Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

FLUVIAL GEOMORPHIC AND EROSION HAZARD ASSESSMENT
STINSON LANDS
OTTAWA, ONTARIO

Prepared for:
NOVATECH ENGINEERING AND CONSULTANTS LTD.

Prepared by:
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1 INTRODUCTION

Novatech Engineers and Consultants Ltd. retained Matrix Solutions Inc. to conduct a fluvial geomorphic and erosion hazard assessment on sections of Mud Creek and the Wilson-Cowan Drain bordering the property at 4386 Rideau Valley Drive North, Ottawa, Ontario (referred to as the Stinson Lands, as requested by the City of Ottawa [Figure 1]). This assessment is necessary to inform the potential development of the Stinson Lands from existing agricultural land use to residential land use. Both watercourses are situated within the Rideau watershed, which is regulated by the Rideau Valley Conservation Authority (RVCA) with respect to riverine flood and erosion hazards. A fluvial geomorphic assessment of the floodplain feature (oxbow) immediately west of Rideau Valley Drive (Figure 1) was also completed to evaluate potential erosion impacts from a new stormwater outlet proposed along the bank of the oxbow. The proposed stormwater outlet would result in increased flow to the oxbow and could potentially enhance erosion within the feature.

Standard protocols for delineating the erosion hazard limit were reviewed to achieve the project objectives, including the provincial *Technical Guide, River & Stream Systems: Erosion Hazard Limit* (the Technical Guide; MNR 2002a) and the Toronto and Region Conservation Authority's (TRCA's) *Belt Width Delineation Procedures* (PARISH 2004a). Historical alteration/channelization of the subject reaches requires an interpretation of standard protocols to appropriately characterize the erosion hazards at the sites.

The following tasks were completed in support of the assignment:

- Background review and desktop assessment: reviewing previous studies, base mapping, historical aerial imagery, and surficial geology mapping.
- Erosion hazard assessment: using information from previous studies (i.e., geotechnical studies) to delineate the stable top-of-slope allowance where watercourses are confined and historical aerial imagery to delineate the meander belt where watercourses are unconfined.
  - The 100-year erosion hazard limit or assessment of lateral channel migration will be delineated using historic and aerial imagery (where possible) to finalize the erosion hazard setback limit.
- Field assessment: completing fluvial geomorphic assessments of the Wilson-Cowan Drain, Mud Creek, and the oxbow feature, including Rapid Geomorphic Assessments (RGAs; MOE 2003), Rapid Stream Assessment Techniques (RSATs; Galli 1996), and detailed topographic channel survey using high-precision GPS equipment.

2 BACKGROUND REVIEW

2.1 Study Area and Reach Delineation

The study area (the Stinson Lands) is located at the northwest corner of Rideau Valley Drive and Bankfield Road in Ottawa (Figure 1). The Stinson Lands are primarily agricultural and bordered by approximately 800 m of watercourse/valleylands split between Mud Creek and the Wilson-Cowan Drain. Mud Creek flows eastward along the northern extent of the Stinson Lands toward the Rideau River, while the Wilson-Cowan Drain flows northerly along the western limit of the study area from Bankfield Road to the confluence with Mud Creek. For the purpose of this study, one reach has been delineated for each watercourse (two reaches total). The reach for Mud Creek extends from the confluence of Mud Creek and the Wilson-Cowan Drain to the confluence of Mud Creek and the Rideau River 300 m downstream, and the reach for the Wilson-Cowan Drain extends from Bankfield Road to the confluence with Mud Creek 500 m downstream. The oxbow has been delineated separately for analysis. It represents an abandoned section of channel cutoff from Mud Creek prior to the earliest photographs available (1954). Since then, it has taken on flows during overbank events and holds water throughout the year. Land use in the broader context reveals a predominantly agricultural use within the Rideau subwatershed (63%), and only approximately 10% of its area is urbanized (City of Ottawa 2015); however, the urban settlement is expanding, such as that through the Manotick area. Figure 1 includes the overall study area and reach delineation.

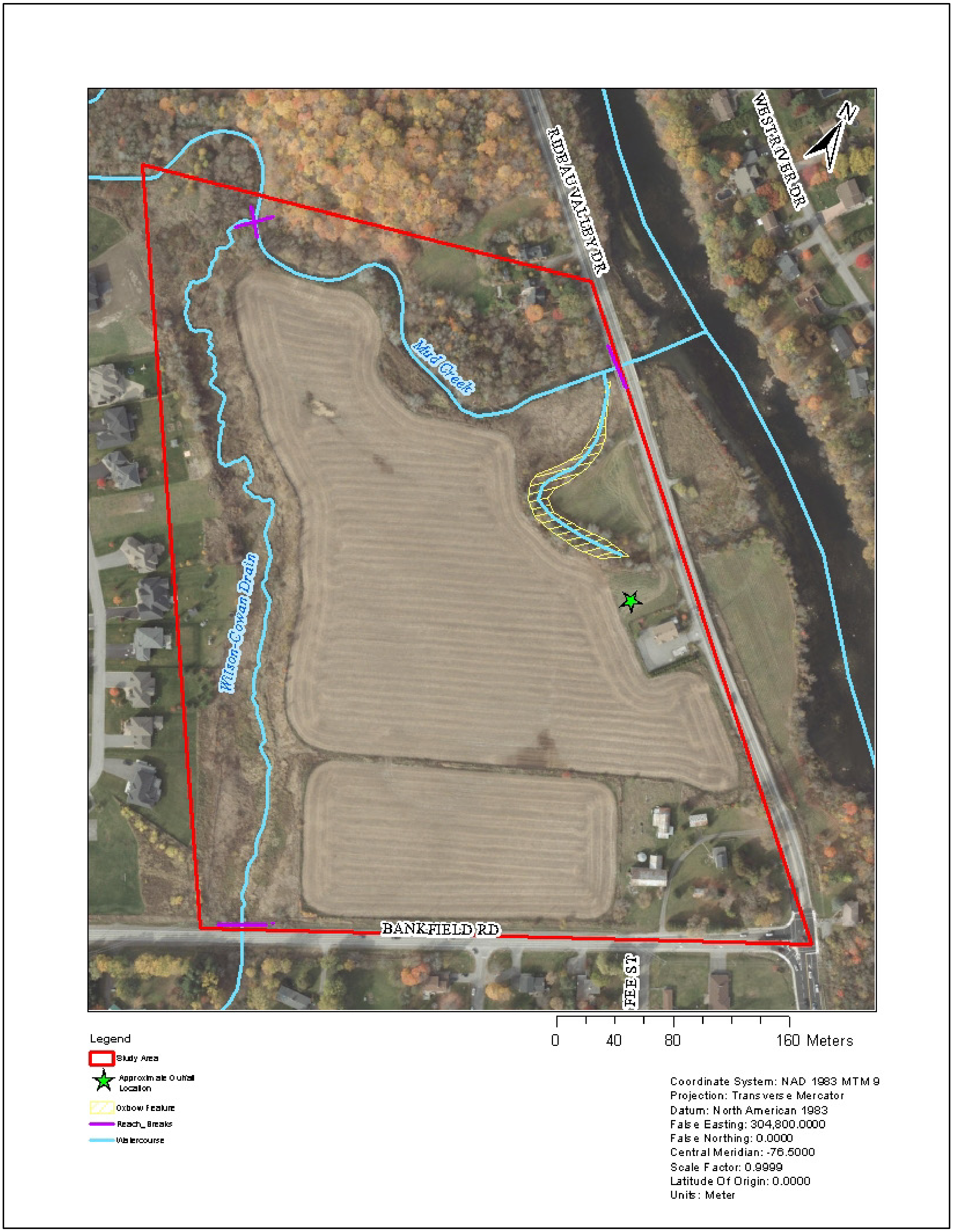


FIGURE 1 Study Area at 4386 Rideau Valley Drive North (Stinson Lands)

2.2 Physiography and Surficial Geology

The study area is situated in the Clay Plains physiographic region, which consists of large regions of clay beds that are interrupted by faulted bedrock and uplifted blocks (Chapman and Putnam 1984). Underlying the clays are limestones that are mildly calcareous and derived from acidic rocks of the Canadian Shield (Chapman and Putnam 1984). Surficial geology mapping indicates that the study area is located within fine-textured glaciomarine deposits, which tend to be well-laminated and include silt and clay with minor additions of sand and gravel (OGS 2010). Figure 2 displays surficial geology mapping for the study area and adjacent lands.

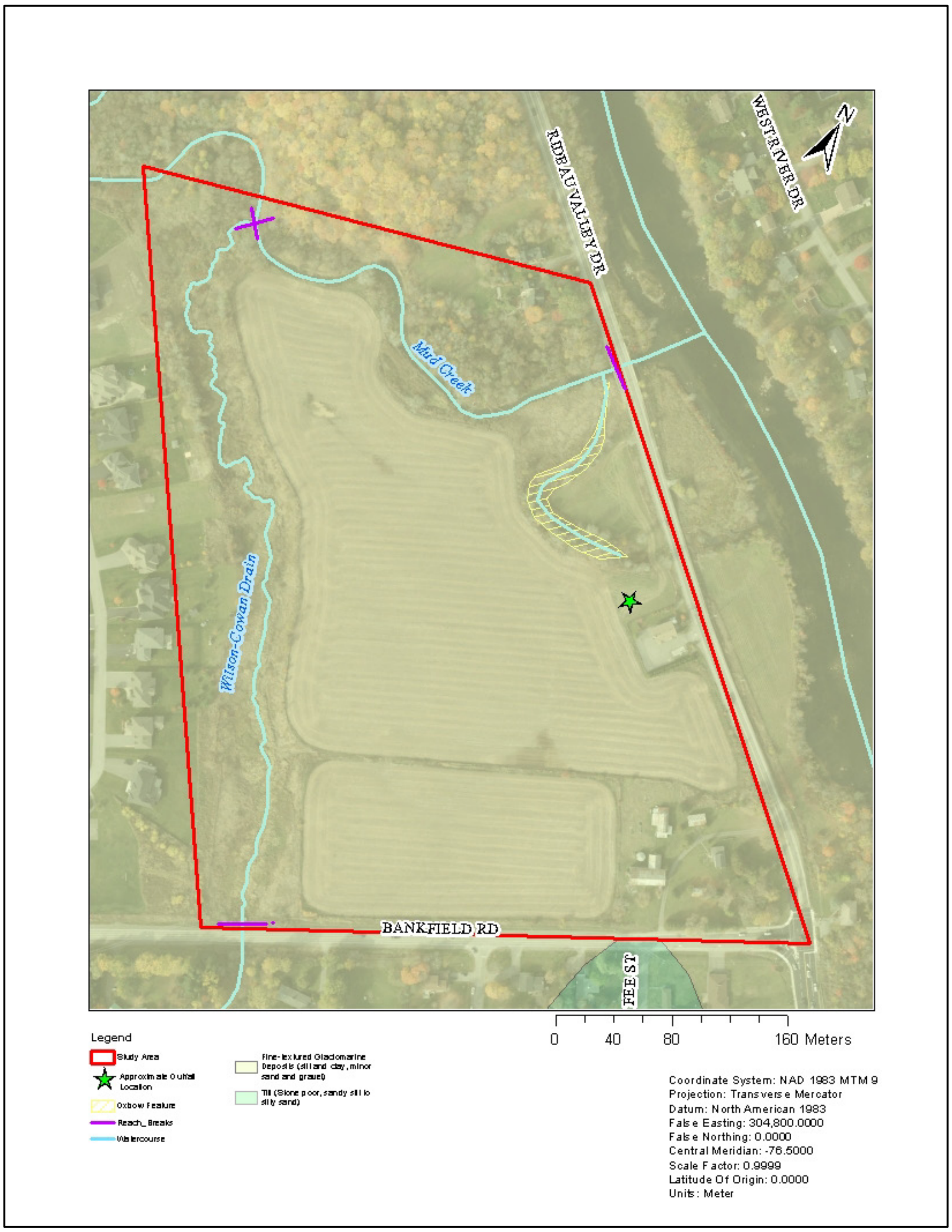


FIGURE 2 Surficial Geology Mapping

2.3 Previous Studies

2.3.1 Mud Creek Subwatershed Existing Conditions Study

In 2004, PARISH Geomorphic Ltd. completed a subwatershed study for Mud Creek on behalf of the City of Ottawa (PARISH 2004b), which documented the existing geomorphic conditions of two reaches of Mud Creek. PARISH completed detailed investigations of Mud Creek Reach 1 (R1), which extends from the Rideau River until the confluence with Wilson-Cowan Drain, and Mud Creek Reach 1-1 (R1-1), which refers to the Wilson-Cowan Drain downstream of Bankfield Road to Mud Creek. R1 was described as an aggrading system with an adjusting planform with some backwatering observed from the Rideau River, which reduced velocities within the channel. Site observations showed siltation in pools, cutoff channels, and island formations along with valley wall contacts resulting in slumped banks. The Wilson-Cowan Drain was described as a largely aggregational system within an entrenched, modified channel heavily impacted by agricultural land use nearby. Table 1 summarizes existing geomorphic parameters and calculated hydraulics for R1 and R1-1 based on the PARISH field assessment.

TABLE 1 Summary of Observations from PARISH (2004)

Parameter	Reach 1 (Mud Creek)	Reach 1-1 (Wilson-Cowan Drain)
Bank height (m)	1.9 (0.7-4.0)	0.99 (0.75-1.20)
Bank angle (degrees)	37.3 (11.5-66.0)	29.4 (3.5-90.0)
Bank materials	clay/silt	clay/Silt
Entrenchment (m)	28.9 (8.0-60.0)	33.2 (21.9-53.2)
Entrenchment ratio	3.74 (1.65-6.03)	12.44 (6.06-16.63)
Average bankfull width (m)	10.95	2.78
Average bankfull depth (m)	0.82	0.37
Maximum bankfull depth (m)	1.50	0.84
Bankfull gradient (%)	0.17	0.36
Average bankfull velocity (m/s)	0.90	0.86
Average bankfull discharge (m^3/s)	5.83	0.69
Meander belt width (m)	80	30

2.3.2 Fluvial Geomorphic and Erosion Threshold Assessment, Wilson-Cowan Municipal Drain, Matrix Solutions Inc. (2021)

Matrix completed an erosion threshold assessment of the Wilson-Cowan Drain from Potter Drive to Bankfield Road in Manotick, Ontario, on behalf of Minto Communities (Matrix 2021). The drain was divided into two reaches: WC(1), from Potter Drive to a pedestrian crossing 175 m downstream, and WC(2), from the pedestrian crossing to Bankfield Road. Both reaches were classified as Transitional though RGAs with Moderate stream health (RSAT) with a clayey-silt substrate and an abundance of organic debris. WC(2) showed evidence of high erosion potential, and the channel showed signs of incision with the presence of bank slumping, undercutting, and toe erosion throughout the reach, making it susceptible to increased erosion from development. A detailed assessment of WC(2) was completed, the results of which are summarized in Table 2.

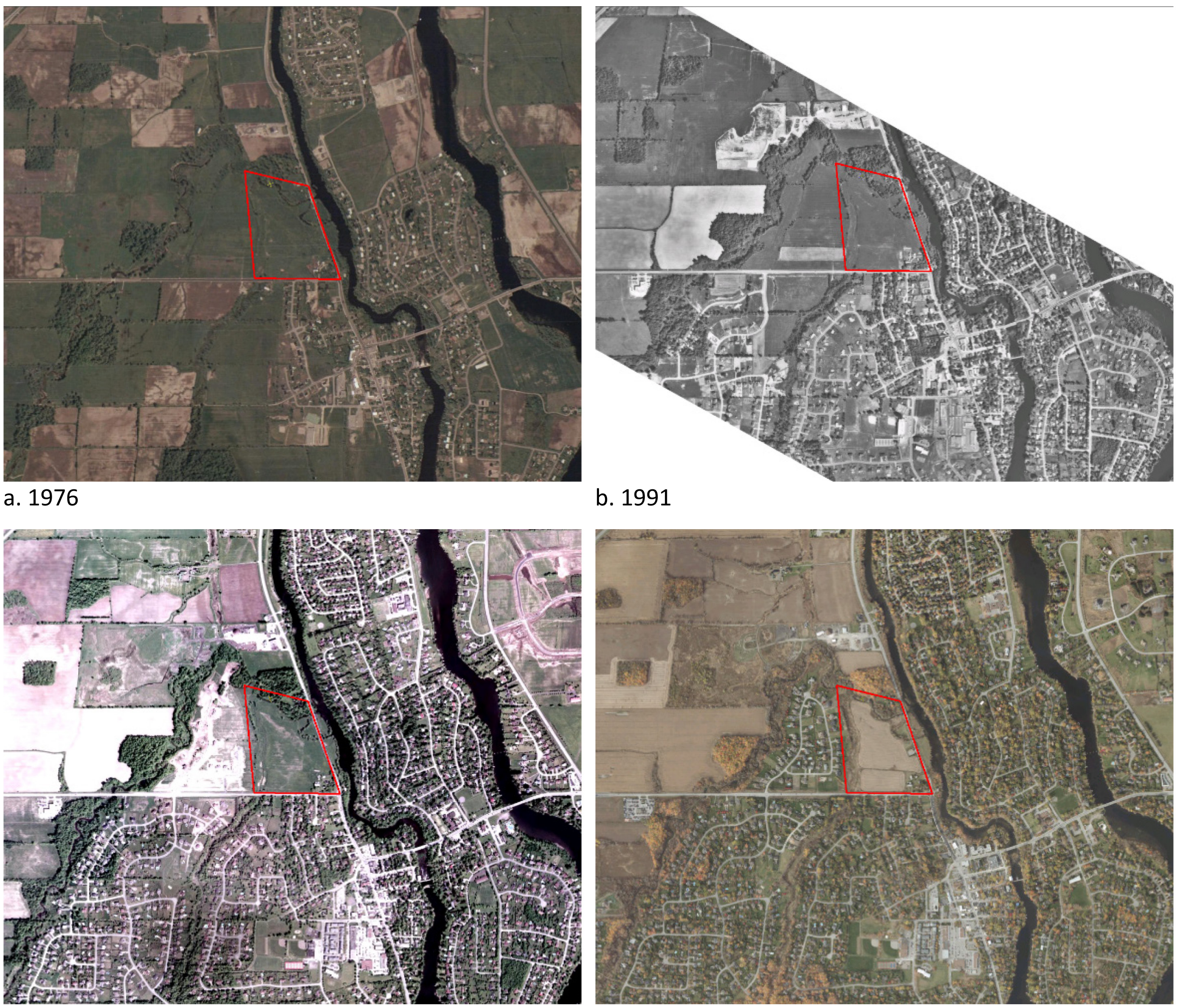
TABLE 2 Average Cross-section Parameters for WC(2), Wilson-Cowan Drain

Channel Parameter	Average
Average bankfull width (m)	2.22
Average bankfull depth (m)	0.31
Maximum bankfull depth (m)	0.46
Average width-to-depth ratio	4.92
Hydraulic radius (m)	0.24
Bankfull gradient (m/m)	0.0029
Bank materials	clay, clayey-silt, trace fine/medium sand
Estimated Manning's roughness, *n*	0.035
Computed	
Average discharge (m^3/s)	0.39
Average velocity (m/s)	0.59
Average shear stress (N/m^2)	6.82
Stream power (W/m)	10.9
Unit stream power (W/m^2)	4.8

2.4 Historical Assessment

Changes in the watershed, such as urbanization and/or deforestation, typically alter the sediment and water contributions to the watercourse, which, in turn, trigger a response of channel adjustment that can be documented through historical aerial photographs. A review of historical aerial images of the Stinson Lands and surrounding area, obtained from the City of Ottawa (via ArcGIS web map service) and the University of Toronto map library (U of T 2022), was undertaken. For the study area, photographs from 1954, 1976, 1991, 2002, 2005, 2015, and 2019 were reviewed. The intent of the historical assessment was to evaluate channel changes in the context of land use adjustment and to quantify the amount and extent of channel migration that may have occurred for Mud Creek and the Wilson-Cowan Drain. The following text describes historical aerial images provided in Figure 3. Figure 4 presents historical planform traces of Mud Creek and Wilson-Cowan Drain adjacent to the Stinson Lands. The historical assessments allowed for meander migration rates to be determined for Mud Creek and the Wilson-Cowan Drain, which have been found to be 17 m per 100 years for both watercourses.

In 1954, land use surrounding the study area consisted of vacant open land, agricultural fields, and wood lots. Mud Creek exhibited a sinuous planform with well-established meanders, some woody vegetation along the northern valley slope, and a wide floodplain bound by valley walls. However, it is apparent that some channelization likely happened prior to 1954 as the planform straightens on approach to the Rideau River. As a result, there is a cutoff feature (oxbow) in the floodplain to the south of the main channel. This cutoff was not visible in 1954 but can be seen in the remainder of the available air photographs and has been confirmed through field surveys. The Wilson-Cowan Drain was also sinuous, set within a small valley with a well-defined, narrow floodplain but with sparse woody vegetation. Aerial photographs from 1976 reveal that no major changes had occurred to the area surrounding Mud Creek or the Wilson-Cowan Drain immediately upstream of Stinson Lands. By 1991, significant urbanization had occurred south of the study site, with the town of Manotick bordering the Stinson Lands and multiple developments encroaching on Mud Creek to the north and south; however, there is no indication of the creek being modified. Air photographs from 2002 show minimal adjustment in the planform of each creek, as it maintains well-vegetated riparian areas in most of the surrounding area. Construction of a subdivision along the west side of the Wilson-Cowan Drain began in 2005, set back from the valley top. This development area is visible in the 2015 photograph; however, limited development expansion was evident in 2019, and planform adjustment revealed little to no change.



a. 1976

b. 1991

c. 2005

d. 2019

The red polygon represents the immediate study area of the current study - Stinson Lands.

FIGURE 3 Historic Land Use and Development Expansion Around the Stinson Lands Study Site

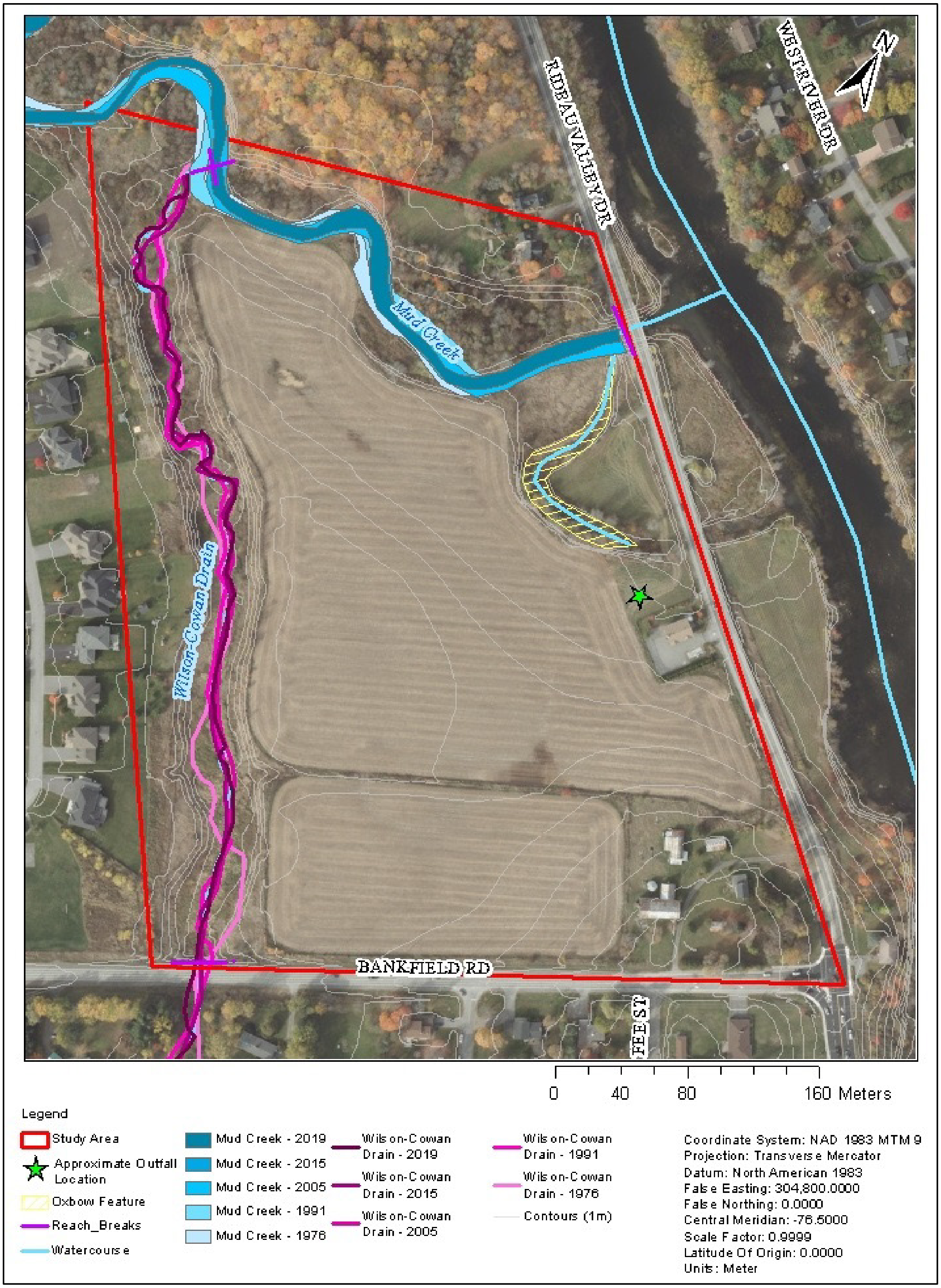


FIGURE 4 Planform Traces of Mud Creek and Wilson-Cowan Drain, 1976 to 2019

3 FIELD ASSESSMENT

Matrix completed synoptic-level field investigations of Mud Creek, Wilson-Cowan Drain, and the oxbow feature within and adjacent to the Stinson Lands on July 25 and 26, 2022. During the field assessments, areas of active channel adjustments (e.g., erosion, deposition, etc.) were noted to provide insight into channel stability and overall health and function and to confirm and/or update the findings of the desktop analysis.

As the draft stormwater management plan intends to discharge unmanaged stormwater (quantity) to the oxbow feature as a mode of conveyance to Mud Creek, Matrix's field assessment includes a characterization of the oxbow feature, including a detailed survey of the profile and cross-section and observations of erosion sensitivity.

A photographic inventory of the field assessment is located in Appendix A, with all references to left and right banks when looking downstream.

3.1 Rapid Assessments and Reach Characteristics

Semi-quantitative and qualitative rapid assessments, including the RGAs (MOE 2003) and RSATs (Galli 1996) were completed along study reaches of Mud Creek and the Wilson-Cowan Drain. These approaches provide a relative means to evaluate channel stability/sensitivity (RGA) and stream health (RSAT). Qualitative observations were also collected for the oxbow feature in the Mud Creek floodplain; however, as the feature does not regularly convey flows and is offline from the main channel, it is not well suited for the completion of RGA or RSAT forms.

The RGA is a semi-quantitative technique developed by the Ontario Ministry of the Environment (currently the Ontario Ministry of the Environment, Conservation and Parks; MOE 2003) to document indicators of channel instability. Observations are quantified using an index that identifies channel sensitivity based on the presence or absence of aggradation, degradation, channel widening, and planform adjustment at the reach scale. Overall, the index produces values that indicate whether the channel is Stable or In Regime (score of less than or equal to 0.20), Transitional or Stressed (score of 0.21 to 0.40), or Adjusting (score of 0.41 or greater).

The RSAT (Galli 1996) uses a broad, more qualitative approach to assess the overall health and function of a reach from a more biological and water quality perspective. The indicators assessed in the RSAT technique are scored on a scale of 1 to 10 (with 10 being the better score), and cumulative scores produce an overall indication of stream health (<20 Low, 20 to 35 Moderate, >35 High). This approach is useful for assessing geomorphic conditions because, in general, the physical and biological features of a healthy stream also indicate geomorphic function.

During the rapid assessments, bankfull channel dimensions are identified and measured. In natural, dynamically stable streams, the bankfull channel area often represents the maximum capacity of the channel before flow spills into the floodplain, and the discharge at this stage is referred to as the bankfull discharge. Field indicators of bankfull flow elevation include obvious breaks or inflections in the cross-section profile, the top elevation of point bars, and changes in vegetation. Disturbances to the flow and sediment regime of a system may result in adjustments to the bankfull channel. For example, increased flows may result in channel enlargement and entrenchment.

3.1.1 Mud Creek

This section of Mud Creek is approximately 300 m in length and flows east between the confluence with the Wilson-Cowan Drain and the confluence with the West Rideau River. The channel substrate is predominately silt and clay and includes coarser riprap material toward the downstream extent, likely entering the system from the road and bridge embankment. Mud Creek has a uniform profile with no evidence of riffles and pools. It has a sinuous planform, with erosion observed along the outer banks of meanders resulting in steep, vertical, exposed banks. Deposition along the inner banks was noted, and point bars had established most often with vegetation. Riparian vegetation consisted of grasses and other aquatic vegetation within the channel and on the point bars and floodplain. Further up the banks, there were established stands of trees, grasses, and shrubs. Due to erosion, tree roots are visible along most of the reach, as well as leaning and/or fallen trees in the channel. Riprap protection was observed at the Rideau Valley Drive crossing, with some vegetation establishment and evidence of displacement into the creek. A small gully was noted along the southern bank of the creek, approximately 100 m upstream of Rideau Valley Drive, where draining water from the adjacent agricultural field had (see Photograph 16 in Appendix A). During the site visit, water was turbid and slow, likely due to the backwater effect from the Rideau River. No fish were observed (fish surveys are not a part of the geomorphic scope). Bankfull dimensions ranged between 8 to 14 m in width and 0.8 to 1 m in depth.

Results of the rapid assessments classified Mud Creek as Transitional stability (RGA) and of Moderate stream health (RSAT) with scores of 0.29 and 26, respectively (Tables 3 and 4). The RGA determined that the dominant mode of adjustment is widening, as evidenced by fallen/leaning trees, exposed tree roots, and basal scour along most of the reach. Channel widening will likely continue as most banks lack well-rooted vegetation and consist of clay (till) with no natural bank protection. Some riprap stone protection (loosely placed) is located along the right bank (looking downstream) at the Rideau Valley Drive crossing. This stone protection was noted to have mobilized into the creek from the bank.

TABLE 3 Summary of Rapid Geomorphic Assessment Scores

Reach	Factor Value				Stability Index	Condition
	Aggradation	Degradation	Widening	Planimetric Adjustment		
Mud Creek	0.29	0.25	0.63	0	0.29	Transitional
Wilson-Cowan Drain	0	0	0.38	0	0.093	In Regime

TABLE 4 Summary of Rapid Stream Assessment Scores

Reach	Factor Value						Overall Score	Condition
	Channel Stability	Scour/ Deposition	Instream Habitat	Water Quality	Riparian Condition	Biological Indicators		
Maximum Score	**11**	**8**	**8**	**8**	**7**	**8**	**50**	-
Mud Creek	5	4	4	3	5	5	26	Moderate
Wilson-Cowan Drain	6	6	3	4	5	3	27	Moderate

3.1.2 Wilson-Cowan Drain

Approximately 500 m of the Wilson-Cowan Drain was assessed from Bankfield Road at the southern limit to the confluence with Mud Creek. The creek enters the study area through a concrete box culvert approximately 2 m high and 3 m wide, passing under Bankfield Road. The culvert is lined with riprap that extends partially downstream at the outlet, where a minor drop was observed. The channel resides within a narrow floodplain set within a well-defined valley. Valley heights were estimated to vary between 3 and 5 m. The valley is well-vegetated, dominated by grasses, cattails, and other wetland and scrub vegetation growing up to 2 m in height. Trees were mostly observed along the top of the valley walls and within the floodplain toward the northern extent of the reach. The bankfull channel was measured between 2 and 4 m in width and 0.5 and 1.1 m in depth. The current channel has a uniform profile with no riffle or pools and a sinuous planform with well-established meanders but becomes wider and more incised further downstream. Channel bed and bank substrate were consistent with those observed in Mud Creek, consisting of clay-silt but no coarse inclusions. The system appeared to experience frequent flooding with aquatic vegetation such as cattails established in the floodplain. In several locations, although more prevalent downstream, the channel banks were eroding with frequent slumped, undercut, and overhanging banks. This is likely attributed to the banks proximal to the creek lacking densely rooted vegetation, reducing their resistance to erosion.

Results of the rapid assessments classified this section of the Wilson-Cowan Drain as In Regime or stable (RGA) and of Moderate stream health (RSAT) with scores of 0.093 and 27, respectively (Tables 3 and 4). Very few geomorphic indicators were observed, and solely those indicative of channel widening, including basal scour along most of the reach and fracture lines on the top-of-bank. It is likely that channel widening will continue to occur as a lot of the banks lack well-rooted vegetation.

3.1.3 Oxbow Feature

The oxbow feature consists of a depression/scar that represents a historic meander of Mud Creek (Figure 4). This is assumed to be a relic feature of Mud Creek based on the feature dimension, orientation/position relative to the upstream planform trends, and straight planform of Mud Creek approaching Rideau Valley Drive. As noted in the historical assessment (Section 14), it has been interpreted that the channel was straightened to support the construction of Rideau Valley Drive prior to 1954 (earliest available air photograph set). The oxbow is approximately 175 m in length and varies in feature width from 2 to 15 m. Observations were made for the length of the feature, extending to Mud

Creek, with detailed surveys of profile and cross-sections being completed for a portion from the apex extending across Mud Creek (Figure 4). Standing water was observed within the feature during the field assessment, with depths exceeding 1.5 m, having a thick layer of unconsolidated silts. The outer banks of the oxbow were well-defined and exhibited signs of previous erosion. The oxbow is currently situated between cropped land to the north and the densely vegetated valley contact to the south. Where defined, widths ranged between 2 and 4 m, while depths ranged between 0.07 and 0.15 m. The entire oxbow is well-vegetated with reeds and cattails. The water depth increases toward the bend in the oxbow with standing water and saturated ground, allowing for survey rods to sink upwards of 0.5 m deep into the sediment. The oxbow becomes shallower in water depth approaching Mud Creek. Evidence of erosion was noted around the confluence with Mud Creek as a result of water flowing over the bank; however, no water was actively flowing from the oxbow into Mud Creek at the time of the site visit and is assumed to occur following precipitation/melt events.

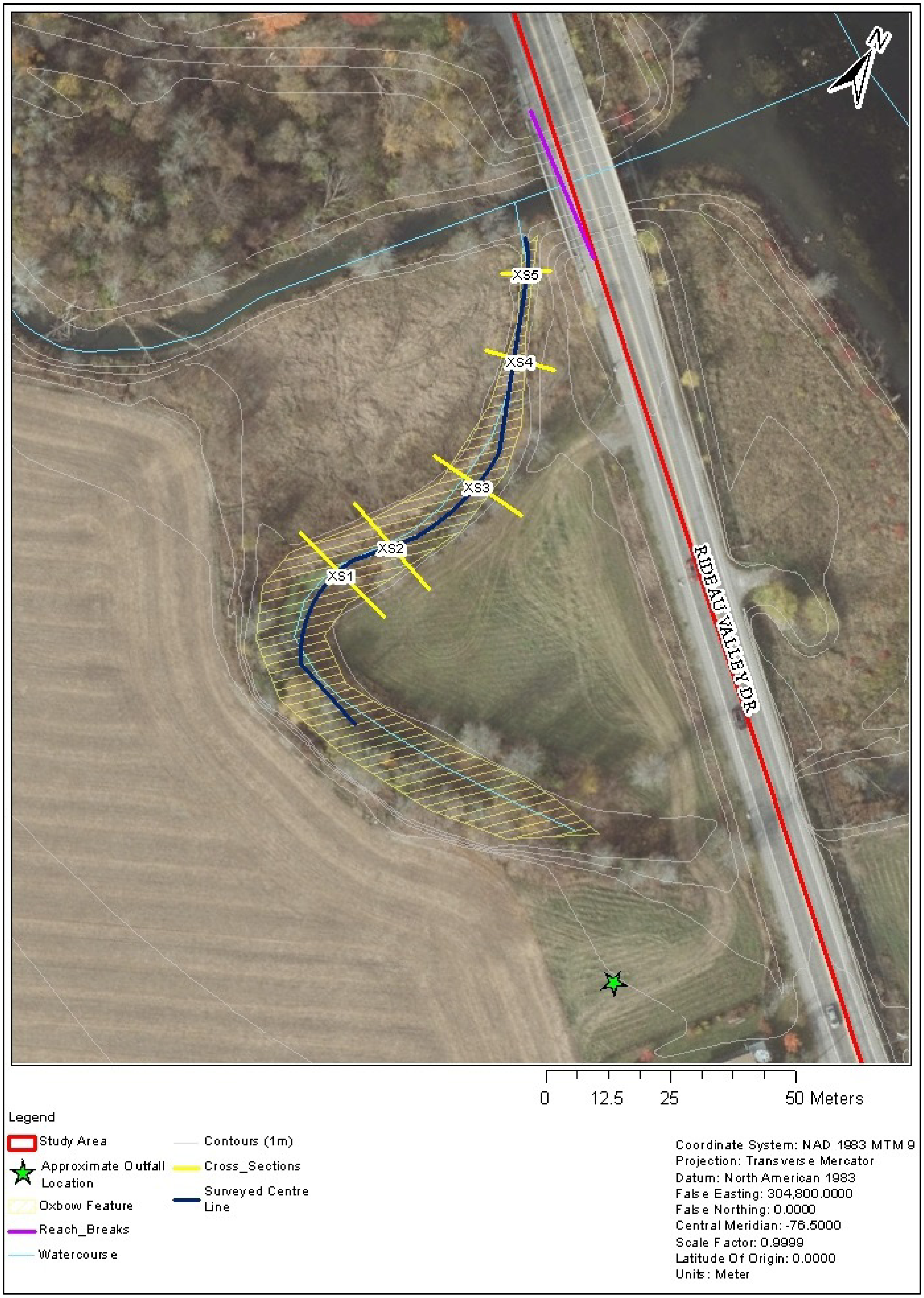


FIGURE 4 Survey Extents and Cross-section Locations Within the Oxbow Feature

4 EROSION HAZARD ASSESSMENT

4.1 POLICIES AND GUIDELINES

Under Section 3.0 of the *Provincial Policy Statement, 2020* (MMAH 2020), "Protecting Public Health and Safety," public costs or risks to residents from natural or human-made hazards are to be reduced. Section 3.1.1 states that development shall generally be directed to areas outside of hazardous lands adjacent to river, stream, and small inland lake systems that are impacted by flooding and/or erosion hazards. Under such provincial guidelines, the study area requires an erosion hazard assessment to define the spatial extents to which development is permitted.

Under the *Conservation Authorities Act*, RVCA has in effect Ontario Regulation 174/06: Rideau Valley Conservation Authority: Development, Interference with Wetlands and Alteration to Shorelines and Watercourse Regulation (O. Reg 174/06; Government of Ontario 2013). This regulation prevents or restricts development or site alterations near water and wetlands to protect the public from flooding, erosion, and other hazards. Given the proximity of the proposed development on the Stinson Lands to Mud Creek and the Wilson-Cowan Drain, RVCA requires the delineation of erosion hazard limits so that the appropriate development limits are established.

4.2 Regulation Limit

O. Reg. 174/06 (Government of Ontario 2013) states that the regulation limit for a river system extends the width of the meander belt, which prohibits development that has not been approved, as defined in Sections 2.1 of the RVCA (2013) Regulation Policies in areas where:

> *(b) river or stream valleys that have depressional features associated with a river or stream, whether or not they contain a watercourse, the limits of which are determined in accordance with the following rules:*
>
> > *(i) where the river or stream valley is apparent and has stable slopes, the valley extends from the stable top of bank, plus 15 metres, to a similar point on the opposite side,*
> >
> > *(ii) where the river or stream valley is apparent and has unstable slopes, the valley extends from the predicted long term stable slope projected from the existing stable slope or, if the toe of the slope is unstable, from the predicted location of the toe of the slope as a result of stream erosion over a projected 100-year period, plus 15 metres, to a similar point on the opposite side,*
> >
> > *(iii) where the river or stream valley is not apparent, the valley extends the greater of,*

(A) the distance from a point outside the edge of the maximum extent of the flood plain under the applicable flood event standard, plus 15 metres, to a similar point on the opposite side, and

(B) the distance from the predicted meander belt of a watercourse, expanded as required to convey the flood flows under the applicable flood event standard, plus 15 metres, to a similar point on the opposite side;

4.3 Erosion Hazard Delineation

Watercourses are naturally dynamic features that change configuration and position within a floodplain by means of erosion and lateral migration processes (e.g., meander evolution). For meandering streams, as meanders adjust in size and position, the associated erosion and depositional processes that enable these changes to occur may pose a risk or damage to private property and infrastructure. For this reason, when development or other activities are contemplated near a watercourse, it is desirable to designate a corridor (the erosion hazard limit) that is projected to contain all the natural meander and migration tendencies of the channel. Outside of this corridor, it is assumed that private property and structures will be safe from channel erosion.

4.3.1 Approach

The erosion hazard delineation drew upon guidance from the Technical Guide; MNR 2002b, in accordance with PPS Section 3.1.1b (MMAH 2020), as well as the TRCA's *Belt Width Delineation Procedures* (PARISH 2004a). The Technical Guide (MNR 2002b) treats confined and unconfined systems differently when defining the erosion hazard limits for a watercourse. Unconfined systems are those with no limits or controls on the spatial occupation of the floodplain by a watercourse, typically associated with no discernable valley slope, allowing the channel to migrate freely. Confined systems are those systems in which the watercourse is adjacent to valley walls within the reach, and meander tendencies are limited by valley contacts. It is also possible to have a partially confined system where the watercourse is adjacent to a valley wall on only one side, restricting migration, while the opposing side is able to freely migrate in the floodplain (or other similar situations).

For unconfined systems, a meander belt is delineated using a combination of base mapping, topographic mapping, and air photographs, as described in PARISH (2004a) or through the use of empirical functions. A factor of safety can be incorporated that represents the 100-year migration rate added to each side of the channel. Where the 100-year migration rate cannot be measured, a distance representing 20% of the measured meander belt width can be applied (10% on each side of the channel) in lieu of the 100-year migration rate. A 6 m erosion access allowance is added to the meander belt allowance on each side of the channel to determine the final erosion hazard limit in accordance with the Technical Guide (MNR 2002b). The erosion access allowance is applied to provide emergency access, to provide construction access for regular maintenance, and to protect against unforeseen or predicted external conditions that could lead to adverse effects on natural conditions (MNR 2002b).

When delineating the erosion hazard limit of a confined system, toe erosion and stable slope are considered (MNR 2002b). Where the valley toe is less than 15 m from the bank, a toe erosion allowance is required in addition to the stable slope and erosion access setbacks (Figure 5 [A]). Where the valley toe is greater than 15 m from the bank, only a stable slope allowance and an erosion access allowance are required (Figure 5 [B]). It is important to note that a detailed geotechnical study may determine a stable slope allowance (other than the assumed 3:1 slope) to refine the erosion hazard limit. Toe erosion allowances and observations of erosion should be supported by practitioners in fluvial geomorphology.

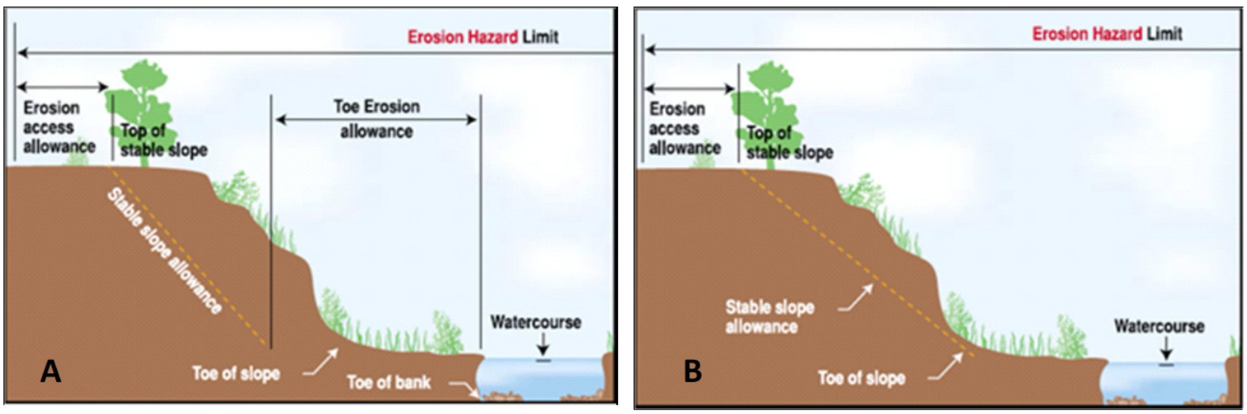


FIGURE 5 Erosion Hazard Delineation for Confined Systems Where Toe or Valley Slope is Located Less than 15 m from Watercourse (A) or Greater than 15 m from Watercourse (B)

Typically, the toe erosion allowance is defined by the 100-year migration rate of the valley toe where the watercourse is within 15 m of the valley wall; however, where an accurate migration rate analysis is not feasible, the allowance can be determined based on an understanding of native soil types and channel properties through guidelines set in the Technical Guide (MNR 2002b) as presented in Table 5. The native soil structure or composition of the site should be confirmed through a site visit or previously generated information (boreholes, etc.). Active erosion is defined as bank material that is exposed directly to streamflow under normal or flood flow conditions, where undercutting, oversteepening, slumping of a bank, or downstream sediment loading is occurring (MNR 2002b).

TABLE 5 Determination of Toe Erosion Allowance (MNR 2002)

Type of Material Native Soil Structure	Evidence of Active Erosion or Where the Bankfull Flow Velocity is Greater than Competent Flow Velocity	No Evidence of Active Erosion Bankfull Width		
		<5 m	5 to 30 m	>30 m
Hard rock (e.g., granite)	0 to 2 m	0 m	0 m	1 m
Soft rock (shale, limestone), cobbles, boulders	2 to 5 m	0 m	1 m	2 m
Clays, clay-silt, gravels	5 to 8 m	1 m	2 m	4 m
Sand, silt	8 to 15 m	1 to 2 m	5 m	7 m

The stable slope allowance is a horizontal setback measured landward from the valley toe or the projected toe erosion allowance, as required. This setback is proportionate to the valley height by a ratio of 3:1, which is an assumed stable slope per the Technical Guide (MNR 2002b), and may be refined through geotechnical study. The inference of the geotechnically stable top-of-slope provides a setback to account for oversteepened slopes where the creek approaches within 15 m of the valley wall. The total erosion hazard limit for a confined system is determined by adding the 6 m erosion access allowance from the greater of the physical top-of-slope or projected long-term stable top-of-slope.

4.3.2 Methodology

A hybrid approach was used to delineate the erosion hazard limits for Mud Creek and the Wilson-Cowan Drain due to the watercourses having a floodplain within which to migrate, set within a well-defined valley system. First, the meander belt was delineated and may be applied for the unconfined valley portions or as guidance for siting erosion hazards within wider valley areas (e.g., lower ~100 m of Mud Creek). Then a long-term stable top-of-slope was mapped by following the Technical Guide (MNR 2002b) along the valley slopes (adjacent to the Stinson Lands only).

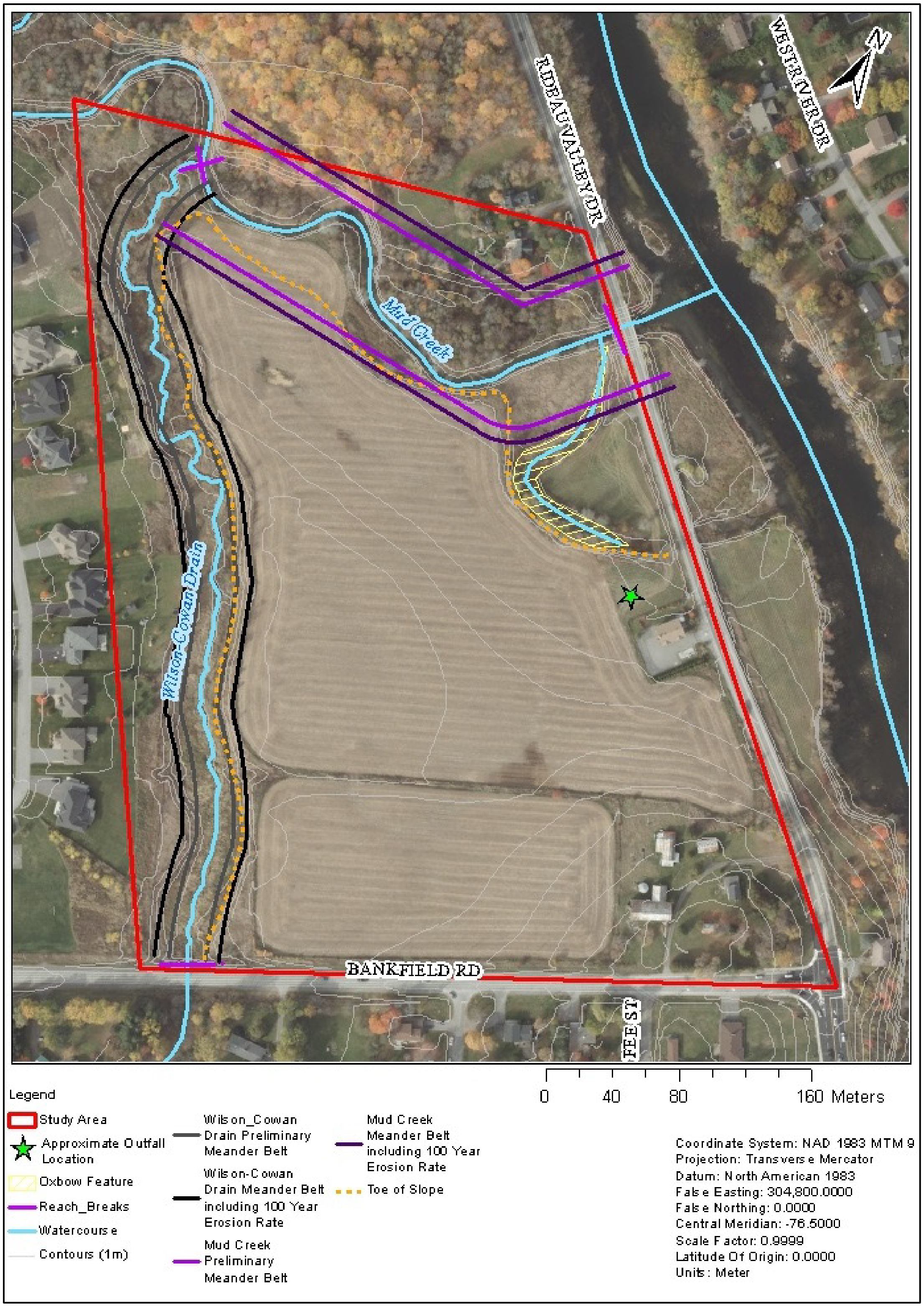
For the meander belt, PARISH (2004a) was referenced and included the following steps:

- Meander belt axis: a review of the historic planform configuration was undertaken to delineate the meander belt axis through each reach; the axis defines the general down-valley orientation of the meandering channel.

- Preliminary meander belt width: this involves drawing tangential lines along the outside bends of laterally extreme meanders within the reach, approximately parallel to the meander axis; this was based on a review of current and historical aerial photography.

- 100-year erosion rate: the maximum erosion rate quantified through the historical assessment and added as a factor of safety.

The confinement of the two channels varied can be seen in Figure 6, meaning the greater hazard of the two approaches was used to provide a final hazard limit. Clay-silt was noted as the dominant substrate during the field investigations, and due to evidence of erosion noted within both channels, a toe erosion allowance of 5 m was selected using the Technical Guide (MNR 2002b) for areas where the watercourse was within 15 m of the valley toe. This value of 5 m also agrees with the findings and recommendations of the Paterson Group Inc. (2021), which applied a 5 m toe erosion allowance to Mud Creek due to its soil type and erosion activity. The 5 m toe erosion allowance was also applied to the Wilson-Cowan Drain due to the observed soil type and the active erosion noted during the field investigations. This value differs from the 1 m toe erosion allowance reported in the Paterson (2021) geotechnical study, as they had not observed active erosion.



Mud Creek and the Wilson-Cowan Drain can be considered confined channels, as their meander belt widths with 100-year erosion rates extend beyond the toe of slope.

FIGURE 6 Meander Belt Delineation

Two sets of stable top-of-slope setbacks were delineated along the valley slope adjacent to the oxbow feature: one without and one with a toe erosion allowance. A 5 m toe erosion allowance was included as one scenario to account for potential erosion occurring, as a stormwater release from the oxbow will result in the feature coming online relatively frequently. The long-term stable top-of-slope without the 5 m toe erosion allowance may be considered if the oxbow does not directly receive stormwater from the proposed development.

4.3.3 Results

The preliminary meander belt width derived for the unconfined portion of Mud Creek is 60 m, as determined from the maximum meander amplitude offset from the meander axis. A 100-year erosion rate of 0.2 m/year (or 20 m per 100 years) was calculated, resulting in a final meander belt width of 80 m. For Wilson-Cowan Drain, the preliminary meander belt was determined to be 22 m in width. The final meander belt was determined by adding a 100-year erosion rate of 17 m as a factor of safety, resulting in a 38 m corridor (Figure 6). In this instance, the meander belt extends beyond the toe and top-of-slope within this confined valley setting.

Given that the proposed development is set atop a defined valley slope, the meander belt does not form the erosion hazard limit to development; rather, it may be used to inform of erosion hazards within the floodplain when siting structures, trails, and other infrastructure (e.g., bridges, maintenance holes).

For this confined setting, Figure 7 presents the combined erosion hazard limit, whereby a single polyline captures the greater of the physical top-of-slope, long-term stable top-of-slope (3:1 setback), or the long-term stable top-of-slope with a toe erosion allowance of 5 m. The Paterson (2021) geotechnical study for the Stinson Lands was reviewed for a potential stable slope allowance (other than the assumed 3:1); however, it was not explicitly stated. Therefore, an assumed 3:1 stable slope allowance was maintained in this analysis. As per the Technical Guide (MNR 2002b), this final erosion hazard limit should include a 6 m erosion access allowance added to each side of the channel.

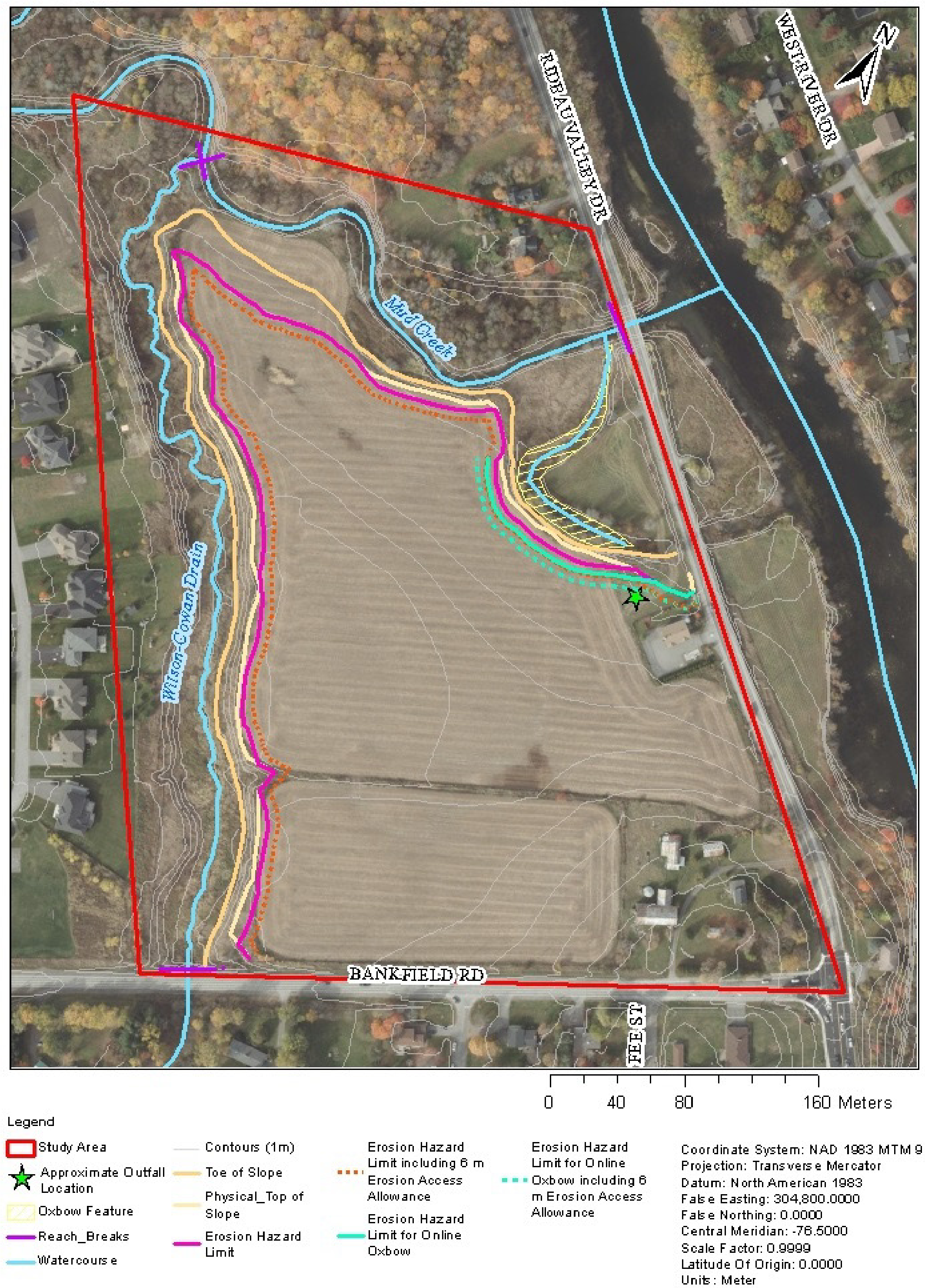


FIGURE 7 Erosion Hazard Limit, Long-term Stable Top-of-slope Assessment for Mud Creek, Wilson-Cowan Drain, and the Oxbow Feature

5 PROPOSED OUTFALL AND EROSION SENSITIVITY

Through a review of the draft development plan and the stormwater management (SWM) report (Novatech 2022) and discussions with Novatech staff, it is understood that the current plan is to discharge unmanaged (quantity) stormflows into the floodplain, with potential for the oxbow feature to receive and convey flows to Mud Creek. Modelling for pre- and post-development stormwater flows shows a 500% increase in discharge to be conveyed through the oxbow feature during the 2-, 5-, and 100-year flow events (refer to Table 4.4 in Novatech [2022]). Energy dissipation at the outlet has been provided through a plunge-pool concept design to reduce outflow velocities prior to discharging into the oxbow/floodplain (refer to Section 4.5.5 and Figure 4.3 in Novatech [2022]). Given that the proposed post-development peak flows are a significant increase, so erosion sensitivity should be characterized to determine if the proposed SWM plan and concept design for the plunge pool are acceptable and to provide recommendations for erosion mitigation where necessary. It is understood that further analysis will be completed at the detailed design stage to ensure that there will be no negative impacts to the oxbow feature, Mud Creek, or the Rideau River that may result from increased peak flows.

As mentioned in Section 3.1.3, a detailed channel survey was completed along the oxbow feature using high-precision GPS equipment. The detailed assessment included a survey of the longitudinal profile and cross-sections of the oxbow, which were used to determine bankfull characteristics as well as measurements of channel and bank characteristics. The long profile could not extend further into the bend of the oxbow, as water depth was over 1 m on top of unconsolidated, soft material presenting a hazard for wading. Longitudinal profile and cross-section plots are illustrated in Appendix B. "Bankfull" represents the maximum capacity for a channel to convey flow before inundating the floodplain. Bankfull parameters of each reach are summarized in Table 6. As this is a relic channel feature in the floodplain, it was difficult to discern any bankfull channel dimensions with complete confidence, and the results in Table 6 were estimated based on inflections in the cross-section for the purpose of a general characterization.

TABLE 6 Estimated Dimensions for Oxbow Feature

Channel Parameter	Oxbow Feature
Average bankfull width (m)	3
Average bankfull depth (m)	0.11
Maximum bankfull depth (m)	0.15
Average width-to-depth ratio	28
Channel bed gradient (m/m)	0.004 (1)
Bed materials	organics and clay

Notes:
(1) Slope derived from Ontario Land Surveyor survey (Annis, O'Sullivan, Vollbekk Ltd. 2022)

Historical erosion is evident along the outer bank at the apex of the oxbow, where tree roots were exposed, and trees had previously fallen into the oxbow. This observation, in addition to observed bed substrates (clay and organics) and evidence of erosion along Mud Creek banks (clay), suggests that this feature may become sensitive to erosion. Consideration of the composition of the banks of Mud Creek is made here, as there is already an informal connection between the oxbow and the main channel, which will potentially be receiving more flows more frequently, and these bank materials provide an analog for what may be present in/below the oxbow.

A permissible velocity approach for observed substrates is proposed to provide a measure of erosion sensitivity. Based on field observations, the oxbow feature and floodplain almost entirely consist of entirely stiff clay, with unconsolidated organics in wet portions of the oxbow. As such, a permissible velocity approach was used to determine an entrainment threshold, which accounts for the cohesion observed in fine sediments. A critical velocity of 0.91 m/s was selected, which represents the maximum permissible velocity for stiff clay, similar to those found in Mud Creek and the oxbow (Fischenich 2001).

The SWM report (Novatech 2022) includes an analysis of outlet velocities through the outflow channel and oxbow feature using PCSWMM. Without mitigation, velocities through the outflow channel mostly exceed the permissible velocity of 0.91 m/s except for the 5-year event (refer to Table 4.7 in Novatech [2022]), while modelled velocities within the oxbow feature all fall below the threshold, with a maximum of 0.83 m/s under the 25 mm event. Velocities in the oxbow are reported to slow due to backwatering from Mud Creek and the Rideau River (Novatech 2022).

To address the modelled higher velocities through the outflow channel, Novatech completed a functional attenuation design at the outlet with flow dissipation chute blocks on a concrete apron and a receiving plunge pool comprising 300 mm riprap (D_{50} is 150 mm). In their preliminary plunge-pool sizing, velocities under events up to the 100-year are at or below the permissible velocity of 0.91 m/s (refer to Appendix C in Novatech [2022]). For additional roughness and protection, Novatech proposes to extend the riprap treatment from the plunge pool through the remainder of the outflow channel prior to connecting with the oxbow feature.

Despite the analysis and functional design, there is still potential for flow concentration and erosion between the oxbow and Mud Creek that should be evaluated, particularly as slopes increase at the connection to Mud Creek. To further evaluate this, a brief analysis of expected velocities under post-development peak flows for the oxbow (Table 1 in Novatech 2022) was completed. A slope of 41.0%, representing the existing slope down the southern bank of Mud Creek at the connection with the oxbow, was evaluated, and the results in Table 7 reveal that there is potential for erosion as velocities exceed the permissible velocity of 0.91 m/s under most scenarios. Further modelling is recommended to confirm and update these results prior to finalizing and determining an appropriate flow path and potential mitigation measures between the proposed outfall and Mud Creek.

TABLE 7 Summary Velocity Outputs Under Future Scenarios

Event	Post-development flows (m^3/s)*	Velocity m/s (Mud Creek Bank Slope of 41.0%)
2-year	0.850	3.91
5-year	1.245	4.40
100-year	2.395	5.37

*Flows obtained from Table 4.4 for the 6-hour Chicago Storm Distribution in Novatech (2022)

With velocities at the connection to Mud Creek being four times the permissible velocity under the 2-year, it is recommended that a connection to Mud Creek be formalized (Figure 8) with a gentler slope, design cross-section, and appropriately sized/selected lining materials to avoid headcutting into the floodplain, towards the oxbow feature. This would have to consider changes in the water level of Mud Creek for sustained stability.

Figure 8 provides the approximate location and extent of required stabilization works for a formalized Mud Creek connection to be developed through detailed design. Furthermore, at the detailed design stage, Matrix recommends the confirmation of stability of the oxbow under future scenarios through detailed hydraulic modelling (e.g., HEC-RAS) and any potential mitigation or alternate design options to convey flows from the development to Mud Creek that may be required pending the result of detailed design analysis. As mentioned earlier in this section, it is understood that further analysis will be completed at the detailed design stage to ensure that there will be no negative impacts to the oxbow feature, Mud Creek, or the Rideau River that may result from increased peak flows (Novatech 2022). The formalization of a connection down the bank of Mud Creek, the outflow channel design, and other floodplain modifications (if required) should be designed by or in collaboration with practitioners in fluvial geomorphology.

FIGURE 8 Recommended Design Opportunities for Stormwater Management Outflows

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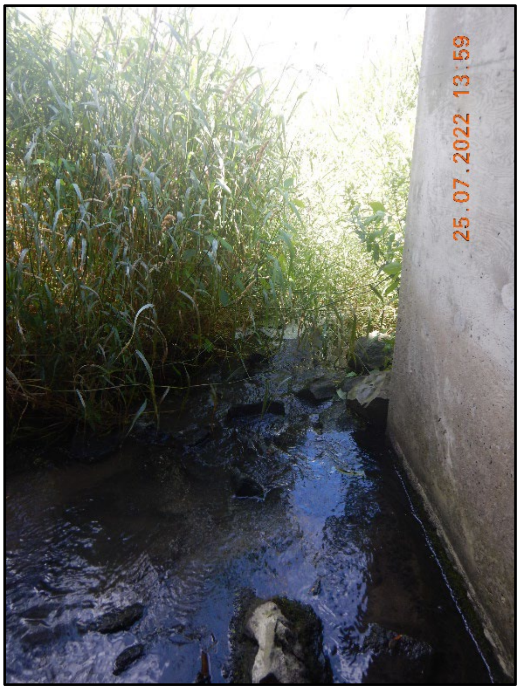
APPENDIX A
Site Photographs

1. Wilson Cowan Drain - Facing downstream, Wilson-Cowan Drain and valley from Bankfield Road

2. Wilson Cowan Drain - Facing upstream from outlet of culvert passing under Bankfield Road



3. Wilson Cowan Drain - Facing downstream from inside culvert, the flow path is to the right side of the culvert flowing into a defined channel

4. Wilson Cowan Drain - Facing downstream from culvert, the valley is well vegetated with tall grasses and aquatic vegetation

5. Wilson Cowan Drain - Looking upstream, despite being well vegetated, the channel maintains it's definition along the reach

6. Wilson Cowan Drain - Facing downstream, the reach showed consistent signs of erosion in the form of steep outside meander banks, slumped banks, and failed banks

7. Mud Creek – Facing downstream, the creek shows low flow velocities at time of visit with established in stream vegetation with step outer meander bends and point bars established on the inside of beds

8. Mud Creek – Facing downstream, creek shows evidence of erosion and widening with many downed and leaning trees

9. Mud Creek – Facing upstream, creek banks commonly show exposed tree roots

10. Mud Creek – Facing parallel to Rideau Valley Drive N, inlet location from the Oxbow feature into Mud Creek with an approximate 1 – 1.5 m elevation change

11. Oxbow Feature– Facing upstream from confluence with Mud Creek, feature is a defined valley that's heavily vegetated with grasses and reeds

12. Oxbow Feature – Facing down, elevated area separating the standing water in the Oxbow and Mud Creek has a clear and define flow path but was above the water level at the time of the field visit

13. Oxbow Feature – Facing downstream, the depression maintained standing water at the time of the site visit, with saturated and unconsolidated soil underneath

14. Oxbow Feature– Facing downstream, between the define banks, the feature is heavily grasses but maintains water

15. Oxbow Feature – Facing down, water surfaces in parts of the oxbow show pollution in the form of mineral staining

16. Mud Creek– Drainage from the adjacent field has resulted in a significant washout along the southern bank of Mud Creek

APPENDIX B
Geomorphic Survey Plots

APPENDIX B

GEOMORPHIC SURVEY PLOTS

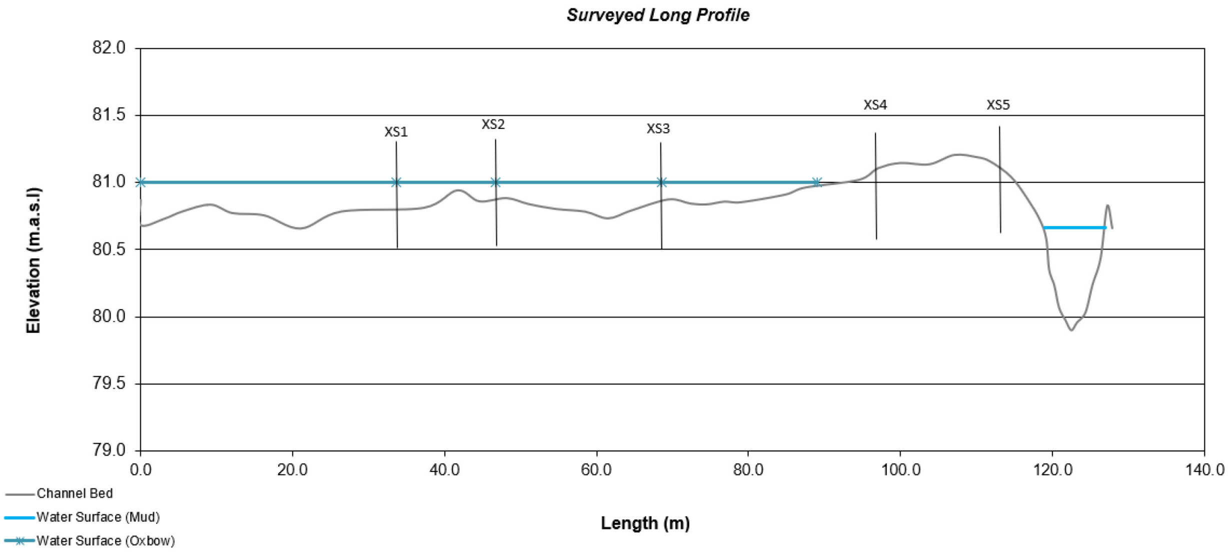


FIGURE B1 **Long profile of the Oxbow feature and Mud Creek showing water levels for both features and cross section locations**

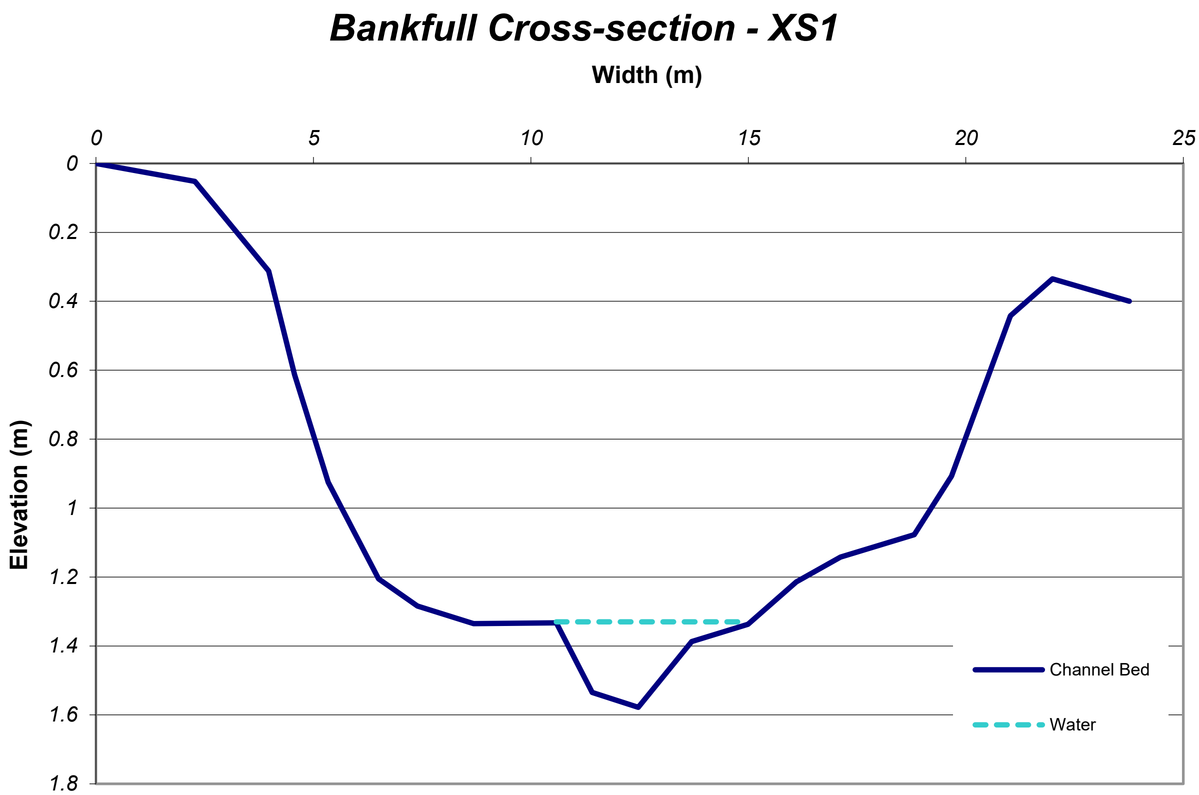


FIGURE B2 Cross section profile at XS1 from tops of slope, right to left facing downstream

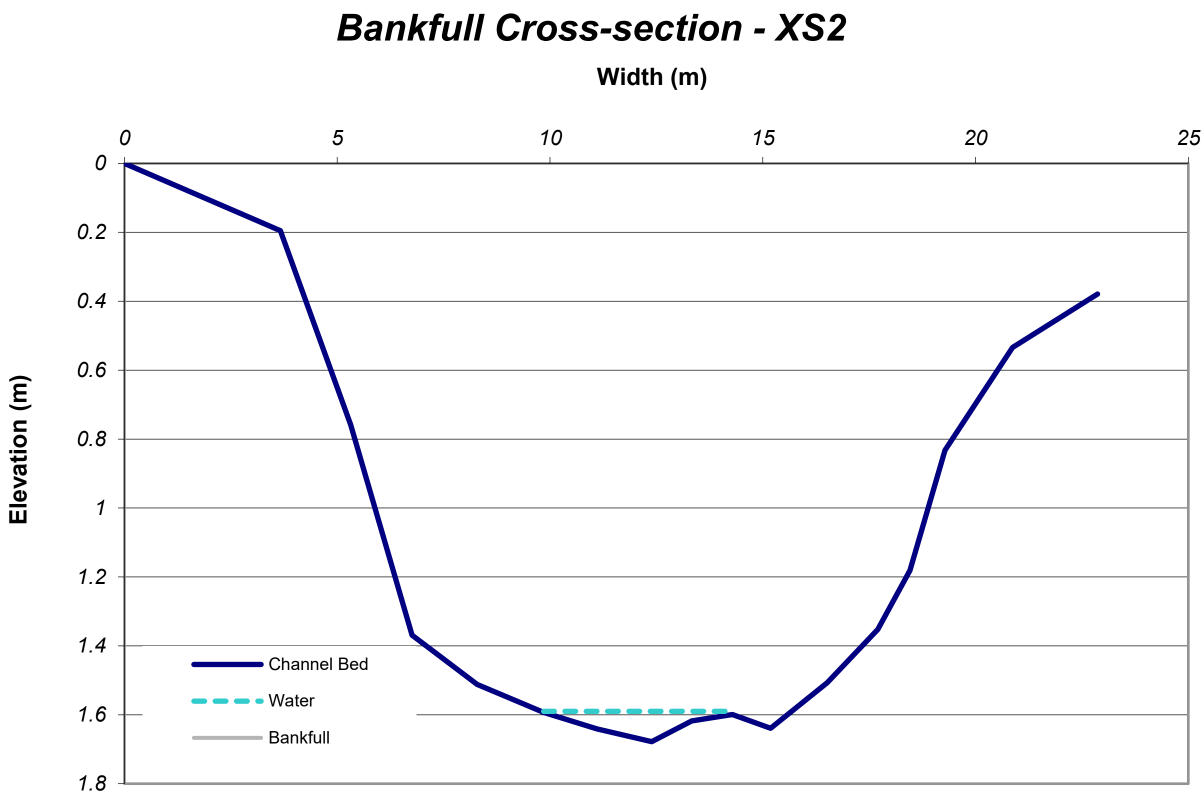


FIGURE B3 Cross section profile at XS2 from tops of slope, right to left facing downstream

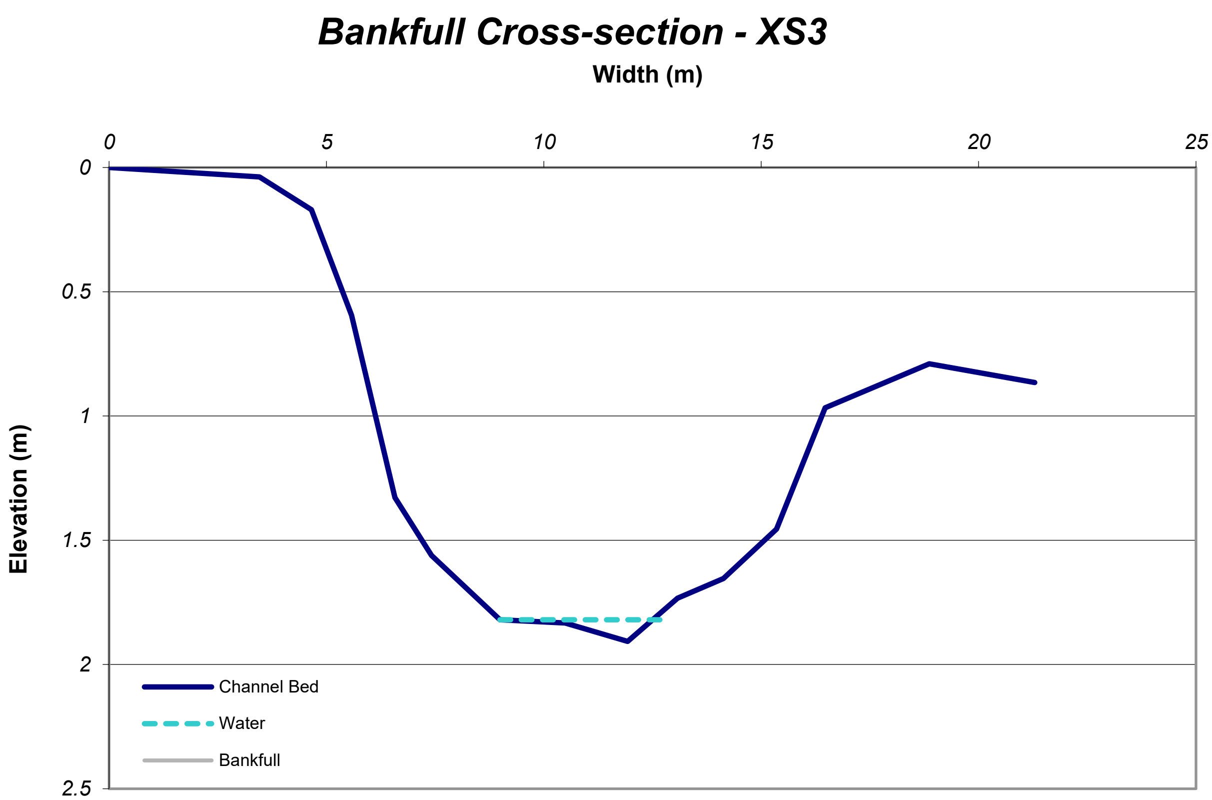


FIGURE B4 Cross-section profile at XS3 from tops of slope, right to left facing downstream

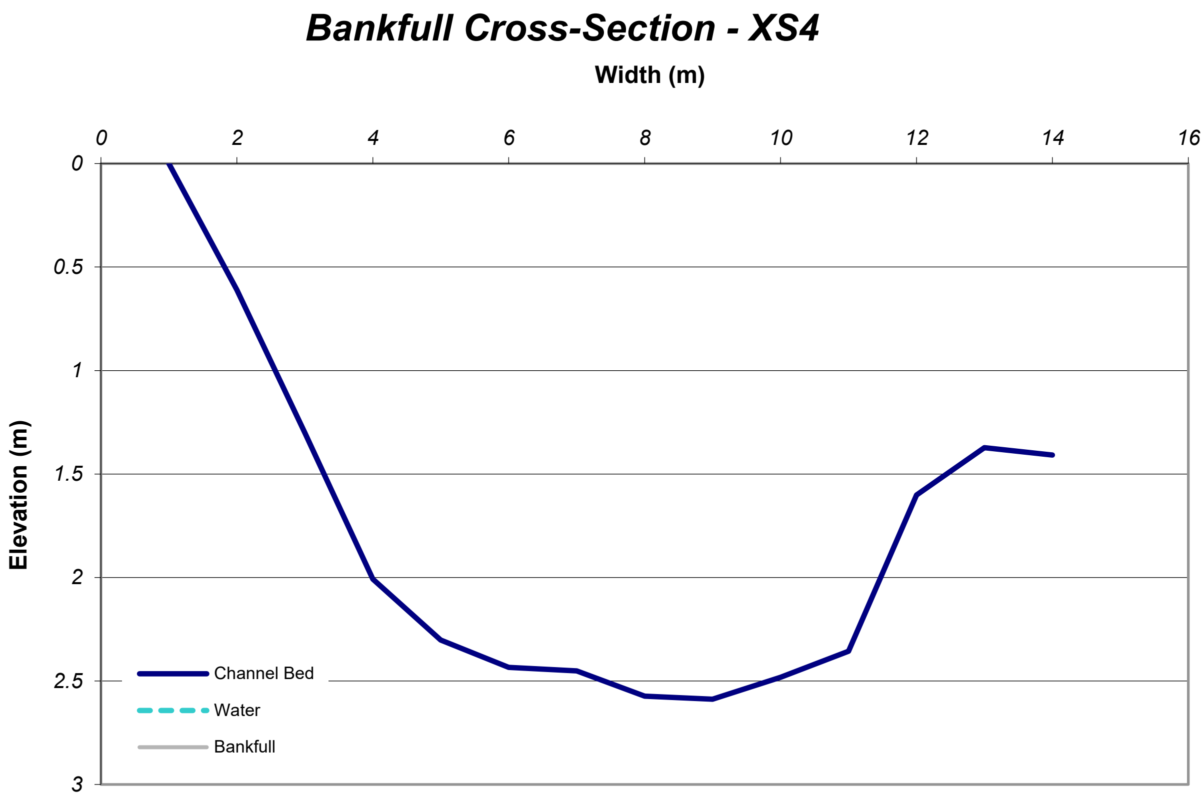


FIGURE B5 Cross-section profile at XS4 from tops of slope, right to left facing downstream

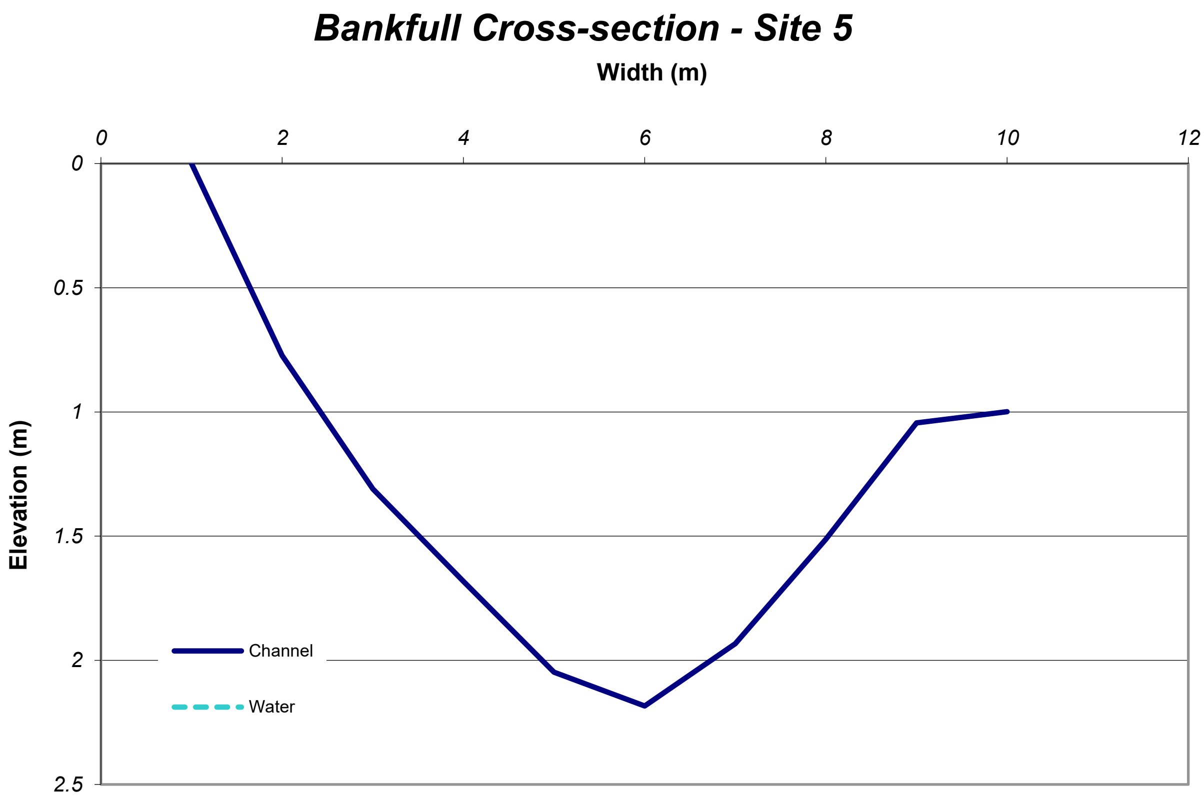


FIGURE B6 Cross-section profile at XS5 from tops of slope, right to left facing downstream