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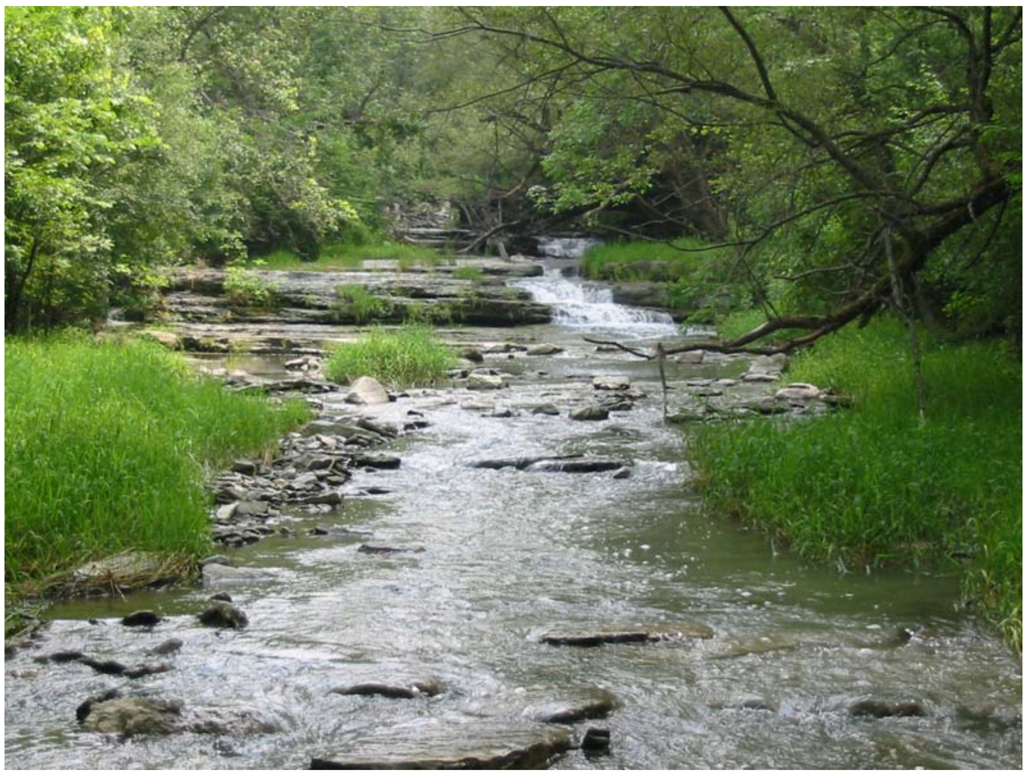
CARDINAL CREEK

GEOMORPHIC ASSESSMENT
CITY OF OTTAWA



April 2007
06300.450

EXECUTIVE SUMMARY

The overall aim of the study was to develop an understanding of the geomorphology of the watercourses within the Cardinal Creek watershed (RV34) and the adjacent Ottawa 1 subwatershed (RV35). This study provides support to future subwatershed studies by assessing stream health and sensitivity, and identifying systematic adjustments and areas of potential concern with regard to degradation and hazard.

The study was approached in two phases – preliminary assessment and detailed assessment. The preliminary assessment included a review of previous reports to provide background on the local geomorphology and controlling factors (i.e., hydrology and geology). Watercourses were then identified, and reaches were delineated including an historical evaluation of reach change over time. The field component of the preliminary assessment included rapid field evaluations (i.e., Rapid Geomorphic Assessment, Rapid Stream Assessment Technique) of each reach and identification of those with the greatest sensitivity.

The results of the RGA and RSAT assessments indicated that most of the reaches within the lower sections of the Cardinal Creek subwatershed are in transition. The headwaters of RV35 are in regime while the downstream reaches are in transition. The limited land use changes over the past one hundred years and local geology (i.e., silt and clay deposits) likely makes many of the reaches reasonably resilient to erosion. Those reaches showing the greatest adjustment are generally flowing through areas with increased gradients.

Overall the channels were relatively ‘healthy’ and reasonable stable, this condition is a product of the limited loss of headwater channels. The main issues with regards to stability and ‘health’ are associated with the loss of riparian vegetation, and straightening and ditching of headwater channels to facilitate drainage. The prominence of drains, along with urbanization downstream are likely the cause of the observed adjustment of the reaches along the main branch of Cardinal Creek. Steep gradients and valley wall contact are the likely cause of the observed adjustment along RV35.

The detailed assessment phase involved the application of detailed geomorphic measurements to the sensitive indicator reaches identified during the preliminary assessment. These reaches were used to quantify erosion thresholds to provide acceptable limits that should prevent an increase in channel erosion and deposition beyond natural rates. The exercise suggested that the watershed would be sensitive to changes in flow regime even for low magnitude flow events, such as those below the two-year return. These results can then be applied to assist with development of suitable stormwater management.

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1.0 INTRODUCTION

1.1 OBJECTIVE

The overall aim of the study is to develop an understanding and geomorphic assessment of the watercourses within the Cardinal Creek watershed (RV34) and the adjacent Ottawa 1 subwatershed (RV35). This study will provide support to future subwatershed studies by assessing stream health and sensitivity, and identifying systematic adjustments and areas of potential concern with regard to degradation and hazard.

Characterizing channel form and function is important in subwatershed planning as it allows stream corridor management plans to be developed that consider natural processes and systematic adjustments within the subwatershed. Stream corridors also provide important natural linkages within the subwatershed. Before management plans can be developed there needs to be an understanding of historic context, drainage pattern and density, reach characteristics, current conditions and issues with respect to erosion and sedimentation. These topics are discussed throughout this report.

In characterizing the form and function of channels within Cardinal Creek both desktop and field components were completed. It was endeavored to assess the subwatershed at a series of scales both temporally and spatially. Observations of changes over time were completed through a systematic assessment of historic aerial photographs. Field observations, which highlighted systematic adjustment, also provide a view of past and future trends. A range of spatial scales was examined, moving from a basin to sub-reach scale.

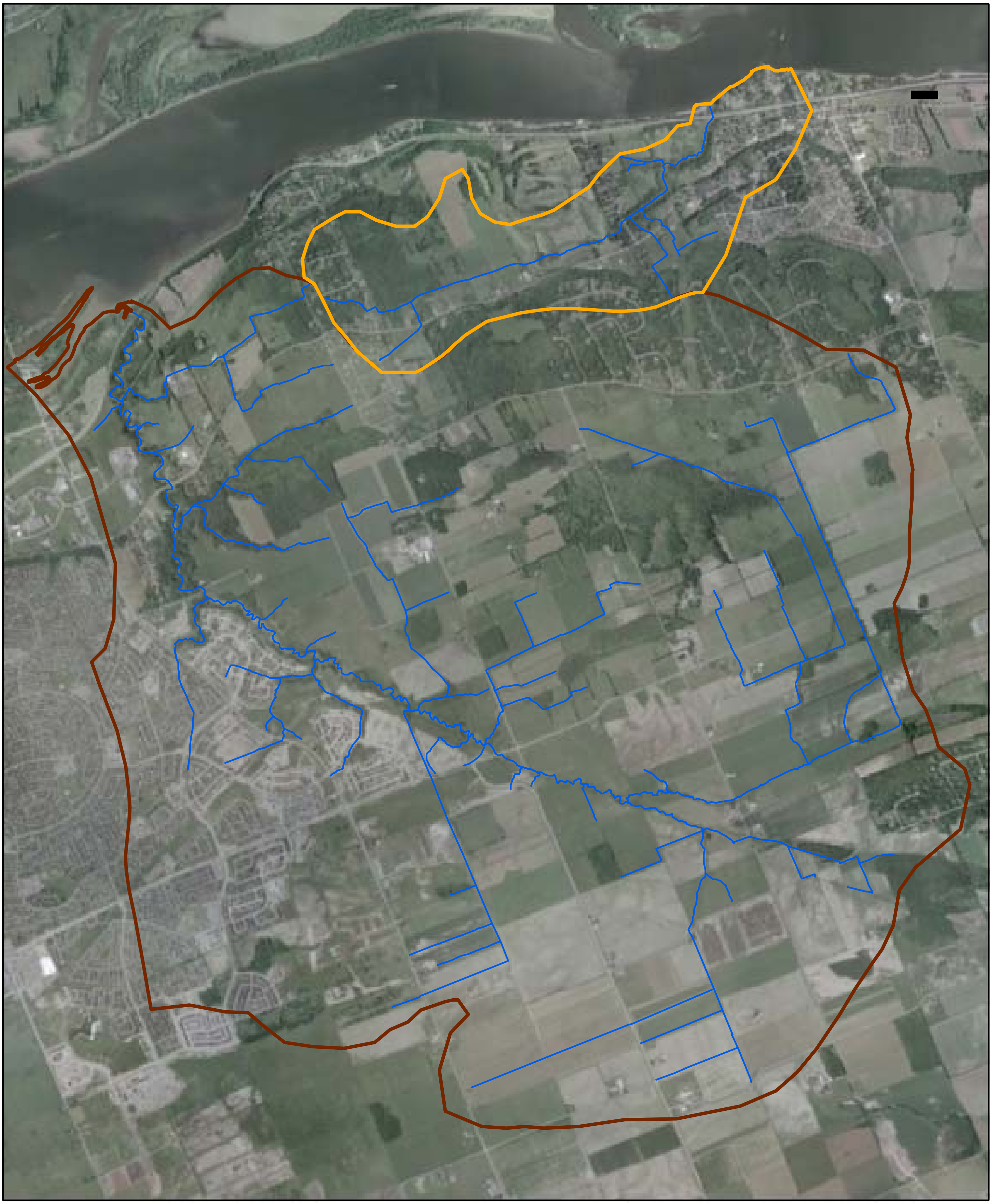
In context of the provincial framework for stream corridor management (MNR and WSC, 2002), this report provides data needed to identify issues, explore past and future trends, channel response, present subwatershed function and forecast the ultimate subwatershed and stream corridor configuration. This provides the information needed to evaluate the feasibility of restoration alternatives and allows options to be defined and assessed. It also provides baseline data for monitoring, a fundamental component of adaptive management.

Stream morphology was characterized to:

- Identify existing and potential constraints and opportunities related to channel form and function.
- Identify systematic adjustments to help identify instability related to land use impacts. Establishment of these baseline conditions is essential for future monitoring efforts that assess the effectiveness of prescriptions implemented as a result of any future subwatershed study.
- Identify links in physical processes that are responsible for existing channel form, to enable identification of links with other subwatershed elements (e.g. riparian conditions, groundwater, fisheries, etc.).

1.2 STUDY AREA

Cardinal Creek flows in a north westerly direction into the Ottawa River (**Figure 1**). The headwater area is approximately bordered by Old Montreal Road to the north, Dunning Road to the east, Trim Road to the west and Regimbald Road to the south. The land use in the headwaters is predominantly agricultural and this activity has resulted in extensive networks of linear agricultural drains that form the upper portion of Cardinal Creek. As Cardinal Creek flows towards the Ottawa River it is becomes bordered by residential development and the creek forms the eastern limit of urban development within the City of Ottawa.



Cardinal Creek and RV 35 Geomorphic Assessment

Study Area

Legend

- Stream Network
- RV35 Subwatershed
- Cardinal Creek Subwatershed

Aerial Photography - City of Ottawa: 2005

Date: March 2007
Project: 06300.450
Drawn By: B.W., W.B.
Figure 1

1.3 BACKGROUND DOCUMENTATION

To initiate the study, a background review was completed using existing reports, historic aerial photographs, topographic mapping and available geology maps. In particular, the following materials were reviewed:

Reports

Golder Associates Ltd. and Speltech Inc. June, 1991. Geotechnical Evaluation: Cardinal Creek Karst Area, Watters Road, Township of Cumberland, Ontario. Prepared for: Cloverhurst Co-Tenancy c/o Tamarack Developments Corporation.

> This report provided background information on the Cardinal Creek Karst Area. Information was obtained from the report regarding soil characteristics, quaternary and surficial geology.

McNeely Engineering Consultants Limited. December, 1992. Master Drainage Plan Township of Cumberland East Urban Community Expansion Area.

> This report provided stormwater management guidelines for the Township of Cumberland Expansion Area. Information was obtained from the report regarding fish species, water quality and general subwatershed conditions.

Rideau Valley Conservation Authority. 2003. City Stream Watch 2003 Annual Report

> As part of the City of Ottawa's Stream Watch Program, Cardinal Creek was evaluated by volunteers, providing preliminary information regarding adjacent land use patterns, riparian conditions, bank stability, bank vegetation, in-stream vegetation, fish and wildlife observations, agriculture impacts, and garbage and pollution.

Aerial Photographs

Historic aerial photographs (black and white: years 1926, 1945 and 1960) were acquired from the National Air Photo Library. Historic aerial photographs (colour digital: years 1976 and 2005) were provided by the City of Ottawa.

Geospatial Data

The City of Ottawa provided topographic data (0.5 m contour interval), watershed delineation, stream layer, surficial geology and other natural environment geospatial data. Ontario Base Mapping was used to supplement the topographic data (5 m contour interval).

2.0 EXISTING GEOMORPHIC SETTING

2.1 SURFICIAL GEOLOGY

Geology is one of the dominant factors that govern channel evolution. Channel form, in turn, is a product of flow regime and the availability and type of sediments within the stream corridor. The dynamic equilibrium of these inputs dictates channel form.

More specifically, surficial geology influences the rate of channel change (e.g. migration), sediment input (i.e. amount and type), and channel geometry. It also impacts hydrology by influencing topography and permeability. The majority of the Cardinal Creek watershed is comprised of lacustrine sediments (silt and clay), with outcrops of fractured bedrock in proximity to the Ottawa River (Chapman and Putnam, 1984). These surficial materials tend to create a dendritic flow pattern with numerous low order channels. The bedrock and cohesive sediments provide significant resistance to erosion. These factors are influenced by land use, physiography and riparian vegetation.

The following section provides an analysis of the basin wide physiography, the drainage network, and historical land use and cover, which, in turn, provides insight into the influencing factors shaping channel form.

2.2 DRAINAGE NETWORK

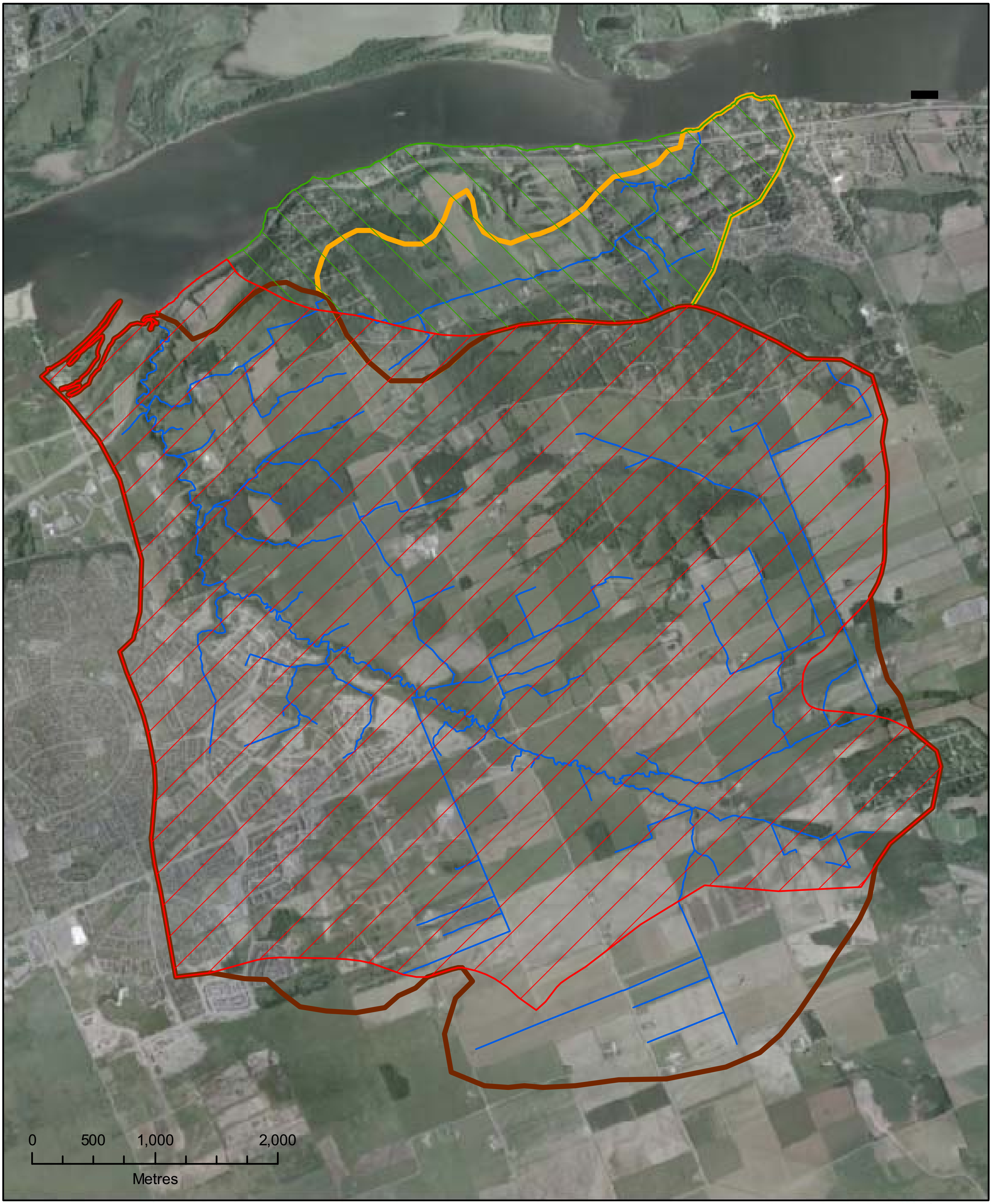
A review of the contributing drainage areas was undertaken due to the presence of agricultural activity within the watershed that may have caused local alterations. In addition, the review was used to refine the catchment boundaries based on recent topographic information. Using 1:10,000 scale Ontario Base Mapping and 1:2000 scale topographic mapping provided by the City of Ottawa, the existing drainage area delineation was reviewed with a focus on three areas:

- The south watershed boundary;
- The east watershed limit; and
- The boundary between RV35 and Cardinal Creek watershed.

The south and east watershed limits were modified for the inclusion of approximately 2.6 km^2 being captured by agricultural surface drains with consideration for topographic relief (**Figure 2**). The largest component of this was the incorporation of a 2.0 km^2 area being drained by a surface drainage network that was field verified as being connected to the Cardinal Creek drainage system.

The north boundary of RV35 was refined such that approximately 2.0 km^2 of area going directly to Ottawa River was removed while ~0.3 km^2 was added from the Cardinal Creek watershed due to capture by agricultural tile drains. Note that ~0.3 km^2 drainage area was also removed from the north limit of Cardinal Creek during the drainage area review to account for direct drainage to the Ottawa River. The resultant drainage areas are presented in **Table 1**.

The overall drainage area calculated for Cardinal Creek was 30.9 km^2 (**Table 1**). The basin level parameters measured for the subwatershed were drainage density and bifurcation ratio. Drainage density is a measure of total stream length divided by the area of the catchment basin. The overall drainage density for Cardinal Creek is 2.18 km/km^2. This value is higher compared to values reported for other eastern Ontario watersheds. For example, a drainage density of 1.39 km/km^2 was reported for Bilberry Creek (Geomorphic Solutions, 2007). The drainage density for Cardinal Creek is indicative of the high number of low order



Cardinal Creek and RV 35 Geomorphic Assessment

Previous and Revised Subwatershed Boundaries

Legend

- Stream Network
- Cardinal Creek - Previous Subwatershed
- RV35 - Previous Subwatershed
- Cardinal Creek - Revised Subwatershed
- RV35 - Revised Subwatershed

Aerial Photography - City of Ottawa: 2005

Date: March 2007
Project: 06300.450
Drawn By: B.W., W.B.
Figure 2

channels, which is a product of the low permeability of the underlying geology. The overall drainage density for RV35 is 1.22 km/km^2 and is indicative of the linear drainage pattern and impacts of agricultural activities.

Bifurcation ratio is a measure of the relationship between the number of streams of different orders. Specifically, it indicates the proportion of small order streams relative to large order streams. The bifurcation ratio for Cardinal Creek is 3.90. This value is lower than what was reported for Bilberry Creek (4.75) (Geomorphic Solutions, 2007). This low value is indicative of numerous tributaries draining the subwatershed that are well branched and distributed. This value is indicative of the extent of the watercourses maintained on the tableland. This drainage network in comparison to an urbanized system would provide an event hydrograph with a relatively broad, gradual shape, with little peakedness during a storm event because water would be gradually delivered from the numerous tributaries to the main channel. The bifurcation ratio for RV35 is 2.50 and is indicative of the low number of tributaries.

The modification of drainage features within the watersheds occurred prior to historic aerial photography. This could have been modified by additional drainage, either by surface and/or subsurface drainage installation. Generally, agricultural practices move towards eliminating, combining or altering existing features. Therefore, the existing drainage network is likely somewhat representative of pre-agricultural conditions.

Within the Cardinal Creek watershed, agriculture represents approximately 57% of the total land use with rural, urban and wetland land use contributing 20%, 20% and 1%, respectively. In the RV35 watershed, land use is divided between rural (60%) and village (30%) (Kevin Cover, City of Ottawa, personal communication, March 9, 2007).

Table 1. Calculated basin relations for Cardinal Creek and RV35 subwatersheds and associated land uses.

	Drainage Area (km^2)	Total Channel Length (km)	Drainage Density (km/km^2)	Bifurcation Ratio
Cardinal Creek	30.92	67.25	2.18	3.90
RV35	5.51	6.91	1.22	2.50

2.3 HISTORICAL AERIAL PHOTOGRAPHS

Review and interpretation of historical aerial photographs provides important insight into the land use changes and processes, both natural and human induced, that influence watershed character. Documenting and understanding these changes provides a context within which current day geomorphological data and trends can be analyzed. Aerial photographs from 1926, 1945, 1960 and 2005 were examined, and the following observations were made:

Cardinal Creek

In 1926, the main branch of Cardinal Creek was largely intact, with only two major crossings occurring in the lower reaches; Old Montreal Road and the rail line. Both of these crossings remain today, although the rail line has been decommissioned. Highway 174 now crosses the main channel of the creek near the confluence with the Ottawa River, which resulted in the removal of a meander bend in the vicinity of the crossing.

At the mouth of Cardinal Creek, a large delta feature was observed in the 1945 aerial photographs. It was not present in the 1926 photographs, and may have originated as a delayed pulse of sediment from initial land clearing activities in the past. The presence of the delta feature in the 1945 photograph was also likely influenced by the season of the photography capturing fluctuations in water levels of the Ottawa River. The delta feature is not present in the recent series of aerial photographs, possibly as evidence of progressive erosion over time, or maintenance dredging activities that could be occurring in that area. During the period that the delta was present, it created an off-channel habitat area isolated from the remainder of the riverine system. Much of this off-channel habitat has now been lost.

From the mouth of the creek upstream to the old rail line, the riparian zone is forested, with agricultural activities occurring on the east and west sides of the riparian zone. This land use matrix in that area has remained consistent from 1926 until present, and the planform of the creek appears to have maintained its general character over time.

Between the rail line and Old Montreal Road, agricultural activities have predominated since 1926, encompassing the lands on both sides of the creek, with limited tree cover remaining. The channel characteristics in this area have varied considerably over time, from being in a wide braided form in the 1920's to being influenced by water impoundments in the 1940's.

South of Old Montreal Road, in the middle reaches of the subwatershed, agriculture predominated in 1926 as a land use adjacent to the creek. At that time, riparian forest cover was sparse and intermittent. Since then, forest cover has increased along the main channel within the valley, but agricultural land uses persist to the top of the valley slopes. Many of the tributaries and gullies observable in the 1945 photographs are devoid of natural vegetation.

As early as 1926, many of the tributaries that were not confined within gully systems were re-aligned to follow agricultural field margins, and very little riparian cover was present. During the next 20 years, riparian cover increased along the re-aligned tributaries, in the form of hedgerows and regenerating forest cover. Overall, the proportion of forest cover to agriculture has remained consistent through the years.

RV35
From 1945 until present, the lower reaches of this watercourse have remained largely forested. In the upper reaches, agricultural land uses dominated, with limited riparian cover present. The riparian cover has not increased significantly, and land uses have adjusted to accommodate conversion of agriculture to golf course, and encroachment of residential areas in the headwaters.

2.4 REACH DELINEATION

To facilitate a systematic evaluation of the watercourses within the study area, drainage features were divided into reaches. Reaches are homogenous sections of channel with regard to form and function. As reaches are generally homogenous, these segments of channel can be expected to behave consistently along their length to changes in hydrology and sediment inputs, as well as modifying factors. Reach delineation considers channel form, function and valley setting in general, and sinuosity, gradient, hydrology, geology, confinement and vegetative control in particular (Montgomery *et al.,* 1997; Richards *et al.,* 1997; Parish Geomorphic, 2001). Reach analysis was completed utilizing historical aerial photographs, surficial geology mapping and field survey. Reaches are generally numbered from upstream to downstream to provide geographic context. In the upstream areas tributaries were grouped into nine subcatchments (labelled A-I). First order tributaries along the main branch of Cardinal Creek were given an alphabetical suffix (e.g., C3B) to indicate the adjacent larger reach. For RV35, reaches were labelled in order from upstream to downstream (Figure 3). Reach characteristics based on desktop assessment including channel length, gradient and sinuosity are provided in Table 2. OBM topographic mapping was used where there was no coverage by City of Ottawa data. As part of the field assessment reach breaks were field truthed and finalized.

Rapid field assessments were completed from July 18-21, 2006 and on October 20, 2006. Channel and riparian conditions were characterized during these initial assessments. Detailed description of the reach-by-reach assessments is provided in the following section. Within this section, a simple typology based on gross geomorphic form and hydrology is provided to set context. Table 2 provides planform characteristics and flow regime for each reach. The reaches are characterized based on Strahler stream order, flow regime, sinuosity, gradient, and channel type. Flow regime was classified as either ephemeral (seasonal flows) or perennial (flows that occur year-round), based on absence or presence of water on field visits. This classification could and should be better refined with future studies. The reaches found in the study area were further characterized based on simple form and dominant process. The categories were: watercourse (channel had well-defined bed and banks), swale (a vegetation controlled drainage feature lacking defined bed and banks), gully (steep channel with limited differentiation between valley and low flow channel, where both fluvial and slope processes were active), and intermittent (a watercourse which lacked continuous definition of bed and banks) (see Appendix A).

Table 2. General reach morphology and flow characteristics.

Reach	Stream Order*	Flow Regime	Sinuosity	Gradient (%)	Channel Type	Length (m)
RV35 Subwatershed						
1	1	Perennial	1.00	1.15	Defined	625
2	1	Ephemeral	1.07	0.21	Swale	725
3**	2	Perennial	1.00	Negligible	Defined	294
4	2	Perennial	1.00	0.23	Defined	462
5	2	Perennial	1.00	0.40	Defined	766
6	2	Perennial	1.04	2.18	Gully	276
7	2	Perennial	1.01	2.76	Gully	620
8	1	Perennial	1.00	3.88	Intermittent	865
9	1	Perennial	1.00	2.00	Intermittent	869
10	2	Ephemeral	1.01	2.91	Gully	311
11	1	Ephemeral	1.03	4.63	Gully	135
12	1	Ephemeral	1.02	5.53	Gully	195
13	3	Perennial	1.13	0.62	Defined	769
Cardinal Creek Subwatershed						
Tributary A						
TRA1**	1	Unknown	1.00	Not measurable from OBM	Unknown	435
TRA2**	1	Perennial	1.00	Not measurable from OBM	Intermittent	306
TRA3**	2	Perennial	1.00	Not measurable from OBM	Intermittent	1317
TRA4**	1	Ephemeral	1.00	Not measurable from OBM	Intermittent	397
Tributary B						
TRB1**	1	Unknown	1.00	Not measurable from OBM	Unknown	281
TRB2**	1	Unknown	1.00	Not measurable from OBM	Unknown	667
TRB3**	2	Perennial	1.00	0.10	Defined	1788
TRB4**	1	Unknown	1.00	Not measurable from OBM	Unknown	672
TRB5**	1	Unknown	1.00	Not measurable from OBM	Unknown	1989
TRB6**	1	Perennial	1.01	Not measurable from OBM	Intermittent	308
Tributary C						
TRC1**	1	Unknown	1.00	0.27	Unknown	1476
TRC2**	1	Unknown	1.00	0.31	Unknown	544

Reach	Stream Order*	Flow Regime	Sinuosity	Gradient (%)	Channel Type	Length (m)
TRC3**	2	Perennial	1.01	0.39	Defined	3022
TRC4**	1	Unknown	1.01	Not measurable from OBM	Unknown	634
TRC5**	1	Ephemeral	1.01	0.29	Swale	642
TRC6**	1	Unknown	1.02	Not measurable from OBM	Unknown	227
TRC7**	2	Perennial	1.00	0.23	Defined	2579
TRC8**	1	Perennial	1.00	Not measurable from OBM	Defined	923
TRC9**	1	Perennial	1.00	Not measurable from OBM	Defined	1276
TRC10**	2	Perennial	1.01	Not measurable from OBM	Defined	906
TRC11**	3	Perennial	1.00	Not measurable from OBM	Defined	770
Tributary D						
TRD1**	1	Perennial	1.00	Not measurable from OBM	Defined	1136
TRD2**	1	Unknown	1.00	0.39	Unknown	542
TRD3**	2	Perennial	1.00	0.19	Defined	710
TRD4**	1	Perennial	1.01	0.21	Defined	493
TRD5**	1	Perennial	1.01	Not measurable from OBM	Defined	752
TRD6	2	Perennial	1.04	1.53	Gully	356
Tributary E						
TRE1**	1	Unknown	1.00	0.07	Unknown	1581
TRE2**	1	Unknown	1.00	0.3	Unknown	509
TRE3	2	Perennial	1.00	0.23	Defined	1719
TRE4**	1	Unknown	1.00	0.19	Unknown	672
TRE5**	1	Unknown	1.00	0.39	Unknown	208
TRE6	2	Perennial	1.00	1.00	Gully	232
Tributary F						
TRF1**	1	Perennial	1.01	Not measurable from OBM	Defined	962
TRF2**	1	Unknown	1.00	0.64	Unknown	125
TRF3**	2	Unknown	1.02	0.25	Unknown	1656
TRF4**	1	Ephemeral	1.00	0.18	Defined	364
TRF5**	1	Unknown	1.00	0.51	Unknown	334
TRF6	2	Perennial	1.01	0.96	Gully	266
Tributary G						
TRG1	1	Ephemeral	1.03	Not measurable from OBM	Intermittent	573
TRG2	1	Ephemeral	1.06	Not measurable from OBM	Intermittent	163
TRG3	1	Ephemeral	1.05	1.10	Intermittent	123
TRG4	2	Perennial	1.02	1.12	Intermittent	448
TRG5	Piped					
TRG6	2	Perennial	1.04	1.05	Gully	255
TRG7	1	Perennial	1.03	1.15	Gully	1098
TRG8	2	Perennial	1.64	Not measurable from OBM	Defined	112
Tributary H						
TRH1**	1	Unknown	1.02	1.55	Unknown	939

Reach	Stream Order*	Flow Regime	Sinuosity	Gradient (%)	Channel Type	Length (m)
TRH2**	1	Unknown	1.02	0.74	Unknown	790
TRH3**	2	Unknown	1.01	2.26	Unknown	827
TRH4**	1	Unknown	1.00	5.07	Unknown	361
TRH5**	1	Unknown	1.03	2.55	Unknown	1285
Tributary I						
TRI1	1	Perennial	1.01	4.86	Intermittent	1294
TRI2	1	Perennial	1.0	0.99	Intermittent	1000
TRI3	2	Perennial	1.01	0.74	Intermittent	376
TRI4	2	Perennial	1.01	4.00	Gully	699
Cardinal Creek						
C1	3	Perennial	1.12	Not measurable from OBM	Defined	831
C1A**	1	Unknown	1.02	Not measurable from OBM	Unknown	275
C2	3	Perennial	1.08	Not measurable from OBM	Defined	683
C2A**	1	Unknown	1.00	Not measurable from OBM	Unknown	811
C3	4	Perennial	1.29	Not measurable from OBM	Defined	1086
C3A	1	Unknown	1.00	Not measurable from OBM	Unknown	306
C3B	1	Ephemeral	1.06	Not measurable from OBM	Gully	142
C3C	1	Perennial	1.02	2.00	Gully	215
C4	4	Perennial	1.03	Not measurable from OBM	Defined	354
C5	4	Perennial	1.40	Not measurable from OBM	Defined	846
C5A	Piped					
C5B	Piped					
C5C	1	Ephemeral	1.01	2.69	Gully	170
C6	4	Perennial	1.36	0.03	Defined	1224
C7	4	Perennial	1.37	0.03	Defined	1422
C7A**	1	Unknown	1.01	1.35	Unknown	285
C7B	1	Ephemeral	1.03	3.19	Gully	274
C7C	Piped					
C7D	1	Perennial	1.02	1.96	Intermittent	590
C8***	4	Perennial	1.16	6.59***	Defined	410
C9	4	Perennial	1.39	1.38	Defined	399
C10	4	Perennial	1.29	0.28	Defined	532
C11	4	Perennial	1.39	0.47	Defined	1160
C11A	1	Perennial	1.00	3.82	Intermittent	400
C11B	1	Perennial	1.03	8.47	Gully	181
C11C	1	Perennial	1.01	5.53	Intermittent	278
C12	4	Perennial	1.31	0.54	Defined	1295

* Strahler, 1952
** No access
*** karst topography within reach C8

The largest channels, particularly those in defined valleys, have the most natural planform and the highest sinuosity. The lower order channels generally have low sinuosity, either due to historic changes associated with agriculture or due to being associated with gullies. Many of the small gullies are first order, have high gradients, short lengths, and limited drainage.

Cardinal Creek is dominated by headwater streams. Headwater streams are defined as first- and second-order streams and are typically short and drain relatively small areas. They tend to be production zones, feeding sediment to the downstream system. Flow within these channels can be perennial or ephemeral and they have narrow or sometimes unconfined channels (Leopold *et al.,* 1964). Low order streams determine the quality and quantity of water in higher order streams (Burt, 1992) and as much as 70% of water in large rivers is derived from first- to third-order streams (Vought *et al.,* 1995). These channels constitute a significant portion of total stream length within watersheds (Sidle *et al.,* 2000) and provide habitat for unique and diverse assemblages of aquatic animals (Dietrich and Anderson, 1995). The majority of the Cardinal Creek headwaters have been influenced by historic and ongoing agricultural activity. As a result, relatively long and straight first order streams dominate the subwatershed. Channelization alters flow paths, sedimentary processes and aquatic habitat (Waters, 1995). The removal of riparian vegetation reduces organic matter inputs and increases light penetration and water temperature (Watzin and McIntosh, 1999). Channelization decreases the drainage density, in turn, creating cumulative effects downstream that may include exacerbated rates of erosion and water quality issues.

Along the main branch of Cardinal Creek, the channel is sinuous with a relatively low gradient. There is limited pool-riffle morphology along the majority of the main branch. The channel is bordered primarily by vegetation and the channel is typically deep and narrow due to the dense and overhanging bank vegetation. The banks are relatively resistant to erosion due to high rooting density and cohesive materials.

Recent studies have shown that erosion resistance has a direct relationship with fine root density within stream banks (Wynn et al. 2004). It is postulated that root systems physically bind bank soils in place, and that root exudates increases soil cohesion chemically, thereby increasing soil critical shear stress values. Therefore, a higher density of fine roots within a stream bank should translate to increased erosion resistance. Herbaceous vegetation typically found in meadows produces a high density of fine roots compared to woody vegetation characteristic of forest cover. The higher root density produces greater critical shear stress values, but the bank reinforcement applies only to the extent of the rooting depth. Recent research has indicated that greater than 75% of the herbaceous root mass in meadows occurs in the upper 30 cm of the soil (Wynn et al. 2004). While woody vegetation tends to have a lower density of fine roots compared to herbaceous species, the rooting depth is greater, adding erosion resistance at the bank toe where hydraulic shear stress increases, and bank stability is more critical. Consequently, stream channels in meadows tend to have stable, steep banks in the upper bankfull area where fine root mass is most dense, and erosion resistance is likewise highest. Below the dense rooting area, undercutting is common, and the stream tends to widen at the base. For stream channels where bankfull depth exceeds the shallow, but high density rooting zone provided by herbaceous vegetation, woody riparian vegetation may be required for provision of long-term bank stability.

From a review of the City Stream Watch 2003 Annual Report (RVCA, 2003), there is a warmwater fish community present throughout Cardinal Creek. Based on field observations there are at least two natural features that could potentially limit fish migration within the main branch of Cardinal Creek. This includes the old mill site along Reach C11 where there is an outcrop of fractured bedrock and the karst area found at Watters Road (Reach C8).

Cardinal Creek and RV 35 Subwatersheds

Reach Delineation, Potential Barriers to Fish Passage, and Stormwater Pond Locations

Legend

- Potential Barrier to Fish Passage
- Stormwater Management Pond
- Reach Break
- Stream Network

Aerial Photography - City of Ottawa: 2005

GEOMORPHIC SOLUTIONS

Date: March 2007
Project: 06300.450
Drawn By: B.W., W.B.
Figure 3

3.0 EVALUATION OF EXISTING GEOMORPHIC CONDITIONS

3.1 PRELIMINARY FIELD ASSESSMENT

Channel classification systems are often applied during the reach delineation process. Channel classification systems provide a simple means of describing channel form or stage of evolution. From a management perspective, they are important for documenting existing channel conditions and setting management priorities, assisting in defining the end state for restoration projects, and providing information about management measures that are likely to be successful (Kondolf, 1995). Many classification schemes have been developed, and two were applied to Cardinal Creek, as described in the following paragraphs.

Under the Rosgen (1996) classification system, stream characteristics are organized into relatively homogeneous stream types based on the degree of entrenchment, gradient, width-to-depth ratio and sinuosity. Each type is then divided into six subcategories depending on the dominant bed and bank materials. Additional reference to the Rosgen approach can be found in Annable (1996). Figures 4 and 5 illustrate the basic elements of the classification system.

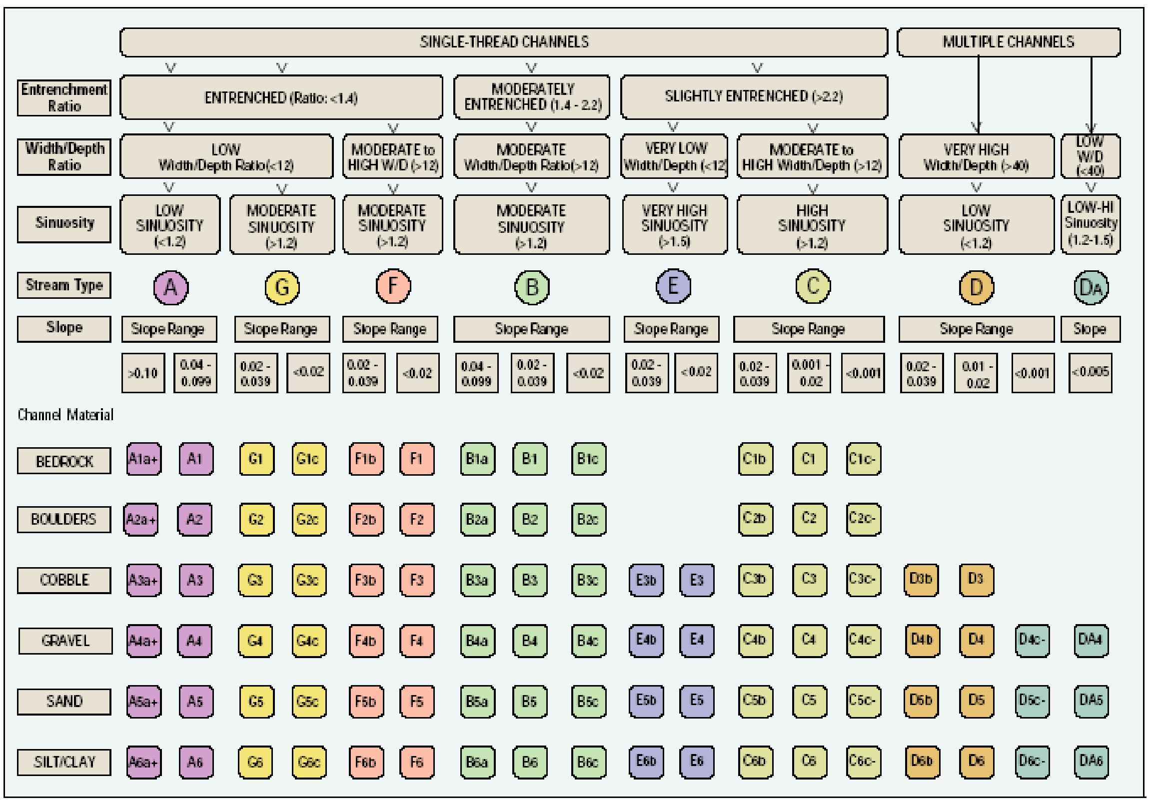


Figure 4. Rosgen's (1994) natural stream classification system (from U.S. EPA).

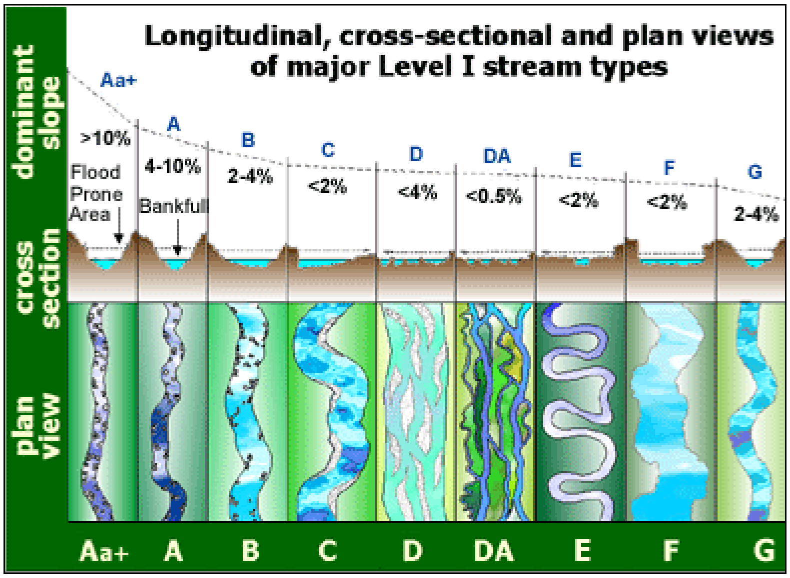


Figure 5. Longitudinal, cross-sectional and plan views of major stream types (Rosgen, 1994 – from U.S. EPA).

The Rosgen classification approach provides a common language for defining channel form and inferring channel process, and provides continuity between this and previous studies. Nevertheless, the Rosgen system is limited in its ability to classify channels that are undergoing adjustment and provides no information on systematic adjustment. Downs (1995) developed a classification scheme to account for trends and patterns of adjustment (Figure 6). Unlike classifications based on morphology, the Downs Evolution Model assesses the current nature morphology and the associated systematic adjustment and stage of evolution. These models need to be assessed in the context of historical changes and with the recognition that historic change may not be representative of future adjustments.

Channel adjustment types are based on the mode of adjustment and include the following: *stable, depositional, lateral migration, enlarging, compound, recovering* and *undercutting*. Application of this classification system requires the researcher to examine the field evidence and determine the predominant mode of adjustment. For example, *depositional* channels can be indicated by various factors including excessive bar development, coarse sediment being deposited over fines, and burying of infrastructure. *Enlarging* channels can be indicated by various factors including leaning trees, outflanked and undermined structures.

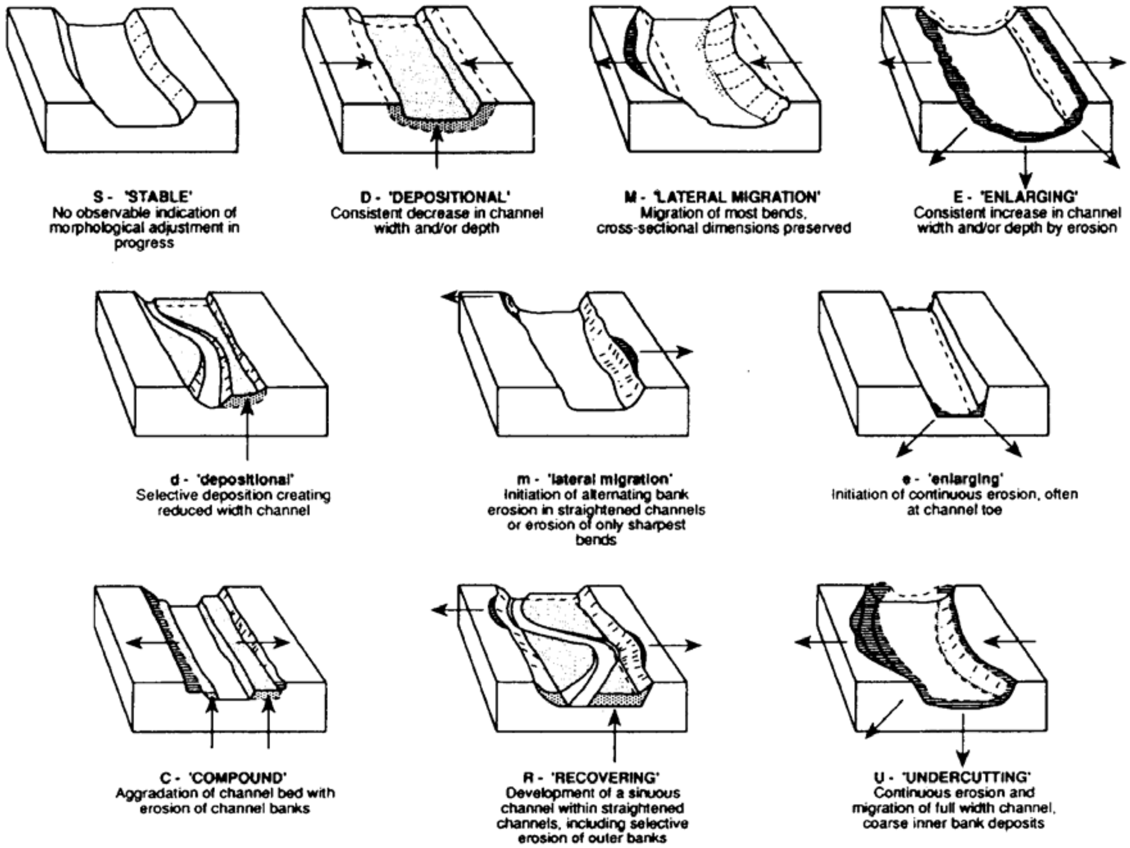


Figure 6. Channel classification based on trends and types of morphological change (Downs, 1995).

These typologies were combined with rapid assessment methods. A combination of the Rapid Geomorphic Assessment (RGA) (MOE, 2003) and Rapid Stream Assessment Technique (RSAT) (Galli, 1996) were used for this study.

Rapid assessments were designed for well-defined perennial watercourses. For each reach that met the classic definition of a defined watercourse, a Rapid Geomorphic Assessment (RGA) and Rapid Stream Assessment Technique (RSAT) was completed. The RGA documents observed indicators of channel instability (MOE, 2003), by quantifying observations using an index that identifies channel sensitivity based on evidence of aggradation, degradation, channel widening and planimetric form adjustment. The index produces values that indicate whether the channel is stable / in regime (score <0.20), stressed / transitional (score 0.21-0.40) or in adjustment (score >0.41). The RSAT provides a broader view of the system by also considering the ecological functioning of the stream (Galli, 1996). Observations are made of instream habitat, water quality, riparian conditions and biological indicators. Additionally, the RSAT approach includes semi-quantitative measures of bankfull channel dimensions, type of substrate, vegetative cover, and channel disturbance. RSAT scores are used to rank the channel as maintaining a low (<20), moderate (20-35) or high (>35) degree of stream health.

Field observations were collected from July 18-21, 2006 and October 20, 2006 to verify the desktop assessment, identify active geomorphological processes, and assess channel stability. During field reconnaissance, all reaches for which permission to access was granted, were surveyed. Evidence of active processes was noted and areas of active erosion identified.

A summary of existing conditions is provided in **Table 3.** Channels classified according to Rosgen (1996) and Downs (1995) are provided in **Table 4.** Summaries of the rapid assessments are also provided in **Table 4.** A photographic inventory was collected and is summarized in **Appendix B.** Photographs have been included to provide a detailed illustration of the present conditions of Cardinal Creek and RV35 watersheds from the headwaters to their confluence with the Ottawa River.

Table 3. General reach conditions.

Reach	Bankfull width(m)	Bankfull depth(m)	Substrate		Riparian vegetation	Notes
			Pool	Riffle		
RV35 Subwatershed						
1	2.0 - 2.5	0.2 - 0.3	Silty clay	Silty clay	Grasses; shrubs; trees	Wide, shallow channel; vegetation encroachment
2	N/A - No access					
3	N/A - No access					
4	2.5	00.4 - 0.5	Silty clay	Silty clay	Grasses	Imperceptible flow, cattle access, organic substrate, dense aquatic vegetation
5	1.5 - 2.0	0.3 - 0.4	Silt; clay	Silt; sand; gravel	Grasses; shrubs	Low bank angles; riparian vegetation – manicured lawn
6	3.0 - 4.0	0.3 - 0.4	Sand; gravel	Gravel; cobble	Forest	Undercuts of 10-20cm, bedrock exposed, wood debris and slumping at downstream extent
7	4.0 - 5.0	0.5 - 0.6	Silty clay	Gravel; cobble; small boulders	Forest	Valley wall contact and slumping, two waterfalls at upstream extent
8	1.0	0.3 - 0.4	Silty clay	Silty clay	Grasses; shrubs	Moderately steep gradient
9	1.0	0.3 - 0.4	Silty clay	Silty clay	Grasses; shrubs	Moderately steep gradient
10	1.5 – 2.0	0.5 – 0.6	Silty clay	Silty clay	Trees	Steep banks; scarcely perceptible flow
11	0.5	0.1	Silty clay	Silty clay	Trees and shrubs	Steep gradient; wood debris
12	1.0	0.1 – 0.2	Silty clay	Silty clay	Trees and shrubs	Steep gradient; evidence of erosion common
13	3.0 - 4.0	0.3 - 0.4	Silty clay	Gravel	Meadow	Sinuous channel with meadow and wet meadow vegetation
Cardinal Creek Subwatershed						
Tributary A						
TRA1	N/A - No access					
TRA2	N/A - No access					
TRA3	1.5 - 2.0	0.1 - 0.2	Silt; clay	Silt; clay	Grasses; trees; shrubs	Channel altered by agricultural activity, heavily encroached

Reach	Bankfull width(m)	Bankfull depth(m)	Substrate Pool	Riffle	Riparian vegetation	Notes
TRA4	0.5	0.1	Organics / muck	Organics / muck	Wetland vegetation	Vegetation encroachment
Tributary B						
TRB1	N/A - No access					
TRB2	N/A - No access					
TRB3	1.0 – 1.5	0.2	Silty clay	Silty clay	Grasses	Fairly entrenched
TRB4	N/A - No access					
TRB5	N/A - No access					
TRB6	1.0	0.1	Organics / muck	Organics / muck	Wetland vegetation / grasses	Fairly entrenched / steep banks
TRB7	N/A – No access					
Tributary C						
TRC1	N/A - No access					
TRC2	N/A - No access					
TRC3	1.0 – 1.5	0.3 – 0.4	Silty clay	Silty clay	Grasses	Good water quality
TRC4	N/A - No access					
TRC5	N/A – see notes		Silty clay	Silty clay	Active agriculture	No defined banks
TRC6	N/A - No access					
TRC7	1.5 – 2.0	0.2 – 0.3	Silty clay	Silty clay	Grasses	Vegetation encroachment
TRC8	1.5 – 2.0	0.2	Silty clay	Silty clay	Pasture	Impacts from cattle
TRC9	1.0 – 1.5	0.2	Silty clay	Silty clay	Pasture	Impacts from cattle
TRC10	N/A - No access					
TRC11	4.0 - 5.0	0.4 - 0.5	Silt; clay	Silt; clay	Grasses; trees	Extensive bank erosion, leaning trees with exposed roots
Tributary D						
TRD1	2.0 – 2.5	0.3 – 0.4	Silty clay	Silty clay	Grasses / trees	Vegetation encroachment
TRD2	N/A - No access					
TRD3	1.5 – 2.0	0.2 – 0.3	Silty clay	Silty clay	Grasses	Vegetation encroachment
TRD4	0.5	0.1	Silty clay	Silty clay	Grasses	Vegetation encroachment
TRD5	0.5 – 1.0	0.2	Silty clay	Silty clay	Grasses	Vegetation encroachment
TRD6	1.5	0.2 – 0.3	Silty clay	Silty clay	Trees	Steep gradient
Tributary E						
TRE1	N/A - No access					
TRE2	N/A - No access					
TRE3	0.5 – 1.0	0.1 – 0.2	Silty clay	Silty clay	Grasses	Extensive linear channel with limited morphology
TRE4	N/A - No access					
TRE5	N/A - No access					
TRE6	1.0	0.2 – 0.3	Organics / muck	Organics / muck	Trees	Low flow

Reach	Bankfull width(m)	Bankfull depth(m)	Substrate Pool	Substrate Riffle	Riparian vegetation	Notes
Tributary F						
TRF1	1.0 – 1.5	0.15	Organics / muck	Organics / muck	Wetland vegetation	Wetland vegetation encroachment
TRF2	N/A - No access					
TRF3	N/A - No access					
TRF4	1.0	0.1	Silty clay	Silty clay	Grasses	Defined ephemeral channel
TRF5	N/A - No access					
TRF6	1.5 – 2.5	0.3 – 0.5	Silty clay	Silty clay	Trees	Fresh deposits of silt / clays at meander bends
Tributary G						
TRG1	1.0	0.1 – 0.2	Silty clay	Silty clay	Wetland vegetation	Wetland vegetation encroachment
TRG2	0.5	0.1	Silty clay	Silty clay	Grasses	Vegetation encroachment
TRG3	0.5 – 1.0	0.1	Silty clay	Silty clay	Grasses	Small intermittent channel
TRG4	1.0 – 1.5	0.2 – 0.3	Silty clay	Silty clay	Grasses	Vegetation encroachment
TRG5	Piped					
TRG6	0.5 – 1.0	0.1 – 0.2	Silty clay	Silty clay	Trees	Wood debris
TRG7	1.0 – 1.5	0.2 – 0.3	Silty clay	Silty clay	Trees / grasses	Low flow; wood debris
TRG8	1.5	0.3 – 0.4	Silt; clay	Silt; clay	Grasses	Highly sinuous
Tributary H						
TRH1	N/A - No access					
TRH2	N/A - No access					
TRH3	N/A - No access					
TRH4	N/A - No access					
TRH5	N/A - No access					
Tributary I						
TRI1	1.0	0.1	Organics / muck	Organics / muck	Wetland vegetation	Intermittent channel
TRI2	1.5 – 2.0	0.3 – 0.4	Silt and organics	Silt and organics	Shrubs / grasses	Wetland vegetation encroachment
TRI3	1.0 – 1.5	0.2 – 0.3	Silty clay	Silty clay	Grasses	Vegetation encroachment
TRI4	1.5 – 2.0	04 – 0.5	Silty clay	Silty clay	Trees	Downcutting / bank erosion
Cardinal Creek						
C1	4.0 - 5.0	0.4 - 0.5	Silt; clay	Silt; clay	Grasses; trees	Extensive bank erosion, leaning trees with exposed roots
C1A	N/A - No access					
C2	N/A - No access					
C3	6.0 - 8.0	0.4 - 0.6	Silt; clay	Silt; clay	Meadow	Channel shows signs of previous alteration
C3A	0.5 – 1.0	0.1	Silty clay	Silty clay	Grasses	Vegetation encroachment

Reach	Bankfull width(m)	Bankfull depth(m)	Substrate Pool	Substrate Riffle	Riparian vegetation	Notes
C3B	1.0	0.25	Silty clay	Silty clay	Meadow / grasses	Ephemeral gully
C3C	1.5	0.3 – 0.4	Silty clay	Silty clay	Meadow / grasses	Substantial flow during rainfall event
C4	5.0 - 7.0	0.4 - 0.6	Silt; clay	Silt; clay	Grasses	Low velocity, good floodplain access
C5	5.0 - 7.0	0.5 - 0.7	Silt; gravel	Silt; gravel	Grasses; shrubs; trees	Good floodplain access
C5A	Piped					
C5B	Piped					
C5C	0.75 – 1.0	0.1 – 0.2	Silty clay	Silty clay	Grasses	Steep gradient; highly entrenched
C6	5.0 - 7.0	0.5 - 0.7	Silt; clay	Silt; gravel	Grasses; shrubs; trees	Highly entrenched
C7	5.0 - 9.0	0.5 - 0.6	Silt; clay	Silt; clay	Grasses; trees	Very wide floodplain, highly sinuous, silt deposition on inside bank
C7A	N/A - No access					
C7B	0.5	0.1	Silty clay	Silty clay	Meadow / grasses	Ephemeral gully
C7C	Piped					
C7D	1.0 – 2.0	0.1 – 0.2	Silty clay	Silty clay	Trees / grasses	Wide valley with low flow; vegetation encroachment
C8	N/A - No access					
C9	N/A - No access					
C10	4.0 - 5.0	0.4 - 0.5	Silt; clay	Silt; clay	Meadow	Good floodplain access
C11	6.0 - 8.0	0.4 - 0.7	Silt; clay; gravel	Gravel; cobble; clay balls	Grasses	Some valley wall contact at downstream extent
C11A	1.5	0.1 – 0.2	Silty clay	Silty clay	Trees / grasses	Intermittent channel flows through natural and agricultural land
C11B	1.0 – 1.5	0.3 – 0.4	Silty clay	Silty clay	Meadow / grasses / trees	Exposed marine deposits
C11C	0.5	0.1	Silty clay	Silty clay	Trees / grasses	Intermittent channel flows through natural and agricultural land
C12	12.0 - 15.0	1.0 - 1.5	Silt; clay	Silt; clay	Wetland	Very low grade

Meadow vegetation predominates adjacent to Cardinal Creek. This type of riparian cover affects channel form and function by influencing bank stability as well as providing allocthonous inputs of organic matter, and where the channel narrows, canopy cover. The substrate in the majority of the channel is a combination of silt and clay. These bed materials are native sediments but the cumulative impacts of agricultural practices likely cause some degree of sedimentation. However, sedimentation is not extensive as reflected in the RGA scores and Downs model.

The majority of headwater streams in the Cardinal Creek watershed have been altered by agricultural activity and converted to agricultural drains. As a result, most are vegetation-controlled and have limited definition. Although they lack channel morphology, they provide important retention and detention functions, in addition to providing source of organics for downstream reaches. Many of the ephemeral, intermittent and perennial watercourses that intersect the valley walls of the third and second order streams are gullies that provide and actively transport materials downstream. These gullied channels vary in size and flow regime but the volumes of water they transmit and their high gradient have produced distinct v-shaped valleys. During dry periods they are encroached by dense herb growth or obscured by forest litter. Unlike swales, gullies tend to be geomorphically unstable due to the steep gradients and relatively high energy available for potential erosion. These features should be retained due to their importance with regard to sediment transport. As many of the features fall within the existing top of slope, they can be retained by delineating the stable/existing top of slope and then providing an additional erosion setback to address the potential hazard. With regards to stormwater management, flows to the gullies should be maintained to these features at their pre-development levels. At minimum pre- to post-development flows should match the gullies erosion threshold, to maintain, but not exacerbate erosion.

Rapid geomorphic assessments were not a suitable tool for most of the low order streams. Where assessments could be completed, most reaches were found to be in transition or in regime. The general stability is likely associated with the maintenance of the headwater channels. Most of the channels were in fair condition with regard to health. Most of the reaches were shown to be stable based on both Downs' model and suggested by the dominance of c-type channels. Where adjustment was noted it was dominated by channel enlargement based on Downs' model or widening based on the RGA scores.

The combination of RGA and RSAT assessments rank the reaches based on channel stability and assist with selecting sensitive reaches for detailed fieldwork. The results indicate that most of the reaches within the lower sections of the Cardinal Creek subwatershed are in transition (Table 4 and Figure 7). The headwaters of RV35 are in regime while the downstream reaches are in transition. The limited land use change and local geology (i.e., silt and clay deposits) likely make many of the reaches reasonably resilient. Those reaches showing the greatest adjustment are generally reaches with increased gradients.

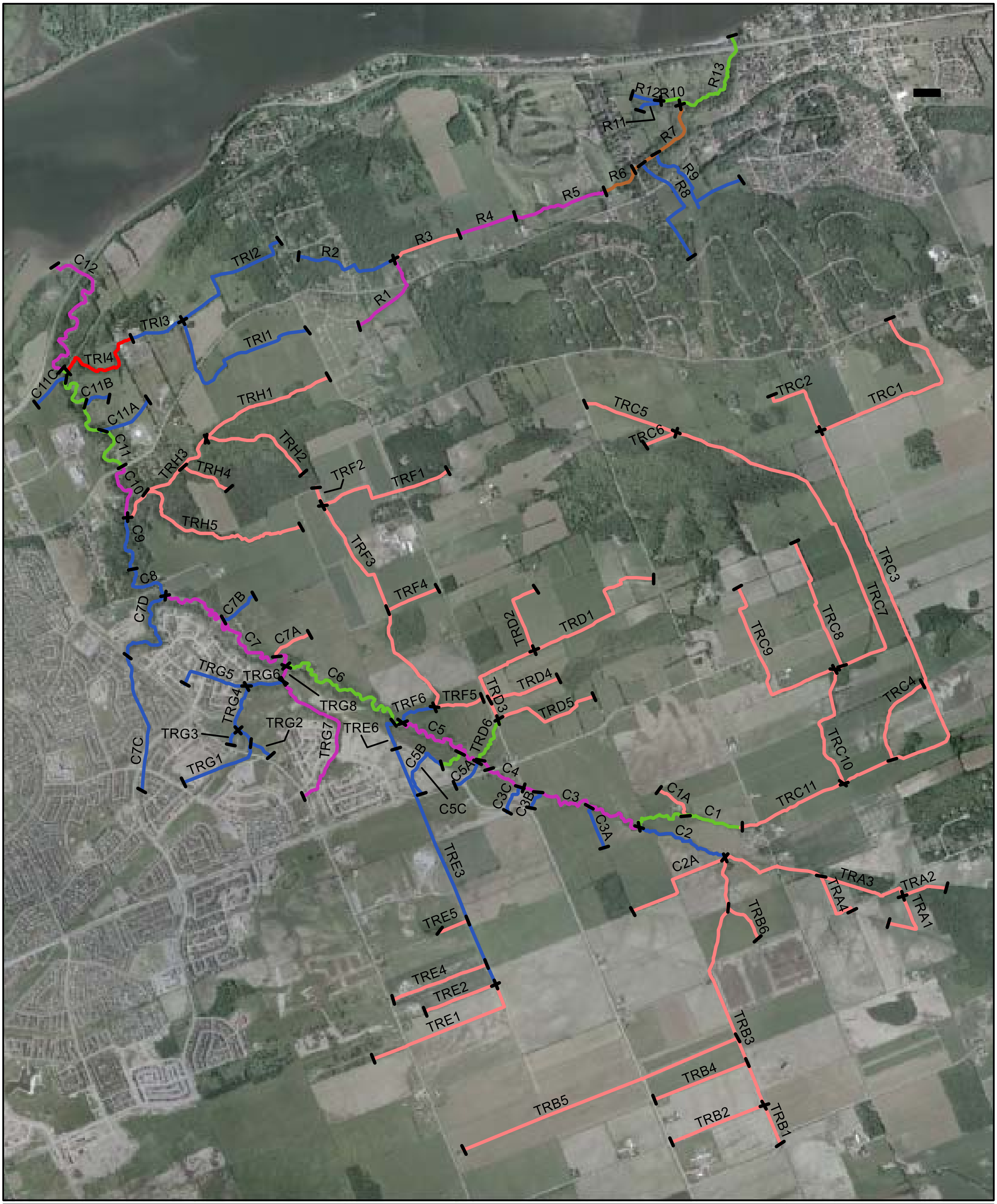
Overall the channels were relatively 'healthy' and reasonable stable, this condition is a product of the limited loss of headwater channels. The main issues with regards to stability and 'health' are associated with the loss of riparian vegetation, and straightening and ditching of headwater channels to facilitate drainage. The prominence of drains, along with urbanization downstream are likely the cause of the observed adjustment of the reaches along the main branch of Cardinal Creek. Steep gradients and valley wall contact are the likely cause of the observed adjustment along RV35.

The identified issues can be addressed to a large extent by improved management for the riparian zone of the headwater systems and improved stormwater management. As opportunities arise habitat improvement of headwater channels and drains should be initiated. The areas of concern/transition along the main branches should be monitored and stabilization at certain locations in the future may be warranted. Habitat appropriate bioengineering should be used where stability issues create potential hazard, if possible. Any stabilization or restoration should take into account active process and systematic adjustments, should incorporate natural channel design principals, and should include effectiveness monitoring.

Table 4. Summary of rapid assessment results and channel classifications.

Reach	RGA			RSAT			Rosgen Classification	Downs Evolution Model
	Score	Condition	Form(s) of Adjustment	Score	Condition	Limiting Feature(s)		
RV35 Subwatershed								
1	0.14	In Regime	-	18	Fair	Riparian habitat conditions	G6c	S-Stable
4	0.11	In Regime	-	15	Fair	Physical instream habitat, riparian habitat conditions, water quality	G6c	S-Stable
5	0.14	In Regime	-	22	Fair	Physical instream habitat, riparian habitat conditions	G6c	S-Stable
6	0.29	In Transition	Widening	27.5	Good	Physical instream habitat	A6	E-Enlarging
7	0.25	In Transition	Widening	27.5	Good	Physical instream habitat	A6	E-Enlarging
10	0.32	In Transition	Widening	13	Fair	Physical instream habitat	A6	E-Enlarging
13	0.33	In Transition	Widening	20	Fair	Riparian habitat conditions	C6	M – Lateral migration
Cardinal Creek Subwatershed								
Tributary D								
TRD6	0.21	In Transition	Widening	17	Fair	Physical instream habitat	A6	E-Enlarging
Tributary G								
TRG7	0.18	In Regime	-	20.5	Fair	Physical instream habitat	A6	S-Stable
TRG8	0.18	In Regime	-	13	Fair	Riparian habitat conditions	E6	S-Stable
Tributary I								
TRI4	0.39	In Transition	Widening / degradation	11	Poor	Channel stability / channel scouring / sediment deposition	A6	E-Enlarging
Cardinal Creek								
C1	0.21	In Transition	Widening	18.5	Fair	Riparian habitat conditions	C6c-	M – Lateral migration
C3	0.14	In Regime	-	19	Fair	Physical instream habitat, riparian habitat conditions	C6c-	S-Stable
C4	0.14	In Regime	-	21.5	Fair	Riparian habitat conditions	C6c-	S-Stable
C5	0.14	In Regime	-	21	Fair	Riparian habitat conditions	C6c-	S-Stable
C5C	0.21	In Transition	Widening / planimetric form adjustment	19.5	Fair	Channel scouring / sediment deposition	A6	E-Enlarging
C6	0.21	In Transition	Widening / planimetric form	21	Fair	Riparian habitat conditions	C6c-	M – Lateral migration

Reach	RGA			RSAT			Rosgen Classification	Downs Evolution Model
	Score	Condition	Form(s) of Adjustment	Score	Condition	Limiting Feature(s)		
			adjustment					
C7	0.18	In Regime	-	16.5	Fair	Physical instream habitat, riparian habitat conditions	C6c-	S-Stable
C10	0.11	In Regime	-	24	Fair	Riparian habitat conditions	C6	S-Stable
C11	0.34	In Transition	Widening	23.5	Fair	Riparian habitat conditions	C6	M – Lateral migration
C12	0.14	In Regime	-	23.5	Fair	Riparian habitat conditions	C6	S-Stable



Cardinal Creek and RV 35 Subwatersheds

Geomorphic Assessment of Existing Conditions

Legend

RGA & RSAT Ratings

- In Regime, Fair
- In Transition, Poor
- In Transition, Fair
- In Transition, Good
- No Access
- Not Applicable
- Reach Break

Aerial Photography - City of Ottawa: 2005

Date: March 2007
Project: 06300.450
Drawn By: B.W., W.B.
Figure 7

3.2 DETAILED FIELD ASSESSMENT

This geomorphic assessment provides support for future stormwater management initiatives, and for identification of reference reaches. As such, a combination of the most stable/healthy reaches and sensitive reaches were selected for detailed assessment. These sensitive reaches are the indicators in the system and will provide conservative erosion thresholds for the development of stormwater management targets. Rapid assessment scores, systematic adjustments indicating erosive environments, and the maintenance of a broad coverage of the drainage basin were the criteria used to make the final selection regarding the location of detailed field sites.

From the preliminary assessment two reaches were identified for detailed assessment. Reach 13 from RV35 and Reach C10 from Cardinal Creek were selected for detailed study. They were selected based on their high RGA scores (Table 4). Reach C4 was selected as a third alternative site due to its stability and general stream health. This reach receives inputs from the majority of the headwater tributaries draining the northeast section of the subwatershed. This provides a natural reference reach for any future restoration activities and baseline data for future activities or land use change within the subwatershed.

The detailed assessments documented a number of key parameters including basic planform geometry, longitudinal, and cross-sectional profiles. Bankfull cross-sectional dimensions of each reach were quantified using standard protocols and field indicators (Parish Geomorphic, 2001). In addition, the composition of the boundary soil at the lower third of the bank, and intact riverbed materials, both pavement and subpavement were documented. It should be noted that channel entrenchment and a large storm event on July 3, 2006 might have resulted in an overestimation of bankfull dimensions. Recent large storm events can provide large or spurious estimations of bankfull channel widths.

Sediment size distribution of the bed substrate was based on a modified Wolman (1954) pebble count, and *in situ* shear stress of bank materials was measured with both penetrometer and torvane instrumentation, where possible. Recent published work on cohesive sediments provides methods to convert penetrometer values to a critical entrainment shear. This information, in part, was used to assess the critical shear strength of the bank.

Monitoring cross-sections and monumented photographs were also taken, as well as installation of erosion pins. The bankfull flow characteristics were then defined using the summarized field data (Appendix C and Table 5). Details of the erosion threshold assessments for the sensitive reaches are provided in the following section.

3.2.1 EROSION THRESHOLDS

The detailed field information was collected in order to hindcast bankfull conditions, as well as, to perform analyses based on critical shear stress and permissible velocities in order to identify erosion thresholds (Table 5).

The calculations performed to determine critical discharge (discharge at which entrainment could potentially occur) were based on critical shear stress (Chow, 1959; Fischenich, 2001) and permissible velocity/flow competency (Chow, 1959; Komar, 1987; Fischenich, 2001). For a review of models see Villard and Parish (2004). The model results are examined for convergence, appropriateness, and compatibility with field observations. Thresholds are generally based on erosion thresholds for the median grain size in non-cohesive sediments. This is the case for RV35 Reach 13 and Reach C10. These values were substantially lower than the critical condition for bank materials. In the case of Reach C4, thresholds estimated using the median grain size would provide unrealistically low values, as they do not consider the cohesive strength of the dominant silts and clays. It would have been in the order of 1 - 2.5 N/m^2 (weakly cohesive sand to non-noncolliodal alluvial silt). Instead, a permissible shear for compact sandy-clay was used to define the threshold, which was likely a conservative but more realistic approximation of the 'true' substrate.

Critical thresholds were converted to a critical flow depth (channel water depth where material is potentially entrained). By incorporating these depths into a representative cross-section and applying Manning's equation they are translated into more meaningful discharge and velocity. A representative cross-section was one with a simple geometry, which generally matched the average values measured. Bankfull gradient was used as a surrogate for water slope and a characteristic roughness (Manning's n) based on visual observations was applied.

It is apparent from comparison of the bankfull discharge values and the critical discharge values that sediments are entrained well below bankfull conditions. This is related to the gradients and reasonably fine materials dominating the bed. This would indicate that sediment is entrained and transported under flows substantially below the 2-year return. This would suggest that the channels would be sensitive to even minor changes in flow regime. As such, stormwater management should address matching flows below the two-year return. This sensitivity is likely in part why the channels are in transition. To reduce potential adverse impacts to the watershed, stormwater management flows should be controlled below the traditional two-year return scenario.

For clarification, an erosion threshold provides a discharge at which the sediment may potentially be entrained. This does not necessarily mean systemic erosion (i.e., widening or degradation of the channel); it simply indicates a flow, which may potentially entrain sediment (i.e. initiation of motion of materials). These values are inherently conservative when applied to natural channels as the shear acting on the bed is assumed to be the total shear. In natural channels additional resistance is provided by the complicated channel bed geometries and roughness, which dissipates a proportion of the shear. This, in turn leads to higher actual in-channel thresholds for entrainment.

It should also be noted that, in many of the channels, exposed parent materials were observed. These tills have relatively high shear strengths compared with those related to the materials for which thresholds were provided. Alluvial silts and tills can have critical shear stresses in the order of 12.5 N/m^2, although with a wide range in variability. With regards to the bank strength, due to the difficulty in defining additional strength associated with vegetation, this was also not taken into account. In both these cases, the additional strength associated with these considerations was not accounted for to provide conservative threshold values.

The erosion thresholds provided in this assessment can be used in the hydrology modeling proposed for the next phase of the subwatershed study. As part of the modeling process it is anticipated that pre- to post-stormwater management plan hydrographs of some form will be compared to assess success of different stormwater management regimes. Pre- to post-stormwater management plan evaluation could include comparison of cumulative time of erosion threshold exceedence or comparison of cumulative excess stream power. If conditions cannot be matched other instream mitigation measures may be warranted in potential problem areas.

Table 5. Erosion threshold measures for detailed study sites.

Parameter	RV35 - 13	Reach C4	Reach C10
Bankfull Gradient (%)	0.34	0.09	0.27
Average Bankfull Width (m)	2.8	7.6	7.47
Average Bankfull Depth (m)	0.63	0.65	0.69
Bed Material D_{50} (m)	0.0053	Silty clay	0.003
Bed Material D_{84} (m)	0.08	Silty clay	0.07
Bank Materials	Clay	Silty clay	Silt
Manning's n	0.033	0.033	0.035
Average Bankfull Velocity (ms^{-1})	1.15	0.57	1.4
Average Bankfull Discharge (m^3s^{-1})	2.03	4.89	7.3
Flow Competence (ms^{-1}) @ D50	0.43	N/A	0.33
Flow Competence (ms^{-1}) @ D84	1.5		1.23
Bankfull Tractive Force (Nm^{-2})	15.5	3.3	27.1
Critical Shear (Nm^{-2}) @ D_{50}	3.86	4.7	2.19
Critical Shear (Nm^{-2}) @ D_{84}	58.27	4.7	38.6
Critical Shear (Nm^{-2}) for bank material	3.5	3.6	3.6
Stream power per unit width (Wm^{-2})	17.7	1.89	38.19
Critical Discharge (m^3s^{-1})*	0.47	1.01	0.05
Critical Depth (m)*	0.37	0.4	0.13
Critical Velocity (ms^{-1})* * at which sediment is potentially entrained	0.77	0.49	0.3

3.3 MEANDER BELT WIDTH AND HAZARD ASSESSMENT

A planning level assessment of meander belt widths, channel migration and erosion set backs in confined systems was also completed. As there is a mix of unconfined and confined channels within the study area, both meander belt widths and erosion setbacks would be required to delineate potential hazard lands. The meander belt width defines the lateral extent that a channel occupies, and considers not only the space currently occupied by the channel, but also the area the channel has occupied in the past, and could potentially occupy in the future. The determination of meander belt widths is useful during the planning stage, for example, to limit development near watercourses thus preventing potential property loss or impact to channel function. Following MNR guidelines (1997, 2001), these hazard assessments identify issues of potential concern and further refinement of site-specific issues may be required.

For the purposes of this study, meander belt widths for reaches that had a visible meandering planform were assessed based on direct measurements from digital aerial photographs and topographic mapping where current aerial photographs were not available. The meander belt is centred on the meander axis but follows the general valley trend. To account for both erosion and corridor expansion it is recommended that a buffer of 10 percent be added to the meander belt widths provided (TRCA, 2004). Where the site or reach has been altered, it is recommended that for future site-specific assessments in support of development applications, unaltered reaches that are situated immediately upstream or downstream of the site of interest be used as a surrogate.

As this was a planning level assessment, along the lower order channels or where the stream branches are heavily modified belt widths are not provided. Again, for future site-specific assessments in support of development applications a simple rule of thumb is to multiply the bankfull width by 20 to provide a very conservative belt width estimate.

Swales are fully vegetation-controlled with limited morphological variability. As such, these channels do not develop typical meandering patterns. Determining meander belt widths for gullies is also not appropriate as these features are confined and in many cases are dominated by slope processes. Gullies typically contain steep channels that are laterally confined between valley walls and, therefore, have limited potential for lateral migration. In these areas defining the hazard through assessment of the geotechnical concern and provision of an erosion setback is more appropriate. Table 6 provides a summary of measured meander belt widths and also assesses the potential need for erosion set backs.

Table 6. Summary of meander belt widths.

Reach	Bankfull Width (m)	Bankfull Depth (m)	Measured Belt Width (m) No Buffer	Measured Belt Width (m) 10% Buffer	Confined Valley? (Y/N)	Erosion Setback? (Y/N)
RV35 Subwatershed						
13	3.0 – 4.0	0.3 – 0.4	14	15	Y	Y
Cardinal Creek Subwatershed						
TRD6	1.5	0.2 – 0.3	11	12	Y	Y
TRH4	N/A – No access		43	47	Y	Y
C1	4.0 - 5.0	0.4 - 0.5	34	38	Y	Y
C2	N/A – No access		28	31	Y	Y
C3	6.0 - 8.0	0.4 - 0.6	59	65	Y	Y
C3C	1.5	0.3 – 0.4	17	19	Y	Y
C4	5.0 - 7.0	0.4 - 0.6	36	40	Y	Y
C5	5.0 - 7.0	0.5 - 0.7	42	46	Y	Y
C6	5.0 - 7.0	0.5 - 0.7	68	75	N	N
C7	5.0 - 9.0	0.5 - 0.6	74	81	Y	Y
C7D	1.0 – 2.0	0.1 – 0.2	38	42	Y	Y
C9	N/A – No access		66	72	Y	Y
C10	4.0 - 5.0	0.4 - 0.5	112	123	Y	Y
C11	6.0 - 8.0	0.4 - 0.7	91	100	Y	Y
C12	12.0 – 15.0	1.0 - 1.5	106	116	Y	Y

Along sections of Cardinal Creek, the valley wall causes channel confinement. As such, the main concern is potential migration of meander bends near the valley wall and the associated hazard. The 100-year erosion limit represents the potential valley wall erosion associated with channel migration. In conjunction with a geotechnical assessment of the stable top of bank, erosion limits provide an appropriate hazard setback for the combined stable top of slope and erosion setback allowance. For a planning level assessment an erosion set back of 15 m, which assumes active erosion is recommended by the Ministry of Natural Resources (1997, 2001). Again this is a conservative value, which could be refined with more detailed assessment. Locations of valley wall contact are shown in Figure 8.

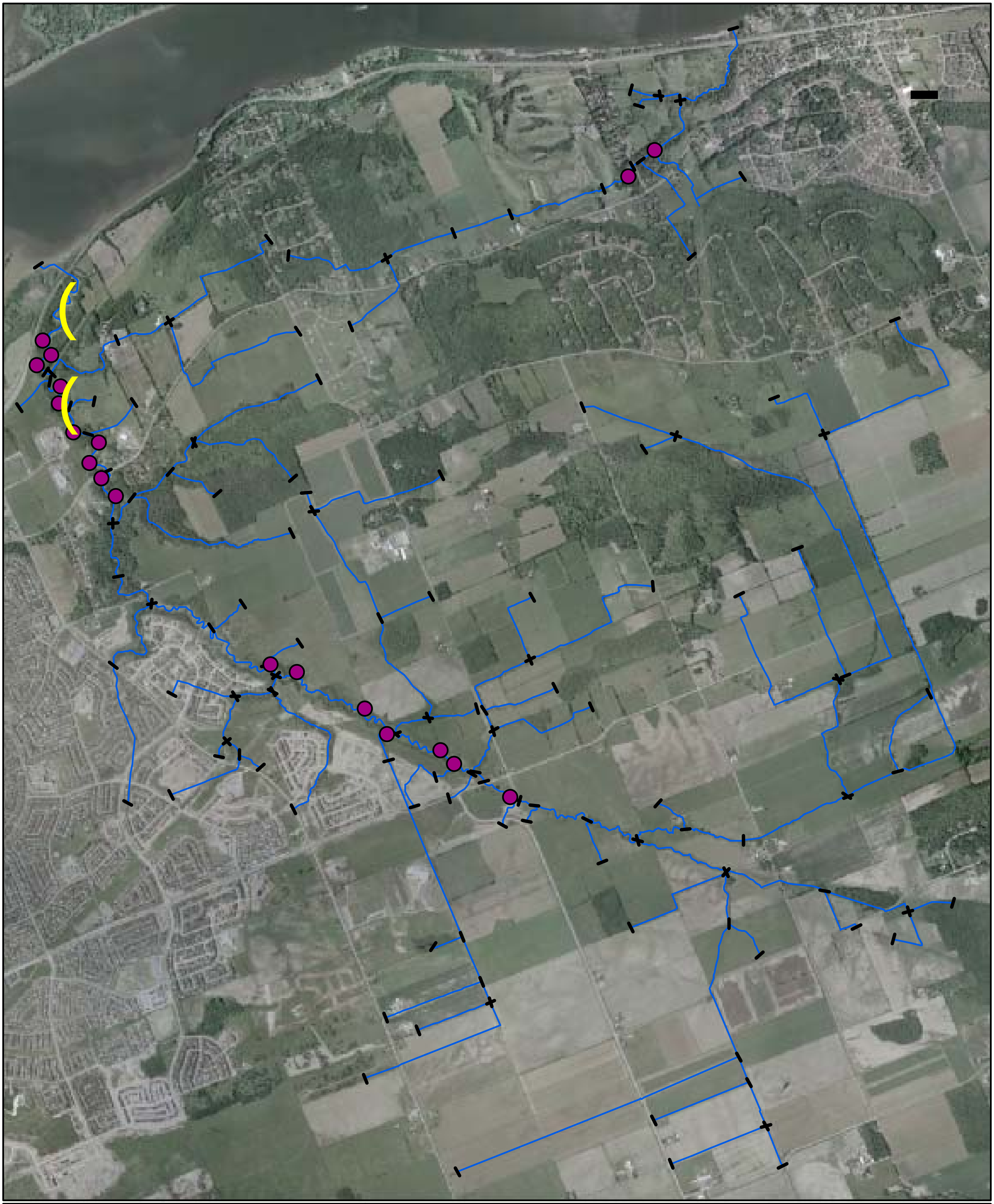
Migration rates were calculated for characteristic meanders along reaches where tracking of meanders between the 1945 black and white aerial photograph and a 2005 digital aerial photograph where possible (Table 7; Figure 8). Along many reaches, this was not possible due to the vegetation cover, size of channel, resolution of the aerial photographs, or the lack of control points for rectification of the aerial photographs. Where migration could be calculated this 60-year record provides planning level assessment of channel planform adjustment and meander migration. This record length is greater than the 25-year minimum time scale suggested by the MNR Guidelines (1997, 2001).

Aerial photographs were georeferenced in ArcView GIS 9.1 using 5 to 6 control points using a first order correction to minimize image distortion. Control points were selected from known control points between photographs. Control points that surrounded the areas of channel of significance were selected to minimize rectification errors. Errors between corrected control points were averaged to provide a correction error. In this case the error was 1.4 m between the 1945 and 2005 aerial photographs. It can be assumed that the error in channel position was smaller, as the channel position was within the selected control points. This method is less error prone, provides a measure of potential rectification/scaling inaccuracy, and is likely more reproducible than manual measurements.

Also, care needs to be taken in application of the erosion of certain reaches due to specific alterations to the creek, such as, decommissioning of the mill downstream of Old Montreal Road after 1945, which likely has impacted channel rates of change. For RV35, only Reach 13 had a meandering planform. However, migration rates could not be determined due to the scale of the historical photographs, riparian vegetation and beaver activity.

Table 7. Summary of migration rates.

	Years	Period (yr)	Downstream Migration Rate (m/yr)	Lateral Migration Rate (m/yr)	Valley Toe Contact (y/n)
C11	1945-2005	60	Negligible	0.14	Y
			Negligible	0.12	Y
			Negligible	0.32	Y
			Negligible	0.17	Y
C12	1945-2005	60	Negligible	0.16	N
			Negligible	0.07	N
			0.14	0.15	N
			0.05	Negligible	N



Cardinal Creek and RV 35 Subwatersheds

Location of Tracked Meanders and Valley Wall Contacts

Legend

Tracked Meander

Valley Wall Contact

Stream Network

Reach Break

Aerial Photography - City of Ottawa: 2005

GEOMORPHIC SOLUTIONS

Date: March 2007
Project: 06300.450
Drawn By: B.W., W.B.
Figure 8

4.0 SUMMARY

The overall aim of the study was to develop an understanding of the geomorphology of the watercourses within the Cardinal Creek watershed (RV34) and the adjacent Ottawa 1 subwatershed (RV35). It provides an assessment of stream health and sensitivity, and identified systematic adjustments and areas of potential concern with regard to degradation and hazard.

The field component of the preliminary assessment included rapid field evaluations (i.e., Rapid Geomorphic Assessment, Rapid Stream Assessment Technique) of each reach and identification of those with the greatest sensitivity.

The results of the RGA and RSAT assessments indicated that most of the reaches within the lower sections of the Cardinal Creek subwatershed are in transition (see Table 4). The headwaters of RV35 are in regime while the downstream reaches are in transition. The limited land use changes over the past one hundred years and local geology (i.e., silt and clay deposits) likely makes many of the reaches reasonably resilient. Those reaches showing the greatest adjustment are generally flowing through areas with increased gradients.

Overall the channels were relatively 'healthy' and reasonable stable, this condition is a product of the limited loss of headwater channels. The main issues with regards to stability and 'health' are associated with the loss of riparian vegetation, and straightening and ditching of headwater channels to facilitate drainage. The prominence of drains, along with urbanization downstream are likely the cause of the observed adjustment of the reaches along the main branch of Cardinal Creek. Steep gradients and valley wall contact are the likely cause of the observed adjustment along RV35.

The identified issues can be addressed to a large extent by improved management of the riparian zone of the headwater systems and improved stormwater management. As opportunities arise habitat improvement of headwater channels and drains should be initiated. The areas of concern/transition along the main branches should be monitored and stabilization at certain locations in the future may be warranted. Habitat appropriate bioengineering should be used where stability issues create potential hazard, if possible. Any stabilization or restoration should take into account active process and systematic adjustments, incorporate natural channel design principles, and should include effectiveness monitoring.

Sensitivity of the watershed to changes in flow regime is quantified by a modeling exercise, which provided erosion thresholds (flow, depth or velocity where channel materials are potentially entrained). The exercise suggested that the watershed would be sensitive to changes in flow regime including low magnitude flow events, such as those below the two-year return. Erosion threshold information for input into stormwater management scenarios are provided in Table 5.

A planning level assessment of meander belt widths, channel migration and erosion set backs in confined systems was also completed. Belt widths and erosion rates are provided in Tables 6 and 7.

Respectfully submitted,

GEOMORPHIC SOLUTIONS

<digitally signed>

Paul Villard, P.Geo., Ph.D.
Senior Geomorphologist, Associate

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APPENDIX A
CHANNEL TYPE AND FLOW REGIME

Cardinal Creek and RV 35

Channel Type and Flow Regime

Legend

Channel Type & Flow Regime

- Defined, Ephemeral
- Defined, Perennial
- Gully, Ephemeral
- Gully, Perennial
- Intermittent, Ephemeral
- Intermittent, Perennial
- Piped, Perennial
- Swale, Ephemeral
- Unknown
- Reach Break

Aerial Photography - City of Ottawa: 2005

GEOMORPHIC SOLUTIONS
A Member of The Sernas Group Inc.

Date: March 2007
Project: 06300.450
Drawn By: B.W., W.B.
Appendix A

APPENDIX B
PHOTOGRAPHIC INVENTORY

RV35 Watershed

July 18, 2006 	**Photo 1.** Reach 1. GPS Point 10. Note: recent channel modifications for culvert installation. View looking upstream.
July 18, 2006 	**Photo 2.** Reach 2. GPS Point 81. Note: wetland vegetation and poorly defined channel. View looking downstream.

July 18, 2006

Photo 3.

Reach 3. GPS Point 1. Note: poorly defined channel and vegetation encroachment. View looking upstream.

July 18, 2006

Photo 4.

Reach 4. GPS Point 4. Note: low gradient and algae growth. View looking upstream.

July 19, 2006 	**Photo 5.** Reach 5. GPS Point 37. Note: limited riparian vegetation. View looking downstream.
July 19, 2006 	**Photo 6.** Reach 6. GPS Point 48. Note: extensive bank erosion, exposed roots and marine deposits. View looking downstream.

July 19, 2006 	**Photo 7.** Reach 7. GPS Point 56. Note: wood debris. View looking downstream.
July 19, 2006 	**Photo 8.** Reach 8. GPS Point 80. Note: steep gradient and poorly defined channel. View looking upstream.

July 19, 2006 	**Photo 9.** Reach 9. GPS Point 79. Note: limited riparian vegetation. View looking upstream.
July 19, 2006 	**Photo 10.** Reach 10. GPS Point 61. Note: limited wetted width and depth. View looking upstream.

<table>
<tr><td>July 19, 2006
</td><td>**Photo 11.**

Reach 11. GPS Point 70. Note: steep gradient. View looking upstream.</td></tr>
<tr><td>July 19, 2006
</td><td>**Photo 12.**

Reach 12. GPS Point 65. Note: steep gradient and wood debris. View looking upstream.</td></tr>
</table>

<table>
<tr><td>October 16, 2006
</td><td></td></tr>
<tr><td></td><td>Photo 13.

Reach 13. GPS Point 186. Note: meadow vegetation extends 2-3 metres along both banks before becoming mature forest. View looking downstream.</td></tr>
<tr><td>July 18, 2006
</td><td></td></tr>
<tr><td></td><td>Photo 14.

Reach 13. GPS Point 9. Confluence with the Ottawa River. View looking downstream.</td></tr>
</table>

Cardinal Creek Watershed

July 21, 2006 	**Photo 15.** Reach TRA3. GPS Point 154. Note: vegetation encroachment and steep banks. View looking downstream.
July 18, 2006 	**Photo 16.** Reach TRB3. GPS Point 26. Note: vegetation encroachment. View looking downstream.

July 18, 2006

Photo 17.

Reach TRC3. GPS Point 88. Note: linear channel with steep banks and vegetation encroachment. View looking downstream.

July 18, 2006

Photo 18.

Reach TRD6. GPS Point 22. Bank erosion immediately downstream of culvert. View looking downstream.

July 21, 2006

Photo 19.

Reach TRE6. GPS Point 160. Note: construction activities impacting channel form and function. View looking downstream.

July 18, 2006

Photo 20.

Reach TRF1. GPS Point 18. Note: wetland vegetation and limited morphology. View looking downstream.

July 20, 2006

Photo 21.

Reach TRG7. GPS Point 150. Note: sinuous channel with bank erosion along outside of meander bends. View looking downstream.

July 18, 2006

Photo 22.

Reach TRH1. GPS Point 13. Small tributary flowing west. Note: wetland vegetation. View looking downstream.

July 20, 2006 	**Photo 23.** Reach TRI4. GPS Point 100. Downstream extent of reach TRI4. Extensive channel downcutting and exposure of marine deposits. Deposits of marine clays observed at confluence with Cardinal Creek. View looking upstream.
July 21, 2006 	**Photo 24.** Reach C1. GPS Point 155. Bank erosion downstream of O'Toole Road. View looking downstream.

July 20, 2006

Photo 25.

Reach C3. GPS Point 24. Note: vegetation encroachment and limited morphology. View looking upstream.

October 13, 2006

Photo 26.

Reach C4. GPS Point 175. Meadow vegetation produces steep and overhanging banks. View looking upstream.

July 21, 2006

Photo 27.

Reach C5. GPS Point 162. Majority of bank erosion along reach occurring along outside of meander bends. View looking upstream.

July 20, 2006

Photo 28.

Reach C6. GPS Point 152. Note: steep banks and meadow vegetation. View looking upstream.

July 20, 2006

Photo 29.

Reach C7. GPS Point 137. View of meander bend. Note: bank erosion and high water mark on vegetation.

October 20, 2006

Photo 30.

Reach C8. GPS Point 142. View looking downstream from Watters Road. Note: channel flows through sink hole and flows through this section of channel during high flows. View looking downstream.

October 20, 2006

Photo 31.

Reach C10. GPS Point 165. Bank slump along left bank near Old Montreal Road. View looking downstream.

November 24, 2006

Photo 32.

Reach C11. GPS Point 193. Note: riffle section (foreground) and valley wall contact (background). View looking downstream.

	**Photo 33.** Reach C12. GPS Point 94. Limited channel morphology immediately downstream of rail crossing. View looking downstream.
	**Photo 34.** Reach C12. GPS Point 92. Confluence with the Ottawa River. View looking downstream.

APPENDIX C
DETAILED FLUVIAL GEOMORPHOLOGY SUMMARIES

GEOMORPHIC SOLUTIONS

Fluvial Geomorphology Summary

RV35 - Reach 13

Location: City of Ottawa	Date: October 16, 2006
Length Surveyed: 130 m	Number of Cross-Sections: 10

GENERAL SITE CHARACTERISTICS

Drainage Area: N/A
Geology/Soils: Clays, River Sediments
Surrounding Land Use: Natural - Forest
Channel Disturbances: None
Aquatic Vegetation:
- Dominant Vegetation Type: Rooted Submerged
- Portion of Reach with Vegetation: 20%

Riparian Vegetation:
- Dominant Vegetation Type: Trees
- Extent of Riparian Buffer Zone: Continuous
- Width of Riparian Buffer Zone: >5 Channel Widths
- Age Class of Riparian Vegetation: Mature
- Extent of Encroachment into Channel: Minimal

Large Woody Debris: Moderate

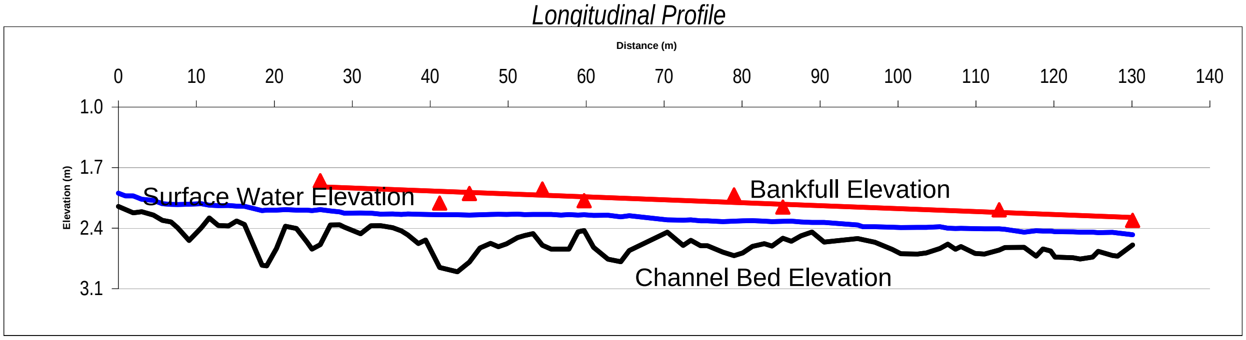
HYDROLOGY

Measured Discharge:	Not measured m^3/s	Calculated Bankfull Discharge:	2.03 m^3/s
Modeled 2-year Discharge:	Not modeled m^3/s	Calculated Bankfull Velocity:	1.15 m/s
Modeled 2-year Velocity:	Not modeled m/s		

PLANFORM CHARACTERISTICS

Profile		*Meander Geometry*		
Bankfull Gradient:	0.34 %	Sinuosity:	1.8	
Channel Bed Gradient:	0.25 %	Belt Width:	14	m
Riffle Gradient:	2.68 %	Radius of Curvature:	Not measured	m
Riffle Length:	5.48 m	Amplitude:	Not measured	m
Riffle-Pool Spacing:	6.08 m	Wavelength:	Not measured	m

Longitudinal Profile



BANK CHARACTERISTICS

	Minimum	*Maximum*	*Average*
Bank Height (m):	0.5	1.5	1.1
Bank Angle (degrees):	25.0	90.0	60.0
Root Depth (m):	0.2	0.4	0.3
Root Density (kg/m^2):	90.0	100.0	95.0
Depth of Undercut (m):	0.1	0.7	0.3

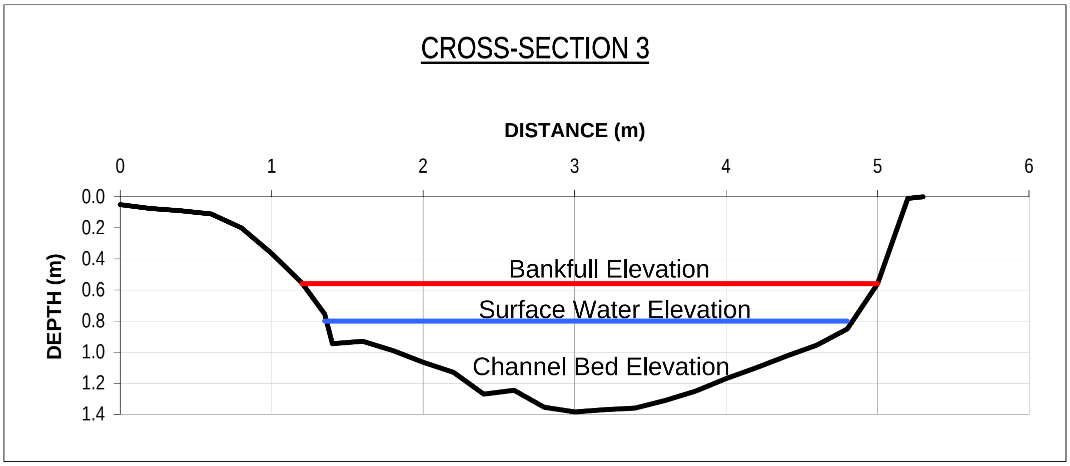
	Minimum	*Maximum*	*Average*
Torvane Value* (kg/cm^2):	0.1	0.3	0.2
Penetrometer Value* (kg/cm^3)	**0.1**	0.3	0.2
Bank Material (range):		Clay/Silt	

* Mechanic shear stress/ failure as measured from instruments is NOT equivalent to a threshold or entrainment shear stress

CROSS-SECTIONAL CHARACTERISTICS

	Minimum	*Maximum*	*Average*
Bankfull Width (m):	2.1	3.8	2.8
Average Bankfull Depth (m):	0.3	0.83	0.63
Bankfull Width/Depth:	7.0	4.6	4.4
Wetted Width (m):	0.4	3.8	2.03
Water Depth (m):	0.06	0.5	0.23
Wetted Width/Depth:	6.7	8.3	8.8
Entrenchment (m):	10	20	16
Entrenchment Ratio:	2.6	9.5	6.2
Maximum Depth (m):	0.3	0.94	0.7
Manning's n:		0.033	

Representative Cross-Section



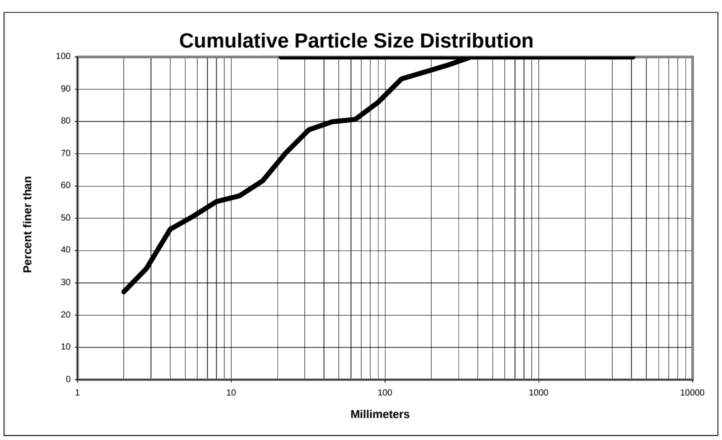
SUBSTRATE CHARACTERISTICS

Particle size

D_{10}	N/A	mm
D_{50}	5.3	mm
D_{90}	115	mm

Subpavement: Marine Deposits -clay
Particle shape: Angular
Embeddedness (%): N/A, Silt/Clay, Unconsolidated
Particle range (riffle): Silt, clay, sand, gravel
Particle Range (pool): Silt, clay

Grain Size Distribution



CHANNEL THRESHOLDS

Flow Competency (non-cohesive sediments):		Tractive Force at Bankfull:	15.5 N/m^2
for D_{50}:	0.4 m/s	Tractive Force at 2-year flow:	N/A N/m^2
for D_{84}:	1.5 m/s	Critical Shear Stress (Bed):	3.9 N/m^2
Stream Power/ Metre Width (bkf):	27.3 W/m^2	Critical Shear Stress (Bank):	3.5 N/m^2

GENERAL FIELD OBSERVATIONS

Large pool formations at most meander bends

Bank erosion associated with meander bends

Substrate predominantly silty clay. Gravels were observed in riffles (slightly angular particles of shale) - likely sourced from Reaches 8 and 9

Good floodplain access

Riparian vegetation predominantly meadow and mature coniferous forest

Erosion Pin Installation

Cross-section # 1; GPS Cordinates: 467028.9963, 5040258.646 NAD 83 ZONE 18N

Erosion pin (left bank) = 10.5 cm; Erosion pin (right bank) = 4.0 cm

Scour pin (mid right channel bed) = 3.0 cm

Representative Photograph

GEOMORPHIC SOLUTIONS

Fluvial Geomorphology Summary

Cardinal Creek - Reach C4

Location: City of Ottawa	Date: October 13, 2006
Length Surveyed: 195 m	Number of Cross-Sections: 10

GENERAL SITE CHARACTERISTICS

Drainage Area: N/A

Geology/Soils: Marine Clays

Surrounding Land Use: Agricultural / residential

Channel Disturbances: Upstream and downstream culverts

Aquatic Vegetation:

- Dominant Vegetation Type: None
- Portion of Reach with Vegetation: N/A

Riparian Vegetation:

- Dominant Vegetation Type: Meadow
- Extent of Riparian Buffer Zone: Continuous
- Width of Riparian Buffer Zone: 1-5 Channel Widths
- Age Class of Riparian Vegetation: Immature
- Extent of Encroachment into Channel: Minimal

Large Woody Debris: None

HYDROLOGY

Measured Discharge:	Not measured m^3/s	Calculated Bankfull Discharge:	4.89 m^3/s
Modeled 2-year Discharge:	Not modeled m^3/s	Calculated Bankfull Velocity:	0.57 m/s
Modeled 2-year Velocity:	Not modeled m/s		

PLANFORM CHARACTERISTICS

Profile

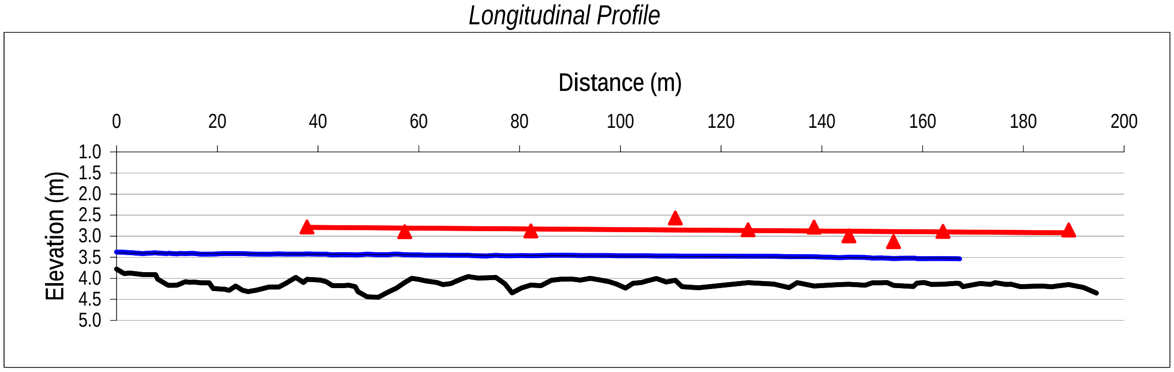
Bankfull Gradient:	0.09	%
Channel Bed Gradient:	0.03	%
Riffle Gradient:	N/A*	%
Riffle Length:	N/A*	m
Riffle-Pool Spacing:	N/A*	m

* no pool riffle morphology

Meander Geometry

Sinuosity:	1.09	
Belt Width:	36	m
Radius of Curvature:	Not measured	m
Amplitude:	Not measured	m
Wavelength:	Not measured	m

Longitudinal Profile



BANK CHARACTERISTICS

	Minimum	*Maximum*	*Average*
Bank Height (m):	0.65	1.6	1.1
Bank Angle (degrees):	35	75.0	57.8
Root Depth (m):	0.25	0.5	0.4
Root Density (kg/m^2):	90	100.0	95.0
Undercut Banks (%)	0	60.0	29.0
Depth of Undercut (m):	0	13.0	2.0

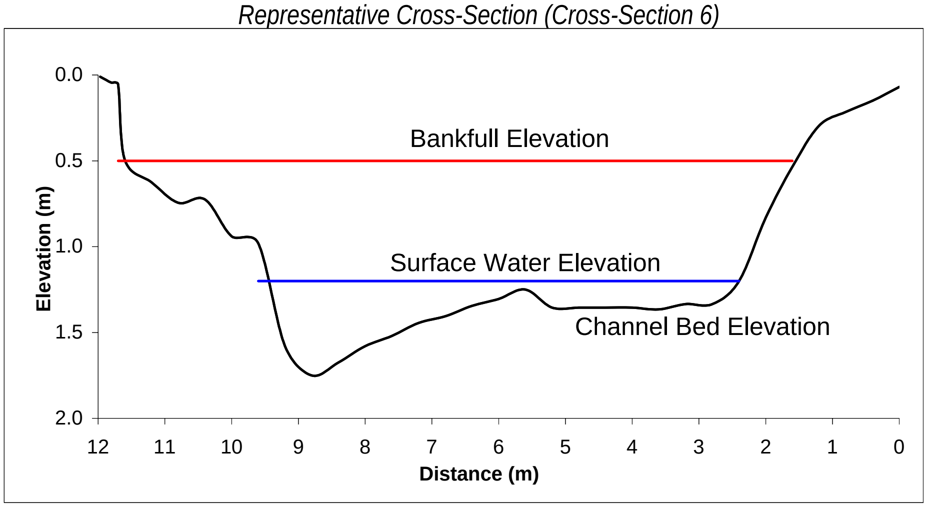
	Minimum	*Maximum*	*Average*
Torvane Value* (kg/cm^2):	0.2	0.35	0.27
Penetrometer Value* (kg/cm^3	0.23	0.43	0.33
Bank Material (range):		Clay to Silt	

* Mechanic shear stress/ failure as measured from instruments is NOT equivalent to a threshold or entrainment shear stress

CROSS-SECTIONAL CHARACTERISTICS

	Minimum	*Maximum*	*Average*
Bankfull Width (m):	5.2	10.1	7.6
Average Bankfull Depth (m):	0.5	0.8	0.6
Bankfull Width/Depth:	6.7	16.1	12.3
Wetted Width (m):	3.6	7.2	5.8
Water Depth (m):	0.2	0.7	0.3
Wetted Width/Depth:	7.2	37.1	19.4
Entrenchment (m):	10	25	19.5
Entrenchment Ratio:	1.5	3.68	2.61
Maximum Depth (m):	0.78	1.83	1.13
Manning's n:		0.033	

Representative Cross-Section (Cross-Section 6)



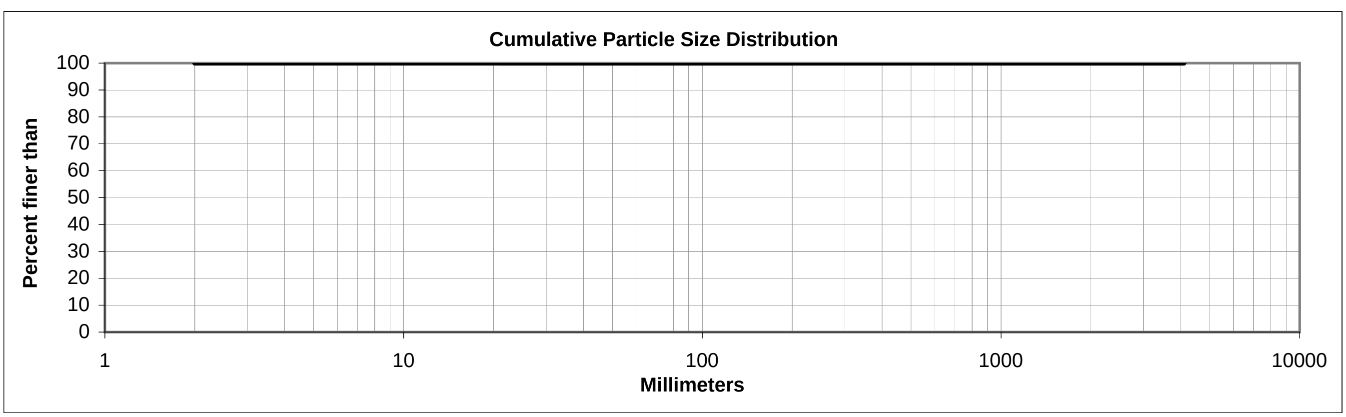
SUBSTRATE CHARACTERISTICS

Particle size

D_{10}		mm
D_{50}	Silty Clay	mm
D_{90}		mm

Subpavement: Marine Deposits (consolidated clay)
Particle shape: Silt/Clay
Embeddedness (%): N/A - no riffle morphology
Particle range (riffle): Silt / clay
Particle Range (pool): Silt / clay

Grain Size Distribution



CHANNEL THRESHOLDS

Flow Competency (non-cohesive sediments):		Tractive Force at Bankfull:	3.3 N/m^2
for D_{50}:	- m/s	Tractive Force at 2-year flow:	N/A N/m^2
for D_{84}:	- m/s	Critical Shear Stress (Bed):	4.7 N/m^2
Stream Power/ Metre Width (bkf):	1.90 W/m^2	Critical Shear Stress (Bank):	3.6 N/m^2

GENERAL FIELD OBSERVATIONS

Steep banks

Undercuts and bank slumping common

Slightly sinuous channel

Majority of erosion occurring at valley wall contact near upstream extent

Substrate predominantly silt / clay

Erosion Pin Installation

Cross-section # 4; GPS Cordinates: 465778.264, 5035653.552 NAD 83 ZONE 18N

Erosion pin (left bank) = 15.0 cm; Erosion pin (right bank) = 13.6 cm

Scour pin (at 6.0 m mark on tape) = 8.5 cm; scour pin (at 6.5 m mark on tape) = 7.0 cm

Representative Photograph

GEOMORPHIC SOLUTIONS

Fluvial Geomorphology Summary

Cardinal Creek - Reach C10

Location: City of Ottawa	Date: November 24, 2006
Length Surveyed: 240 m	Number of Cross-Sections: 10

GENERAL SITE CHARACTERISTICS

Drainage Area:
Geology/Soils: Marine Clays, Till
Surrounding Land Use: Forest, Meadow
Channel Disturbances: None
Aquatic Vegetation:
- Dominant Vegetation Type: Rooted macrophytes
- Portion of Reach with Vegetation: 10%

Riparian Vegetation:
- Dominant Vegetation Type: Meadow
- Extent of Riparian Buffer Zone: Continuous
- Width of Riparian Buffer Zone: >15 channel widths
- Age Class of Riparian Vegetation: Mature
- Extent of Encroachment into Channel: Minimal

Large Woody Debris: Present in Channel and banks

HYDROLOGY

Measured Discharge:	Not measured m^3/s	Calculated Bankfull Discharge:	7.3 m^3/s
Modeled 2-year Discharge:	Not modeled m^3/s	Calculated Bankfull Velocity:	1.4 m/s
Modeled 2-year Velocity:	Not modeled m/s		

PLANFORM CHARACTERISTICS

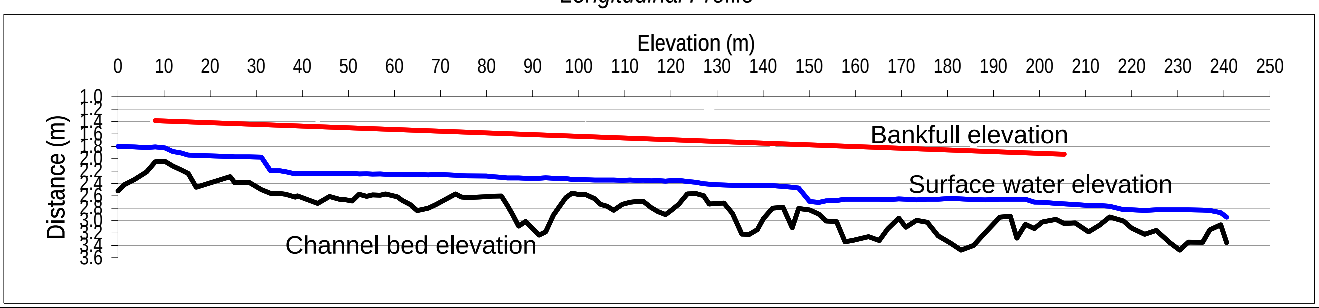
Profile

Bankfull Gradient:	0.27 %
Channel Bed Gradient:	0.39 %
Riffle Gradient:	1.7 %
Riffle Length:	4.3 m
Riffle-Pool Spacing:	6.02 m

Meander Geometry

Sinuosity:	2.03	
Belt Width:	112	m
Radius of Curvature:	Not measured	m
Amplitude:	Not measured	m
Wavelength:	Not measured	m

Longitudinal Profile



BANK CHARACTERISTICS

	Minimum	Maximum	Average
Bank Height (m):	0.6	8.0	1.5
Bank Angle (degrees):	30.0	85.0	65.0
Root Depth (m):	0.3	1.0	0.5
Root Density (kg/m^2):	10	100.0	70.0
Depth of Undercut (m):	0.10	0.25	0.15

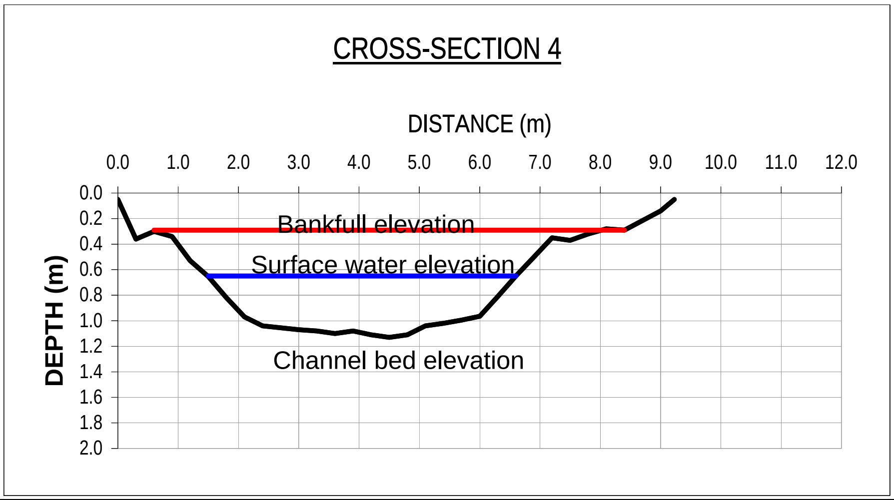
	Minimum	Maximum	Average
Torvane Value* (kg/cm^2):	0.05	0.35	0.2
Penetrometer Value* (kg/cm^3)	Not Available		
Bank Material (range):	Clay to Gravel		

* Mechanic shear stress/ failure as measured from instruments is NOT equivalent to a threshold or entrainment shear stress

CROSS-SECTIONAL CHARACTERISTICS

	Minimum	*Maximum*	*Average*
Bankfull Width (m):	5.70	10.10	7.47
Average Bankfull Depth (m):	0.40	0.91	0.69
Bankfull Width/Depth:	11.42	34.24	19.86
Wetted Width (m):	3.90	8.70	5.59
Water Depth (m):	0.09	0.37	0.25
Wetted Width/Depth:	13.62	98.85	29.25
Entrenchment (m):	14	22	17.6
Entrenchment Ratio:	1.49	3.17	2.43
Maximum Depth (m):	0.45	1.1	0.8
Manning's n:		0.035	

Representative Cross-Section



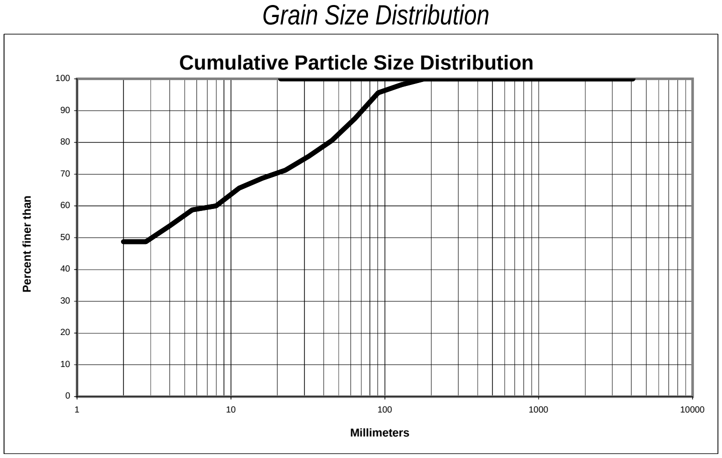
SUBSTRATE CHARACTERISTICS

Particle size

D_{10}	N/A mm
D_{50}	3.0 mm
D_{90}	70.0 mm

Subpavement: Marine deposits (consolidated clay)
Particle shape: Sub-angular to sub-rounded
Embeddedness (%): 20
Particle range (riffle): Sand to Cobble
Particle Range (pool): Clay to Gravel

Grain Size Distribution



CHANNEL THRESHOLDS

Flow Competency (non-cohesive sediments):		Tractive Force at Bankfull:	27.1 N/m^2
for D_{50}:	0.33 m/s	Tractive Force at 2-year flow:	N/A N/m^2
for D_{84}:	1.23 m/s	Critical Shear Stress (Bed):	2.2 N/m^2
Unit Stream Power at Bankfull:	38.19 W/m^2	Critical Shear Stress (Bank):	3.6 N/m^2

GENERAL FIELD OBSERVATIONS

Formation of islands at the downstream section of the reach

Large wood debris scattered in and around stream

Valley wall contact along downstream extent of survey

Steep banks

Substrate - Consolidated clay and clay aggradations (clay balls - gravel sized)

Erosion Pin Installation

Cross-section # 5; GPS Cordinates: 462906.0211, 5038248.874 NAD 83 ZONE 18N

Erosion pin (left bank - upper) = 10.5 cm; (left bank - lower) = 8.5 cm; Erosion pin (right bank) = 12.0 cm

Scour pin (at 2.9 m mark on tape) = 5.2 cm; Scour pin (at 6.0 m mark on tape) = 3.5 cm

Representative Photo

APPENDIX D
GLOSSARY

GLOSSARY

100-year Erosion Allowance	The erosion allowance is usually applied to confined or terrain-dependent systems consisting of cohesive materials. A minimum 25 years of record or data is required to provide a measure of reliability when determining an average annual recession rate extended over a 100 year planning horizon.
Aggradation	Systematic adjustment where a streambed is raised in elevation by the deposition of sediment transported from upstream.
Allochthonous	In aquatic ecology, allochthonous inputs of organic matter may include riparian vegetation and leave litter not originating from within the aquatic ecosystem, whereas autocthonous inputs may include macrophytes or algae originating from within the system.
Alluvial Stream	Streams that have erodible boundaries and are free to adjust dimensions, shape, pattern and gradient in response to change in slope, sediment supply or discharge.
Autochthonous	Applied to a material that was formed in its present condition. No significant transport has been involved. In aquatic ecology, autochthonous inputs of organic matter may include macrophytes or algae in the system, whereas allocthonous inputs may include riparian vegetation and leave litter not originating from within the aquatic ecosystem.
Bankfull	This stage is delineated by the elevation point of incipient flooding, indicated by deposits of sand or silt at the active scour mark, break in stream bank slope, perennial vegetation limit, rock discoloration, and root exposure.
Bankfull Discharge	A flow of water large enough to fill the width and depth of a stable, alluvial stream. Water fills the channel up to the first flat depositional surface (active floodplain) in the stream. Theoretically, such a discharge occurs approximately every 1.5 years. It is the formative flow of water that characterizes the morphology of a fluvial channel.
Baseflow	Flow in a channel generated by subsurface flow or groundwater.
Bed Erosion	The process by which water entrains and transports sediment from the bottom of a channel, usually resulting in a deepening of the channel.
Bedload	The part of a channel's sediment transport that is not in suspension, consisting of coarse material that is moving on or near the channel bed.
Bioengineering	An engineering technique that mimics natural systems and uses vegetation, in part, for stabilization.
Bifurcation Ratio	A quantitative measure of the rate at which a stream network bifurcates. This is calculated by dividing the number of lower order streams by the number of the next higher order stream. The bifurcation ratio is an average of these calculations.
Critical Discharge / Velocity	The minimum discharge / velocity of a flow that could potentially entrain materials.

Cross-Section	A transect taken at right angles to the stream flow direction.
Deposition	The settlement of material onto the channel bed.
Discharge	The rate of flow expressed in volume per unit of time (usually expressed in m^3s^{-1}). Discharge is the product of the mean velocity and the cross-sectional area of flow.
Drainage Density	The average length of stream channel per unit area of a drainage basin, giving a measures of the degree of fluvial dissection.
Entrenchment	The vertical containment of a river and the degree in which it has incised into the valley floor. This provides an indication of the connection between a channel and its floodplain. The entrenchment ratio is calculated by dividing the channel width at two times the bankfull width by the bankfull width.
Ephemeral	A stream that flows only after rain or snowmelt and has no base flow component.
Erosion	A process or group of processes whereby surface soil and rock is loosened, dissolved, or removed from one place to another by natural means.
Facies	The sum total of features that reflect a particular sedimentological / depositional unit.
Floodplain	Any lowland that borders a stream and is inundated periodically by water.
Flow Competence	The maximum particle size capable of being entrained based on equations by Komar (1987).
Fluvial Geomorphology	The science of or pertaining to river processes. Also, the distinctive channel features produced by the action of a stream or river.
Gradient	The slope of a stream-channel bed or water surface, expressed as a percentage of the drop in elevation divided by the distance in which the drop is measured.
Gully	A steep channel with limited differentiation between valley and low flow channel, where both fluvial and slope processes are active.
Hydraulic Radius	The ratio of a stream's wetted perimeter length to the cross-sectional flow in a channel.
Intermittent	A watercourse lacking continuous definition of bed and banks.
Karst	A terrain with distinctive landforms and drainage (often underground), mainly originating from solutional erosion and commonly developed on carbonite rocks or evaporites
Macrophytes	A plant large enough to be visible to the naked eye, especially in reference to aquatic plants.
Manning's n	A resistance term within the Manning's equation.
Perennial	A stream that flows year-round.
Physiography	The study of landforms and soil forming materials.
Planform	The course of a river, as visualized on a two-dimensional surface, such as a map or photograph.

Reach	A channel type unit length with the same channel type existing for a length over twenty bankfull channel widths (Rosgen). The length of channel uniform with respect to discharge, depth, area, and slope. The length of a channel for which a single gage affords a satisfactory measure of the stage and discharge. The length of a river between two gaging stations. More generally, any length of a river.
Riffle	A reach of stream in which the water flow is shallower and more rapid than the reaches above and below.
Riparian	The area adjacent to flowing water (e.g. rivers, perennial or intermittent, streams, seeps or springs) that contains elements of both aquatic and terrestrial ecosystems.
Scour	The process of removing material from the bed or banks of a channel through the erosive action of flowing water.
Sediment Load	The sum total of sediment available for movement in a stream, whether in suspension (suspended load) or at the bottom (bedload).
Shear Stress	The force per unit area exerted tangentially to a given surface.
Shear Strength / Critical Tractive Force	The internal resistance of a material to shear stress. It is measured as the maximum shear stress on an original cross-sectional area that can be sustained. In soils, it is the maximum resistance of a soil to shearing forces under specific conditions. The peak shear strength is the highest stress sustainable just prior to complete failure of a sample under load; after this, stress cannot be maintained and major strains usually occur by displacement along failure surfaces.
Strahler System	A classification of stream order n + 1 is initiated at the confluence of two streams of order n, so that entry of a stream of lower order does not increase the order of the main stream.
Stream Order	Measure of the position of a stream within the hierarchy of the drainage network. A commonly used approach allocates order '1' to unbranched tributaries, '2' to the stream after the junction of the first tributary, and so on. It is the basis for quantitative analysis of the network.
Stream Power	The rate at which a stream can do work, especially the transport of its load, and measured over a specific length. It is largely a function of channel slope and discharge and is expressed by: Power = (the specific weight of water) x discharge x slope. Streams tend to adjust their flow and channel geometry to minimize their power.
Swale	A vegetation controlled drainage feature lacking defined bed and banks.
Tractive Force	Force, parallel to the streambed, exerted by flowing water on a sediment particle at rest.
Watercourse	Is flowing water, though not necessarily continuous, within a channel possessing bed and banks that usually discharges into some other stream or body of water.
Watershed	The land drained by a river or creek and its tributaries.