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ENVIRONMENT & ENGINEERING

EAGLE HEIGHTS GEOMORPHIC ASSESSMENT
CITY OF BURLINGTON, ONTARIO

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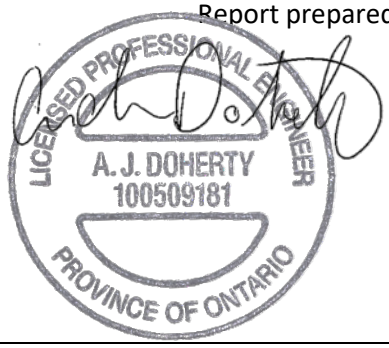
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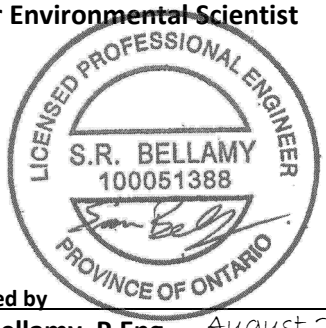
Report prepared for Penta Properties Inc., August 2018



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DISCLAIMER

We certify that this report is accurate and complete and accords with the information available during the site investigation. Information obtained during the site investigation or provided by third parties is believed to be accurate but is not guaranteed. We have exercised reasonable skill, care, and diligence in assessing the information obtained during the preparation of this report.

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EXECUTIVE SUMMARY

Matrix Solutions Inc. completed a geomorphic assessment of three Grindstone Creek tributaries to support planning and regulatory review for the proposed Eagle Heights Development (the Development) in the City of Burlington. These tributaries are referred to as Tributary 4, Tributary 5, and Tributary 6 were assessed by reach (i.e., a defined length of channel with relatively uniform characteristics; Figure 1). The purpose of this geomorphic assessment was to determine erosion thresholds and erosion hazard setbacks, develop a conceptual design for a channel realignment, and provide recommendations for watercourse crossings.

In December 2016, Matrix evaluated and documented geomorphic conditions of the tributaries using the Rapid Geomorphic Assessment (RGA) field technique. The RGA was used to evaluate dominant geomorphic processes using an indexed rating of channel sensitivity based on aggradation, degradation, channel widening, and lateral adjustment. The combined indices were used to determine whether the tributary reaches are in regime, stressed/transitional, or adjusting.

Informed by the RGA field results and desktop analysis, Matrix established geomorphic setbacks for each tributary reach depending on whether the reach is confined or unconfined:

- Where a reach is confined, the watercourse flows within a well-defined valley corridor and erosion of the watercourse into the valley wall is possible. To account for this potential erosion, Matrix established toe erosion allowances at each of the confined reaches to inform Development setback distances from the tributaries. The toe erosion allowances established at the Development are 1.0 m or 3.0 m as detailed in Section 4 of the report.

- Where a reach is unconfined, the watercourse flows within an undefined or poorly defined valley corridor. To inform Development setbacks at the unconfined reaches, Matrix established meander belt widths to delineate the areas that the tributaries currently occupy and the areas the tributaries may occupy in the future. The meander belt widths established for the Development range between 18 and 24 m as detailed in Section 5 of this report.

The upper portion of Reach 5-5 has the characteristics of both a confined and unconfined watercourse. At the upper portion of Reach 5-5, the Development setback was established using the largest (i.e., most conservative) of the stable top of bank, flood elevation, and meander belt width. Based on this approach, the flood elevation and meander belt width of 24 m was used to inform the Development setback.

In addition to providing recommendations to inform development setbacks, Matrix surveyed reach cross-sections and profiles to calculate erosion thresholds in the receiving channels downstream of the proposed stormwater facilities. These erosion thresholds define the flow required to entrain and transport sediment of a particular size. In this assessment, Matrix established the thresholds required to transport the D_{50} channel sediment sizes. The critical discharges calculated for the Development range

between 0.08 m^3/s and 1.1 m^3/s as detailed in Section 8 of this report. The erosion thresholds were used by stormwater management (SWM) designers to assess the relative change in erosion conditions and hydrologic regime between pre- and post-development conditions.

Reach 4-6 is a poorly vegetated, ephemeral tributary that is incised into an agricultural field. Savanta Inc. (2018) assessed Reach 4-6 to be a headwater drainage feature requiring "mitigation" management. This management classification requires site development to maintain the hydrologic function of the reach and maintain or enhance the riparian corridor (TRCA and CVC 2014). To facilitate the Development plans, maintain the hydrologic function, establish a riparian corridor, and improve the geomorphic function, Matrix developed a conceptual channel realignment for Reach 4-6 (Section 6).

As the final element of the Eagle Heights geomorphic assessment, Matrix provided watercourse crossing recommendations for the Development. In addition to including geomorphic considerations, the recommendations incorporate the considerations and constraints provided by the project team from the perspective of fish and wildlife, SWM and hydraulics, and civil works (i.e., road right-of-way and utility services). These recommendations are detailed in Section 9 of this report.

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1 INTRODUCTION

The proposed Eagle Heights Development (the Development) is located in the City of Burlington north of Highway 403 and is bounded by Waterdown Road to the east and Grindstone Creek to the west (Figure 1). Penta Properties Inc. retained Matrix Solutions Inc. to complete a geomorphic assessment of the three Grindstone Creek tributaries at the Development to support planning and regulatory review. These tributaries are referred to as Tributary 4, Tributary 5, and Tributary 6. In this assessment, these tributaries were assessed by reach (i.e., a defined length of channel with relatively uniform characteristics).

The purpose of this geomorphic assessment was to determine erosion thresholds, erosion hazard setbacks, and provide conceptual design recommendations for a channel realignment and watercourse crossings. The erosion threshold analyses were used to design stormwater management (SWM) features that will discharge into the Grindstone Creek tributaries. The erosion hazard setbacks were combined with the work of Metropolitan Consulting Inc. and Peto MacCallum Ltd. to determine setback distances between the tributaries and the Development. The watercourse crossing recommendations will provide guidance to help ensure that the long-term, geomorphic function of the tributaries is considered within detailed designs. Additionally, this assessment forms part of the responses to regulatory comments received between 2010 and 2013 for the Development.

1.1 Existing Conditions

Three Grindstone Creek tributaries flow south through the Development site toward Highway 403 (Figure 1). These tributaries are close together and flow nearly parallel to one another. The combined drainage area of these tributaries measured from the downstream end of the Development is approximately 150 ha (Metropolitan Consulting 2018a). The Development will encompass approximately 110 ha. The upper portion of the Development site features ephemeral, headwater drainage features (Savanta 2018) that become increasingly defined through the Development site. The tributaries drain into Grindstone Creek approximately 600 m downstream of Highway 403.

The Development is bisected by Flatt Road. Upstream of Flatt Road, the current land use is agricultural fields, forested valleys, and residential properties. Downstream, land use includes forested area, unfarmed fields, existing residential properties, a utility corridor, and the storage yard of a landscaping company. The Development downstream of Flatt Road was formerly referred to as the Taylor property.

Grindstone Creek, located west of the Development, is set within a forested valley with a top valley width that is up to 300 m wide and approximately 35 m deep. Immediately downstream of the Development, the valley floor is developed with residential properties along Hidden Valley Road.

1.2 Policy Considerations

The following planning policies were in effect in 2002 when Paletta International Corporation (currently Penta Properties) originally applied for development approvals:

- *Planning Act* as amended to 2002
- The 1995 Halton Region Official Plan including the North Aldershot Planning Area Amendment (1998)
- The 1997 Burlington Official Plan
- the 1978 Parkway Belt West Plan

This policy regime requires the protection of watercourses at the Development. For example, The 1995 Halton Region Official Plan designates the tributaries at the Development as an "Environmentally Sensitive Area." Current policy further emphasizes the importance of protecting watercourses at Eagle Heights. For example, it is the current policy of the Region of Halton to "encourage the protection and enhancement of watercourses and headwater areas as an integral component for maintaining natural hydrological processes with a watershed" (Halton Region 2009).

Matrix assessed the tributaries of Grindstone Creek at the Development from a fluvial geomorphic perspective to establish erosion thresholds, erosion hazard setbacks (e.g., toe erosion analysis and meander belt widths), and recommend watercourse crossing options. These analyses and recommendations will inform the long-term protection and enhancement of the Grindstone Creek tributaries in accordance with the goals and objectives of both the applicable policy regime, corresponding to the original application date for the development, and current planning policy.

The technical methods used in this assessment are based on the Ontario Ministry of Natural Resources' (OMNR) *Technical Guide, River and Stream Systems: Erosion Hazard Limits* (Technical Guide; OMNR 2002). This technical guide was developed in support of the *2014 Provincial Policy Statement* (MAH 2014). Additionally, Matrix believes that this assessment is consistent with *Policies and Guidelines for the Administration of Ontario Regulation 162/06 and Land Use Planning Policy Document* (Conservation Halton 2006).

1.3 Background Studies

PARISH Geomorphic Ltd. (now Matrix) reviewed and summarized previous geomorphic studies of Grindstone Creek and its tributaries as part of a 2010 Eagle Heights erosion assessment (PARISH 2010). These previous studies highlight the need to incorporate geomorphic recommendations and design considerations into development plans. The previous geomorphic studies of Grindstone Creek include the following:

- *Grindstone Creek Subwatershed Study: City of Burlington* (Cosburn Patterson Wardman Ltd. 1995)
- *Grindstone Creek Watershed Study* (HRCA 1998)

- *Grindstone Creek Stream Restoration Class Environmental Assessment* (TSH 2000)

1.4 Assessment Basis

This assessment is based on the following information:

- *Eagle Heights Erosion Assessment Burlington, Ontario* (PARISH 2010)
- site assessment and channel surveys by Matrix completed in December 2016
- *Environmental Impact Assessment Eagle Heights* (Savanta 2018)
- Eagle Heights Property City of Burlington Functional Servicing Report Update (Metropolitan Consulting 2018b)
- design flows for the Reach 4-6 conceptual channel realignment calculated by Metropolitan Consulting Inc. and provided on February 14, 2018
- historical aerial photography obtained from Open License Ontario, an online mapping tool (2005 and 2016), and Metropolitan Consulting

2 ASSESSMENT OVERVIEW

Natural watercourses are dynamic features on the landscape that move within their floodplains over time. The overall geometry and meandering pattern of a watercourse is governed by the interaction between erosive (e.g., flow, channel slope) and resisting forces (e.g., vegetation, sediment, geology). In a dynamically stable watercourse, the erosive and resisting forces are in balance (i.e., in regime). When this balance is achieved, the planform and characteristics of the watercourse are generally maintained as it moves within its floodplain.

When erosive and resisting forces are not in balance, a channel will adjust its form to minimize the work required to transport water and sediment. Adjustment is expected when there are significant land use changes within a watershed, such as urbanization. For example, uncontrolled, urban runoff increases the flow volume and intensities to receiving watercourses compared to natural conditions. Often in such cases, a watercourse will adjust to these increased flows by widening and straightening to re-establish the balance between erosive and resistive forces.

Matrix evaluated geomorphic processes using a combination of techniques, including the following:

- **Rapid Geomorphic Assessment (RGA)**: This technique evaluated channel stability using field observations to determine whether a watercourse is in regime, in transition, or in adjustment. When a channel is in regime, erosive and resistive forces are in balance. When these forces are not in balance, a channel will adjust by erosion or aggradation.

- **Review of Historical Aerial Photography**: Historical aerial images were used to define planform characteristics and track changes over time. When planform characteristics are maintained over time, erosive and restive forces are in balance and the channel is in regime. When a system is in

adjustment, aerial photographs can be used to observe changes in planform. The use of aerial photographs was limited for this geomorphic assessment due to tree cover, the quality of historical images, and the narrow widths of the tributaries.

- **Erosion Thresholds Analysis**: Channel surveys and critical discharge estimates were used to quantify the sensitivity of the tributaries to erosion. SWM designers use these thresholds to minimize post-development impacts to watercourses receiving stormwater discharge.

3 RAPID GEOMORPHIC ASSESSMENT

In December 2016, Matrix evaluated site conditions and documented geomorphic conditions using the RGA field technique. The RGA is used to evaluate dominant geomorphic processes. Field observations were evaluated using an indexed rating for channel sensitivity based on aggradation, degradation, channel widening, and lateral adjustment. The combined indices were used to determine whether each channel was in regime, stressed/transitional, or adjusting. The RGA is applied on a per reach basis (i.e., a defined length of channel with relatively uniform characteristics).

Table A summarizes results of the RGAs, and Appendix A provides site photographs. The RGA provides insight into the dominant geomorphic processes affecting channel form. The RGAs from this assessment are compared to the RGAs completed for the Development in 2009 (PARISH 2010). RGAs provide a snapshot of conditions at the time of the field assessment, in absence of any development, and include an element of subjectivity in the field observations. The 2016 and 2009 RGAs show overall channel adjustment and transition at the downstream reaches of the Development and increased stability toward the upstream reaches.

TABLE A Rapid Geomorphic Assessment (2016 and 2009)

Reach	2016 RGA		2009 RGA		Reach Notes
	Index	Geomorphic Condition	Index	Geomorphic Condition	
4-1 (Confined)	0.27	Transitional	0.29	Transitional	• No proposed development adjacent to this reach. This reach is just downstream of the proposed Block K Wetlands. • Sections of the bank are eroding into the valley wall. • Typical bankfull dimensions: 1.8 to 2.0 m width and 0.5 to 0.9 m depth.
4-2 (Confined)	0.056	In Regime	0.37	Transitional	• This reach is confined within a relatively shallow valley. • Left side (east) of the valley: existing residential properties. • Right side of the valley: proposed development lots and Block K Wetlands. • Typical bankfull dimensions: 2.0 m width and 0.3 m depth.
4-3 (Confined)	0.42	In Adjustment	0.27	Transitional	• No proposed development lots adjacent to this reach. • Left (east) overbank: Waterdown Road embankment confines reach. • Right overbank: Hydro One Limited corridor. • Typical bankfull dimensions: 3.5 m width and 1.3 m depth.
4-4 (Unconfined)	0.067	In Regime	0.26	Transitional	• No proposed development lots adjacent to this reach. • There are existing residential properties adjacent to this reach. • Typical bankfull dimensions: 0.5 to 1.3 m width and 0.3 and 0.70 m depth.
4-5 (Unconfined)	0.031	In Regime	0.13	In Regime	• Left (east) overbank area: proposed Block TT, Block SS, and cluster housing. • Right overbank area: proposed residential lots. • Typical bankfull dimensions: 1.3 to 1.7 m width and 0.75 m depth.
4-6 (Unconfined)	0.00	In Regime	0.00	In Regime	• Left (east) overbank area: proposed Block TT cluster housing and residential lots. • Right (west) overbank area: proposed residential lots. • Minimal geomorphic function due to its setting in an agricultural field and minimal riparian vegetation. • Typical bankfull dimensions: 1.3 m width and 0.3 m depth.
5-1 (Confined)	0.34	Transitional	-	-	• No proposed development along this reach. • This reach has a tortuous meander pattern. The channel bottom is composed of stiff clay and shale. The channel is eroding into the valley wall. • Typical bankfull dimensions: 3.5 to 4.0 m width and 1.3 m depth.
5-2 (Confined)	0.24	Transitional	-	-	• Left (east) overbank: two proposed residential lots adjacent to reach. • Right (west) over bank: the valley has been infilled. The tributary flows through a 200 m long culvert. • Typical bankfull dimensions: 4.5 m width and 1.5 m depth.

Reach	2016 RGA		2009 RGA		Reach Notes
	Index	Geomorphic Condition	Index	Geomorphic Condition	
5-3 (Confined)	0.23	Transitional	-	-	• No proposed development lots through this reach. This reach is through a Hydro One corridor. • Typical bankfull dimensions: 2.5 to 3.0 m width and 0.5 to 1.0 m depth. • The planform has changed since 1953 aerial photographs. Planform change may be due to clearing forested trees for utility corridor. The vegetation is low brush through this reach instead of the large trees that are typical of upstream reaches.
5-4 (Confined)	0.094	In Regime	0.428	Adjusting	• Left (east) overbank area: forested valley corridor, no proposed development lots. • Right (west) overbank area: a existing residential property and proposed Block JJ cluster housing. • Typical bankfull dimensions: 1.5 m width and 0.5 m depth. • The downstream section (downstream of Flatts Road) of Reach 5-4 was not assessed in 2016 because this section requires access through private residential property. This downstream section is known to have erosion concerns that were not included in the 2016 RGA score. Watercourse crossing recommendations should account for and improve erosion.
5-5 (Partially Confined)	0.16	In Regime	-	-	• Left (east) overbank area: proposed Block CC and Block BB cluster housing. • Right (west) overbank area: proposed Block JJ housing cluster and residential lots. • Typical bankfull dimensions: 1.4 m width and 0.6 m depth.
5-6 (Confined)	0.16	In Regime	-	-	• Left (east) overbank area: proposed Block OO cluster housing and residential lots. • Right (west) overbank area: proposed Block DD cluster housing and residential lots. • Typical bankfull dimensions: 1.5 to 2.5 m width and 0.6 to 1.0 m depth.
6-2 (Confined)	0.13	In Regime	0.07	In Regime	• Left (east) overbank area: proposed Block K cluster housing. • Right (west) overbank area: proposed residential lots. • Typical bankfull dimensions: 1.2 m width and 0.2 m depth. • Concrete blocks installed along Flatt Road embankment for stability.
6-3 (Confined)	0.21	Transitional	0.23	Transitional	• Left (south) side of the valley: proposed Block K cluster housing. • Right (north) side of valley: proposed Block H clustering housing. • Typical bankfull dimensions: 0.6 m width and 0.7 m depth.
6-4 (Confined)	0.25	Transitional	-	-	• Left (east) overbank area: proposed Block H cluster housing and residential lots. • Right (west) overbank area: proposed Block E cluster housing and residential Lots. • Typical bankfull dimensions: 2.2 m width and 1.0 m depth.

Note:
Stability Index ≤ 0.2 = In Regime, 0.21-0.40 = Transitional, ≥ 0.40 = In Adjustment
Left/right convention relative to looking the tributaries in the downstream direction

4 TOE EROSION ALLOWANCE

Where a watercourse is confined in a valley setting, an erosion hazard assessment is used to determine setbacks for development. Erosion hazard setbacks include three components:

- toe erosion allowance
- stable valley slope setback
- access setback

For the Development, the slope stability and access setbacks were determined by Peto MacCallum Ltd. Matrix recommended toe erosion allowances (Section 4.1) for the Grindstone Creek tributaries in accordance with the Technical Guide (OMNR 2002) that was developed in support of the *2014 Provincial Policy Statement* (MAH 2014). Where the tributaries are unconfined a toe erosion allowance is not required. At the unconfined reaches, Matrix estimated meander belt widths to inform development setbacks (Section 5).

A dynamically stable watercourse moves within its floodplain over time. Matrix used historical aerial photographs of planform and the current channel stability to estimate whether the tributaries were laterally migrating and thereby creating a risk for valley toe erosion. Typically, if available data allows, a toe erosion allowance equals the average annual rate toe erosion times 100 years (e.g., if the toe erodes 5 m in 20 years, then the toe erosion allowance is set to 25 m; OMNR 2002).

4.1 Grindstone Creek Tributaries

Table B summarizes the recommended erosion allowance setbacks at the confined reaches within the Development. The Development tributaries are small (i.e., bankfull width less than 5 m) with cohesive soils (i.e., clays, silt-clays). The Technical Guide (OMNR 2002) recommends a 1 m minimum toe erosion allowance for these tributaries based on the bankfull width and soil type.

Typically, throughout the Development, Matrix recommends a toe erosion allowance of 1 m (Table E) as per the OMNR recommendation. This setback is appropriate because the Grindstone Creek tributaries have bankfull widths of less than 5 m, and at reaches adjacent to the proposed development, meander bend planforms appear to have generally propagated downstream over time (as observed from 2005 versus 2016 online mapping tool imagery), rather than lateral migration. Lateral channel migration, in contrast to downstream meander propagation, would introduce a risk of toe erosion that would therefore be addressed with a larger than 1 m toe erosion allowance. During the site assessment active toe erosion was observed at Reaches 4-1 and 5-1. There is no proposed development adjacent to these two reaches.

In Reach 5-5, where the tributary flows within the forested valley, there is a large bend that meanders toward the valley toe directly adjacent to Flatt Road. An additional 2 m toe erosion allowance above the

1 m minimum is recommended because of the alignment of this meander bend. Because no toe erosion was observed during the site assessment at Reach 5-5 and considering the size of the valley (typical 50 m top width and 6 m depth) relative to the tributary (typical 1.4 m bankfull width), this toe erosion allowance is considered conservative and the additional 2 m allowance compared to the other reaches at the Development is provided as a factor or safety.

TABLE B Toe Erosion Allowances for Confined Reaches

Reach	Geomorphic Condition	Toe Erosion Allowance		Notes
		Left (East) Valley (m)	Right (West) Valley (m)	
4-1	In Adjustment	-	-	• No proposed development along this reach. • Observed channel erosion into valley wall during site assessment.
4-2	In Regime	-	1.0	• Right (west) side of the valley: proposed residential lots.
4-3	In Transition	-	1.0	• This reach is through a Hydro One corridor. • There are proposed development lots on the right side of the valley near the downstream reach break.
5-1	In Transition	-	-	• No proposed development along this reach.
5-2	In Transition	1.0	-	• The portion of this reach adjacent to development flows through a 200 m long culvert. • No proposed development along on right side of valley.
5-3	In Transition	-	-	• This reach is through the Hydro One corridor. No proposed developments lots along this reach. • Planform adjustment since 1953 possibly due to removal of trees during installation of Hydro One corridor. The corridor is currently vegetated with low, dense shrubs.
5-4	In Regime	1.0	1.0	• Minimal lateral migration of reach observed between 2005 and 2016.
5-5	In Regime	1.0	3.0	• Minimal lateral migration of reach observed between 2005 and 2016. • A toe erosion allowance of 3.0 m is recommended at the right valley because the tributary meanders toward the valley toe. • See erosion hazard limit assessment for upper portion of reach (Section 7)
5-6	In Regime	1.0	1.0	• Downstream migration of meander bends observed between 2005 and 2016.
6-2	In Regime	1.0	1.0	• Minimal lateral migration of planform observed between 2005 and 2016.
6-3	In Regime	1.0	1.0	• Minimal lateral migration of planform observed between 2005 and 2016.
6-4	In Regime	1.0	1.0	• Minimal lateral migration of planform observed between 2005 and 2016.

4.2 Grindstone Creek

The Development is located east of the Grindstone Creek valley (Figure 1). A toe erosion allowance along the top of this valley is not recommended at the Development. This recommendation is based on on the consideration that Grindstone Creek is typically more than 15 m away from the valley toe along the Development (OMNR 2002). Therefore, Grindstone Creek can migrate and adjust within its forested valley floor without eroding into the east valley toe along the Development. Additionally due to the depth of the valley (typically 35 m) and slope of the valley wall (typically 2.5H:1V), the boundary of the Development is located 150 m away from Grindstone Creek.

5 MEANDER BELT WIDTH ASSESSMENT

Where the tributaries are unconfined, a meander belt width assessment was used to inform the erosion hazard setbacks. The meander belt widths capture the area that the tributaries currently occupy and the area the tributaries might occupy in the future. The meander belt widths are based on aerial photographs, the planform of each tributary planform, and current channel stability. Due to the small channels, overhead vegetation, and quality of photographs, the analysis of historical aerial photographs was limited for the Development. Recent aerial photographs, including the photographs on the figures, were used to delineate the meander belt widths. To account for the limited use of historical photographs, a 20% factor of safety was added to the meander belt widths. Given the assessed stability of the unconfined reaches (Table A), this factor of safety is considered conservative for meander belts that are less than 50 m wide (PARISH 2004). Table C summarizes the recommended meander belt widths for the unconfined reaches within the Development area.

TABLE C Meander Belt Widths for Unconfined Reaches

Tributary Reach	Geomorphic Condition	Preliminary Meander Belt width (m)	Final Meander Belt width (m)	Notes
4-4	In Regime	15	18	• Preliminary belt width encompasses meander bends and sections of braided channel in this reach. • Final meander belt width 20% wider than preliminary belt width for factor of safety. • Figure 2
4-5	In Regime	18	22	• Preliminary belt width encompasses meander bends and sections of braided channel near upstream reach break. • Final meander belt width 20% wider than preliminary belt width for factor of safety. • Figure 3

Tributary Reach	Geomorphic Condition	Preliminary Meander Belt width (m)	Final Meander Belt width (m)	Notes
4-6	In Regime	-	-	• See Section 6 and Figures 4 to 6 for proposed conceptual channel realignment.
5-5	In Regime	20	24	• Final meander belt width 20% wider than preliminary belt width for factor of safety. • Meander belt width considered as part of conservative setback at Reach 5-5 (See Section 7 and Figure 7).

6 REACH 4-6 CONCEPTUAL CHANNEL REALIGNMENT

Reach 4-6 is a poorly vegetated, ephemeral tributary that is incised into an agricultural field. Savanta Inc. (2018) assessed Reach 4-6 to be a headwater drainage feature requiring "mitigation" management. This management classification requires site development to maintain the hydrologic function of the reach and maintain or enhance the riparian corridor (TRCA and CVC 2014). To facilitate the Development plans, maintain the hydrologic function, establish a riparian corridor, and improve the geomorphic function at Reach 4-6, Matrix developed a conceptual channel realignment presented on Figures 4 to 6.

Highlights of the conceptual channel realignment include the following:

- The planform of the realignment channel was developed to mimic the sinuosity typical of downstream reaches of this tributary and adjacent tributaries to Grindstone Creek.

- The bankfull channel was sized to convey the 2-year design flow (Table D). Larger flows will overtop the channel and dissipate energy into a floodplain corridor to provide stability and maintain hydrologic function. The capacity of the designed floodplain corridor is sufficient to convey the regional design flow (Table D).

- The floodplain corridor will smoothly transition into the adjacent, post-development grade. The side slopes of the floodplain corridor will be 2H: 1V or flatter and may vary depending on local topographic conditions.

- The floodplain corridor will be vegetated to establish a riparian buffer between Reach 4-6 and the proposed Development.

- The downstream end of the realignment channel will tie into Reach 4-5. Savanta classified Reach 4-5 as a headwater drainage feature requiring "protection" management. No modifications to Reach 4-5 are proposed as part of this channel realignment.

TABLE D Reach 4-6 Conceptual Realignment Design Parameters

Bankfull Channel Parameters		Floodplain Corridor Parameters	
Minimum Bankfull Channel Slope (%)	2.2	Minimum Floodplain Slope (%) (Bankfull channel meanders in floodplain and therefore has shallower slope)	2.4
Bankfull Depth (m)	0.25	Minimum Depth (m)	0.5
Bankfull Width (m)	1.05	Minimum Top Width (m)	9.5
Bankfull Area (m^2)	0.19	Minimum Area (m^2)	4.3
Hydraulic Radius (m)	0.14	Minimum Hydraulic Radius (m)	0.43
Assumed Manning's n value for roughness	0.055	Assumed Manning's n value for roughness	0.085
Flow Capacity (m^3/s) = $(1/n)AR^{2/3}S^{1/2}$	0.14	Flow Capacity (m^3/s) = $(1/n)AR^{2/3}S^{1/2}$	4.5
2-year Design Flow (m^3/s; calculated by Metropolitan Consulting using 24-hour Chicago Storm)	0.08	Regional Design Flow (m^3/s; calculated by Metropolitan Consulting using 24-hour Chicago Storm)	0.32

Note:
The hydraulic calculations assume that the Flatt Road watercourse crossing will be adequately sized to pass the regional design flow and the realignment channel will not be impacted by backwater conditions caused by the Flatt Road crossing.

7 REACH 5-5 EROSION HAZARD SETBACK

Development is proposed along Flatt Road Extension at the upper portion of Reach 5-5 (Figure 7). The upper portion of this reach is a small, ephemeral tributary with a bankfull width of less than 1.0 m. The tributary flows through a poorly vegetated, agricultural field within a topographic setting that gives the upper reach the characteristics of both a confined and unconfined watercourse.

Typically, setbacks in a confined valley setting are based on a physical top of bank (i.e., top of valley) plus an allowance for toe erosion and access. A valley is defined by a 2 m change in topography (Conservation Halton 2006). This definition of a valley setting does not relate the 2 m change in topography to a valley slope or horizontal distance. The upper portion of Reach 5-5 is defined as a valley based on a 2 m change in topography. However, the valley slope at the upper portion of Reach 5-5 is significantly flatter (i.e., typically 7H:1V to 8H:1V) than the assumed stable slope of 3H:1V (OMNR 2002).

Because the valley slopes are gentle through the confined portion of this section of Reach 5-5, the physical top bank will not be affected by the natural migration and erosion of the watercourse below. Therefore, it is Matrix's opinion, considering these site-specific characteristics, that the Development setback should be based on an erosion hazard limit delineated using the largest (i.e., most conservative) of the following:

- flood elevation
- meander belt width

- stable top of bank

In this upper portion of Reach 5-5, either the flood elevation or meander belt width produces the largest setback and was therefore used to delineate the erosion hazard limit (Figure 7). The stable top of bank was estimated by adding a 1 m erosion allowance to the valley toe then determining where a conservatively assumed 3H:1V stable slope intersects existing ground.

This erosion hazard limit will accommodate and protect the long-term function of Reach 5-5. The erosion hazard limit can be used to enhance the geomorphic function of the reach by establishing a riparian buffer around the tributary within the erosion hazard limit. This riparian buffer will link the forested areas both upstream and downstream of this section of Reach 5-5, forming a continuous corridor for wildlife movement.

8 EROSION THRESHOLD ASSESSMENT

One SWM pond (Block EE), one wetland feature (Block G), and underground stormwater storage and outlet pipes are proposed as part of the Development (Figure 1). These SWM facilities will discharge into the Grindstone Creek tributaries. To assist with the design of these features, Matrix surveyed reach cross-sections and profiles to calculate erosion thresholds in the receiving channels downstream of the proposed stormwater discharge outfalls.

The erosion thresholds for the Grindstone Creek tributaries were used to design SWM facilities at the Development. The erosion thresholds formed the basis for SWM designers to assess the relative change in erosion conditions and hydrologic regime between pre- and post-development conditions.

8.1 Methodology and Results

The erosion thresholds are expressed as a critical discharge, a critical maximum depth, and a critical maximum velocity. These critical thresholds define the flow required to entrain and transport sediment of a particular size. In this assessment, Matrix established the erosion thresholds required to transport the D_{50} channel sediment size. Manning's equation was used to relate flow to the threshold conditions (e.g., critical shear stress, critical velocity) required for sediment entrainment and transport estimated using empirical methods.

With the exception of Reach 4-1b, the surveyed tributaries in the Development area are composed of cohesive materials (e.g., clays and silt-clays). The empirical method by Chow (1959) was used to estimate the critical shear stress that would cause sediment entrainment and transport as this methodology accounts for the cohesive properties of clay. At Reach 4-1b, the empirical method by Komar (1987) was used to estimate the critical velocity as this method is appropriate for the relatively large channel substrate in this reach that includes gravels and pieces of large, flat shale.

TABLE E Erosion Threshold Analysis

Reach	Critical Discharge (m^3/s)	Critical Maximum Depth (m)	Critical Maximum Velocity (m/s)	Notes
Reach 4-4	0.08	0.14	0.92	• Reach 4-4 is in regime. Because the reach is stable, critical values from the 2010 report are used (PARISH 2010).
Reach 4-1a	0.10	0.17	1.3	• Reach 4-1a has a silty-clay channel bottom, typical of this tributary. • Reach 4-1b has widened and deepened since 2009 survey. This erosion exposed large substrate at the channel bottom, including flat shale characteristic of the local bedrock. • Chow (1959) methods were used to calculate erosion threshold at Reach 4-1a because of cohesive soils. • Komar (1987) methods were used to calculate erosion threshold at Reach 4-1b because of relatively large channel substrate.
Reach 4-1b	1.1	0.31	1.7	
Reach 5 Ravine	0.070	0.14	1.4	• The ravine is incised into the valley wall through the ravine/gully. The cross-sections are about 1.2 m deep. • Chow (1959) methods were used to calculated erosion threshold because cohesive soils.
Reach 5-4	0.04	0.090	1.1	• Reach 5-4 is in regime. Because the reach is stable, critical values from the 2010 report are used (PARISH 2010).
Reach 6-2	0.18	0.14	1.1	• This reach has a relatively wide channel bottoms compared to upstream Reaches 6-3 and 6-4. The slope is relatively flat (1.4%). • This reach is upstream of culvert road crossing with a small inlet. Inlet may be creating backwater conditions during high flows. • Chow (1959) methods were used to calculate erosion threshold because of cohesive soils.

With the exception of Reach 4-1b, the calculated critical discharges are low. This is due to the fine channel substrate and steep gradients (surveyed between 1.5% and 2.7%) of the tributaries. The erosion thresholds are consistent with the study completed by Cosburn Patterson Wardman Ltd. (1995), which concluded that uncontrolled, post-development runoff would likely result in erosion within the study area.

The thresholds represent erosion of the channel bed. The channel bed is typically more sensitive to erosion compared to the channel banks at the Development based on the following considerations:

- Typically there is less shear on banks compared to the channel during the critical flow.
- Both the bed and banks are generally composed of fine material (e.g. silty clays).
- Vegetation and root mass in the banks provide resistance to shear and erosion.

At Reach 4-1b, the erosion threshold is based on a channel bed consisting of large substrate. At this reach, the channel banks may be more sensitive to erosion than the channel bed. To account for this, an erosion threshold was calculated immediately downstream at Reach 4-1a. The erosion threshold at Reach 4-1a is more sensitive than Reach 4-1b and represents erosion of the channel bed, which is considered more sensitive to erosion than the banks. Therefore, the erosion threshold at Reach 4-1a governs the erosivity of Reach 4-1.

9 WATERCOURSE CROSSINGS

The Development plan by Metropolitan Consulting includes following watercourse crossing locations (Figure 1):

- WC 1: Reach 4-6 at Flatt Road, 50 m west of Waterdown Road
- WC 2: Reach 5-6 at Flatt Road, 240 m west of Waterdown Road
- WC 3: Reach 5-5 at Flatt Road, 300 m west of Waterdown Road
- WC 4: Reach 6-2 at Flatt Road 110 m west of Flatt Road ExtensionWC 5: Reach 5-5 at proposed Street C, 450 m north of Flatt Road.

The crossing locations were considered against the geomorphic conditions at the tributaries to provide recommendations for crossing sizes and types. Recommendations for the crossings are provided to address risks associated with lateral and downstream channel migration. The following site-specific conditions were considered for crossing recommendations:

- **Channel Size**: The potential for lateral channel movement and erosion generally increases with channel size. Erosive forces in larger watercourses often exceed the resistive forces of vegetation, resulting in channel erosion and migration. Whereas headwater streams typically exhibit low rates of erosion and migration due to the stabilizing properties of vegetation. The Development is located

near the headwaters of the Grindstone Creek watershed. Channel bankfull widths upstream of the watercourse crossings were considered in the recommendations.

- **Valley Setting**: Watercourses with wide, flat floodplains, and low valley setting tend to migrate laterally across the floodplain over time. Watercourses that are confined in narrow, well-drained valleys are less likely to erode, but are susceptible to down-cutting and channel widening. The Development crossings are in both confined and unconfined valley settings.

- **Meander Belt Width**: A meander belt width defines the area that a meandering watercourse currently occupies and is expected to occupy in the future. This value has been used by regulatory agencies for corridor delineation of natural hazards. The use of the meander belt width for structure sizing represents a conservative approach for crossing design.

- **RGA**: The RGA provides a measure of channel stability. Channels that are unstable tend to be actively adjusting. Conservative crossing design approaches are required to accommodate unstable, actively adjusting channels. The reaches at the Development's watercourse crossings were assessed to be stable and in regime.

- **100-year Migration Rates**: Migration rates are estimated using historical aerial photography (when available). Higher migration rates indicate a more unstable system and higher geomorphic risk. In general due to tree cover, narrow tributary widths, and the quality of historical aerial photographs, 100-year migration rates could not be estimated. However, the reaches upstream of the crossings were assessed to be stable and in regime.

The upstream reaches at the five watercourse crossing locations (Figure 1) were assessed to be in regime. For this reason, the crossing recommendations are based on bankfull widths and meander belt widths.

9.1 Crossing Recommendations

In addition to providing geomorphic considerations, the watercourse crossing recommendations incorporate the considerations and constraints provided by the project team from the perspective of fish and wildlife, SWM and hydraulics, and civil works (i.e., road right-of-way and utility services). The watercourse crossing recommendations are summarized in Tables F-1 to F-5.

TABLE F-1 Watercourse Crossing 1 Recommendations - Tributary 4-5 at Flatt Road

Existing Structure	Watercourse Crossing Design Considerations and Recommendations			Crossing Recommendations
	Fish and Wildlife (by Savanta)	Geomorphology (by Matrix)	Civil Works and Stormwater Management (by Metropolitan Consulting)	
Type Corrugated Steel Pipe Opening 400 mm diameter Length 14 m	CONSIDERATIONS • Target wildlife species for passage through the watercourse crossing include the following: ✦ amphibians (e.g., frogs) ✦ reptiles (e.g., snakes) ✦ small mammals (e.g., mice) ✦ medium mammals (e.g., fox) • Fish passage should be considered through the watercourse crossing. RECOMMENDATIONS • The following minimum culvert diameters are recommended to accommodate the passage of the target wildlife species: ✦ 0.3 m for amphibians and reptiles ✦ 0.5 m for small-sized mammals ✦ 1.0 m for medium-sized mammals • The culvert, if feasible, should be embedded into the channel bed to a depth of 30 cm or 10% of the culvert diameter (whichever is greater). The invert of the culvert should be filled with substrate that is stable at the design flow. • Where feasible, a low flow channel should be constructed within the culvert to provide suitable water depths for fish passage during low flow conditions. To maintain a suitable water depth through the culvert to facilitate upstream fish passage. • The culvert should be installed at a similar gradient to upstream and downstream stream reaches and should not be perched. • Riverstone should be used for erosion protection below the ordinary highwater mark. The use of riprap should be restricted to areas above the ordinary high water mark. • Where riprap is required, smaller material should be placed on top of riprap to fill voids and create a relatively smooth surface to support amphibian and small mammal movement.	CONSIDERATIONS • Upstream of the crossing, Tributary 4-5 was assessed to be stable (in regime) with a relatively straight alignment. RECOMMENDATIONS • Based on the upstream planform and channel stability, the recommended culvert opening width is 3.9 m (3 times the bankfull width). • If a smaller opening width is constructed because of design constraints, then erosion protection measures must be incorporated into the culvert design. • To mimic natural channel conditions, and if practical based on the size of the culvert, a substrate and a bankfull channel should be placed at the culvert bottom to mimic geomorphic channel function. The substrate should be sized to be stable at the design flow of the watercourse crossing.	CONSIDERATIONS • The culvert should be sized to accommodate the regional flood (0.90 m^3/s) at Tributary 4-5. • The culvert size and elevation must agree with the road grade and elevation of site services (e.g., sanitary line). The vertical clearance between the proposed road grade and site services are as follows: ✦ 2.6 m for the proposed water main ✦ 1.9 m for the existing watermain (to be removed) ✦ 3.9 m for the sanitary line RECOMMENDATIONS • The maximum height of the culvert is 750 mm. This height will provide a recommended clearance of approximately 0.5 m above the proposed watermain, and approximately 1.25 m below the proposed road grade. • To accommodate the regional flood, the minimum recommended culvert diameter is 750 mm.	CULVERT Type Concrete pipe or corrugated steel pipe Opening 750 mm diameter Length Approximately 20 m KEY DESIGN CONSTRAINT • The size and type of the culvert is governed by the civil works. The proposed culvert is larger than the existing structure. The elevation, diameter, and gradient of the proposed culvert are constrained by the grade of Flatt Road and the elevation of site services. • Due to the size of the culvert, it may not be feasible to construct a bankfull channel with stable substrate through the culvert. DESIGN FEATURES • The culvert elevation will require grading of the existing channel upstream of the culvert inlet. This channel grading should incorporate fish passage considerations and natural channel design techniques. • To satisfy geomorphic design recommendations, erosion protection measures must be incorporated at the inlet of the design. • The size of the culvert will allow the passage of amphibians, reptiles, and small mammals during low flow conditions; however it is not practical to construct a bankfull channel to facilitate passage during larger flows.

Note:
The conceptual culvert design is illustrated on Figures 2-4 and 2-13 of the *Eagle Heights Property City of Burlington Functional Servicing Report Update* (Metropolitan Consulting 2018b).

TABLE F-2 Watercourse Crossing 2 Recommendations - Tributary 5-6 at Flatt Road

Existing Structure	Watercourse Crossing Design Considerations and Recommendations			Crossing Recommendations
	Fish and Wildlife (by Savanta)	**Geomorphology (by Matrix)**	**Civil Works and Stormwater Management (by Metropolitan Consulting)**	
Type Corrugated Steel Pipe Opening 750 mm diameter Length 24 m	CONSIDERATIONS • Target wildlife species for passage through the watercourse crossing include the following: ✦ amphibians (e.g., frogs) ✦ reptiles (e.g., snakes) ✦ small mammals (e.g., mice) ✦ medium mammals (e.g., fox) • Fish passage should be considered through the watercourse crossing. RECOMMENDATIONS • The following minimum culvert diameters are recommended to accommodate the passage of the target wildlife species: ✦ 0.3 m for amphibians and reptiles ✦ 0.5 m for small-sized mammals ✦ 1.0 m for medium-sized mammals • A grated skylight is required in culverts that are longer than 25 m to allow natural lighting. The grated skylight should be contained within a vegetated traffic island. • The culvert, if feasible, should be embedded into the channel bed to a depth of 30 cm or 10% of the culvert diameter (whichever is greater). The invert of the culvert should be filled with substrate that is stable at the design flow. • A low flow channel should be constructed within the culvert to provide suitable water depths for fish passage during low flow conditions. • The culvert should be installed at a similar gradient to upstream and downstream stream reaches and should not be perched. • If riprap is used for erosion and embankment protection, it should be restricted to areas above the average annual high water mark. Riverstone is the preferred material for erosion protection below the ordinary high water mark. • Where riprap is required, smaller material should be placed on top of riprap to fill voids and create a relatively smooth surface to support amphibian and small mammal movement.	CONSIDERATIONS • Upstream of the crossing, Tributary 5-6 was assessed to be stable (in regime) with a meandering planform alignment. RECOMMENDATIONS • Based on the upstream planform and channel stability, the recommended culvert opening width is 5 m (the approximate upstream meander amplitude). This size will accommodate the downstream migration of the meander over time. • If a smaller opening width is constructed based on other constraints, then erosion protection measures should be incorporated into the culvert design. • Minor channel realignment works may be required as part of the detailed design of the crossing to allow road widening. • To mimic natural channel conditions, and if practical based on the size of the culvert, a substrate and a bankfull channel should be placed at the culvert bottom to mimic geomorphic channel function. The substrate should be sized to be stable at the design flow of the watercourse crossing.	CONSIDERATIONS • The culvert should be sized to accommodate the regional flood (3.4 m^3/s) at Tributary 5-6. • The culvert size and elevation must agree with the road grade and elevation of site services (e.g. sanitary line). The vertical clearance between the proposed road grade and site services are as follows: ✦ 1.7 m for the proposed watermain ✦ 1.2 m for the existing watermain (to be abandoned) ✦ 5.4 m for the proposed sanitary line • Due to the depth of the valley at the crossing, and the requirement to keep Flatt Road open to traffic during development, it is expected that direction drilling (or similar) will be the construction method used to install the culvert. RECOMMENDATIONS • The recommended maximum culvert height is 2,400 mm. This height will provide a recommended clearance of 0.3 m below the proposed sanitary service. • To accommodate the regional flood, the minimum recommended culvert diameter is 1,050 mm. • A round pipe is recommended for the watercourse crossing. It is feasible to install this type of culvert with directional drilling (or similar) construction methods. Directional drilling is required to keep Flatt Road open to traffic during construction.	CULVERT Type Concrete pipe or corrugated steel pipe Opening 2,400 mm diameter Length Approximately 60 m KEY DESIGN CONSTRAINT • The size and type of the culvert is governed by the civil works. The proposed culvert is larger than the existing structure. The elevation, diameter, and gradient of the proposed culvert are constrained by the location of site services and required construction methods. ADDITIONAL DESIGN FEATURES • Minor channel realignment works may be required as part of the detailed design of the crossing to facilitate road widening. • To satisfy geomorphic design recommendations, erosion protection measures must be incorporated at the inlet of the design. • Substrate and a low flow channel will be incorporated through the 2,400 mm diameter culvert as much as practical. • A grated skylight is required to allow for natural lighting. • The size of the culvert will allow the passage of amphibians, reptiles, and small- to medium-sized mammals.

Note:
The conceptual culvert design is shown on Figures 2-4 and 2-13 of the *Eagle Heights Property City of Burlington Functional Servicing Report Update* (Metropolitan Consulting 2018b).

Table F-3 Watercourse Crossing 3 Recommendations- Tributary 5-4 at Flatt Road

Existing Structure	Watercourse Crossing Design Considerations and Recommendations			Crossing Recommendations
	Fish and Wildlife (by Savanta)	Geomorphology (by Matrix)	Civil Works and Stormwater Management (by Metropolitan Consulting)	
Type Corrugated Steel Pipe Opening 750 mm diameter Length 28 m	CONSIDERATIONS • Target wildlife species for passage through the watercourse crossings include the following: ✦ amphibians (e.g., frogs) ✦ reptiles (e.g., snakes) ✦ small mammals (e.g., mice) ✦ medium mammals (e.g., fox) • Fish passage should be considered through the watercourse crossing. RECOMMENDATIONS • The following minimum culvert diameters are recommended to accommodate the passage of the target wildlife species: ✦ 0.3 m for amphibians and reptiles ✦ 0.5 m for small-sized mammals ✦ 1.0 m for medium-sized mammals • • Because the culvert is longer than 25 m, a grated skylight is required to allow natural lighting. The grated skylight should be contained within a vegetated traffic island. • The culvert, if feasible, should be embedded into the channel bed to a depth of 30 cm or 10% of the culvert diameter (whichever is greater). The invert of the culvert should be filled with substrate that is stable at the design flow. • A low flow channel should be constructed within the culvert to provide suitable water depths for fish passage during low flow conditions to maintain a suitable water depth through the culvert to allow upstream fish passage. • The culvert should be installed at a similar gradient to upstream and downstream stream reaches and should not be perched. • If riprap is used for erosion and embankment protection, it should be restricted to areas above the average annual high water mark. Riverstone is the preferred material for erosion protection below the ordinary high water mark. • Where riprap is required, smaller material should be placed on top of riprap to fill voids and create a relatively smooth surface to support amphibian and small mammal movement.	CONSIDERATIONS • Upstream of the crossing, Tributary 5-5 was assessed to be stable (in regime) with a meandering planform. Directly downstream of the existing crossing, erosion is occurring at a private residence. RECOMMENDATIONS • The recommended culvert opening width is 5 m (the approximate upstream meander amplitude). This size will accommodate the downstream migration of the meander over time. • If a smaller opening width is constructed based on other constraints, then erosion protection measures should be incorporated into the culvert design. • Velocity control at the outlet (e.g., a plunge pool) may be incorporated into the detailed crossing design to improve the erosion known to be occurring directly downstream of the culvert. • To mimic natural channel conditions, and if practical based on the size of the culvert, a substrate and a bankfull channel should be placed at the culvert bottom to mimic geomorphic channel function. The substrate should be sized to be stable at the design flow of the watercourse crossing.	CONSIDERATIONS • The culvert should be sized to accommodate the regional flood (1.4 m^3/s) at Tributary 5-4. • The culvert size and elevation must agree with the road grade and elevation of site services (e.g., sanitary line). The vertical clearance between the proposed road grade and site services are as follows: ✦ 1.7 m for the proposed watermain ✦ 1.1 m for the existing watermain (to be abandoned) ✦ 5.5 m for the proposed sanitary line • Due to the depth of the valley at the crossing, and the requirement to keep Flatt Road open to traffic during development, it is expected that direction drilling (or similar) will be the construction method used to install the culvert. RECOMMENDATIONS • The recommended maximum culvert height is 1,200 mm. This height can allow a recommended clearance of 0.3 m below the proposed sanitary service. • To accommodate the regional flood, the minimum recommended culvert diameter is 900 mm. A similarly sized culvert should be constructed at the private drive located just downstream of this crossing. • A round pipe is recommended for the watercourse crossing. It is feasible to install this type of culvert with directional drilling (or similar) construction methods. Directional drilling is required to keep Flatt Road open to traffic during construction.	CULVERT Type Concrete pipe or corrugated steel pipe Opening 1,200 mm diameter Length Approximately 50 m KEY CONSTRAINTS • The size and type of the culvert is governed by the civil works. The proposed culvert is larger than the existing structure. The elevation, diameter, and gradient of the proposed culvert is constrained by the location of site services and required construction methods. • Due to the size of the culvert, it is not practical to construct a bankfull channel with stable substrate through the culvert. ADDITIONAL DESIGN FEATURES • To satisfy geomorphic design recommendations, erosion protection measures must be incorporated at the inlet of the design. • A grated skylight is required to allow for natural lighting. • The size of the culvert will allow the passage of amphibians, reptiles, and small- to medium-sized mammals during low flow conditions; however it is not practical to construct a bankfull channel to facilitate passage during larger flows.

Note:
The conceptual culvert design is illustrated on Figures 2-4 and 2-13 of the *Eagle Heights Property City of Burlington Functional Servicing Report Update* (Metropolitan Consulting 2018b).

TABLE F-4 Watercourse Crossing 5 Recommendations - Tributary 6-5 at Flatt Road

Existing Structure	Watercourse Crossing Design Considerations and Recommendations			Crossing Recommendations
	Fish and Wildlife (by Savanta)	Geomorphology (by Matrix)	Civil Works and Stormwater Management (by Metropolitan Consulting)	
Type Corrugated Steel Pipe Opening 500 mm diameter Length 75 m (estimated)	CONSIDERATIONS • Wildlife fish passage at Tributary 6-5 crossing is not required given that the reach downstream of the culvert is buried over a distance of approximately 75 m and no upstream fish passage is possible.	CONSIDERATIONS • Upstream of the crossing, Tributary 6-5 was assessed to be stable. • Directly upstream of the culvert the tributary flows against the toe of the Flatt Road embankment. There are concrete block along this toe for erosion protection. RECOMMENDATIONS • No geomorphic recommendations are provided for this crossing because the existing, downstream tributary is buried and highly modified from natural conditions.	CONSIDERATIONS • Downstream of the watercourse crossing, the tributary is piped through a 500 mm diameter corrugated steel pipe at a private property. Increasing the size of the culvert at Flatt Road will not increase hydraulic conveyance. The hydraulic conveyance would be controlled by the 500 mm corrugated steel pipe downstream of the road crossing. RECOMMENDATIONS • No change to the existing crossing	CULVERT Type Corrugated Steel Pipe (maintain existing) Opening 500 mm diameter (maintain existing) Length 75 m (estimated) (maintain existing) KEY CONSTRAINTS • Tributary 6-5 is buried over an estimated length of 75 m downstream of Flatt Road. Downstream of the buried section, the tributary is modified through the storage yard of a landscaping company.

Note:
The conceptual culvert design is illustrated on Figures 2-4 and 2-13 of the *Eagle Heights Property City of Burlington Functional Servicing Report Update* (Metropolitan Consulting 2018b).

TABLE F-5 Watercourse Crossing 5 Recommendations - Tributary 5-4 at Proposed Street C

Existing Structure	Watercourse Crossing Design Considerations and Recommendations			Crossing Recommendations
	Fish and Wildlife (by Savanta)	Geomorphology (by Matrix)	Civil Works and Stormwater Management (by Metropolitan Consulting)	
No existing structure	CONSIDERATIONS • Target wildlife species for passage through the watercourse crossings include the following: ✦ amphibians (e.g., frogs) ✦ reptiles (e.g., snakes) ✦ small mammals (e.g., mice) ✦ medium mammals (e.g., fox) • Fish passage should be considered at this crossing. • Upstream fish passage at Tributary 6-5 crossing is not required given that the reach downstream from the culvert is buried over a distance of approximately 75 m, and no upstream fish passage is possible. RECOMMENDATIONS • The following minimum culvert diameters are recommended to accommodate the passage of the target wildlife species: ✦ 0.3 m for amphibians and reptiles ✦ 0.5 m for small-sized mammals ✦ 1.0 m for medium-sized mammals • If riprap is used for erosion and embankment protection, it should be restricted to areas above the average annual high water mark. Riverstone is the preferred material for erosion protection below the ordinary high water mark. • Where riprap is required, smaller material should be placed on top of riprap to fill voids and create a relatively smooth surface to support amphibian and small mammal movement.	CONSIDERATIONS • Tributary 5-5 at the proposed Street C is a stable, ephemeral watercourse with a bankfull width of 0.5 m meander planform. RECOMMENDATIONS • Based on the upstream planform and channel stability, the recommended culvert opening width is 2 m (the approximate upstream meander amplitude). This size will accommodate the downstream migration of the meander over time.	CONSIDERATIONS • The vertical clearance between site services and the tributary are as follows: ✦ 2.0 m for the proposed watermain ✦ 1.1 m for the proposed sanitary line • The culvert should be sized to accommodate the regional flood. The regional flood is 1.4 m^3/s downstream of this crossing at Flatt Road. RECOMMENDATIONS • The site services at this proposed road will not restrict the size of the culvert. • To accommodate the regional flood, the minimum culvert diameter is 750 mm.	CULVERT Type Open bottom concrete box culvert Opening 2,000 mm × 2,000 mm Length Approximately 20 m KEY CONSTRAINTS • The geomorphology, and fish and wildlife recommendations can be incorporated the watercourse crossing at proposed Street C. ADDITIONAL DESIGN FEATURES • The open bottom will allow a defined channel to flow through the crossing. Channel substrate through the culvert should be sized for stability during the design storm. • The size of the culvert will allow the passage of amphibians, reptiles, and small- to medium-sized mammals.

Note:
The conceptual culvert design is illustrated on Figure 2-11 of the *Eagle Heights Property City of Burlington Functional Servicing Report Update* (Metropolitan Consulting 2018b).

10 SUMMARY AND CONCLUSIONS

Matrix evaluated and documented geomorphic conditions of the tributaries using the RGA field technique. The RGA was used to evaluate dominant geomorphic processes using an indexed rating of channel sensitivity based on aggradation, degradation, channel widening, and lateral adjustment. The combined indices were used to determine whether the tributary reaches are in regime, stressed/ transitional, or adjusting.

Informed by the RGA field results and desktop analysis, Matrix established geomorphic setbacks for each tributary reach depending on whether the reach is confined or unconfined. At confined reaches, Matrix recommended toe erosion allowances to inform Development setbacks from the tributaries. At unconfined reaches, Matrix delineated meander belt widths to inform setbacks. The setback recommendations will inform the long-term protection and enhancement of the Grindstone Creek and will be combined with the work of Metropolitan Consulting Inc. and Peto MacCallum Ltd. to determine final setback distances between the tributaries and the Development.

The upper portion of Reach 5-5 has the characteristics of both a confined and unconfined watercourse. At the upper portion of Reach 5-5, the Development setback was established using the largest (i.e., most conservative) of the stable top of bank, flood elevation, and meander belt width. Based on this approach, the flood elevation and meander belt width of 24 m was used to inform the Development setback.

Matrix surveyed reach cross-sections and profiles to calculate erosion thresholds in the receiving channels downstream of the proposed stormwater facilities. These erosion thresholds define the flow required to entrain and transport sediment of a particular size. In this assessment, Matrix established the thresholds required to transport the D_{50} channel sediment sizes. The erosion thresholds were used by SWM designers to assess the relative change in erosion conditions and hydrologic regime between pre- and post-development conditions.

Reach 4-6 is a poorly vegetated, ephemeral tributary that is incised into an agricultural field. Savanta (2018) assessed Reach 4-6 to be a headwater drainage feature requiring “mitigation” management. This management classification requires site development to maintain the hydrologic function of the reach and maintain or enhance the riparian corridor (TRCA and CVC 2014). To facilitate the Development plans, maintain the hydrologic function, establish a riparian corridor, and improve the geomorphic function, Matrix developed a conceptual channel realignment for Reach 4-6.

Matrix provided watercourse crossing recommendations for the Development. In addition to providing geomorphic considerations, the recommendations incorporate the considerations and constraints provided by the project team from the perspective of fish and wildlife, SWM and hydraulics, and civil works (i.e., road right-of-way and utility services). The watercourse crossing recommendations balance

the considerations and constraints from these multiple perspectives and technical disciplines to inform a future, feasible detailed design for the crossings.

11 REFERENCES

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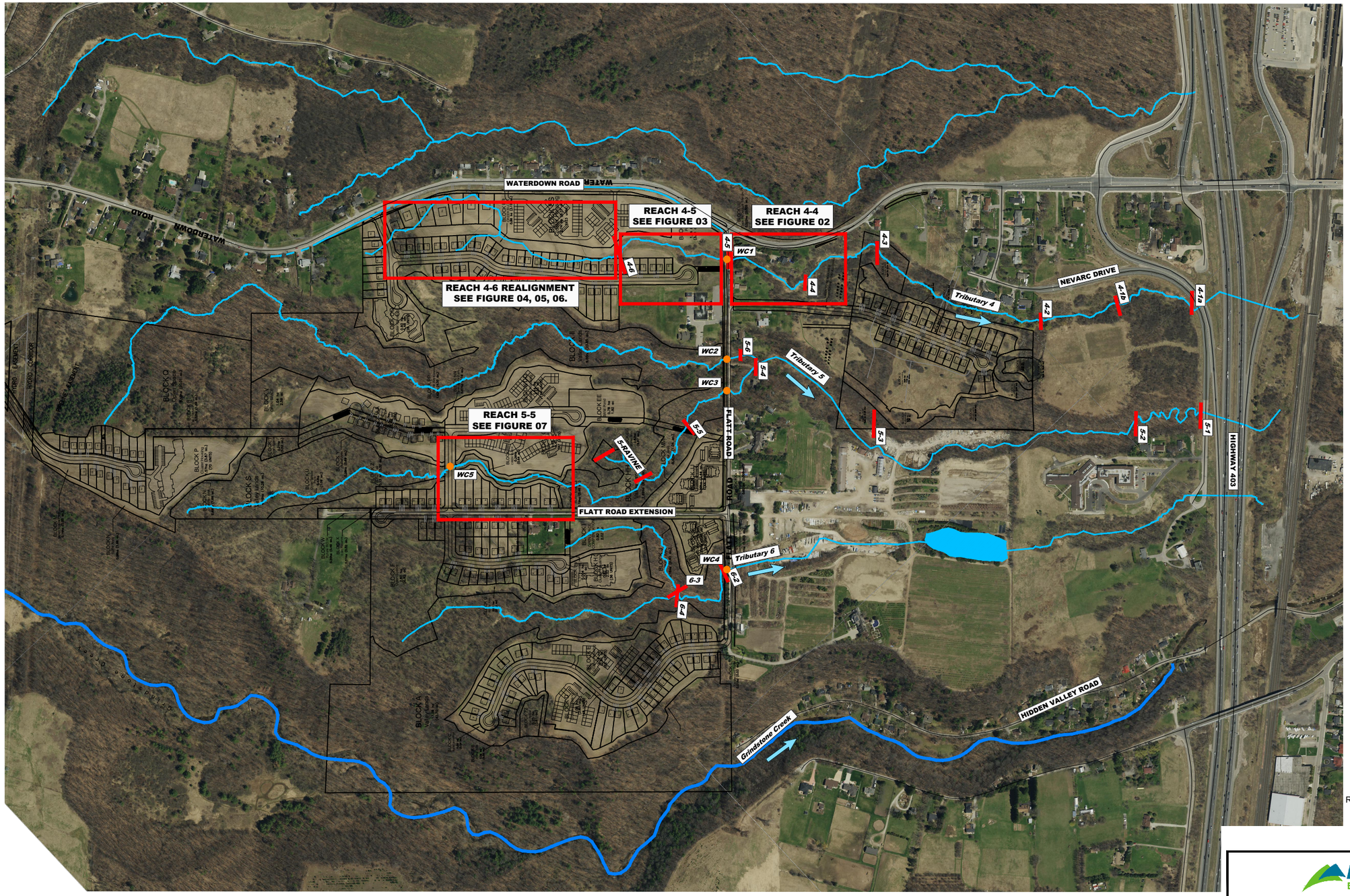
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Legend

- Grindstone Creek
- Grindstone Creek Tributaries
- 5-3 Reach Breaks and ID
- Direction of Flow
- WC1 Watercourse Crossing Location

Scale 1:7,500

75 0 75 150

Reference:

1. All external data provided by from Metropolitan Consulting Inc. (MCI),
2. Draft Plan of Subdivision, Eagle Heights 24T-04006/B Revised, Project# P09006, dated May 2018.

Note:

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01	05/15/2018	Updated Draft Plan	AD	SB	AM
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No.	DATE	DESCRIPTION	BY	CHK.	DRN.

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ENVIRONMENT & ENGINEERING

Penta Properties Inc.
Eagle Heights Property

Location Plan

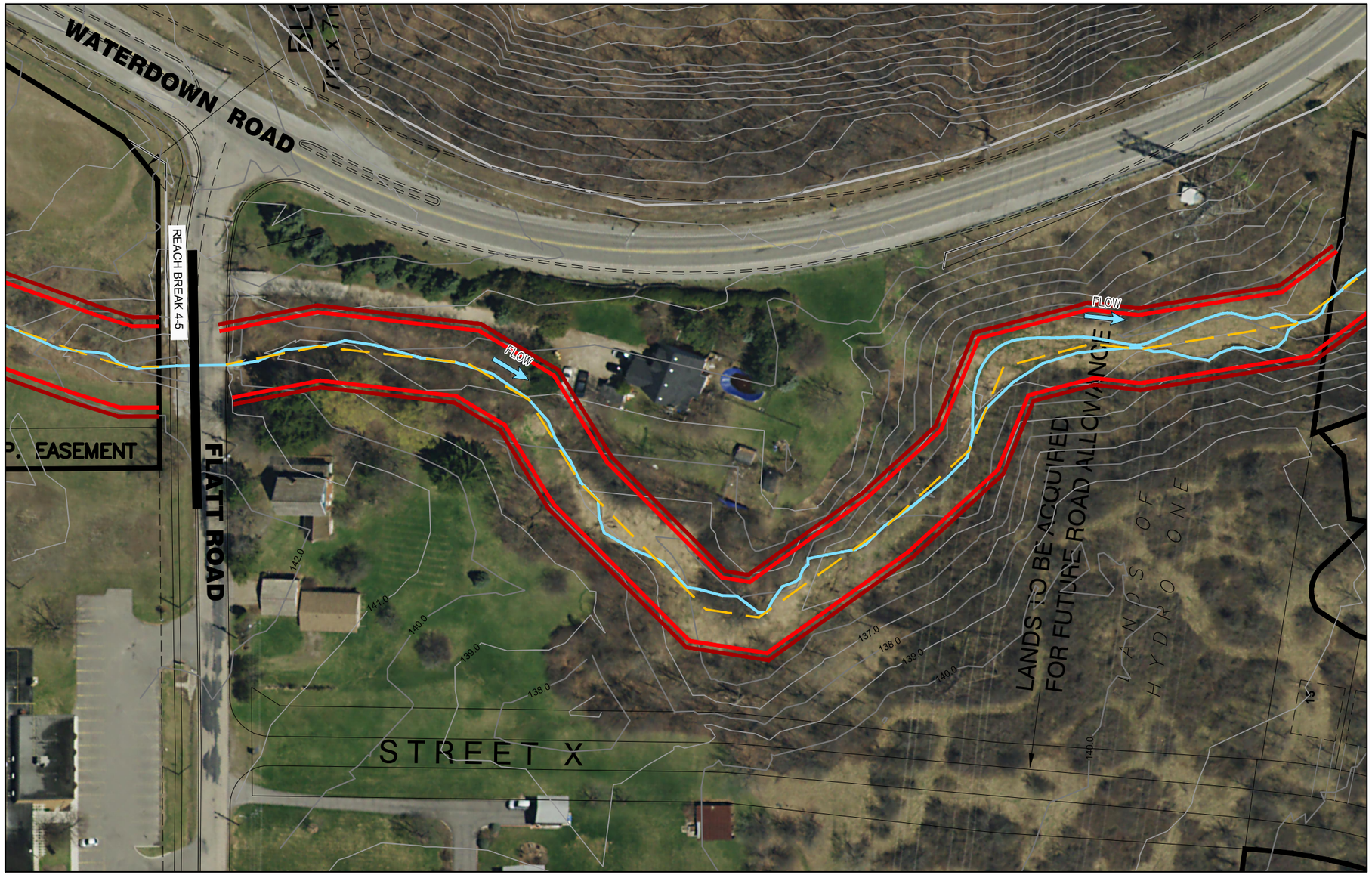
Date:	Project:	Technical:	Reviewer:	Drawn:
02/02/2018	24432	A.Doherty	S.Bellamy	A.Miszczak

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Figure 01

Plot 1:1 = Tabloid (L)
N:\PROJECTS\24432 - Eagle Heights\4 Project Data\CAD\Drafting\C3D\Eagle Heights\C3D\Design\24432-Location Plan-Aug 17 2018.dwg - Tabloid_L - Friday, August 24, 2018 11:55:05 AM - Eric.Drost

Plot 1:1 = Tabloid (L)



Legend:

- Reach 4-4
- Meander Axis Centreline
- Preliminary Belt Width (15m)
- Final Belt Width (18m)
- FLOW Direction of Flow
- Property Line (MCI)
- ~~151.00~~ Existing Contour (1.0m Int.)

Note:
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A. J. DOHERTY
100509181
PROVINCE OF ONTARIO

1:1000 Meters
10 0 10 20
Datum

Reference:
1. All external data provided by from Metropolitan Consulting Inc. (MCI),
2. Draft Plan of Subdivision, Eagle Heights 24T-04006/B Revised, Project# P09006, dated May 2018.

REVISION					
02	08/24/2018	Issued As Final	AD	SB	AM
01	05/15/2018	Updated Draft Plan	AD	SB	AM
00	02/08/2018	Issued for Client Review	AD	SB	AM
No.	DATE	DESCRIPTION	BY	CHK.	DRN.

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Eagle Heights Property

Reach 4-4 Meander Belt Width

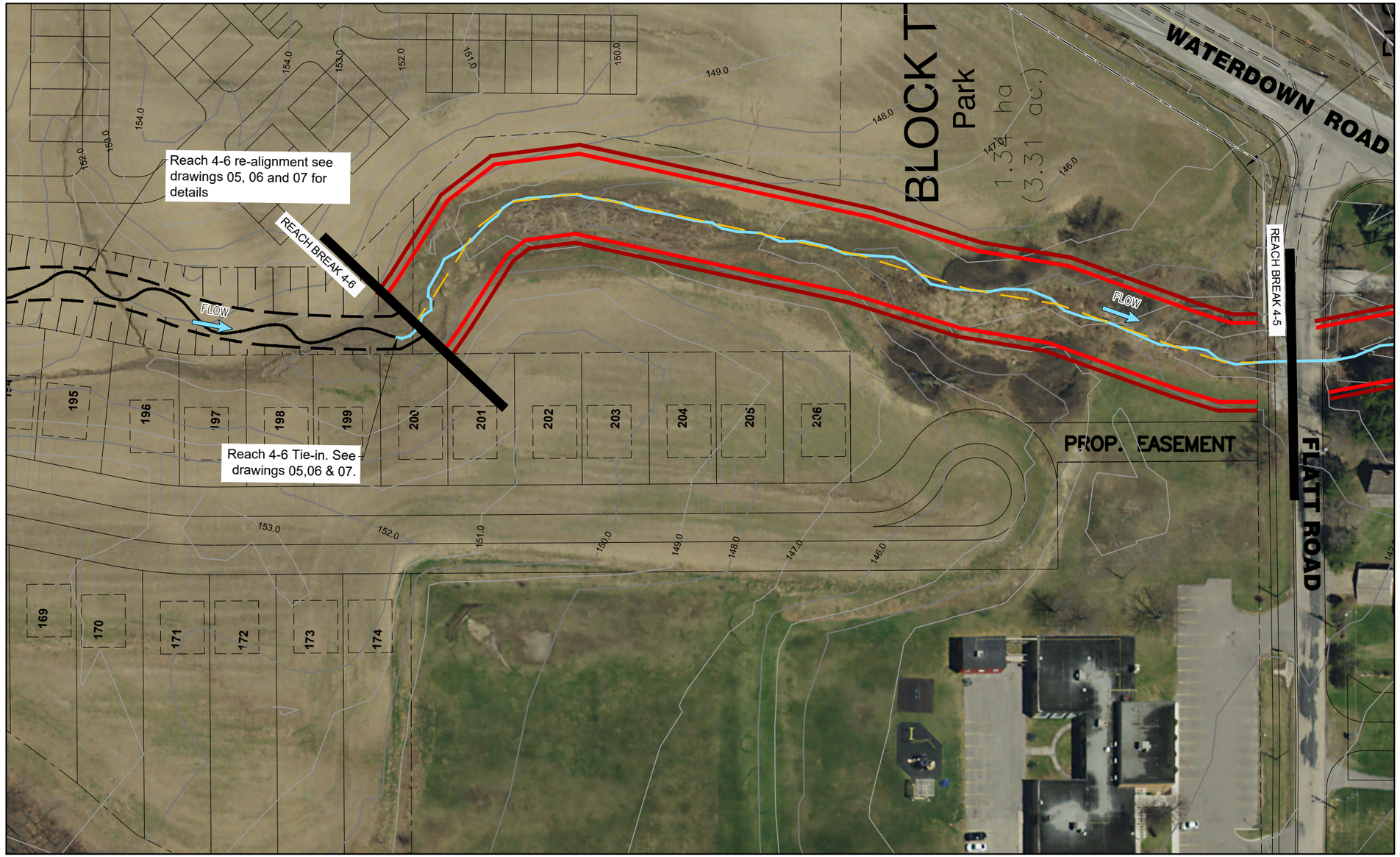
Date:	Project:	Technical:	Reviewer:	Drawn:
02/08/2018	24432	A.Doherty	S.Bellamy	A.Miszczak

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02

August 24, 2018

N:\PROJECTS\24432 - Eagle Heights\4.Project Data\CAD\Drafting\C3D\Eagle Heights\C3D\Design\24432-Figures-Aug 17 2018.dwg - 4-4 Figure 2 - Friday, August 24, 2018 11:24:56 AM - Eric Drost



Legend:

- Reach 4-5
- Meander Axis Centreline
- Preliminary Belt Width (18m)
- Final Belt Width (22m)
- FLOW — Direction of Flow
- Property Line
- 151.00 — Existing Contour (1.0m Int.)

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1:1000
10 0 10 20 Meters
Datum

Reference:
1. All external data provided by from Metropolitan Consulting Inc. (MCI),
2. Draft Plan of Subdivision, Eagle Heights 24T-04006/B Revised, Project# P09006, dated May 2018.

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Eagle Heights Property

Reach 4-5 Meander Belt Width

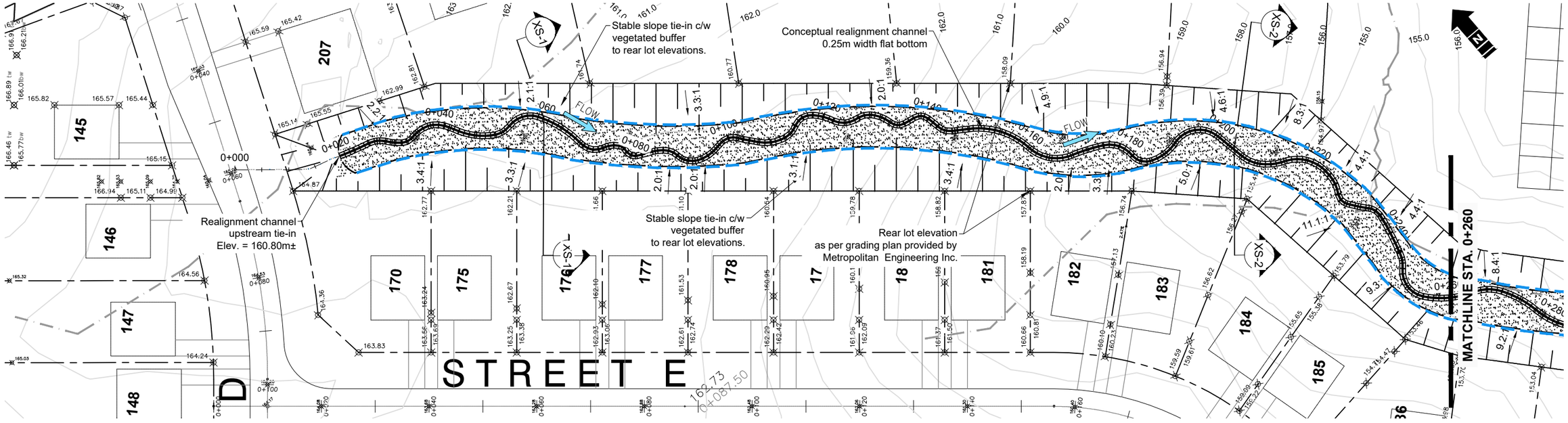
Date:	Project:	Technical:	Reviewer:	Drawn:
02/08/2018	24432	A.Doherty	S.Bellamy	A.Miszczak

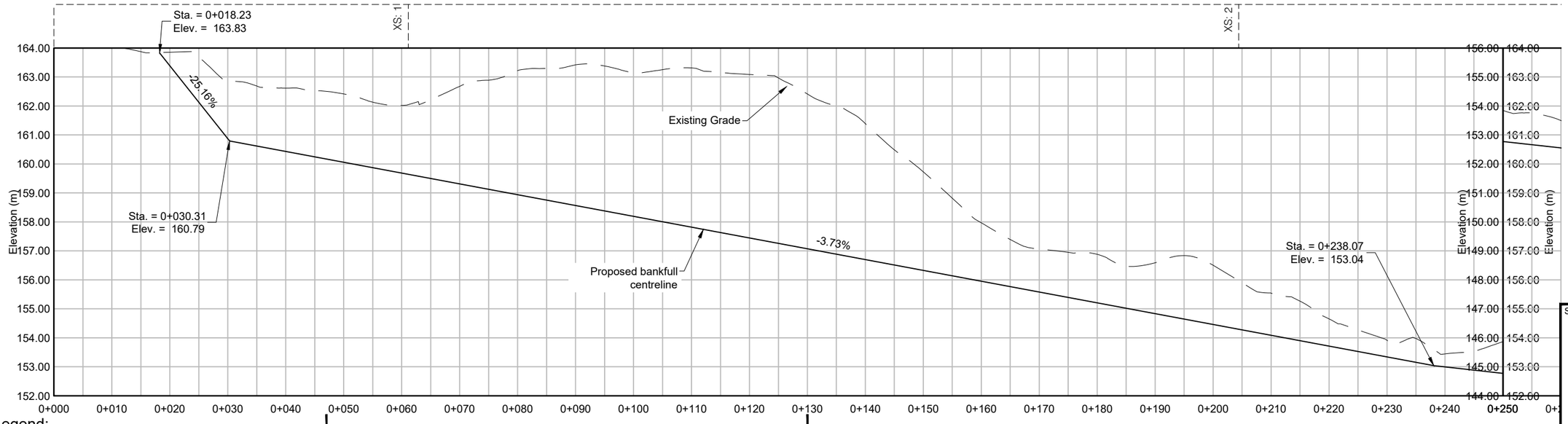
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03

Plot 1:1 = Tabloid (L)
N:\PROJECTS\24432 - Eagle Heights\4 Project Data\CAD\Drafting\C3D\Eagle Heights\C3D\Design\24432-Figures-Aug 17 2018.dwg - 4-5 Figure 3 - Friday, August 24, 2018 11:24:58 AM - Eric Drost

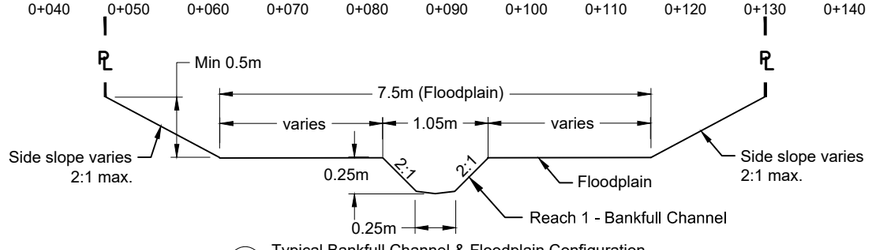
Plot 1:1 = Tabloid (L)





Legend:

- Property Line (MCI)
- Bankfull Centreline
- Limit of Floodplain
- 151.00 Existing Contour (1.0m Int.)
- Slope Grading
- Floodplain
- Floodline (Based on MCI regional design flows)



D1 Typical Bankfull Channel & Floodplain Configuration
N.T.S

Note:
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Reference:
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02	05/15/2018	Updated Draft Plan	AD	SB	AM
01	02/08/2018	Issued for Client Review	AD	SB	AM
00	10/17/2017	For Client Discussion	AD	ST	AM
No.	DATE	DESCRIPTION	BY	CHK.	DRN.

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August 24, 2018

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Penta Properties Inc.
Eagle Heights Property

Reach 4-6 Channel Realignment Conceptual - Plan and Profile Sta. 0+000 - 0+250

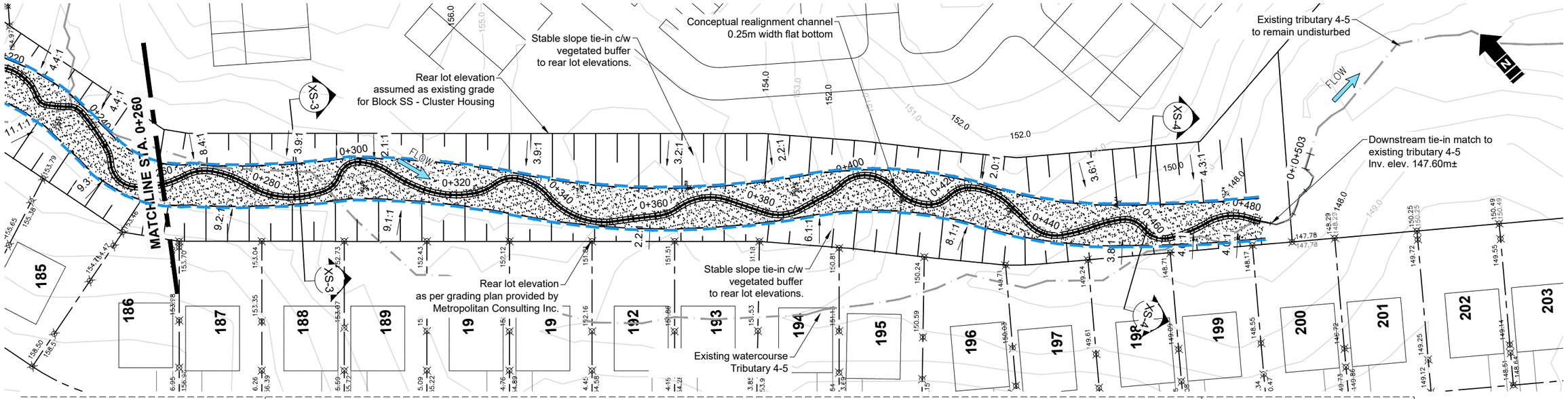
Date:	Project:	Technical:	Reviewer:	Drawn:
10/27/2017	24432	A. Doherty	S.Bellamy	A.Miszczak

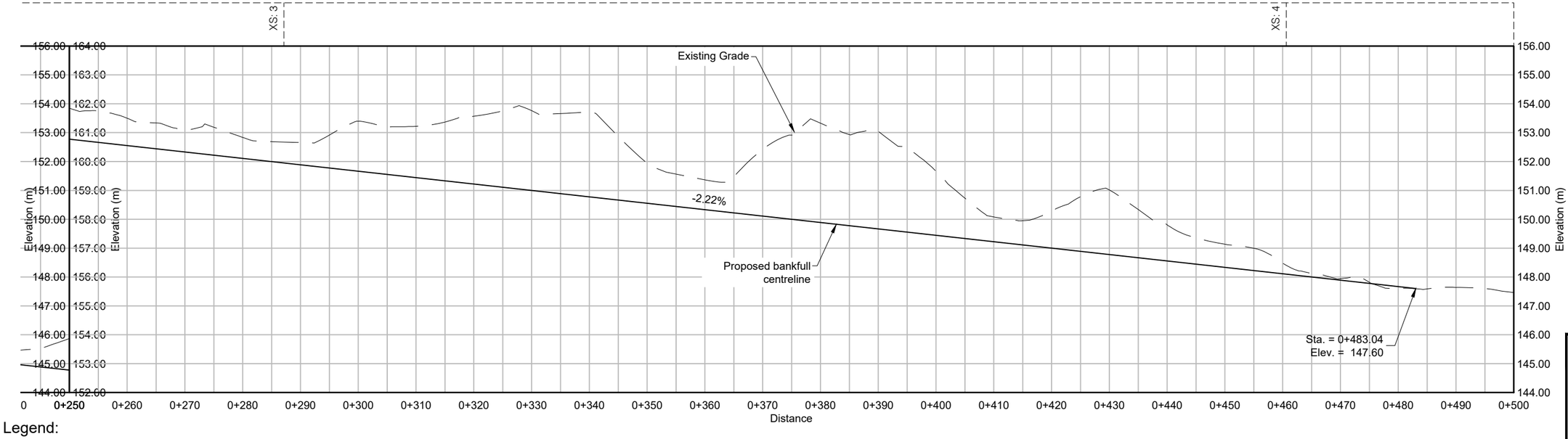
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Figure 04

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Plot 1:1 = Tabloid (L)

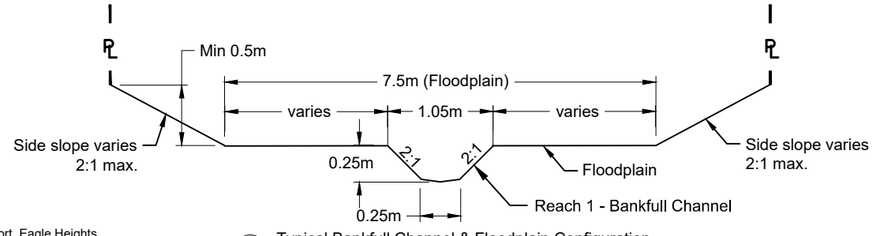




Legend:

- Property Line (MCI)
- Bankfull Centreline
- Limit of Floodplain
- 151.00 Existing Contour (1.0m Int.)
- Slope Grading
- Floodplain
- Floodline (Based on MCI regional design flows)

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D1 Typical Bankfull Channel & Floodplain Configuration
N.T.S

CONCEPTUAL

Vert. 1:750 Meters 7.5 0 7.5 15
Datum
Horz.1:150 Meters 1.5 0 1.5 3.0

Reference:
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Penta Properties Inc.
Eagle Heights Property

Reach 4-6 Channel Realignment Conceptual - Plan and Profile Sta. 0+250 - 0+498

Date:	Project:	Technical:	Reviewer:	Drawn:
10/27/2017	24432	A. Doherty	S.Bellamy	A.Miszczak

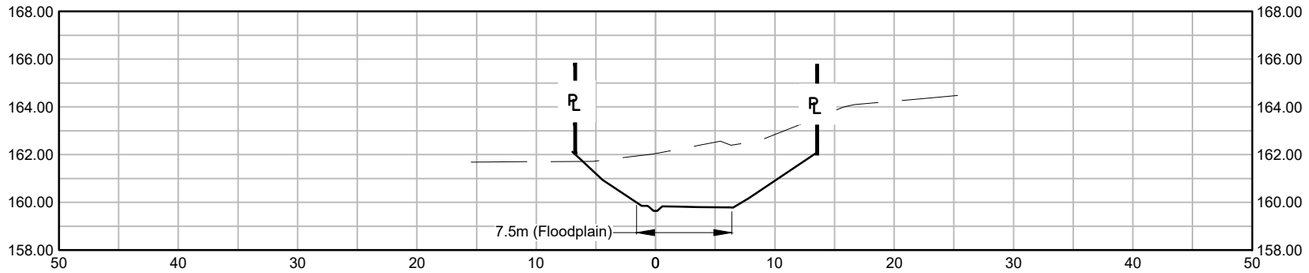
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Figure 05

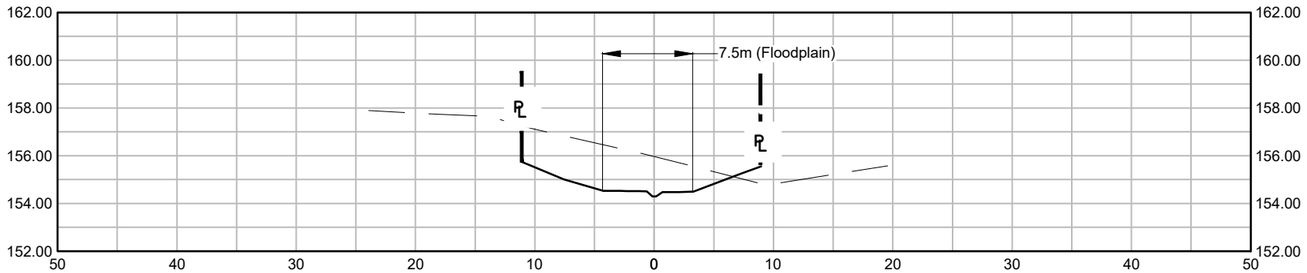
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Plot 1:1 = Tabloid (L)

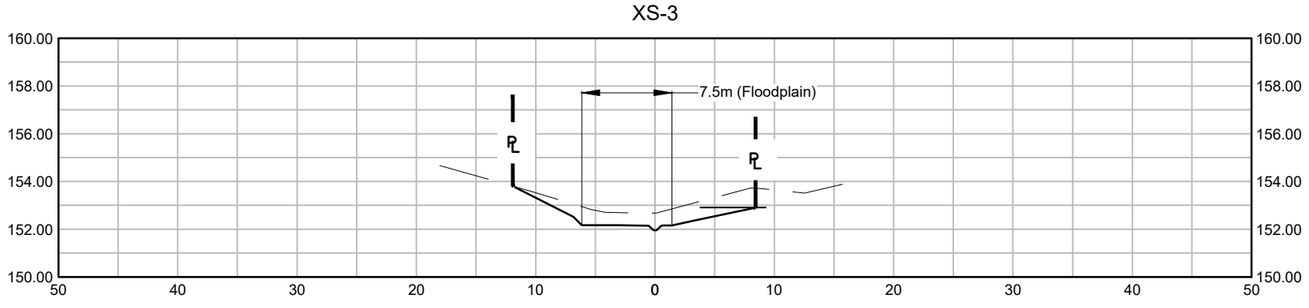
XS-1



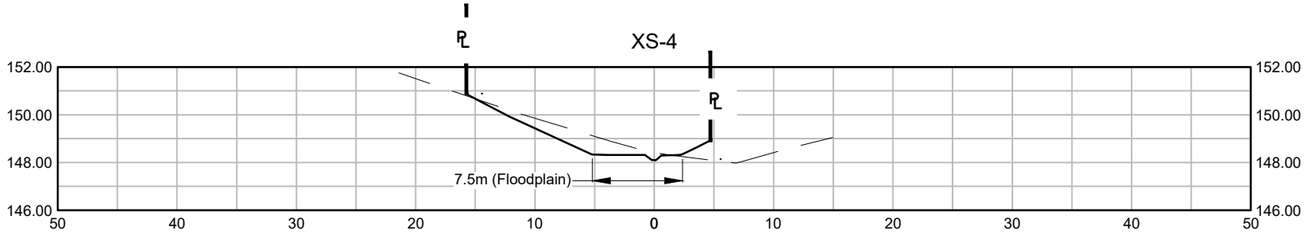
XS-2



XS-3



XS-4



Reference:

Legend:

- Proposed Bankfull & Floodplain
- Existing Ground

Horizontal Scale 1:500

5 0 5 10

Vertical Scale 1:250

2.5 0 2.5 5.0

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No.	DATE	DESCRIPTION	BY	CHK.	DRN.

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Penta Properties Inc.
Eagle Heights Property

Reach 4-6 Channel Realignment Conceptual - Sections

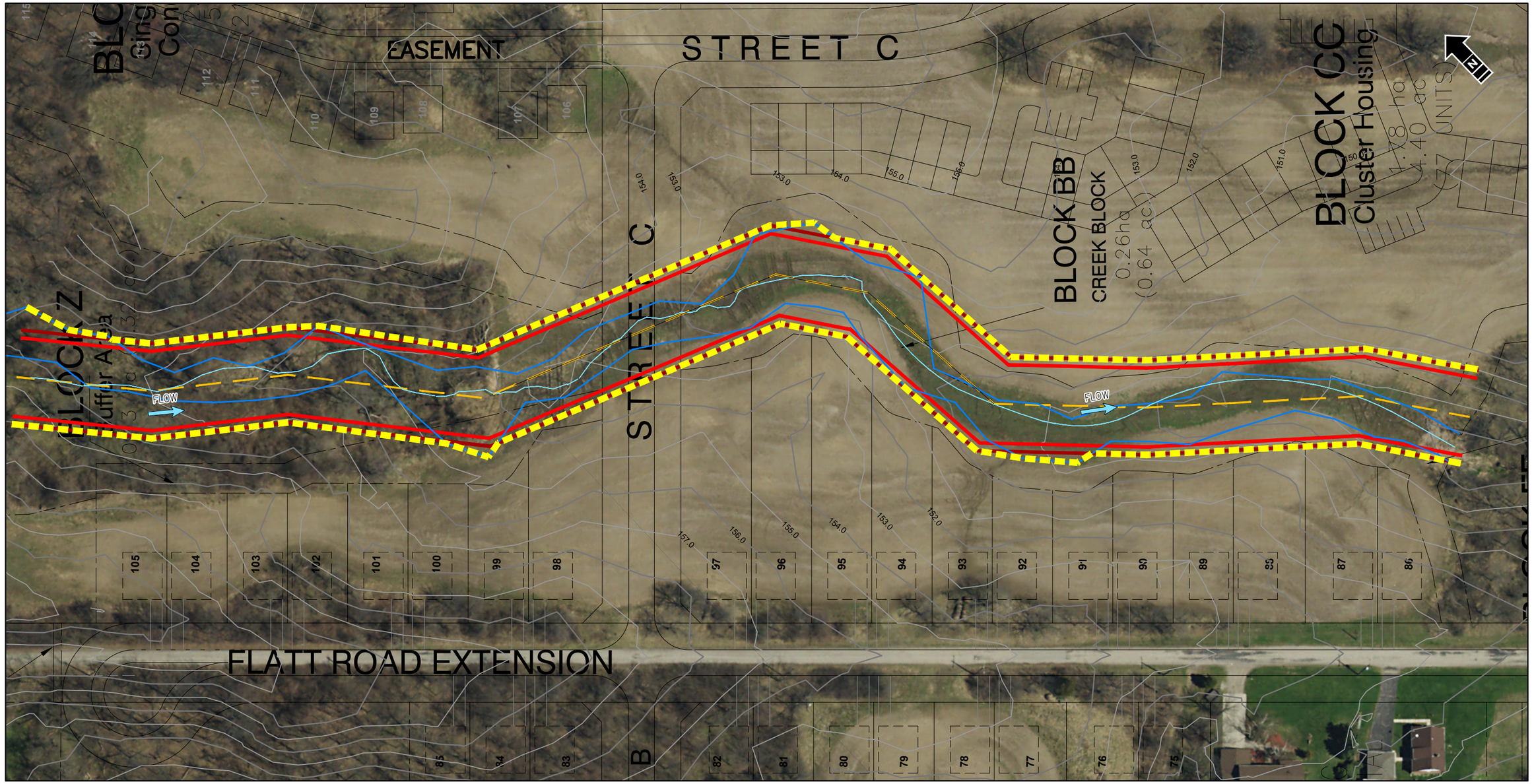
Date:	Project:	Technical:	Reviewer:	Drawn:
10/27/2017	24432	A. Doherty	S.Bellamy	A.Miszczak

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Figure 06

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Plot 1:1 = Tabloid (L)



Legend:

- Reach 5-5
- Meander Axis Centreline
- Preliminary Belt Width (20m)
- Final Belt Width (24m)
- Floodline (MCI)
- FLOW — Direction of Flow
- Property Line (MCI)
- ~~151.00~~ — Existing Contour (1.0m Int.)
- Erosion Hazard Limit

1:1000 Meters
10 0 10 20
Datum

Reference:
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00	02/08/2018	Issued for Client Review	AD	SB	AM

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Penta Properties Inc.
Eagle Heights Property

Location Plan
Reach 5-5 Setback Delineation

Date:	Project:	Technical:	Reviewer:	Drawn:
10/19/2017	24432	A.Doherty	S.Bellamy	A.Miszczak

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Figure 07

N:\PROJECTS\24432 - Eagle Heights\4 Project Data\CADD\dwg\C3D\Eagle Heights\C3D\Design\24432-Figures-Aug 17 2018.dwg - 5-8 Figure 7 - Friday, August 24, 2018 11:24:56 AM - Eric Drost

APPENDIX A
Site Photographs



Matrix Solutions
December 13, 2016

1. Reach 4-1 (Transitional) – Looking upstream at exposed roots on channel bank



Matrix Solutions
December 13, 2016

2. Reach 4-1 (Transitional) – Looking upstream at fallen trees and woody debris



Matrix Solutions
December 13, 2016

3. Reach 4-2 (In Regime) – Looking upstream at channel confined within shallow valley



Matrix Solutions
December 13, 2016

4. Reach 4-2 (In Regime) – Looking upstream at undefined channel



Matrix Solutions
December 13, 2016

5. Reach 4-3 (In Adjustment) – Looking upstream at eroded side channel and exposed tree roots



Matrix Solutions
December 13, 2016

6. Reach 4-3 (In Adjustment) – Looking upstream at exposed roots along bank



Matrix Solutions
December 13, 2016

7. Reach 4-4 (In Regime) – Looking upstream at unforested valley floor through utility corridor



Matrix Solutions
December 13, 2016

8. Reach 4-4 (In Regime) – Looking upstream at channel



Matrix Solutions
December 14, 2016

9. Reach 4-5 (In Regime) – Looking upstream from Flatt Road



Matrix Solutions
December 14, 2016

10. Reach 4-5 (In Regime) – Looking upstream at small, vegetated channel



Matrix Solutions
December 14, 2016

11. Reach 4-6 (In Regime) – Looking upstream at channel through agricultural field



Matrix Solutions
December 14, 2016

12. Reach 4-6 (In Regime) – Looking at small, defined channel through agricultural field



Matrix Solutions
December 13, 2016

13. Reach 5-1 (Transitional) – Looking downstream at tortuous meander pattern



Matrix Solutions
December 13, 2016

14. Reach 5-1 (Transitional) – Looking at channel erosion into valley wall



Matrix Solutions
December 13, 2016

15. Reach 5-2 (Transitional) – Looking Downstream at gabion basket lined channel



Matrix Solutions
December 13, 2016

16. Reach 5-2 (Transitional) – Looking at inlet of 200 m long channel



Matrix Solutions
December 13, 2016

17. Reach 5-3 (Transitional) – Looking downstream at channel through hydro corridor



Matrix Solutions
December 13, 2016

18. Reach 5-3 (Transitional) – Looking downstream at valley through hydro corridor



Matrix Solutions
December 13, 2016

19. Reach 5-4 (In Regime) – Looking downstream at valley floor



Matrix Solutions
December 13, 2016

20. Reach 5-4 (In Regime) – Looking downstream at valley floor



Matrix Solutions
December 14, 2016

21. Reach 5-6 (In Regime) – Looking upstream at channel



Matrix Solutions
December 14, 2016

22. Reach 5-6 (In Regime) – Looking upstream at channel



Matrix Solutions
December 13, 2016

23. Reach 6-2 (In Regime) – Looking upstream at valley floor



Matrix Solutions
December 13, 2016

24. Reach 6-2 (In Regime) – Looking upstream at valley floor



Matrix Solutions
December 13, 2016

25. Reach 6-3 (Transitional) – Looking upstream at channel



Matrix Solutions
December 13, 2016

26. Reach 6-4 (Transitional) – Looking upstream at channel