St. George Industrial Development Erosion Threshold Assessment

DRAFT REPORT

Prepared for

Panattoni Development Company

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1. Introduction

GeoProcess Research Associates (GRA) was retained by Panattoni Development Company to conduct an erosion threshold assessment of three watercourses that may receive stormwater discharge from a proposed development at 282a Highway 5 in St. George, ON. This assessment is intended to provide guidance for the design of the stormwater management facilities by determining flows in the receiving watercourses that initiate bed and bank erosion. These erosion thresholds can then be used to assess the release rates from the SWM ponds to ensure that these flows do not result in channel erosion above the existing conditions. This report only addresses establishing erosion threshold limits and does not investigate impacts of stormwater on channel erosion; that specific assessment will occur once storm flows from the site are available.

The objectives of the study were to characterize the existing geomorphological conditions of the watercourses and to estimate erosion thresholds to inform the stormwater management (SWM) design criteria. To address the objectives, a field assessment and geomorphic survey were undertaken. These data were used to complete erosion threshold modelling to estimate discharges associated with the initiation of erosion for each delineated watercourse reach.

2. Study Area and Background

The subject property is in the community of Saint George, ON, and is generally bounded Highway 5 and the Commerce Ave industrial park to the north and northeast. The rest of the property is bound by neighbouring agricultural lands. Currently, the subject lands are primarily comprised of agricultural and forested lands.

Two watercourses are located along the boundary of the lands; the first (FCT-1) flows from Highway 5 towards Commerce Ave, adjacent to the most northeastern extent of the property. The second tributary (FCT-2) flows along the western limit of the property through a small woodlot. There are several other small watercourses beyond the western and southern limits of the property, however, they are beyond the property boundary. All the watercourses eventually confluence with Fairchild Creek downstream of Main Street and south of Governors Road East. Figure 1 shows the study area location.

For this study, the area of focus was contained to the portions of the subject watercourses that are located immediately downstream of the property and may be impacted by stormwater discharge. The study area extent was limited to those properties to which GRA was granted access by the landowners.

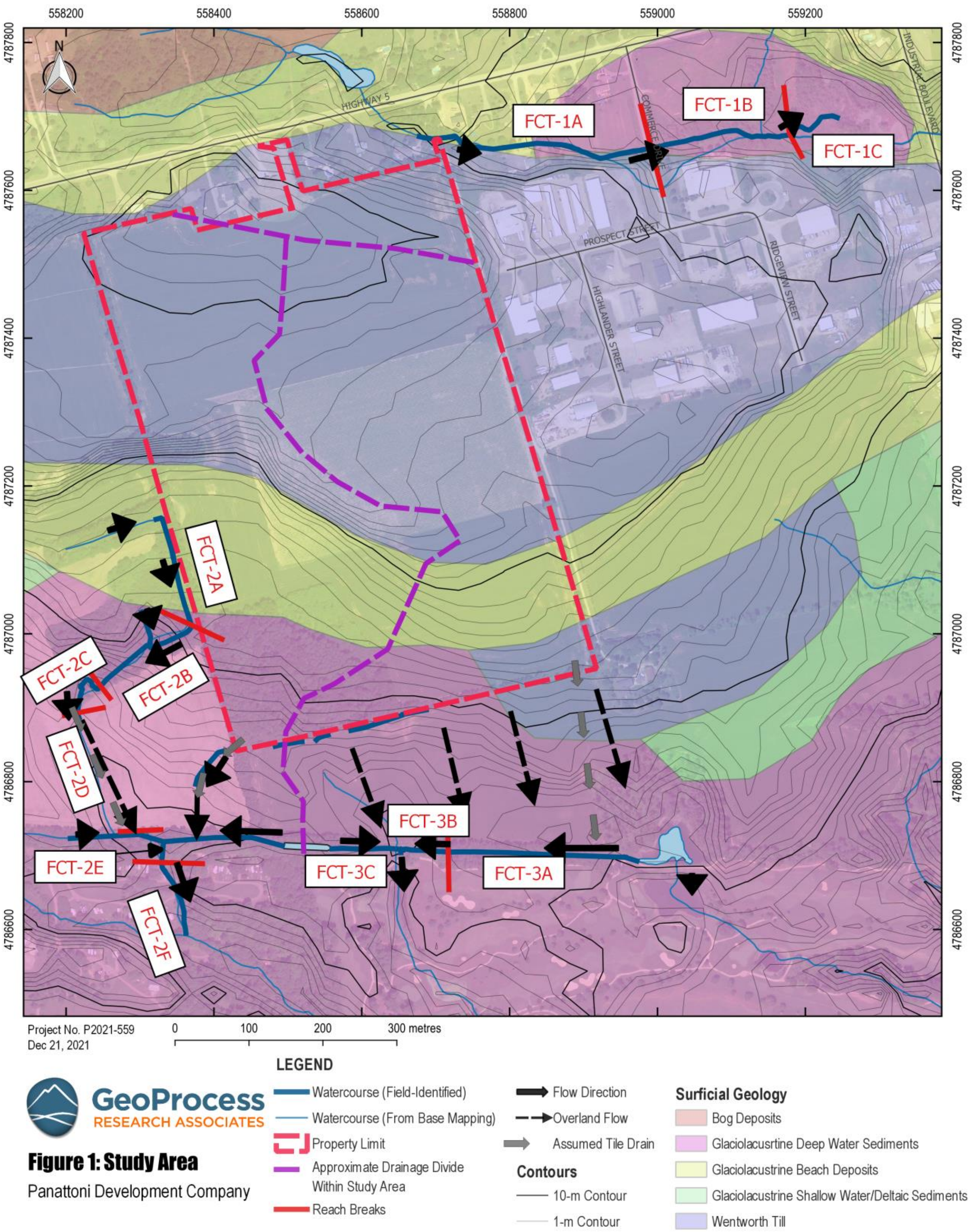

Figure 1: Study Area

3. Methods

3.1. Reach Delineation

A river may transition between different morphologies due to changes in geology, slope, valley type, sediment sources, anthropogenic influences, or discharge. As such, it is common to separate rivers into segments, or reaches for assessment purposes. A reach can range in length, depending on the size and characteristics of the river, however, it should be sufficiently long such that average hydraulic and morphologic characteristics can be confidently estimated. Often, in urban settings, reaches are delineated based on interactions with infrastructure such as bridge crossings or channel erosion protection (e.g., segments entirely lined with gabion baskets). In this assessment, reaches were delineated based on geomorphic criteria, including channel slope, cross-sectional geometry, channel confinement and dominant bed material, as well as anthropogenic interventions such as pipes/culverts. This delineation helped to identify areas of highest risk of erosion.

3.2. Field Methods

A reconnaissance-level field assessment and geomorphic survey was conducted on November 9, 2021. Indicators commensurate with morphologic adjustment were identified and noted. For example, vertical or undercut streambanks bare of vegetation are indicators of channel widening. The primary objective of the reconnaissance investigation was to identify the relative stability of the different reaches in the study area (e.g., stable, in transition, or adjusting). This information provides qualitative insight into the resilience of the watercourse, insofar as additional flow inputs (from stormwater) and the areas where increased erosion may be anticipated.

A geomorphic survey was completed for the study area. The survey consisted of a longitudinal profile, where significant breaks in slope were measured. Cross-sections were surveyed to characterize the dominant cross-sectional morphology. All measurements were conducted using an RTK survey-grade GPS.

Additional data collected during the field assessment included pebble counts to characterize the grain size distribution of the bed material and shear strength measurements using a TORVANE. The latter is a handheld vane shear device for in-situ measurement of the shear strength of fully saturated cohesive soils.

4. Existing Conditions Channel Morphology

4.1. Watershed Characteristics

The subject watercourses are tributaries of Fairchild Creek, which is in the Grand River watershed. The watercourses are identified as Fairchild Creek Tributaries (FCT) 1 to 3. These watercourses are shown in Figure 1. The Ontario Flow Assessment Tool (OFAT) (MNRF, 2017) was used to estimate the catchment sizes and land uses. This data is summarized in Table 1.

Table 1: Summary of catchment areas and landuse for surrounding watercourses.

Watercourse	Catchment Area (ha)	Landuse
FCT-1	46.3	Agricultural (74%) Infrastructure (21%) Swamp lands (5%)
FCT-2	13.2	Agricultural (74%) Forested (26%)
FCT-3	35.46	Agricultural (89%) Forested (11%)

4.2. Geology

The area lies within the Norfolk Sand Plain physiographic region (Chapman & Putnam, 1984), which was formed by the proglacial Lakes Whittlesey and Warren which developed in the Lake Erie basin (Barnett, 1982). Most of the subject lands, the headwaters of the tributaries, and portions of FCT-1 and FCT-2 are within a "nearshore geologic environment" and have surficial geology composed of sands and gravel. These sand and gravel deposits are one likely source of the coarse-grained sediments observed in the watercourses. The southern portion of the subject lands and FCT-3 have a surficial geology primarily formed from glaciolacustrine deep-water deposits (stratified silt and clay) that are locally overlain by a veneer of sand (Ontario Geological Survey, 2010).

4.3. Reach Delineation

Each of the subject watercourses was delineated into reaches based on channel morphology and the degree of valley confinement. The following sections describe the geomorphic features of each reach. Locations of the delineated reaches are shown in Figure 1.

4.4. Tributary FCT-1

Tributary FCT-1 begins in a wetland upstream of Brant County Highway 5. After crossing Highway 5, FCT-1 flows east adjacent to the northeast corner of the subject property and through several residential properties fronting Highway 5, before entering a wetland upstream of Industrial Boulevard. During a preliminary desktop review, this wetland was identified as an attenuating feature, and was therefore chosen as the downstream study area extent. Downstream of Industrial Boulevard, FCT-1 flows generally southeast, eventually confluencing with Fairchild Creek.

FCT-1 has been subdivided into three reaches based on the field investigation. The subsequent sections describe the existing conditions of each reach.

4.4.1. FCT-1A

Reach FCT-1A starts at the northeast corner of the subject property and ends at Commerce Drive. Within Reach FCT-1A, the watercourse flows through a series of residential lots fronting Highway 5. Reach FCT-1A is characterized by a steep average slope of 2.3%, with local slopes ranging from 3.4% at the upstream end to 1.4% at the downstream end. The upstream portion is confined, flowing through a series of culvert with banks composed of fill that has been used to elevate the residential backyards. After exiting this series of culverts, with the bankfull depth decreases to between 0.2 and 0.3 m. Note that permission to access was not granted for the properties located at 262, 264 and 266 Brant County Highway 5, so the assessment did not include the portion of the watercourse that flows through these properties. Visually, the existing conditions within these three properties appeared to be similar to the rest of Reach FCT-1A.

Ready floodplain access is present for the remainder of the reach, down to Commerce Drive. Riparian vegetation varies from manicured lawn grass to grasses and reeds with infrequent young to mature trees. Despite the steepness of the channel, minimal evidence of active bank erosion was noted, which is attributed to the good floodplain access.

The channel bed is composed of an alluvial layer of sand and fine gravel overlying fine-grained silt and clay sediments. One representative pebble count was conducted at the upstream end of the reach to characterize the alluvial bed material. Photo 1, Photo 2, Photo 3 and Photo 4 provide typical channel views in Reach FCT-1A.

Photo 1: Culvert at upstream end of reach (looking upstream)

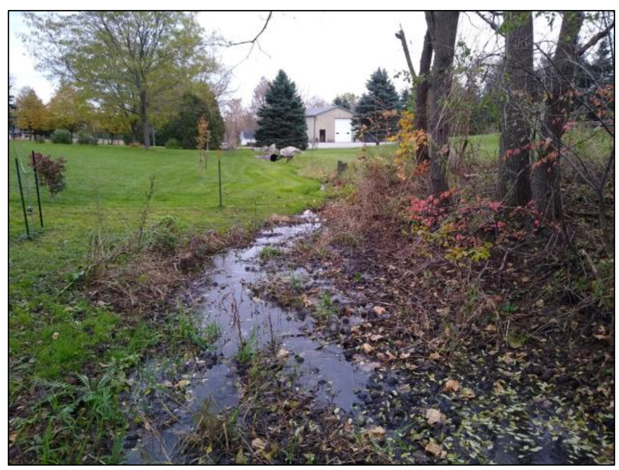

Photo 2: Typical channel view (looking downstream)

Photo 3: Typical channel view (looking upstream)

Photo 4: Channel bed gravel substrates

4.4.2. FCT-1B

Channel FCT-1B begins at Commerce Drive and ends at the limits of the open-water wetland. Reach FCT-1B is characterized by well-established riparian vegetation comprising tall grasses, reeds, woody plants and shrubs, and trees (particularly cedars). The width to depth ratio of Reach FCT-1B is notably higher than that of Reach FCT-1A, and the slope is shallower (approximately 0.5%). As with Reach FCT-1B, floodplain connectivity is excellent. The floodplain connection, large width to depth ratio and shallow slope combine to create a depositional environment, with bed material composed of silt and silty sand. The bank material is poorly cohesive, composed primarily of silt and organics. A TORVANE measurement was taken to characterize the shear strength of the bank material. While exposed banks were observed intermittently throughout the channel, active erosion was not observed. This is attributed to the combination of riparian vegetation, shallow gradient, large width to depth ratio and ready floodplain access. Based on these field observations, Reach FCT-1B was identified as being less sensitive to erosion than Reach FCT-1A. Photo 5, Photo 6, Photo 7 and Photo 8 show typical channel views in Reach FCT-1B.

Photo 5: Typical channel view, looking upstream

Photo 6: Typical channel view, looking downstream

Photo 7: Typical channel view, highlighting high width to depth ratio and woody riparian vegetation

Photo 8: Lateral bar, indicating sediment deposition

4.4.3. FCT-1C

Reach FCT-1C is located near the upstream extents of the open-water wetland. This reach is heavily influenced by backwater and is dominated by marsh grasses and reeds, with a number of dead trees. Due to the moderate gradient (0.3%), backwatered condition, and lack of erosion indicators observed in the field, this reach is not considered to be sensitive to erosion. Photo 9 and Photo 10 show typical conditions in Reach FCT-1C.

Photo 9: Reach FCT-1C typical view.

Photo 10: Open-water wetland.

4.5. Tributary FCT-2

Tributary FCT-2 is located at the southwest corner of the subject property. This watercourse begins immediately to the west of the subject property and flows east, flowing along the western property boundary before eventually turning to the west and re-entering the western property. The watercourse then enters a tile drain system before re-emerging at the southern railway corridor, then flowing south and confluencing with another tributary of Fairchild Creek approximately 500 m downstream of the subject property. The water then flows east, through the Oaks of St George Golf Club, eventually confluencing with FCT-1 just upstream of its confluence with Fairchild Creek.

The limit of this erosion threshold assessment is the confluence with the tributary within the trailer park. This study limit was determined based on a preliminary desktop analysis and finalized within a terms of reference with the Grand River Conservation Authority (GRCA). However, further evaluation of the relative catchment areas indicated that the reach break dividing Reaches FCT-2D and FCT-2E is a confluence with another tributary (the railway ditch). Furthermore, the contributing catchment of the railway ditch is larger than that of Reach FCT-2D. Therefore, while the bankfull characteristics, reach-averaged erosion thresholds and critical discharges for Reaches FCT-2E and FCT-2F were investigated and reported in keeping with terms of reference, it is recommended that these reaches not be included in the erosion exceedance analysis (to be completed at a later date).

4.5.1. FCT-2A

Reach FCT-2A is characterized by low sinuosity and a steep slope (2.3%). Despite being moderately confined, low bank angles and the presence of woody riparian vegetation appears to be stabilizing the reach, and active erosion was not observed.

A short 6 m long connecting channel is present between Reach FCT-2A and FCT-2B. The connecting channel is very steep (16% slope), however, no active erosion or incision was observed in the field. A TORVANE measurement was taken on the channel bank. Photo 11 and Photo 12 show typical views of Reach FCT-1A.

Photo 11: Typical channel view

Photo 12: Typical channel view

4.5.2. FCT-2B

Reach FCT-2B begins downstream of the short connecting channel and flows west for approximately 130 m. There is a short 10 m channel upstream of the confluence with Reach FCT-1A that begins at the subject property; this was not characterized as a distinct reach, but a cross-section was surveyed through this channel and its centreline profile was surveyed.

Reach FCT-2B is a very steep (5.5%) incised gulley. Mature tree roots are providing some stability (Photo 15), but the presence of leaning trees (Photo 14), large woody debris (Photo 19) and undercut banks (Photo 16) indicates that the gulley is actively widening. The substrate in this reach is composed of a mix of alluvial material ranging from silt to cobbles. Some evidence of incision was noted in this reach; in particular, a headcut located in the downstream half of the reach. Based on the field assessment, Reach FCT-2B was identified as the reach most sensitive to erosion.

One representative pebble count was taken to characterize the grain size distribution of the coarse-grained substrate. A TORVANE measurement was taken on the channel bank.

Photo 13: Incised channel

Photo 14:Leaning trees

Photo 15: Bank stability provided by roots

Photo 16: Thalweg flowing under bank, undercut by at least 1.5 m.

Photo 17: Typical channel view, facing upstream

Photo 18: Leaning tree

Photo 19: Large woody debris in channel

Photo 20: Headcut

4.5.3. FCT-2C

Reach FCT-2B and FCT-2C are separated by a distinct change in channel slope and cross-sectional geometry. Where Reach FCT-2B is steep, incised and over-widened, Reach FCT-2C is comparatively shallow (1.3%). Floodplain connectivity in Reach FCT-2C is very high, with a meandering low-flow channel situated within a low-lying grassy floodplain hollow. This hollow, which was saturated during the field assessment, is expected to flood frequently, resulting in a considerable fraction of floodplain flow following a rain event. As a result of this frequent flooding, active adjustment of the low-flow channel, resulting from the formation of new floodplain channels, is expected; however, due to the depositional floodplain environment, this type of adjustment is not likely to cause excess downstream sediment loading and is therefore not of concern.

At the downstream end of Reach FCT-2C, a riser pipe has been constructed above the low-flow channel. On the date of the field assessment, the riser was lying on the ground, disconnected from the base (Photo 23), but the base of the pipe is intact (Photo 24). This riser pipe would not have sufficient capacity to capture all water during larger flow events, and some flow would pass to the downstream field as overland flow. The location of the pipe outlet could not be determined by GRA field staff.

Photo 21: Typical channel view showing active floodplain (looking downstream)

Photo 22: Typical channel view showing active floodplain (facing upstream)

Photo 23: Fallen riser pipe

Photo 24: Riser pipe base

4.5.4. FCT-2D

Reaches FCT-2C and FCT-2D are differentiated by the limits of the woodlot. Within Reach FCT-2D, the watercourse enters an agricultural field. Immediately upon entering Reach FCT-2D, the watercourse enters a pipe. The pipe inlet was obscured by vegetation and fine sediments, but it was measured to have an approximate diameter of 0.2 m (Photo 25). The location of the pipe outlet could not be identified by GRA field staff. On the date of the field assessment (November 9, 2021), the pipe was conveying the entire baseflow of tributary FCT-2. Ponding was observed downstream of the pipe inlet (Photo 26), but the overland flow did not extend to the downstream extent of the reach. Rather, the low-lying area surrounding the pipe inlet gradually slopes upward in the downstream direction, until it abruptly ends at the edge of an agricultural field (Photo 28). During a large flow event, it is anticipated that the ponding in this low-lying area would increase until the water surface elevation reached the downstream crest, at which point overland flow through the agricultural field would occur. The ponded area in Reach FCT-2D is dominated by maintained (cut) grass.

Photo 25: Inlet of 0.2 m pipe

Photo 26: Ponding in Reach FCT-2D (looking upstream)

Photo 27: Reach FCT-2D (looking downstream)

Photo 28: Reach FCT-2D, looking downstream toward agricultural field

4.5.5. FCT-2E

While the outlet of the pipe in Reach FCT-2D was not identified, it is presumed to outlet to the ditch that flows east-west along the railway corridor. As outlined in Section 4.5, the contributing catchment of this ditch is larger than that of Reach FCT-2D. Furthermore, the railway ditches were generally observed to have less evidence of existing erosion, and presumably greater resiliency to erosion due to generally low channel slopes and wide cross-sectional areas. Therefore, it is recommended that FCT-2E and FCT-2F not be included in the future erosion exceedance analysis. A description of existing conditions is nevertheless provided.

Reach FCT-2E begins at the railway ditch, quickly turning south and flowing through a pipe under the railway embankment and into a trailer park. The approximate location of the pipe was identified, but the pipe itself was obscured and could not be measured by GRA field staff.

Downstream of the railway embankment, Reach FCT-2E becomes a shallow, heavily vegetated channel. The channel flows for approximately 30 m, through a roadway crossing that was under construction (culvert replacement) at the time of the field assessment and terminating at a 0.5 m corrugated steel pipe (CSP) culvert within the trailer park. This reach is generally well-vegetated with tall grasses and has a moderate slope of 1.3%.

Photo 29: Inlet of pipe under railway embankment

Photo 30: Typical channel view

Photo 31: Typical channel view

Photo 32: Culvert at downstream reach extent (looking downstream)

4.5.6. FCT-2F

Reach FCT-2F is 50 m long, extending from the 0.5 m CSP culvert to a confluence with another tributary of Fairchild Creek. This reach is steep (3% slope) and actively widening, as evidenced by leaning trees and undercut banks. The 0.5 m CSP culvert is perched (Photo 33), with a plunge pool having formed immediately downstream. Photo 33, Photo 34, Photo 35 and Photo 36 provide typical views of Reach FCT-2F. One TORVANE measurement was taken on the channel bank.

Photo 33: Perched culvert and plunge pool (facing upstream)

Photo 34: leaning trees (facing downstream)

Photo 35: leaning trees adjacent to private property

Photo 36:Undercut bank

4.6. Tributary FCT-3

Tributary FCT-3 is comprised of the eastern portion of the railway ditch. This watercourse is separated into three reaches. FCT-3A and FCT-3B flow in a westerly direction, while FCT-3C is actually a separate tributary that flows in an easterly direction. FCT-3B and FCT-3C confluence at their respective downstream limits before turning south and flowing into a series of ponds in the Oaks of St George Golf Club. A long, linear pond is situated on the drainage divide separating Reach FCT-3C from Reach FCT-2E (Photo 37).

Photo 37: Linear pond on drainage divide. Pond outflows to both Reach FCT-2E and FCT-3C

4.6.1. Reach FCT-3A

Reach FCT-3A is a confined, over widened ditch with shallow bank angles and a gradual slope (0.3%). Flow is contributed to Reach FCT-3A from an artificial pond to the east (Photo 38) as well as tile drains from the north (Photo 39). The channel is perfectly straight, following the alignment of the former rail corridor. A considerable amount of large woody debris is present within the channel (Photo 40), and localized instances of bank erosion/exposed roots were noted (Photo 41), but, in general, well-established woody vegetation and trees are providing bank stability, and there is limited evidence of reach-scale channel widening. Bed material in Reach FCT-3A is composed primarily of alluvial silt, suggesting that aggradation is the dominant geomorphic process in this reach. One TORVANE measurement was taken on the channel bank. This reach terminates at a 0.2 m culvert (Photo 42).

Photo 38: Pond at upstream end of Reach FCT-3A

Photo 39: Tile drain outlet

Photo 40: Leaning trees, large woody debris

Photo 41: Straightened channel with localized erosion on right bank

Photo 42: Culvert at downstream end of ReachFCT-3A (looking downstream)

4.6.2. FCT-3B

Reach FCT-3B begins downstream of the 0.2 m culvert and flows west for a total length of 75 m to the confluence with Reach FCT-3C. This reach is steep (1.9%). The low-flow channel is straightened and appears to have been recently excavated within the broader valley, having bare, unvegetated banks exposed to erosive flows. One TORVANE measurement was taken on the excavated bank. It is anticipated that vegetation will eventually establish on the low-flow channel banks, but the steep bed slope, low width to depth ratio and exposed banks make Reach FCT-3B potentially sensitive to erosion. This was confirmed by 1D at-a-station hydraulic modelling, which indicates high bankfull hydraulic forces within the excavated channel (see Table 2 in Section 4.7).

Photo 43: Fallen trees, some woody vegetation

Photo 44: Excavated low-flow channel with exposed banks

4.6.3. FCT-3C

Reach FCT-3C flows in an easterly direction from the linear pond shown in Photo 37. This reach can be characterized as a steep (2.9%) ravine with no defined low-flow channel. Reach FCT-3C was dry on the date of the field assessment. Bed material is composed of topsoil and cobbles (Photo 46).

Reach FCT-3C is a separate tributary that confluences with FCT-3B. Downstream of the confluence, Reaches FCT-3B and FCT-3C flow through three parallel pipes/culverts (Photo 47) to a pond within the Oaks of St George Golf Club (Photo 48).

Photo 45: Outlet of linear pond at upstream end of Reach FCT-3C

Photo 46: Reach FCT-3C typical channel view (looking upstream)

Photo 47: Outlet of three parallel pipes connecting Reaches FCT-3B and FCT-3C to downstream pond

Photo 48: Pond downstream of Reaches FCT-3B and FCT-3C

4.7. Bankfull Hydraulic Summary

The *bankfull flow* refers to the flow when the water level becomes higher than the channel banks and begins to enter the overbanks. This corresponds to the maximum capacity of the low-flow channel and often corresponds to a local maximum of channel shear stress and velocity. Due to this association with peak hydraulic forces, bankfull flow is frequently associated with channel-forming processes and is an important indicator of erosional thresholds within the channel. The surveyed channel cross-sections and bed slopes were used to develop at-a-station models to assess the bankfull geometric and hydraulic characteristics. Reach-averaged bankfull parameters are provided in Table 2.

Table 2: Reach-Averaged Bankfull Channel Characteristics

Parameter	FCT-1A	FCT-1B	FCT-2A	FCT-2B	FCT-2C	FCT-2E	FCT-2F	FCT-3A	FCT-3B	FCT-3C
Cross-Sectional Area (m^2)	0.6	0.2	0.7	1.5	0.3	0.2	2.0	0.5	0.4	0.8
Top Width (m)	2.2	1.6	2.6	2.7	1.5	1.7	3.1	3.2	1.2	3.5
Mean Depth (m)	0.2	0.1	0.3	0.4	0.2	0.1	0.6	0.1	0.3	0.2
Max Depth (m)	0.3	0.2	0.4	0.7	0.5	0.2	0.8	0.2	0.4	0.4
Wetted Perimeter (m)	2.3	1.7	2.8	3.2	1.9	1.7	3.9	3.3	1.6	3.6
Hydraulic Radius (m)	0.2	0.1	0.3	0.4	0.2	0.1	0.5	0.1	0.2	0.2
Width:Depth	10.0	12.7	9.6	7.0	6.2	14.8	4.8	22.8	3.8	15.4
Velocity (m/s)	2.1	0.6	1.7	3.3	1.5	1.6	2.7	0.6	2.1	2.5
Discharge(m^3/s)	1.8	0.1	1.3	6.9	0.5	0.3	5.5	0.3	0.8	2.0
Froude Number	1.4	0.5	1.1	1.8	1.1	1.5	1.2	0.5	1.4	1.7
Channel Slope (%)	2.5	0.5	2.3	5.5	1.3	3.0	2.3	0.3	1.9	2.9
Shear Stress (N/m^2)	50.8	6.0	57.8	200.7	23.2	32.4	113.5	4.1	44.1	62.6
Shear Velocity (m/s)	0.2	0.1	0.2	0.4	0.2	0.2	0.3	0.1	0.2	0.3
Unit Stream Power (Watts/m^2)	155.7	4.0	114.0	1002.8	43.0	53.0	397.0	2.5	126.0	160.0

5. Erosion Threshold Assessment

An erosion threshold is the maximum value of a hydraulic parameter (typically velocity or shear stress) that a channel can sustain without eroding. The erosion threshold is determined based on the channel's bed and bank material properties, the channel geometry, and the hydraulic conditions. Erosion thresholds provide an understanding of resiliency, describing the channel's inherent ability to absorb changes to the flow and/or sediment regime while maintaining form and function. The thresholds provide guidance and targets for any proposed changes to the flow regime (e.g., due to urbanization). If properly managed, additional flow inputs from stormwater management practices should not generate excess erosion relative to the existing flow regime, ideally beyond a condition representative of the stable channel morphology.

The watercourses in this study are semi-alluvial, having fine-to-coarse-grained alluvial bed material over the clay, with clay/till channel banks. Bankfull flows could mobilize this coarse sediment and deposit it further downstream. With sufficient entrainment of the surficial alluvial material, the underlying native silt, clay and till soils may be exposed. Subsequent erosion of the underlying soil would result in a permanent change to the channel morphology. Channel bed stability is therefore governed by both the overlying alluvium and the underlying soils, while bank stability is governed by the resiliency of the native soil. This approach does not consider the increased bank stability created by vegetation rooting, which is present within the channel and in riparian areas throughout some of the reaches.

5.1. Cohesive Material Erosion Thresholds

Characteristics pertaining to the erodibility of cohesive material (e.g., critical shear stress) are known to have considerable variability, even at the local scale, sometimes spanning multiple orders of magnitude (Hanson and Simon, 2001; Shugar et al., 2007). For this reason, it is necessary to investigate different data sources and incorporate a range of uncertainty into the analysis and results. Literature-based estimates are widely used for estimating erosion thresholds in cohesive material. While these estimates implicitly include some of the variability associated with local fluctuations in velocity, shear stress, and material properties, they must be used with caution and should be related to site-specific characteristics, wherever possible. Therefore, a literature-based approach was taken for this project, using common erosion thresholds empirically derived from field and laboratory testing, which was then supported by the field measurements.

The cohesive material in the tributaries was characterized as firm loam and alluvial silt. This characterization is based on visual observation and corresponds to the surficial geology mapping. Laboratory material analysis and characterization were not undertaken as part of this assessment.

To determine erosion thresholds, the critical velocity and shear stress for the channel materials were established. The critical velocity and shear stress are threshold hydraulic values that are predicted to cause the material in the channel to erode. Critical hydraulic shear stress for cohesive sediments can vary considerably, with reported values in literature ranging in multiple orders of magnitude (Briaud, 2008). The duration of erosion exceedance is another important factor to consider, as it has been shown that erosion thresholds for cohesive soil decrease with increasing duration of competent flows (Figure 3).

In reviewing the literature for loam and alluvial silt, Briaud (2008) provides a range for the critical shear stress (referred to as τ_c or τ_{ci}) between ~1-10 Pa for low plasticity clays, and Fischenich (2001) reports a value of 3.6 Pa value for firm loam and 12.4 Pa for alluvial colloidal silt. In situ shear stress measurements taken on the channel banks indicate that the critical shear stress of the cohesive material is between 7 - 69 Pa.

Critical velocity thresholds (referred to as V_c in the literature) were identified to be 0.8 for firm loams and 1.1 m/s for stiff clay and alluvial silt (Fischenich, 2001). In reviewing literature that considers the flow duration, the average critical velocity for bare clay can range between 0.6 and 1.8 m/s (Fischenich and Allen, 2000). A summary of the critical shear stress and velocity thresholds are summarized in Table 3.

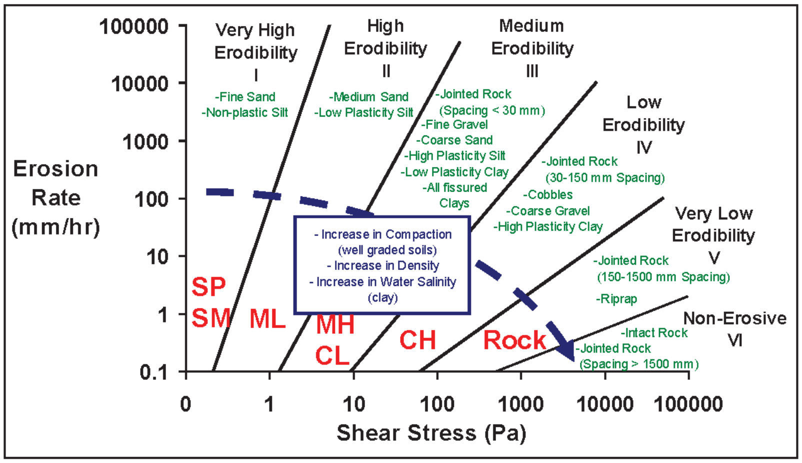

Figure 2: Critical shear stress for various materials (Briaud, 2008)

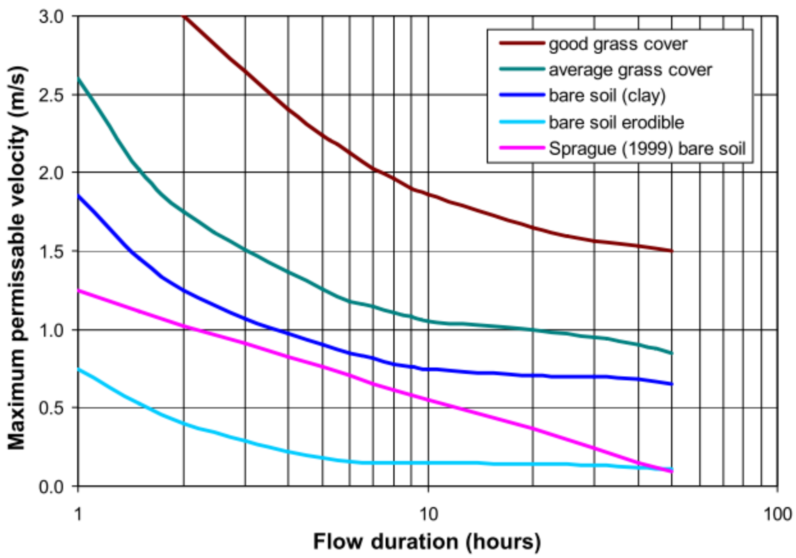

Figure 3: Flow duration curve. Source: Fluvial Systems Pty Ltd. (Adapted from Fischenich and Allen (2000))

Table 3: Critical shear stress and velocity for observed cohesive sediment.

Source	Material Classification	Critical Shear Stress τ_c or τ_{ci} (Pa)	Critical Velocity V_c (m/s)
Briaud, 2008	Low plasticity clay	1-10	NA
Fischenich, 2001	Firm Loam	3.6	0.8
	Alluvial silt (colloidal)	12.4	1.1
Fischenich and Allen, 2000	Bare clay	NA	0.6-1.8
In-Situ Testing (TORVANE® measurements)	Loam to stiff clay	7 - 69	NA

Table 4: Summary of Torvane critical shear stress measurements (all measurements taken on exposed channel bank)

Reach	Number of Measurements	Range (Pa)	Average (Pa)
FCT-1B	3	7 – 19	13
FCT-2A	3	22 – 27	24
FCT-2B	3	46 – 69	60
FCT-2F	3	18 - 27	22
FCT-3A	4	13 - 38	24
FCT-3B	3	25 - 37	31

5.2. Coarse-Grained Substrate Erosion Threshold

Erosion thresholds for coarse grained material are calculated by determining the forces required to initiate incipient motion; this corresponds to the lowest flow required to start the movement of the coarse-grained material. To complete these assessments, it is necessary to have an understanding of the size of the granular material in the channel, as this is the primary factor that controls the stability and movement of an individual pebble. We completed two Wolman Pebble Counts (Wolman, 1954) to characterize the grain size distribution of the coarse substrate in Reaches FCT-1A and FCT-2A. Measured grain size distributions are presented in Table 5.

Table 5: Grain size distributions of coarse-grained substrate

Percentile of Distribution	Grain Size (mm)	
	Reach FCT-1A	Reach FCT-2B
D_{16}	0.19	0.06
D_{35}	0.81	0.17
D_{50}	1.55	2.52
D_{65}	2.55	48.28
D_{84}	5.24	94.8
D_{95}	13.77	121.95

Erosion thresholds of the bed material were then established using the grain size distributions. A tractive force approach was used to predict the shear stress and velocity that correspond to the initiation of incipient motion for the observed sediment distribution (i.e., the *critical shear stress* and the *critical velocity)*. Critical shear stresses were estimated using both a modified Shields equation (Julien, 1995) and the size-selective approach of Komar (1987). These approaches are based on different theories of sediment transport, with the Shields equation assuming grain size independence (i.e., not considering influences of a sediment mixture of multiple grain sizes) and the Komar approach considering interactions between different grain sizes in a mixture. Komar (1987) also provides a method of estimating the critical velocity for a given grain size:

$$v_c = \left[\frac{d_s}{0.03394}\right]^{\frac{1}{2.1739}}$$

Where: d_s = diameter of a particle at incipient motion (m)

v_c = velocity (m/s).

Critical shear stresses and velocities corresponding to the D_{50} and D_{84} grain sizes were calculated using the methods described above. The D_{50} and D_{84} particles were selected to be representative of moderately large bed material particles. Entrainment of these particles by a competent flow could result in a significant morphological adjustment of the channel. A range of threshold values (of varying degrees of conservatism) can be established depending on whether the D_{50} or D_{84} particles are used. Table 6 provides a summary of the calculated critical values.

Table 6: Critical shear stress and velocity for coarse-grained substrate

Reach	Particle Size (mm)		Critical Shear Stress: τ_c (Julien, 1995) (Pa)		Critical Shear Stress: τ_{ci} (Komar, 1987) (Pa)		Critical Velocity: V_c (Komar, 1987) (m/s)	
	D_{50}	D_{84}	D_{50}	D_{84}	D_{50}	D_{84}	D_{50}	D_{84}
FCT-1A	1.55	5.24	0.82	3.57	1.52	2.48	0.24	0.42
FCT-2A	2.52	94.80	1.59	80.05	10.80	46.10	0.30	1.60

5.3. Governing Erosion Thresholds and Critical Discharge

Using all the analysis and data reviewed in Sections 5.1 and 5.2, governing erosion thresholds were determined. The governing erosion thresholds take into consideration the most vulnerable areas, the stability of the bed and bank material, and the range of resilience to erosion. The governing erosion thresholds used in the assessment are provided in Table 7.

Table 7: Governing erosion thresholds

Material	Parameter	Units	FCT-1A	FCT-1B	FCT-2A	FCT-2B	FCT-2C	FCT-2E	FCT-2F	FCT-3A	FCT-3B
Firm Loam	Shear Stress	Pa	3.6(1)	3.6(1)	3.6(1)	3.6(1)	3.6(1)	3.6(1)	3.6(1)	3.6(1)	3.6(1)
	Velocity	m/s	0.8(1)	0.8(1)	0.8(1)	0.8(1)	0.8(1)	0.8(1)	0.8(1)	0.8(1)	0.8(1)
Alluvial Silt (Colloidal)	Shear Stress	Pa	12.4(2)	12.4(2)	12.4(2)	12.4(2)	12.4(2)	12.4(2)	12.4(2)	12.4(2)	12.4(2)
	Velocity	m/s	1.1(2)	1.1(2)	1.1(2)	1.1(2)	1.1(2)	1.1(2)	1.1(2)	1.1(2)	1.1(2)
D_{84}	Shear Stress	Pa	2.48(3)	N/A	N/A	46.1(3)	N/A	N/A	N/A	N/A	N/A
	Velocity	m/s	0.42(3)	N/A	N/A	1.6(3)	N/A	N/A	N/A	N/A	N/A

Source References:
1. "Firm loam" value from Fischenich, 2001
2. "Alluvial silt (colloidal)" value from Fischenich, 2001
3. "Field measured grain sizes used as inputs to the Komar, 1987 equation

For the coarse material (i.e., D_{84} in Table 7), the governing shear stress and velocity thresholds were taken from the Komar equation because it considers relative particle motion within the entire grain-size mixture (it also provides a more conservative estimate for the D_{84} shear stress thresholds).

Using the surveyed channel geometry and bed slope, a 1D at-a-station hydraulic assessment was undertaken to identify the critical discharges at which the thresholds in Table 7 were exceeded on both the channel bed and channel bank. Table 8 lists the minimum, median and maximum critical discharge for each reach calculated using this approach, and Figure 4 graphically shows the results. Table 9 lists the governing critical discharge in each watercourse. At certain cross-sections, the calculated critical discharge exceeded the total discharge of the surveyed cross-section. In these instances, it was assumed that the total floodplain width was restricted to the width of the surveyed cross-section by means of a vertical wall at the cross-section extents. This represents a conservative assumption with respect to calculated critical discharges, since this approach will tend to underestimate the discharge at which a given velocity or shear stress occurs.

Table 8: Critical thresholds and discharge for all material types within Tributary 201.

Critical Discharge (L/s)	FCT-1A	FCT-1B	FCT-2A	FCT-2B	FCT-2C	FCT-2E	FCT-2F	FCT-3A	FCT-3B
Minimum	0.2	33.1	1.2	0.1	3.1	2.5	9.8	205.9	3.4
Median	31.6	436.8	85.4	50.8	48.2	41.1	141.0	1142.7	44.9
Maximum	679.9	1082.9	464.2	333.3	244.6	95.3	351.6	3929.0	95.8

Table 9: Governing critical discharges by watercourse

Tributary	Governing Reach	Critical Discharge (L/s)		
		Minimum	Median	Maximum
FCT-1	FCT-1A	0.2	31.6	679.9
FCT-2	FCT-2B*	0.1	50.8	333.3
FCT-3	FCT-3B	3.4	44.9	95.8

*Reach FCT-2C is excluded from table because erosion in this reach is not a concern (see Section 4.5.3). Reaches FCT-2D and FCT-2E excluded because they are downstream of a significant confluence

The critical discharges reported in Tables 8 and 9 indicate that all three watercourses are sensitive to erosion at low flows. Tributary FCT-1 has low critical discharges due to its steep gradient, high energy setting and the lack of coarse bed material (i.e., cobble-sized) in the system. Tributary FCT-2 has a wider range of critical discharges than FCT-1 due to the very steep bed slope and wide range of material in the system (ranging from silt to cobbles), but the values converge at less than 100 L/s. In general, Reach FCT-2 was observed in the field to be unstable and actively eroding, corroborating the erosion modelling. The critical discharges in Tributary FCT-3 are very high in the upstream reach (FCT-3A) but Reach FCT-3B has critical discharges similar to that of FCTD-2B. This is due to the steepness of Reach FCT-3B as well as the fact that a low-flow channel has been excavated through the reach. The low-flow channel has banks consisting of bare exposed soil and has a low width to depth ratio with a relatively high bankfull discharge of 0.8 m^3/s, resulting in the potential for frequent erosive flows with a high velocity and flow depth.

It is noted that the results presented above are preliminary at this time. No flow data has been reviewed as part of this assessment at this time, and it will be necessary to corroborate these results. This part of the assessment will be completed with the erosion exceedance analysis.

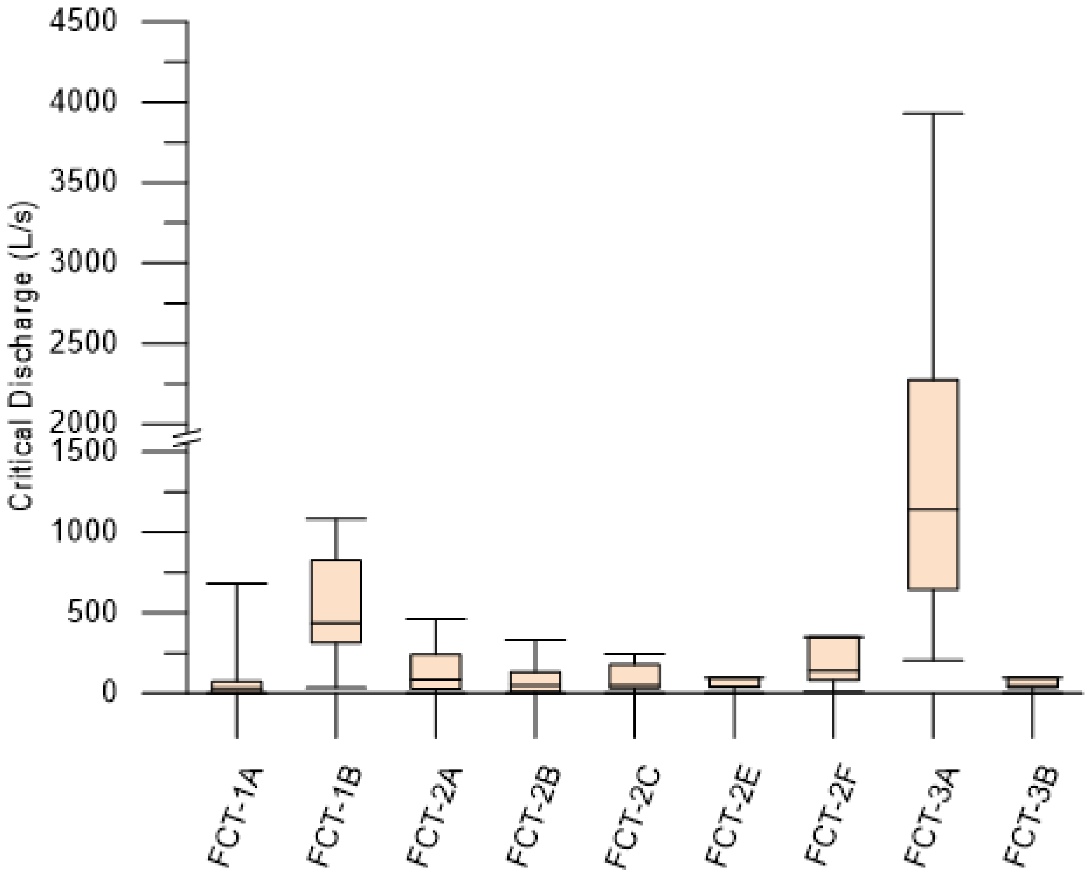

Figure 4: Box-and-whisker plot showing minimum, median, maximum and interquartile range of critical discharges for each reach.

6. Conclusions and Recommendations

Key conclusions of the study are as follows:

- All three tributaries have low critical discharge values due to the presence of steep (>=1.5% slope) reaches in each tributary.
- Tributary FCT-2 was identified in the field to be actively eroding. It is anticipated that this tributary has limited resiliency to absorb additional flows.
- Tributary FCT-3 is generally stable, with very high critical discharge values in the range of 1-4 m^3/s, but, due to a short, steep excavated channel (FCT-3B) at the downstream end, the governing critical discharge values for the reach are similar to that of FCT-1 and FCT-2.

7. Limitations

The field investigation and assessments were limited to those lands for which we received permission to enter. A diligent effort was made to contact residents and inspect all lands, and the data collected is expected to be representative of the receiving watercourses.

The results from the in-situ shear strength measurement can be subjective due to operator bias. To limit this bias, the same operator completed all the measurements. However, due to the inherent variability of the instrument, these results were not directly used to determine the erosion thresholds and critical discharges. Rather, they were used to complement and help validate the literature-based threshold selections.

8. Closing

An erosion threshold study was conducted on three tributaries of Fairchild Creek within the town of Saint George. The objective of this study was to estimate erosion thresholds to inform the design of the stormwater management system. Field investigations and desktop assessments were undertaken to establish critical thresholds and discharges. These values will be used to complete an erosion exceedance analysis that will assess the erosion potential associated with the proposed stormwater management plan.

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St. George Industrial Development
Erosion Threshold Assessment (DRAFT)

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