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Memorandum

Date: August 16, 2018

Project #: 170461

To: Dania Chehab, Abra Ens, John Bourrie

From: Michael Brierley, Samantha Feist, Dan McParland

cc: Susan Liver, Jason Cole, Robin McKillop

Re: Phase 2600 – Geomorphic and Erosion Hazard Limit Assessment
Class Environmental Assessment for Water and Wastewater Servicing in Nobleton

1. Introduction and Background

Palmer Environmental Consulting Group Inc. (PECG) is pleased to provide Black & Veatch (BV) with our geomorphic and erosion hazard assessment to support the Class Environment Assessment (EA) for expanding and optimizing existing water and wastewater infrastructure to accommodate anticipated population growth in the Community of Nobleton. The fluvial geomorphological assessment focused on two reaches: the headwater tributary of the Humber River (herein referred to as "Headwater Tributary") immediately south of the Nobleton Water Resources Recovery Facility (WRRF) and the Humber River within the vicinity of the WRRF effluent outlet (**Figure 1**). The existing WRRF is located approximately 50 m north of the Headwater Tributary. An erosion hazard assessment (i.e. meander belt assessment) is necessary to inform potential expansion of the existing WRRF. Furthermore, the WRRF currently outlets treated effluent through a constructed wetland to the Humber River within the TRCA-owned Nashville Conservation Reserve (NCR). An erosion threshold is required to inform and evaluate potential changes to the effluent discharge regime and mitigate potential geomorphological impacts.

A summary of methods (Section 2) is followed by an overview of the physical setting and historical changes near the Headwater Tributary and the Humber River (Section 3); a description of channel morphology and erosional processes along the subject reaches (Section 4); presentation of the meander belt width assessment and erosion threshold results (Section 5); and a summary of the geomorphic assessment and recommendations to mitigate potential erosional processes.

Client: Black & Veatch
Project: Nobleton Water and Wastewater EA

PREPARED BY:

PALMER ENVIRONMENTAL CONSULTING GROUP INC.

DRAWN: S. Feist
CHECKED: M. Brierley
PROJECT: 170461
DATE: Jun 13, 2018

LEGEND

- Road
- Watercourse (OHN)
- Contour (5 m Interval)
- Contour (1 m Interval)
- Flow Direction
- Cross Section (XS)
- Reach Break
- Meander Belt Boundary

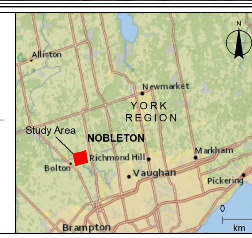
Historic Channel Centerlines

- 2016
- 2007
- 2002
- 1999
- 1978
- 1970

0 100 200 Meters

Scale 1:7000 NAD 1983 UTM Zone 17N

DATA SOURCES: Natural Resources Canada (National Road Network - Ontario). Ontario Ministry of Natural Resources and Forestry (Ontario Hydrographic Network (OHN)). Ontario Municipal Affairs (Municipal boundaries). Imagery (2015) Source: York Region Web Map Services.



Fluvial Geomorphological Assessment Sites

FIGURE 1

*Contains public sector Information made available under The Regional Municipality of York's Open Data Licence and information licensed under the Open Government Licence - Ontario and Canada.

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2. Methods

The fluvial geomorphology of the Humber River and the Headwater Tributary was assessed through a combination of desktop and field investigations. We reviewed a number of important background information sources for the study area, including the Toronto and Region Conservation Authority's (TRCA) *Humber River State of the Watershed Report – Fluvial Geomorphology* (2008) report and existing Ontario Geological Survey bedrock and surficial geology mapping (OGS, 2006, 2010). Historic and recent aerial imagery (1954, 1970, 1978, 1999, 2002, 2007, 2016) was obtained from York Region's Web Map Service (https://ww6.yorkmaps.ca/Yorkmaps/sindex.html) through ArcGIS to characterize historical channel conditions and previous anthropogenic disturbance. Aerial imagery also provided a basis for characterizing historical channel conditions, forecasting future channel adjustments and identifying reach breaks. Reaches were confirmed during field reconnaissance.

The meander belt was delineated for the Headwater Tributary following TRCA's *Belt Width Delineation Procedures* (Parish Geomorphic Ltd., 2004) in order to inform predictions of future erosion along the Headwater Tributary. The meander belt width was established by delineating and then buffering the meander belt axis until the boundary lines encompassed the current and historical planform alignments. The final belt width was delineated through a further, parallel set-back of the boundary lines by a 20% factor of safety to account for potential changes to hydrological regime associated with upstream land use and climate change. In addition, channel dimensions were measured at three locations along the reach to characterize existing bankfull conditions (**Figure 1**).

Field reconnaissance was completed on May 8, 2018. The daily discharge of the Humber River as measured at Elder Mills Water Survey of Canada (WSC) gauge 11 km downstream of the Humber River site was 3.4 m^3/s, which is above the historical mean annual flow recorded at the WSC gauge (2.5 m^3/s). From April 15, 2018 to April 25, 2018 there were three significant precipitation events of 15.2 mm, 18.6 mm and 18.8 mm, respectively, as measured at Toronto's International Airport. In addition, from May 3, 2018 to May 5, 2018, 17 mm of cumulative precipitation was recorded, which led to elevated flows prior to the field visit (**Figure 2**). The purpose of the field visit was to examine patterns and processes of local erosion near the WRRF effluent outlet, verify bankfull measurements, observe bed and bank materials, and ground truth aerial photograph-based interpretations in order to inform appropriate erosion threshold analysis. The grain size distribution of the alluvial bed material within the Humber River near the WRRF outlet was determined through modified Wolman (1954) pebbles counts.

A longitudinal profile of the Humber River extending 115 m upstream of the WRRF outlet to 170 m downstream was measured. The channel bed and water surface elevation were surveyed approximately every 10 m or at prominent changes in bed profile. The longitudinal profile data were analyzed to determine pool depths (i.e. natural zones of scour), riffle slopes, and energy gradients. Additionally, five channel cross-sections were surveyed downstream of the WRRF outlet (**Figure 3**). Due to high water levels and deep pool an upstream representative cross-section immediately upstream of the WRRF outlet could not be surveyed (cross-sections upstream of the WRRF outlet are not required for erosion threshold analyses). The surveyed cross-sections were strategically positioned in representative morphological units (e.g. pools, riffles). Bankfull dimensions were based on field indicators defining the principal limit of scour, including abrupt changes in bank vegetation, material and steepness (Harrelson et al., 1994), which is assumed to represent the ‘channel-forming discharge.

All bed erosion threshold and critical discharge analyses were completed based on a Shields (1936) approach as outlined by Church (2006), as it is a semi-empirical approach (as opposed to completely empirical) and is well-suited for gravel bed rivers. A bed erosion threshold is the hydraulic condition at which the channel bed is in a state of incipient motion, and the critical discharge is the flow that produces that threshold condition at a particular location along the channel. A representative median grain size (D_{50}) was applied to erosion threshold calculations. Erosion thresholds were compared to hydraulic conditions at bankfull flows (established from the field survey) to better understand the propensity for scour downstream of the WRRF overflow. Furthermore, the established critical discharges were compared to the WRRF peak daily effluent discharges from 2014 to 2017 (provided by B&V) to better understand the alteration of the natural sediment transport regime from WRRF flow contributions.

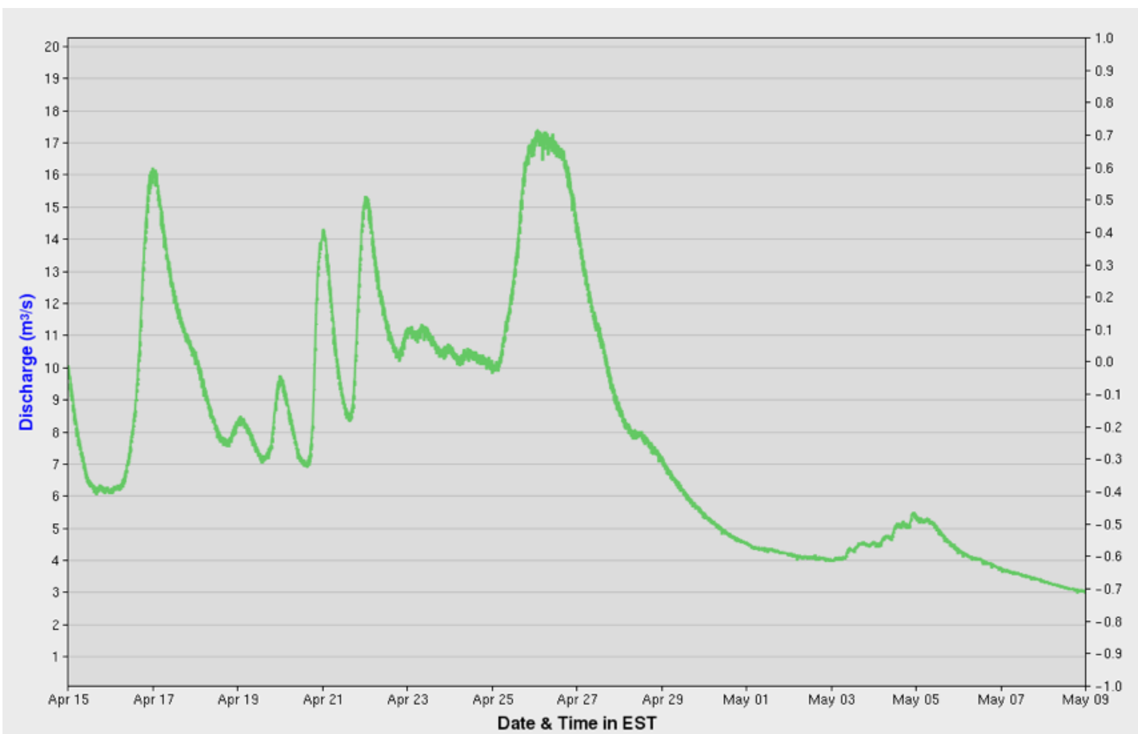

Figure 2. Discharge recorded at the WSC Humber River at Elder Mills gauge (02HC025) located approximately 11 km downstream of the study reach from April 15, 2018 to May 9, 2018

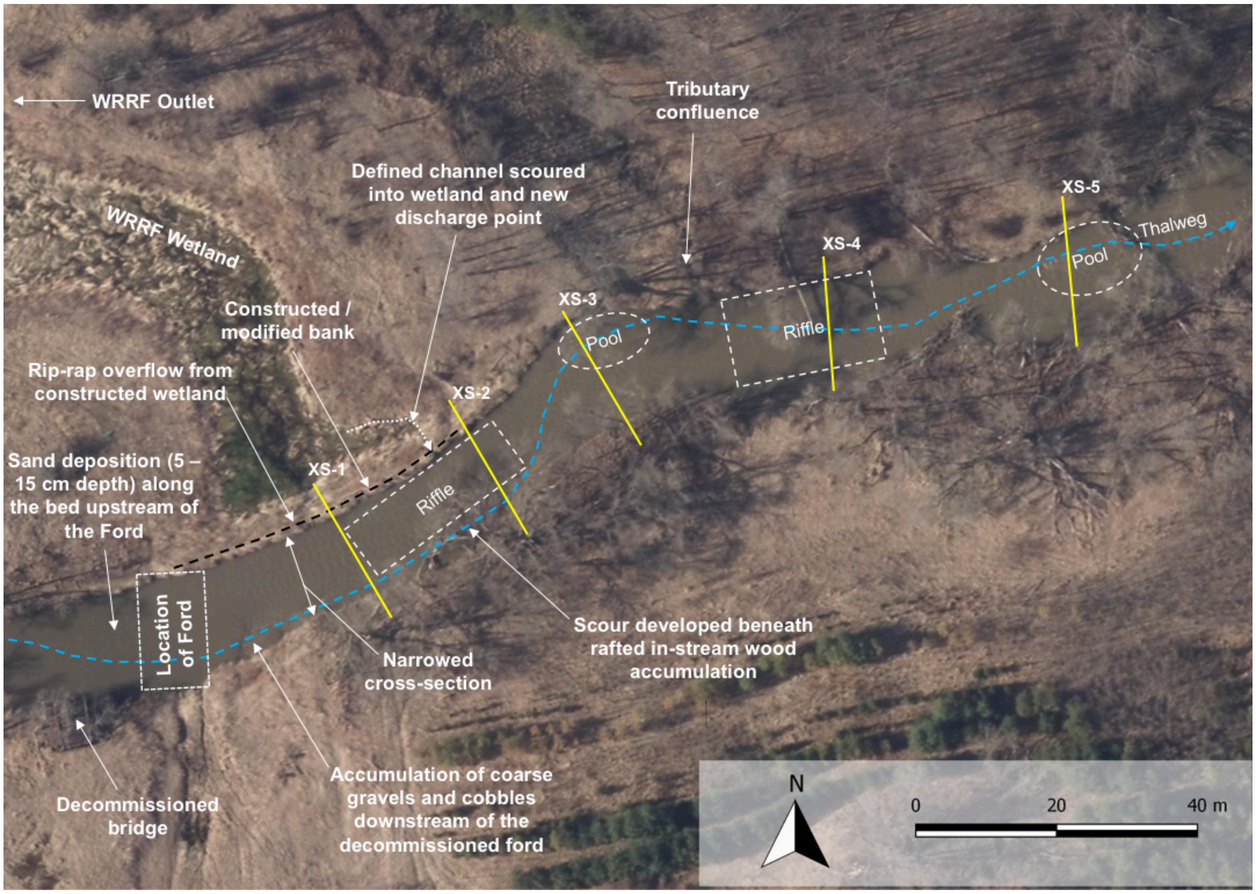

Figure 3. Cross-section locations, anthropogenic disturbances, and site-scale geomorphic processes near the WRRF outlet on the Humber River

3. Physical Setting and Historical Changes

The Headwater Tributary and the Humber River at the WRRF outlet are situated in the Main Humber subwatershed within the larger Humber River watershed. The Main Humber subwatershed drains approximately 357 km^2, with headwaters originating in the Niagara Escarpment and Oak Ridges Moraine (TRCA, 2008). Significant areas of groundwater discharge and gravel sediments sources are associated with the southern flanks of the Oak Ridges Moraine, which are located north of the Community of Nobleton. Both subject watercourses flow across the South Slope, a clayey silt till plain. Within the study area, the Headwater Tributary and the Humber River site are second order and seventh order streams, respectively.

Land use in the broader study area was historically, and remains, predominantly agricultural (**Figure 1**). Near the Humber River site, residential buildings were situated within the floodplain on both sides of the river prior to 1970. As well, Concession Road 11 extended across the Humber River. Between 1970 and 1978 the buildings south of the River and the Concession Road 11 bridge were removed. A shallow ford vehicle crossing was established approximately 15 m downstream of Concession Road 11 crossing following bridge removal. The ford, composed of coarse gravel and cobble, was still in active use as late as 2007 (**Figure 3**). Beginning in the mid-1990s and early 2000s, former agricultural plots started to transition to small forested areas, presumably through reforestation efforts by TRCA within the NCR. The existing WRRF outlet and wetland were constructed between 2009 and 2011.

The Headwater Tributary is located within agricultural lands (**Figure 1**). In the 1954 aerial photograph, the tributary flows through a dense forest, obscuring the channel alignment. By 1970, the forest had been completely cleared for agricultural use, revealing a sinuous, well-defined planform and the existing online pond at the downstream end of the reach was constructed. The area surrounding the Headwater Tributary has remained largely unchanged since 1970 with the exception of the WRRF construction between 2007 and 2011. The planform of the Headwater Tributary has remained relatively consistent following the construction of the WRRF.

4. Description of Channel Morphology and Erosion Processes

4.1 Headwater Tributary

The Headwater Tributary originates downstream of a wetland feature (**Photo 1**) and WRRF stormwater management pond. A defined channel (**Photo 2**) was identified beneath the hydro corridor (upstream reach break), approximately 35 m from the southeast corner of the WRRF property limit (**Figure 1**). The Headwater Tributary has a meandering planform within a defined valley through the reach. Bed morphology (e.g. pool-riffle sequences) and bank erosion has been limited by dense bank and in-channel vegetation. The majority of the channel bed is covered by a layer of silts and organic matter. Sands and gravels are locally present on the channel bed where in-channel vegetation was absent. The channel is narrow and relatively deep, creating a low bankfull width: depth ratio (**Table 1**). The Headwater Tributary discharged into an anthropogenic pond at the downstream extent of the reach.

Photo 1. Lack of channel definition upstream of Headwater Tributary reach.

Photo 2. Downstream view of Headwater Tributary meandering along the bottom of a defined valley.

Table 1. Surveyed cross-section dimensions for the Headwater Tributary

Measure	Cross-section 1	Cross-section 2	Cross-section 3	Average
Wetted Depth (m)	0.2	0.3	0.2	0.2
Wetted Width (m)	0.3	0.4	0.2	0.3
Average Bankfull Depth (m)	0.3	0.4	0.3	0.3
Bankfull Width (m)	0.5	0.5	0.4	0.5
Bankfull Width:Average Depth	1.7	1.4	1.6	1.6

4.2 Humber River Site

Near the WRRF outlet, the Humber River flows within a defined valley and displays an irregularly meandering planform. The channel is generally well connected to its floodplain (overbank deposition of sand and large wood was observed) but is locally confined by fluvial terraces (**Photo 3**) and both valley walls, which limits planform development and floodplain access. A small tributary adjoins the Humber River along the left bank (defined looking downstream) near Cross-section 3 (**Figure 3**).

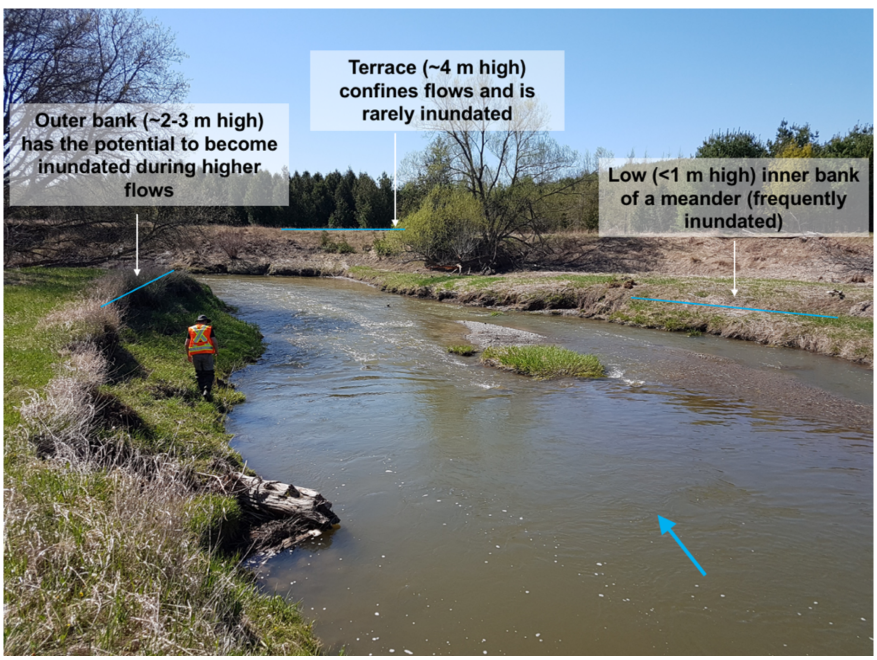

Photo 3. Downstream view of variable bank and terrace elevations upstream of WRRF outlet.

Bed materials within the Humber River ranged from silt to cobble and were dominated by gravels (**Figure 4**). Remnant gravel and cobble from the decommissioned ford was observed along the right bank and within the riffle adjacent the WRRF outlet (**Figure 3**, **Photo 4**). The remnant gravel and cobbles were both rounded and angular and algae was observed on the coarser materials indicating they are rarely entrained. Upstream of the decommissioned ford, the bed was dominated by loose sand deposits ranging from 5 to 15 cm in depth (**Photo 5**). Sand deposits were derived from easily erodible alluvium comprising the upper portion of the banks. The representative median grain size (D_{50}) of the Humber River within the study area was estimated to be 28 mm (**Figure 4, Table 2**).

Photo 4. Downstream view (Top) and overview (Bottom) of remnant gravel and cobble accumulation downstream of the decommissioned ford. Algae has established on the coarser material indicating they are rarely entrained.

Photo 5. Decommissioned bridge and pool upstream of the degraded ford (looking upstream). Loose sand deposits ranging from 5 to 15 cm in depth cover gravel and cobble bed material within the pool.

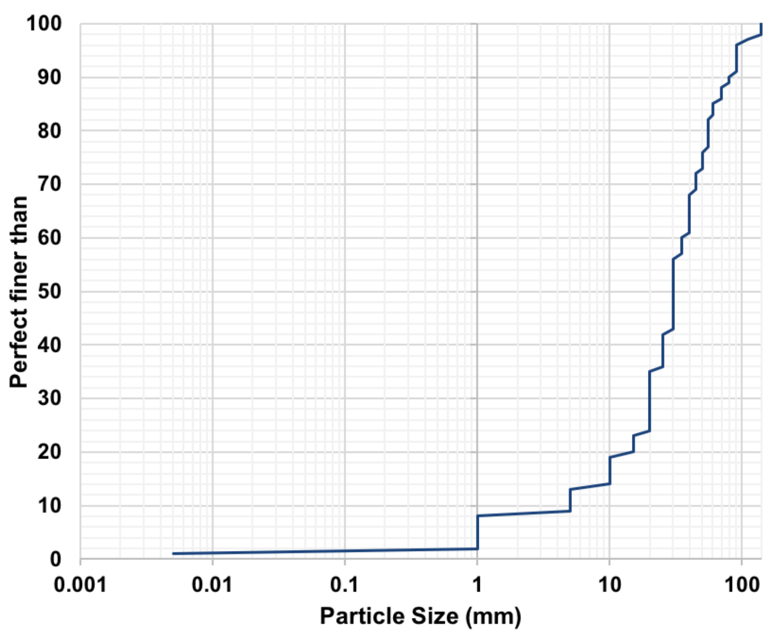

Figure 4. Representative Humber River bed material grain size distribution in the vicinity of the WRRF outlet

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Table 2. Summary statistics for Humber River grain size distribution

Measure	Grain size (mm)
D_{16}	9
D_{35}	20
D_{50}	28
D_{65}	38
D_{84}	60

Notes: D_x is the grain size at which X% of the substrate is finer

Pool-riffle morphology is generally well developed along the reach. Averaged bed gradient upstream and downstream of the WRRF outlet are 0.07% and 0.19%, respectively (**Figure 5**). The channel exhibits a natural, roughly trapezoidal to a rectangular cross-section along its riffles and an asymmetric cross-section deepest along its outer bank within pools along meanders. Riffles tend to have the coarsest material based on field measurements. Sand veneers were observed atop gravel beds in pools. Emerging and submerged sandbars were present along the inner banks of meander bends. The average bankfull width and depth of the surveyed cross-sections are approximately 15.6 and 1.1 m, respectively (**Table 3**). Maximum depth at bankfull stage averages 1.6 m. The bankfull discharge for the sub-reach was estimated as 28.8 m^3/s.

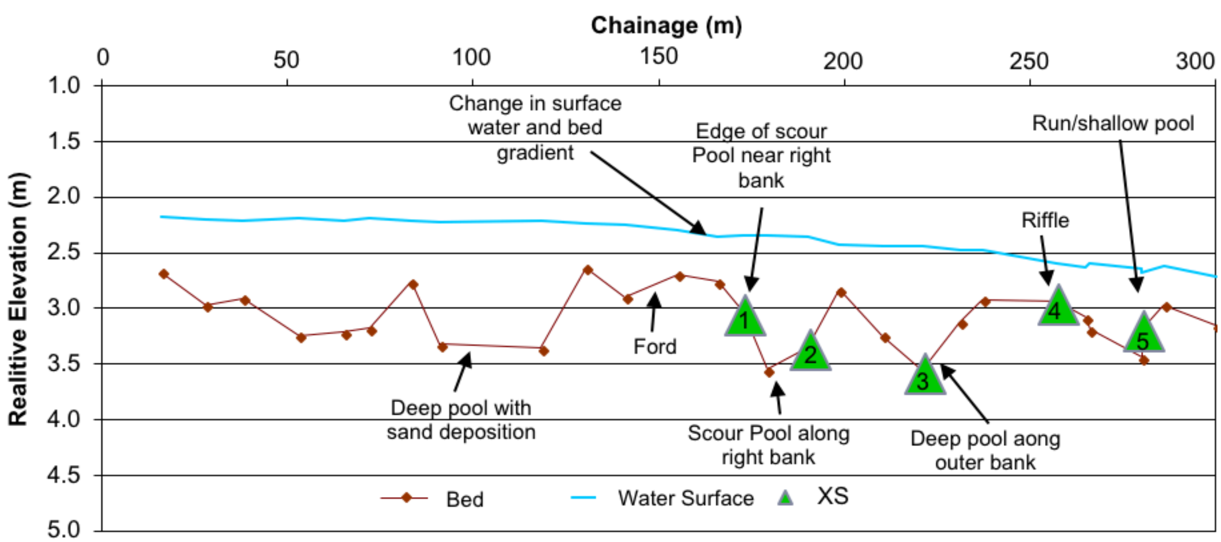

Figure 5. Longitudinal profile of Humber River along surveyed sub-reach

Table 3. Bankfull dimensions and hydraulics in the immediate vicinity of the WRRF wetland

XS	Geomorphic Unit	W_{bfl} (m)	D_{bfl} (m)	W_{bfl}:D_{bfl}	XS Area (m^2)	Q_{bfl} (m^3/s)	V_{bfl} (m/s)
1	Riffle Crest	14.5	0.9	15.9	14.1	17.8	1.1
2	Riffle Tail	12.4	0.9	13.5	12.3	15.4	1.1
3	Pool	15.9	1.2	12.9	21.5	35.6	1.4
4	Riffle tail	17.8	1.2	14.7	24.0	38.7	1.3
5	Run	17.4	1.1	14.9	22.9	36.6	1.3
Average		**15.6**	**1.1**	**14.4**	**18.9**	**28.8**	**1.2**

Notes:
All cross-sections in the immediate vicinity of WRRF constructed wetland.
Abbreviations: XS: cross-section, Q_{bfl}: bankfull discharge, W_{bfl}: bankfull width, D_{bfl}: bankfull depth (maximum), V_{bfl}: bankfull velocity (average).
V_{bfl} and Q_{bfl} estimated using a Manning's 'n' of 0.035 (Hicks and Mason, 1998) and energy gradient of 0.19%.

Banks are generally composed of alluvial sediments, with stratified deposits present (**Photo 6**) grading from silts and fine sands (flood deposits) at the surface to coarse sands and gravels near the bank toe. Clay and silty till was locally exposed near the bottom of banks and on the channel bed. Localized toe-slope erosion and slumping are active along high terraces (**Photo 3**). The riparian vegetation is a mix of grasses, shrubs, and trees. Few mature trees are present along the channel banks, which is likely attributed to historic agricultural activity. Large wood was observed locally along channel banks but no channel spanning jams were present.

Photo 6. View of stratified bank deposits (left bank), graded from silts and sands at the surface to gravels and till at depth.

4.2.1 Site-Scale

The site-scale considers the immediate area downstream of the ford to cross-section 3, a distance of approximately 65 m, focusing on local-scale geomorphic processes near the WRRF wetland and outlet (**Figure 3**). The median grain size of the riffle adjacent to the constructed wetland is 55 mm, which is significantly larger than the representative grain size for the sub-reach (28 mm) due to the presence of anthropogonic gravels and cobble from the upstream decommissioned ford (**Figure 4**). Pool-riffle morphology is more pronounced downstream of the ford (**Photo 7**, **Figure 3**) caused by an increase in bed gradient (**Figure 5**). The thalweg is located along the right bank leading to localized scour and cross-section asymmetry.

The channel within the vicinity of the constructed wetland, is narrower and shallower than upstream and downstream areas (see dimensions for Cross-section 1 and 2 in **Table 2**). The reduced cross-sectional area has increased floodplain interaction as high flows can access the floodplain along both banks more readily than further downstream. Downstream, the floodplain is only accessed along the right bank due to localized valley wall confinement. Vertical and clean-faced banks are present along the outer bank at Cross-section 2 and 3, with till exposed on the bed at Cross-section 3. Leaning trees, in-stream wood accumulation, and exposed tree roots were observed. Fresh and active bank erosion highlight the potential for the development of increased sinuosity at the site and sub-reach scales. Overall, at site scale, the Humber River is slowly adjusting its channel form to historical land use and in-channel anthropogenic modifications.

Photo 7. Defined pool (foreground) and riffle (background) sequence downstream of Cross-section 2 (looking downstream).

4.2.2 Nobleton WRRF Constructed Wetland Outlet

The effluent from the WRRF discharges into a constructed wetland, which originally came to a confluence with the Humber River at a designed rip-rap overflow along the left bank (**Figure 3**). However, a failure/breach of the rip-rap overflow in 2013 and 2016 (York Region, personal communication) and the associated lack of ponding has resulted in formation of a defined flow path within the wetland (**Photo 8**) , which has shifted the confluence 20 m downstream from its designed confluence (**Figure 6**). The new outlet channel within the wetland is narrow (<2 m) and relatively deep with gravel and till exposed along its bed. A knickpoint (0.5 m in height) 3 m upstream of the confluence has developed and may propagate upstream into the wetland; however, the new outlet channel and knickpoint do not present an erosional risk to the headwall. Within the Humber River at the new confluence, bed material is characterized by gravel and cobbles with sands embedded. Coarsest bed material is concentrated along the left bank where WRRF flow discharges (**Photo 8**), consisting of poorly organized cobbles. No bed scour within the Humber River was observed at the designed rip-rap overflow or the new discharge location.

Photo 8. Upstream view of deep and narrow channel scoured within the constructed wetland (left). Looking toward the left bank where the newly developed outlet confluences with the Humber River (right).

Figure 6. Upstream view at Cross-section 2 highlighting WRRF flow path along the left bank in relation to thalweg position.

5. Results of Desktop Analyses

5.1 Meander Belt Assessment

Comparative overlay analysis using recent imagery indicated a relatively stable channel planform with low/negligible meander migration and few channel avulsions. The historical removal of mature forest vegetation between 1954 and 1970 does not appear to have exacerbated channel migration or instability. Based on site reconnaissance, the physical factors influencing channel morphology (i.e. channel slope, discharge, bed and bank material and vegetation) and evidence of the long-term stability of the contemporary channel, a meander belt width of 20 to 28 m sufficiently captures future geomorphic adjustment for the subject reach (**Figure 1**). A range is presented due to local valley confinement mid-reach. These meander belt values include a 20% factor of safety for future changes in the hydrological regime (Parish Geomorphic Ltd., 2004).

5.2 Humber River Hydraulics and Erosion Threshold

Using a representative D_{50} of 28 mm for both riffles and pools allowed for a conservative approach to quantify sediment entrainment and transport potential downstream of WRRF outlet. The established erosion threshold using a Shields (1936) approach was 20.3 N/m^2 and based on the five surveyed cross-sections the average critical discharge was estimated as 13.6 m^3/s (**Table 4**).

Maximum shear stress at bankfull conditions at all five cross-sections (estimated from maximum depths) exceeds the erosion threshold, suggesting the D_{50} is entrained under bankfull flow conditions. In addition, average shear stress at bankfull conditions exceeds this erosion threshold at Cross-section 3, 4, and 5. The grain sizes entrained by the average and maximum shear stresses at bankfull conditions were calculated for all five cross-sections (**Table 4**). The entrained grain sizes at maximum shear stress (i.e. depth) exceeded the D_{50} but are less than the D_{84} (**Table 2**) at every cross-section, suggesting that the coarse tail of the bed material gradation is not entrained at bankfull flows. Observed algae growth on the coarse cobble corroborates this result. Above bankfull flow conditions, the channel spills onto the floodplain, which distributes tractive forces along a large wetted width.

Table 4. Grain sizes entrained at average and maximum shear stresses during bankfull flow conditions.

Measure	XS1	XS2	XS3	XS4	XS5	Average
Critical Discharge (m^3/s)	12.8	9.9	11.1	19.4	14.6	**13.6**
Critical / Bankfull Discharge (%)	72	65	31	50	40	**52**
Average Bankfull Shear Stress (N/m^2)	17.9	17.8	24.9	24.5	24.4	**21.9**
Grain Size Entrained[1] (mm)	*25*	*24*	*34*	*34*	*34*	***30***
Maximum Bankfull Shear Stress[2] (N/m^2)	24.9	26.0	36.6	31.0	33.4	**33.4**
Grain Size Entrained (mm)	*34*	*36*	*50*	*43*	*46*	***42***

Notes:

1. *Critical Shields parameter assumed to be 0.045 (Church, 2006)*
2. *Estimated from maximum bankfull depth at each cross-section*

5.3 Humber River – Geomorphological Impacts of Effluent Discharge

The peak daily effluent discharges from WRRF from 2014 to 2017 are presented in **Table 5**. The average peak daily discharge of 0.029 m^3/s is 0.21% of the critical discharge (13.6 m^3/s) and 0.10% of the bankfull flow (28.8 m^3/s). Sediment transport occurs almost exclusively during moderate to high flow events, once a local erosion threshold has been exceeded, and thus, channel morphology (and the aquatic habitat it supports) is largely determined by moderate to high flows (Knighton, 1998). The peak daily effluent discharge represents an extremely small flow contribution to the Humber River downstream of the WRRF outlet during annually reoccurring moderate to high flow events. Furthermore, the Humber River has a relatively stable geomorphological form due to limited upstream urbanization and good connectivity to its floodplain. Thus, recorded peak daily effluent rates have had negligible impacts on natural erosional processes along the Humber River. It is unlikely that WRRF effluent discharge will disrupt existing geomorphic processes within the Humber River or exacerbate existing localized instabilities if the peak daily effluent discharge remains below 1% of critical discharge. If the proposed peak daily effluent discharge exceeds 1% of the critical discharge, continuous modelling (both pre and post conditions) of the Humber River should be conducted to better understand erosion threshold exceedance downstream of the WRRF outlet (see TRCA, 2007).

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Table 5. WRRF peak daily effluent discharge from 2014 to 2017

Year	Peak Daily Effluent Discharge (m^3/s)	Percentage of Critical Discharge (%)	Percentage of Bankfull Discharge (%)
2014	0.029	0.17	0.08
2015	0.020	0.15	0.07
2016	0.029	0.22	0.10
2017	0.043	*0.32*	*0.15*
Average	0.029	*0.21*	*0.10*

Note: A partial data-set for 2018 (January to March) was not included as part of the data analysis

6. Conclusions and Recommendations

PECG completed a fluvial geomorphology assessment of the Humber River and a nearby Headwater Tributary to support the EA for water and wastewater services in the Community of Nobleton, Ontario. A meander belt assessment (**Figure 1**) of the Headwater Tributary was completed to inform potential expansion of the existing WRRF. The Headwater Tributary is located within a defined valley setting with a meandering planform that has remained stable over the historical period of record (1970-2017). Dense vegetation within the channel and across the riparian zone has limited the potential for erosion and lateral adjustment. The final meander belt width of the Headwater Tributary ranged from 20 to 28 m, which includes the addition of a 20% factor of safety for future changes in the hydrological regime.

An erosion threshold assessment was also completed to inform and evaluate ongoing and potential geomorphological adjustments in the Humber River downstream of the WRRF effluent outlet. The erosion threshold assessment indicates that sediment entrainment and transport along the bed will occur at or near a critical discharge of 13.6 m^3/s. The average daily peak effluent discharge from 2014 to 2017 (0.029 m^3/s) is approximately 0.21% of the established critical discharge, which represents a very small contribution of WRRF effluent at flows capable of entraining and transporting sediment. It is unlikely that WRRF effluent discharge will disrupt existing geomorphic processes within the Humber River or exacerbate existing localized instabilities if the peak daily effluent discharge remains below 1% of critical discharge.

Erosion within the WRRF effluent wetland has led to the development of a defined channel and new confluence with the Humber River. It is recommended that confluence of the wetland and the Humber River be restored to the constructed riprap overflow structure in order to reduce fine sediment input to the Humber River and reduce the risk of bank erosion/instability along the Humber River at the existing confluence. The integrity of the riprap overflow should be assessed by a Water Resources Engineer. Periodic monitoring of bedform morphology and stability of the Humber River adjacent and downstream of the WRRF outlet is recommended.

7. Certification

This report was prepared and reviewed by the undersigned:

Prepared by:

Michael Brierley, M.Sc.
Fluvial Processes Specialist

Prepared by:

Samantha Feist, M.Sc., GIT
Environmental Scientist

Reviewed by:

Dan McParland, M.Sc., P.Geo.
Fluvial Geomorphologist

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