available floodplain, attenuating forces and depositing sediment/nutrients. Cross-sections 3 and 4 from Reach MC-7 and 8 are located in MC-7 have high width to depth ratios as the channel is widening. But this may also be a residual backwater effect under larger flood events. Channel entrenchment is low to moderate for most cross-sections, with the exception of XS2 in Reach 8, which was quite confined to the previously channelized banks.

Estimated bankfull hydraulics show an increase in discharge and shear stress between upstream and downstream reaches, as expected. Under these bankfull conditions coarse gravels and finer can be expected to mobilize.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bankfull Width (m)</td>
<td>MC-1 5.95</td>
</tr>
<tr>
<td>Bankfull Mean Depth (m)</td>
<td>0.45</td>
</tr>
<tr>
<td>Bankfull Max Depth (m)</td>
<td>0.62</td>
</tr>
<tr>
<td>Bankfull Area (m²)</td>
<td>2.74</td>
</tr>
<tr>
<td>Wetted Perimeter (m)</td>
<td>6.30</td>
</tr>
<tr>
<td>Hydraulic Radius (m)</td>
<td>0.43</td>
</tr>
<tr>
<td>Width-Depth Ratio</td>
<td>13.24</td>
</tr>
<tr>
<td>Entrenchment Ratio</td>
<td>2.76</td>
</tr>
<tr>
<td>Bankfull Slope (m/m)</td>
<td>0.005</td>
</tr>
<tr>
<td>Channel Substrate D₅₀ (mm)</td>
<td>17.58</td>
</tr>
<tr>
<td>Channel Substrate D₈₄ (mm)</td>
<td>79.47</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Reach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Roughness (m)</td>
<td>MC-1 25.54</td>
</tr>
<tr>
<td>Shear Velocity (m/s)</td>
<td>0.14</td>
</tr>
<tr>
<td>Velocity based on ff/RR (m/s)</td>
<td>1.47</td>
</tr>
<tr>
<td>Bankfull Discharge (m³/s)</td>
<td>4.27</td>
</tr>
<tr>
<td>Froude #</td>
<td>0.69</td>
</tr>
<tr>
<td>Stream Power (W/m)</td>
<td>209.49</td>
</tr>
<tr>
<td>Unit Stream Power (W/m²)</td>
<td>33.74</td>
</tr>
<tr>
<td>Mean Bed Shear (N/m²)</td>
<td>19.27</td>
</tr>
<tr>
<td>Critical Particle Size (mm)</td>
<td>25.33</td>
</tr>
</tbody>
</table>
5. EROSION THRESHOLD ANALYSIS

An erosion threshold assessment calculates the channel hydraulics such as discharge, velocity, and flow depth that produces enough shear stress to mobilize an index particle size (e.g. D\textsubscript{50} or D\textsubscript{84}). This analysis can evaluate the sensitivity of a channel to erosion by comparing the boundary shear stress under bankfull conditions with the critical shear stress for particle entrainment. Similarly, the discharge and flow depths can also be compared.

To determine the critical shear stress for particle entrainment, the methods presented by Komar (Critical velocity - 1987) and Fischenich (critical shear stress - 2001) were used. These methods adapt and update the work of Shields (1936). The Komar method is most appropriate to gravel sized material, while Fischenich also incorporates finer material (sands). Based on the critical shear stress determined by each method, a critical depth is back-calculated and a critical discharge is determined. The median particle size (D\textsubscript{50}) was used as the index grain in this analysis (see Table 4.6). Selection of appropriate threshold values was based on site conditions and the assumptions under which these two models are applicable.

Erosion threshold values were completed for cross-sections within each site, and averaged (Table 5.1). Essentially, flows are modeled through each cross-section until the critical depth to mobilize the median particle size (D\textsubscript{50}) is achieved, then the critical discharge is calculated.

The results in Table 5.1 reveal that critical thresholds vary through the reaches that are actively moving material. What is interesting is that the upstream and downstream most reaches (MC-1 and MC-8) have the highest values, while MC-7 has a much lower threshold. This is likely a sediment supply issue. Reach MC-1 has the CN Culvert impeding the passage of sediment downstream, resulting in a coarser bed fraction developing downstream as fines are continually removed but not supplied. Similarly, Reach MC-8 originates at a stormwater outfall and depends on it is existing channel boundaries for sediment supply. Conversely, MC-7 is downstream of a tributary that supplies fines from upstream.

Comparing these estimates of critical discharge using both methods to the bankfull estimates (Table 4.7), these critical flows appear to be occurring with a greater frequency than the bankfull discharge, with critical flow values only a fraction of the bankfull flow. If these flows are sustained for a long period of time, or occur with relatively high frequency, excessive erosion will occur. Excessive erosion was noted in each of these reaches during field inspections, as beds were artificially armouring and the less resistant banks scouring. Depending on the risk associated with these channels (e.g. property risk), designs may need to account for some bank protection and roughness, or addition of some grade control to slow flow velocities through these reaches.

These results differ from those in the PGL (2013) document, with lower values for reaches MC-1 and MC-7 (MC-8 was not assessed previously). There are many possible reasons for this including different cross-section locations, different grainsize distributions, and potential channel adjustments or flood events that occurred between surveys. What could be derived during a comparison between the two studies is that PGL measured a slope in MC-1 of 0.25%, which is half of what Water’s Edge determined (0.5%). Slopes increase velocities and shear stresses, so this may be the reason for the lower threshold here. Differences between studies for MC-7 can be attributed to different median grainsizes. PGL had a median size 248mm (coarse cobble), compared to 5.79mm (fine gravel) in the current study. These differences highlight that caution needs to be applied when using erosion threshold values as flow-targets, as such things like the timing of floods and channel adjustment can ultimately change the existing characteristics of a channel.
6. CONCEPTUAL CHANNEL DESIGN
The main objective of natural channel/corridor design is to restore, and where possible, enhance long term form and function of a creek system. Additionally, attempts should be made to reduce flooding risk by conveying existing or predicted storm events. These upgrades should be made with consideration of local constraints by proposed development, local area residents, and natural features. Geomorphological and hydraulic analyses (modeling), are used to determine the appropriate channel form and design elements (e.g. treatments). It is the intent of natural channel design to mimic the natural adjustments that streams typically undergo. Dynamically stable streams maintain an equilibrium form that responds to prevailing discharge and sediment regimes. Channels need to be designed that balance erosive forces (i.e. shear stresses) against resistive forces (i.e., boundary roughness – bed material and vegetation). The designed channel cross-section, profile, planform, and materials control the rate at which energy is expended through the system. Flows contained within the equilibrium bankfull channel are controlled by existing bedforms and channel variation. While energy associated with flows greater than bankfull are dissipated on the floodplain, provide there is sufficient connection to the floodplain (i.e. not entrenched).

Channel designs proposed in this study aim to develop a channel configuration that conveys a specific discharge, with sufficient floodplain area and connectivity, while attempting to adhere to constraints and concerns of local residents. Unlike previous iterations of conceptual designs for the remediation of Mud Creek, two new alternatives have been proposed that include a lowered and enlarged CN Rail Culvert. These are identified as Alternatives 3 and 4, and are the focus of the natural channel/corridor design component. Alternative 3 essentially maintains the current planform geometry of Mud Creek, and utilizes the existing culverts at Oxford Street and Proudfoot Lane. Alternative 4 realigns the channel upstream of Proudfoot Lane and would require a new crossing installation at Oxford Street further to the East, then flowing through the existing Proudfoot Lane culvert and adapting the same geometry as Alternative 3 downstream of Proudfoot. The realignment of Alternative 4 does not restore the previous planform, but is more representative of the geometry prior to the construction of the Proudfoot Lane crossing. Furthermore, relocation of the channel away from the roadside reduces the lateral constraint, and lends to the design and establishment of a more natural corridor/buffer.

6.1. Design Considerations and Constraints
Within both a natural and urbanized system, there are a number of considerations to be made. The following list includes considerations from an variety of perspectives including natural, economical, socio-political, and constructability:

<table>
<thead>
<tr>
<th>Method</th>
<th>Parameter</th>
<th>Reach</th>
<th>MC - 1</th>
<th>MC-7</th>
<th>MC-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOMAR 1987</td>
<td>Critical Shear (N/m²)</td>
<td>16.75</td>
<td>4.22</td>
<td>12.80</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ratio of Critical Shear/Bed Shear</td>
<td>1.12</td>
<td>3.76</td>
<td>1.72</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Critical Depth (m)</td>
<td>0.28</td>
<td>0.09</td>
<td>0.26</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Critical Flow (m³/s)</td>
<td>0.298</td>
<td>0.015</td>
<td>0.413</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ratio of Critical Flow/Bankfull Flow</td>
<td>0.155</td>
<td>0.004</td>
<td>0.173</td>
<td></td>
</tr>
<tr>
<td>FISCHENICH 2001</td>
<td>Critical Shear (N/m²)</td>
<td>13.82</td>
<td>4.09</td>
<td>11.33</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ratio of Critical Shear/Bed Shear</td>
<td>1.34</td>
<td>3.88</td>
<td>1.88</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Critical Depth (m)</td>
<td>0.23</td>
<td>0.08</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Critical Flow (m³/s)</td>
<td>0.187</td>
<td>0.014</td>
<td>0.291</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ratio of Critical Flow/Bankfull Flow</td>
<td>0.098</td>
<td>0.003</td>
<td>0.117</td>
<td></td>
</tr>
</tbody>
</table>
Flooding at Oxford Street West
Oxford Street in London, Ontario is one of the main East-West throughways through the City. Under existing conditions, the backwater effect that has constricted the movement of water and sediment causes extreme rainfall events to surcharge flow from Mud Creek (Reach MC-5) over the road, creating a mobility hazard to vehicular and pedestrian traffic. The City of London requires that floods with a return period of 250-years under future (developed) conditions to pass without flooding Oxford Street.

Constructability of the CN Culvert
The size of the existing rail berm/embankment, and explicit desire from CN to maintain rail traffic during the construction process, does not permit for an open cut installation. Therefore, less invasive methods like directional drilling or jack-and-bore need to be utilized. These more favourable technologies in this instance limit the size and shape of the culvert that can be designed. As a result, the design needs to consider the installation of a new culvert with a diameter of 3m at a maximum.

Residential Concerns
Through public consultation a number of concerns were brought forth by residents that own property along Mud Creek, or others whom enjoy the natural setting of the corridor. Typical concerns of flooding and loss of property were highlighted, as were concerns for local habitat and the preservation of trees. Attempts to minimize negative impacts were made in the design as flood mitigation at Oxford was addressed. In areas that are impacted, recommendations and examples for re-naturalization will be discussed and provided.

Floodplain Access
With the lowering of the CN Culvert, channel entrenchment becomes a possible issue throughout. To avoid entrenchment, where possible, a floodplain bench of three times the bankfull width has been designed, from which grading at a 3:1 slope is made up to the existing ground. In areas that are laterally constrained such as those around culverts, efforts to stabilize the bed and banks with rock treatments will be proposed to avoid excessive erosion.

Erosion and Sedimentation
Appropriate bank and bed treatments will be recommended with respect to the output channel shear stresses from modeling of future conditions for each alternative. The improved slopes from lowering the CN Culvert should improve the conveyance of sediment at a range of flows, reducing aggradations upstream, and the excessive erosion downstream. Other recommendations of bank stabilization may be made for properties at risk to erosion.

Channel Planform and Topographical Variation
The relatively low slopes through these reaches and lateral constraints lend to a straighter design channel to be created close to the existing planform, however improvements at tight bends were made. In light of the inability to fully meander the design reaches, topographic variation will be recommended through the design of riffles. This functional design will not develop the specific number, spacing, and geometry of these riffles, but recommendations on material size will be made using shear stresses from the hydraulic modeling. It is expected that a low flow channel will develop and meander through the larger bankfull design cross-section.

Tie-In Elevations and Road Crossings
Upstream and downstream tie-in elevations of the entire design were selected at stable or relatively stable locations, with a surveyed riffle at the upstream end (MC-7), and the invert of the Riverside Drive Culvert at the downstream end. Alternative 3 has tie-in elevations 0.3m above the invert of each the Oxford and the Proudfoot culverts. Alternative 4 is only required to tie into the Proudfoot culvert (0.3m of cover), and the new Oxford culvert will have an open bottom. The CN culvert was arbitrarily lowered by 2m, to roughly fit with the straight line slope between Proudfoot Lane and Riverside Drive.
Stream and Riparian Ecology
Riffle materials will be sized relative to the predicted shear stresses, but will contain gravels for fish and invertebrate habitat. Banks will be planted with scrub vegetation, and the floodplain and constructed valley will be a combination of scrub vegetation, shrubs, and trees. Recommendation of other floodplain habitat features and variation will be made at a high level with terrestrial and aquatic species considered.

6.2. Design Discharge
The selection of a design discharge is essential in developing a cross-section of a bankfull geometry, whether it reflects the existing conditions or some future alteration. Future development in the East Mud Creek watershed will alter the existing flow regime, including the frequency and magnitude of flows, and discharge points along the channel (i.e. outfalls). Although modelling has incorporated some assumptions of SWM to manage runoff, the existing channel instabilities throughout cannot be used to determine a design discharge entirely using field indicators of the bankfull elevation. Therefore, in this conceptual design, the 2-year modeled flow from Hec-Ras has been selected as the design discharge. This may be altered to a lower value in the design of the bankfull channel (e.g. 1.5-year event) during detailed design. But for the purposes of developing functional design concepts, the 2-year is sufficient in creating a bankfull channel for the future flow conditions of Mud Creek. As design slopes and flow inputs affect the 2-year flow volume, a number of design segments were delineated for each alternative with different design discharges assigned to each (Figure 6.1 and Table 6.1).

Figure 6.1: Alternative Planform Configuration and Design Sections
Table 6.1: Design Discharge Summary

<table>
<thead>
<tr>
<th>Section</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length (m)</td>
<td>Slope (%)</td>
</tr>
<tr>
<td>1</td>
<td>551.97</td>
<td>0.27</td>
</tr>
<tr>
<td>2</td>
<td>325.95</td>
<td>0.27</td>
</tr>
<tr>
<td>3</td>
<td>31.05</td>
<td>0.23</td>
</tr>
<tr>
<td>4</td>
<td>136.48</td>
<td>0.23</td>
</tr>
<tr>
<td>5</td>
<td>58.67</td>
<td>0.35</td>
</tr>
<tr>
<td>6</td>
<td>513.04</td>
<td>0.35</td>
</tr>
<tr>
<td>7</td>
<td>23.85</td>
<td>0.35</td>
</tr>
</tbody>
</table>

6.3. Bankfull Channel

Preliminary design concepts proposed here lack detail such as the size and specific location of bedforms (pools and riffles). During detailed design, it is recommended that riffles are designed with appropriate dimensions to ensure that the channel has the capacity to convey the bankfull or design discharge before inundating the floodplain. Riffles should be spaced so that the crest of a riffle just begins to backwater the tail of the next riffle upstream, effectively creating a pool that may naturally scour under larger events. Enlarged pool sections should be created downstream of culverts and any other flow constrictions to dissipate energy resulting from increased flow velocities. Additionally, pools can be initially enlarged at meander bends to provide some refugia and overwintering habitat for resident aquatic organisms.

Appropriate dimensions are required to ensure that the channel capacity is sufficient to convey the design discharge before inundating the floodplain. Cross-sections developed for the conceptual design of each alternative, and can be considered the “typical” cross-section with 2:1 bank slopes, and width to depth ratios that balance the erosive forces within the cross section (see section 4.3). Table 6.2 provides bankfull channel parameters for each alternative. The design of the bankfull channel was an iterative process between design and modeling to determine appropriate dimensions that convey the 2-year flood within the main channel before inundating the floodplain. The dimensions in Table 6.2 were enlarged relative to the initial design cross-section, and present the final adjustments made in the model for the bankfull channel. Overall, the slight reduction in channel length for Alternative 4, only results in a slope adjustment of 0.01%, therefore cross-sections do not dramatically change between alternatives.

Table 6.2: Bankfull channel design summary

<table>
<thead>
<tr>
<th>Section</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Width (m)</td>
<td>Depth (m)</td>
</tr>
<tr>
<td>1</td>
<td>12.6</td>
<td>1.2</td>
</tr>
<tr>
<td>2</td>
<td>11.1</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>12.6</td>
<td>1.2</td>
</tr>
<tr>
<td>4</td>
<td>12.6</td>
<td>1.2</td>
</tr>
<tr>
<td>5</td>
<td>12.7</td>
<td>1.2</td>
</tr>
<tr>
<td>6</td>
<td>9.4</td>
<td>0.9</td>
</tr>
<tr>
<td>7</td>
<td>8.0</td>
<td>0.7</td>
</tr>
</tbody>
</table>
6.4. Chanel and Bank Treatments

Recommended bank and bed materials and treatments will be limited to the design sections, with some future recommendations provided for those reaches upstream that may be altered separately when the remaining area is developed. Slopes through the design reaches are relatively low, and the bankfull channel has been designed with an accessible floodplain area, limiting the amount of entrenchment/confainment to areas of convergence (i.e. culverts). Hec-ras output tables provided Channel Shear (N/m$^2$) for a number of cross-sections within each design reach. Shear was highest immediately downstream of culverts, and would decrease with distance downstream. Stone treatments using the maximum critical particle size with a factor of safety (e.g. 1.5 to 2-times) should be used in the vicinity of these culverts (Table 6.3). Elsewhere, shear stresses are relatively low. It is recommended that constructed banks are secured with coir fabric and live stakes (Permissible Shear of 105 N/m$^2$). The coir should extend onto the floodplain for 1m of width outside of the bankfull channel and secured with live stakes. This table can also be used as a guide for sizing riffle material where the average critical particle size can be applied as the median diameter for a distribution of particles. A factor of safety maybe required for riffle material sizing to make the features static. This may be necessary if it is revealed that development will severely reduce sediment supplied from upper reaches.

<table>
<thead>
<tr>
<th>Table 6.3: Summary Shear Stresses and Critical Particle Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Section</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Alternative 3</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td><strong>Alternative 4</strong></td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
</tbody>
</table>

6.5. Ecological Enhancements

Treatments can also be applied for ecological enhancement. The design corridor includes a bankfull channel, set within a floodplain, from which new valley slopes grade up to the existing land-surface. This extensive clearing and grading will require the removal of a number of trees. Therefore, treatments and plantings are required to help establish a healthy riparian zone and provide immediate habitat following construction.

Gravel riffles discussed above create areas of fast and slow moving water, as well as suitable substrates for local aquatic organisms. Overhanging vegetation and debris are also essential features of Southern Ontario streams that provided added habitat (cover, backwater, scour pools) and nutrients. We recommend harvesting trees to use for rootwad structures along the outer bank of the few available meander bends. Additionally, where erosion risk to property or infrastructure is less of a factor, trees can also be embedded into stream banks, parallel to flow. Leaving some
logs on the floodplain can provide some wood debris to the channel under higher events, but culverts will need to be monitored to avoid the development of severe debris-jams.

The existing floodplains in the area have depressions such as side-channels, or general wet depressions. The floodplain should be constructed with undulations (high and low) that divert and direct flow under high events, while also storing water and material between floods.

7. SUMMARY and CONCLUSIONS
Over the past 20 years, Mud Creek has been studied for the purpose of development planning, with a focus on flood remediation. Coupled with reduction in flooding is the development of a functional channel of a relatively (dynamically) stable form. Common to each was the recognition that the CN Rail Culvert impedes the natural conveyance of water and sediment in the downstream direction. Recommendations were made to enlarge and/or lower the culvert to restore the stream function through Mud Creek and reduce flooding. However, the potential complications and costs with such an undertaking resulted in the recommendation of more minor channel work - “cleaning” and “deepening” – which may have provided a short term solution, but ultimately the CN Culvert would continue to act as barrier. The current study includes the development and assessment of alternatives with an upgrade to the CN Culvert.

The current study updated and confirmed findings of the existing conditions of East Mud Creek. Then through identifying a list of considerations and constraints, developed functional designs for two new alternatives to assess for remediation of the watercourse. Hec-ras modeling was used to refine the channel dimensions, and select appropriate channel materials and bank treatments based on the channel shear modeled for each alternative. Ecological enhancements for the channel, riparian zone, and floodplain that focus on providing habitat features and variation in topography were also recommended.

We feel that these design recommendations include enough detail to move forward with the planning and development of Mud Creek. The Detailed Design phase can build upon these recommendations and update accordingly with specific dimensions and sizes of features, and treatments. The conceptual design drawings that have been submitted with this Environmental Assessment include typical locations and details for the recommended features and erosion control applications.

Respectfully submitted,

Ed Gazendam, M.Eng., P.Eng.,
President, Sr. Geomorphologist

John McDonald, M.Sc,
Fluvial Geomorphologist

Water's Edge Environmental Solutions Team Ltd.
REFERENCES:


Delcan. 2014. Mud Creek Subwatershed Study – Update of the Water Resources Components. Submitted to the City of London.


APPENDIX A:
Detailed Survey
Figure 1: Mud Creek - Existing Profile of Mud Creek Detailed Survey - Reaches 7 & 8
Figure 8: Mud Creek - Existing Profile of Mud Creek Detailed Survey - Reach 1
Reach 1 Cross Section 1

Reach 1 Cross Section 2
PHOTOGRAPH NO.: 1
FROM: Reach MC-1
LOOKING: Upstream from Riverside Culvert
COMMENT: Rip rap along channel

PHOTOGRAPH NO.: 2
FROM: Reach MC-1
LOOKING: Upstream towards CN Rail Embankment
COMMENT: Mud Creek, London
PHOTOGRAPH NO.: 3
FROM: Reach MC-2
LOOKING: Downstream towards CN Rail Embankment
COMMENT: Backwater due to CNR culvert

PHOTOGRAPH NO.: 4
FROM: Reach MC-3
LOOKING: Upstream from Pedestrian Bridge
COMMENT:
PHOTOGRAPH NO.: 5
FROM: Reach MC-4
LOOKING: Upstream from Proudfoot Lane
COMMENT: 

PHOTOGRAPH NO.: 6
FROM: Reach MC-5
LOOKING: Upstream from Golf Course Driveway
COMMENT: Cattail encroachment

Mud Creek, London
PHOTOGRAPH NO.: 7
FROM: Reach MC-6
LOOKING: Upstream
COMMENT: Backwater effect still evident

PHOTOGRAPH NO.: 8
FROM: Reach MC-6
LOOKING: Downstream
COMMENT: Backwater effect causing soft sediment deposits on margins

Mud Creek, London
PHOTOGRAPH NO.: 9
FROM: Reach MC-6A
LOOKING: Upstream
COMMENT:

PHOTOGRAPH NO.: 10
FROM: Reach MC-7
LOOKING: Upstream
COMMENT: Lateral bar formation

Mud Creek, London
PHOTOGRAPH NO.: 11
FROM: Reach MC-7
LOOKING:
COMMENT: Confluence

PHOTOGRAPH NO.: 12
FROM: Reach MC-7A
LOOKING: Upstream
COMMENT:

Mud Creek, London
Mud Creek, London

PHOTOGRAPH NO.: 13
FROM: Reach MC-7A at upstream end
LOOKING: Upstream
COMMENT: multi thread channels

PHOTOGRAPH NO.: 14
FROM: Reach MC-7B
LOOKING: Upstream
COMMENT: Eroding cutbank, gravel riffle and point bar.
PHOTOGRAPH NO.: 15
FROM: Reach MC-7B
LOOKING: Downstream
COMMENT: Medial bar

PHOTOGRAPH NO.: 16
FROM: Reach MC-7C
LOOKING: Upstream
COMMENT: Well defined valley. Cobble/boulder bed material
PHOTOGRAPH NO.: 17
FROM: Reach MC-8
LOOKING: Upstream
COMMENT:

PHOTOGRAPH NO.: 18
FROM: Reach MC-8
LOOKING: At right bank
COMMENT: Bank Erosion of sands and gravels.

Mud Creek, London
PHOTOGRAPH NO.: 19
FROM: Reach MC-8
LOOKING: At upstream end.
COMMENT: Sewer outfall and deep plunge pool