Appendix G

Fluvial Geomorphology Report

Environment

City of Ottawa

East LRT Planning and Environmental Assessment – Fluvial Geomorphology Report

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Appendix A. Photographic Record

1. Introduction

AECOM, in association with Parsons, MMM Group Limited (MMM) and Houle Chevrier Engineering Limited (HCEL) were retained to undertake the Planning and Environmental Assessment (EA) for the Ottawa East Light Rail Transit (LRT). This report describes the geomorphic conditions of the watercourse that occur in the study area based on a review of existing background documents and historical aerial photos as well as field reconnaissance. Results of this investigation are used to identify channel sensitivities and potential constraints that may inform the design process and environmental commitments for the EPR.

1.1 Project Background

The Eastern LRT from Blair Station to Trim Road project is identified in the City of Ottawa 2013 Transportation Master Plan (TMP) to extend the Confederation Line further east to Orléans. The 2013 TMP envisions the Eastern LRT facility along the Ottawa Road 174 (OR174) corridor. Within this road corridor, a multi-jurisdictional Environmental Assessment (EA) Study is currently underway on a proposed widening of the OR174, extending from the Highway 417/174 Split to the County Road 17 (CR17) and Landry Road in Clarence-Rockland in the United Counties of Prescott-Russell.

Co-locating the Eastern LRT within the OR174 road corridor will have ramifications on the OR174 widening options, and both projects will need to be coordinated and undertaken concurrently. For each proposed integrated solution (OR174 widening and Eastern LRT), a comprehensive review of environmental conditions and potential impacts will need to be assessed and evaluated to understand the impacts and tradeoffs associated with each solution.

1.2 Project Study Area

The project study area extends from approximately Blair Road in the west to Trim Road in the east (Figure 1).

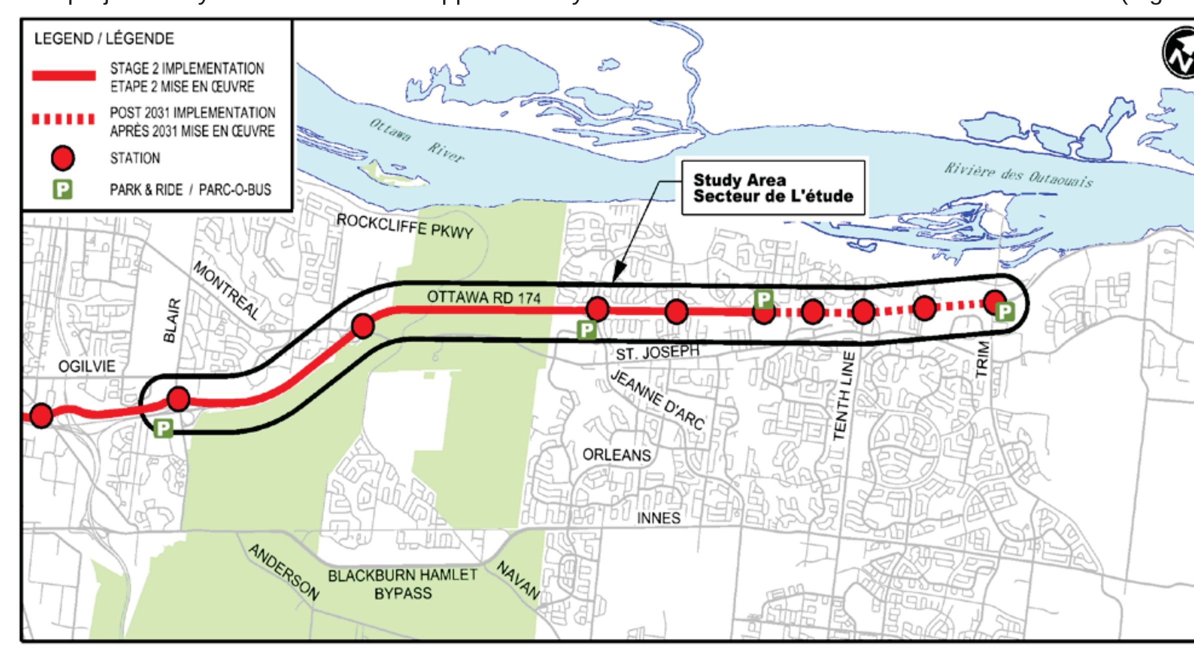


Figure 1. Eastern LRT and EA Study Area

1.3 Report Goals

The key goals for this Fluvial Geomorphology Report are to:

- Provide an understanding of the geomorphologic characteristics and conditions of watercourses within the study area
- Identity opportunities and constraints to be considered during route evaluation and design of the transit route/crossings

2. Background Review

A number of previous studies have been conducted in relation to the watercourses in the vicinity of the Ottawa East LRT study area. The depth and extent of fluvial geomorphic characterization in these studies varies by watercourse and reflects the scope of the reports (e.g., general fluvial risk assessment versus a localized site evaluation). The following documents were reviewed and found to contain information useful to define existing conditions of the watercourses:

- Bilberry Creek Geomorphic Assessment, City of Ottawa (Geomorphic Solutions, 2007)
- Conceptual Study for the Realignment of Brisebois Creek from Place d'Orléans Dr. to Tenth Line Road (R. V. Anderson Associates Limited, 2007)
- Phases 1 & 2 Class EA report Taylor Creek Erosion Control (Stantec Consulting Limited, 2007)
- Memo: Taylor Creek Erosion Control Hydraulic Modelling - DRAFT (Stantec Consulting Limited, 2007)
- Bilberry Creek Storm Water Management and Erosion Control Study (Cumming Cockburn Ltd. and Golder Associates, 1987)
- City Stream Watch Annual Reports (Rideau Valley Conservation Area, 2007, 2008, 2009, 2010)
- Historic aerial photographs (1926, 1945, 1950, 1959, 1960, 1973, and 1991)
- Green's Creek Watershed Integrated Fluvial Geomorphological and Hydrological Study (JTB Environmental Systems Inc., and J.F. Sabourin & Associates, Inc., 2009)
- Green's Creek Watershed Fluvial Risk Mapping (JTB Environmental Systems Inc., 2011)
- Characterization of Ottawa's Watersheds: An Environmental Foundation Document with Supporting Information Base. (City of Ottawa, March 2011)

Review of background information provided insight for many watercourses within the study area. Information for several watercourses, through the study area, was limited or non-existent. It is possible that additional background materials exist but have not yet been located and could be used to update the report. In other cases, further study of the creeks and/or their tributaries may be necessary. Specific creeks for which background information was limited were:

- Voyager Creek
- Taylor Creek
- Cyrville Drain

The acquisition of additional background materials may provide further insight into geomorphic channel conditions that could define constrains for improvements to the Ottawa East LRT. In many cases, potential impacts can be mitigated through appropriate crossing design.

3. Study Area Characterization

3.1 Physical Environment

Geology and topography are key controls of channel form and function. These characteristics influence the rate of channel migration and evolution, the rate of incision, the volume of sediment delivered to the watercourse, channel dimensions, and characteristics of bed morphology. Human modifications of the landscape (e.g., urbanization) alter the influence of natural physical characteristics within a watershed, often leading to an exacerbation of channel processes. A review of the general physical environment within the study area was undertaken which will provide a context for subsequent observations and analyses of channel form and function.

3.1.1 Geology

The Ottawa area lies in a rift valley known as the Ottawa Bonnechere Grabben, bounded by the Mattawa and Pettawawa Faults. Locally, the City of Ottawa and study area are surrounded by the Precambrian rocks of the Canadian Shield to the North and by the Frontenac Axis to the West (Chapman and Putnam, 1973). The bedrock geology of the study area is presented in Figure 2. The underlying bedrock within the basin is predominantly limestone and dolomite of the Ordovician period; with the exception of the Greens Creek subwatershed which is underlain by shale (City of Ottawa, 2011). The bedrock is gently folded, resulting in broad bedrock-controlled plains, tilting to the west. Bedrock is generally near the surface and exposed at faults, which form the major topographic features of the area and cross the study area in several locations. The complex form of block faulting in the Ottawa area created a basin into which marine sediments were deposited during the time that the Champlain Sea occupied the area (Marshall et al., 1979). Bedrock is also exposed in some areas where fluvial erosion has removed surface sediments.

The surficial geology of the study area is presented in Figure 3. Review of this map suggests that the watercourses within the study area are situated in a range of materials including bedrock, colluvial deposits, deltaic sediment, massive-well laminated tills, and alluvial deposits. Table 3-1 provides an overview of the dominant geology that occurs along the stream corridors.

3.1.2 Physiography

The physiography of the Ottawa area is related largely to the former occupancy of the region by the Champlain Sea. Following glacial retreat and prior to isostatic uplift, what is presently the Ottawa area was part of an inlet connected by the St. Lawrence River to the Atlantic Ocean. Marine water occupied the area for 2,000 to 3,000 years during which time marine clay was deposited on the underlying bedrock and till beds of the sea floor forming the clay plains that make up much of the Ottawa area physiography today. As the Champlain Sea receded, becoming an estuarian environment, sand was deposited overtop the clays. Glacial melt water continued to flow through this area, creating finely textured deltaic deposits. The Ottawa River, at that time, occupied a much larger area than it does currently and was split into two branches around what is now Orleans. The shifting channels of the Ottawa River created terraces and abandoned channels and also left fluvial sediments in some areas. Most of what was the south branch of the Ottawa River is now occupied by the Mer Bleue bog. Bedrock outcrops and glacial tills were affected by the presence of the Champlain Sea, and many of these features that are present at surface have been modified and reworked, such as by wave action (Marshall et al., 1979). Most of the watercourses in the study area flow over areas of the marine clay beds and these clays can be seen on eroded beds and banks.

3.2 Drainage Networks

The study area passes through five subwatersheds which are situated within the jurisdictions of Rideau Valley Conservation Authority (RVCA). These subwatersheds drain north to the Ottawa River. They are listed below from west to east and are illustrated in Figure 4:

1. Cyrville Drain (a tributary of mid-Green's Creek)
2. Green's Creek
3. Voyager Creek (West Bilberry Creek)
4. East Bilberry Creek
5. Taylor Creek

In addition to these five subwatersheds, the study area also includes portions of the Rideau Downstream, Ottawa East of Core 2 (within the RVCA jurisdiction), and North Indian Creek subwatersheds. Due to the lack of surface water features within these subwatersheds, they will not be discussed in this report. Initial evaluation of available GIS mapping indicates there are three major creek crossings (Green's, East Bilberry, Taylor).

Table 3-1. Overview of physical characteristics for each watershed (from west to east) along the study area

Subwatershed	Drainage Area (km^2)	Study area (km^2)	Physiographic unit	Surficial Geology	Dominant Landuse
Cyrville Drain	7.20	2.97	Till Plains (Drumlinized)	Clay and silt underlying erosional terraces; upper part of marine deposits removed to variable depths by fluvial erosion so in places clay is uniform blue-grey; unit includes lenses, bars and channel fills to sand and pockets of nonmarine silt that were formed during terrace (or channel) cutting.	Mixed
Greens Creek	14.12	6.71	Clay Plains	Clay and silt underlying erosional terraces; upper part of marine deposits removed to variable depths by fluvial erosion so in places clay is uniform blue-grey; unit includes lenses, bars and channel fills to sand and pockets of nonmarine silt that were formed during terrace (or channel) cutting. The watershed typically has a high degree of permeable overburden (City of Ottawa, 2011)	Agriculture/ Recreation/ Forest
West Bilberry Creek (Voyager Creek)	9.97	1.22	Clay Plains	Clay and silt underlying erosional terraces; upper part of marine deposits removed to variable depths by fluvial erosion so in places clay is uniform blue-grey; unit includes lenses, bars and channel fills to sand and pockets of nonmarine silt that were formed during terrace (or channel) cutting.	Mixed
East Bilberry Creek	11.71	3.80	Clay Plains	Clay and silt underlying erosional terraces; upper part of marine deposits removed to variable depths by fluvial erosion so in places clay is uniform blue-grey; unit includes lenses, bars and channel fills to sand and pockets of nonmarine silt that were formed during terrace (or channel) cutting.	Mixed
Taylor Creek	9.72	5.50	Clay Plains	Clay, silty clay and silt, commonly calcareous and fossiliferous; locally overlain by thin sands. Upper parts are generally mottled or laminated reddish brown and bluish grey and may contain lenses and pockets of sand, but at depth the clay is uniform and blue-grey.	Residential

Figure 2: Bedrock Geology

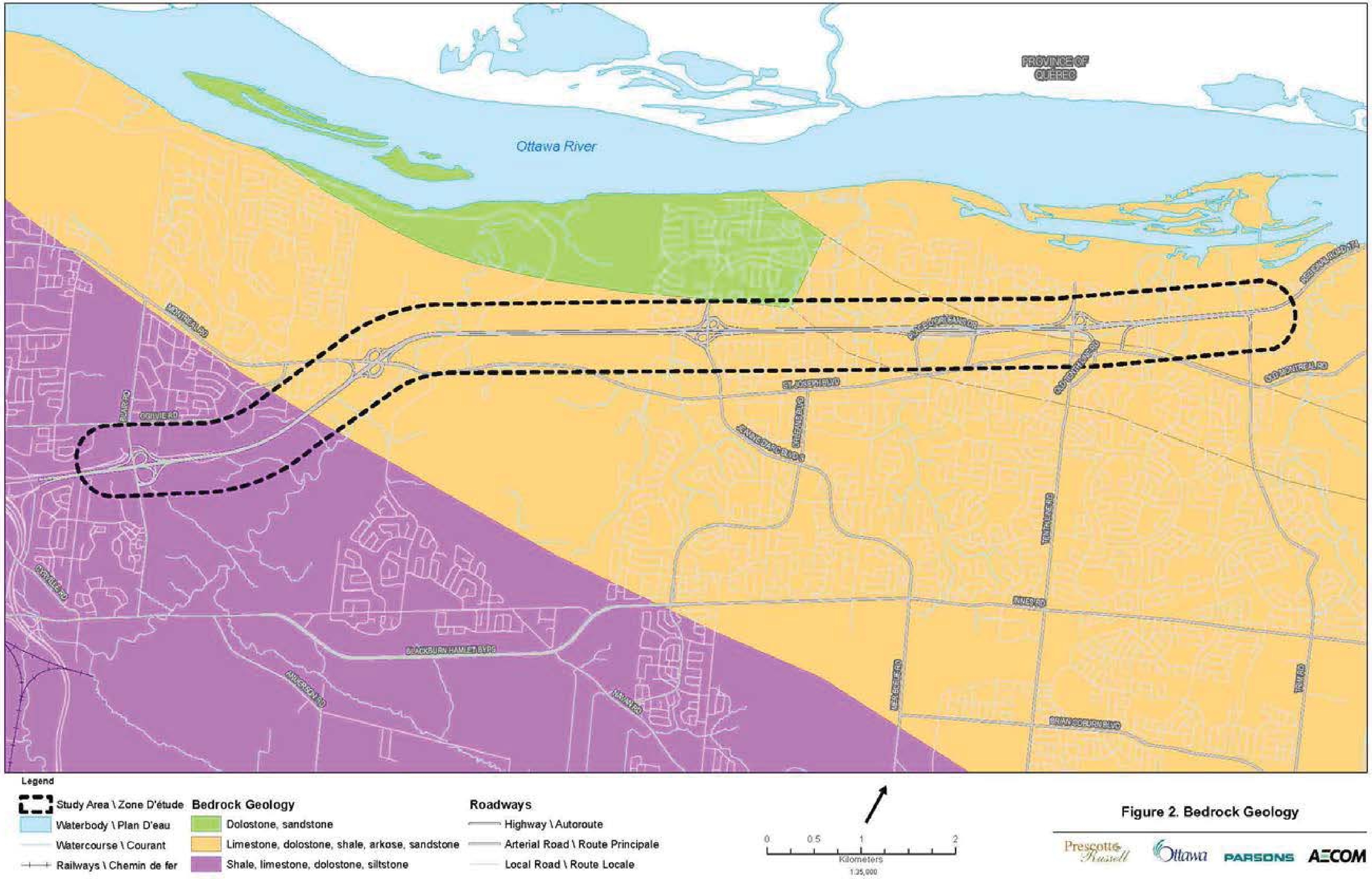


Figure 3. Surficial Geology

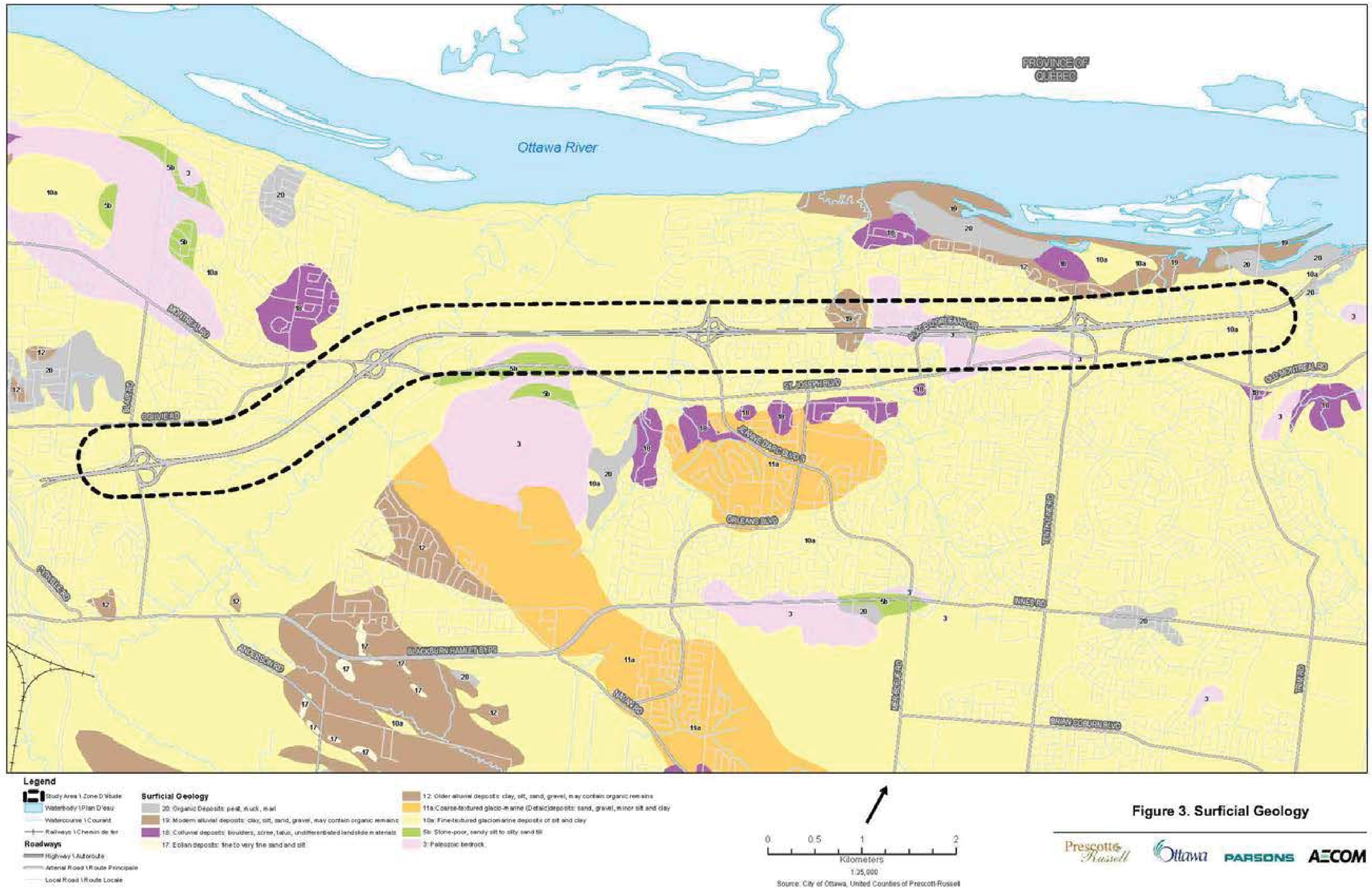
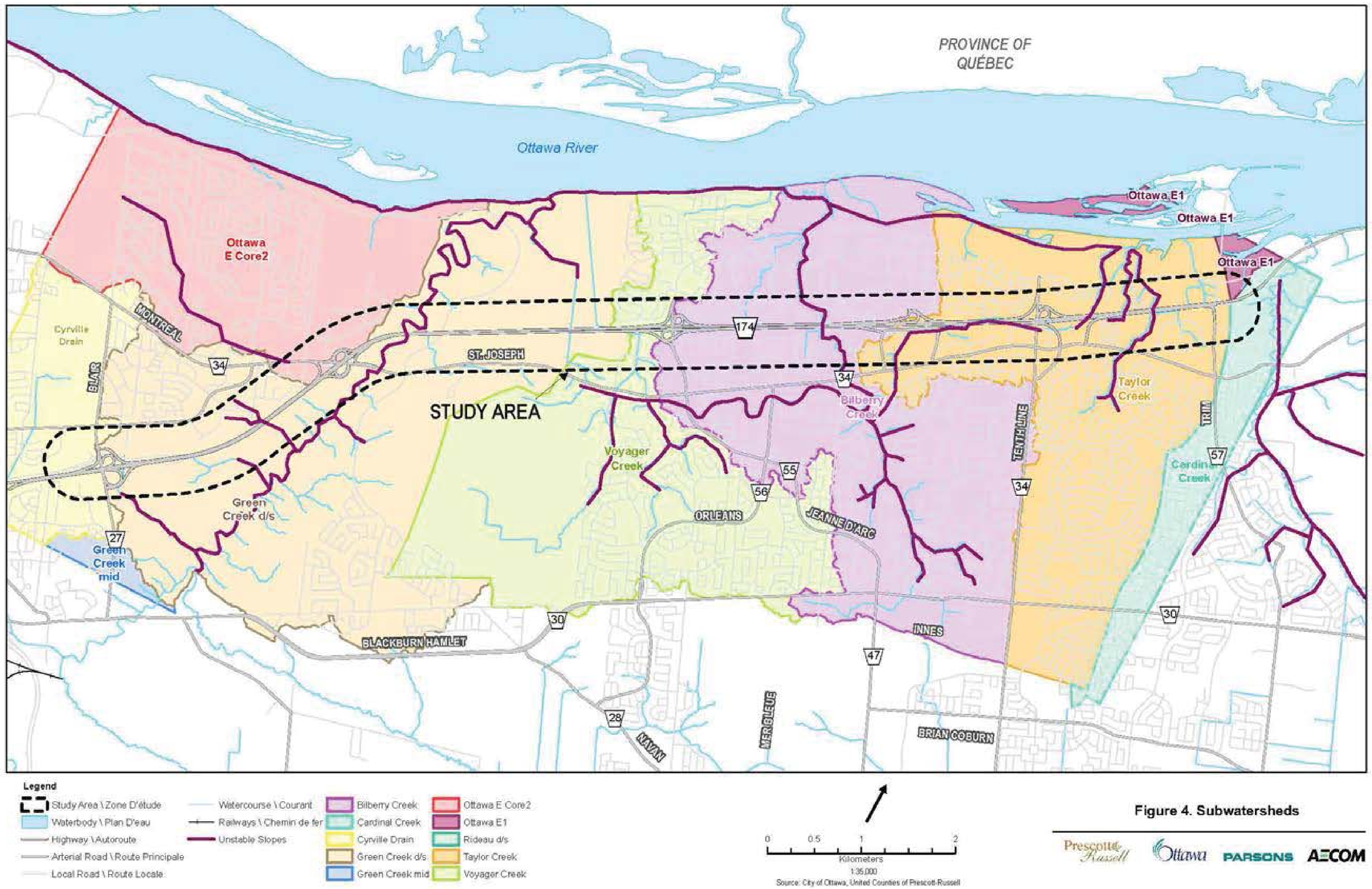


Figure 4. Subwatersheds within the study area



4. Historical Assessment

Review of aerial photography enables identification of changes in land-use and landcover that directly affect controlling (e.g., runoff) and modifying (e.g., vegetation) influences of channel form. By identifying the nature of change that has occurred within the watershed and general study area, future channel responses can often be predicted, in conjunction with an understanding of site geology and physiography. This leads to an understanding of potential channel sensitivity and identification of mitigation factors to be considered in the alternative identification/selection process for the proposed road alternatives.

The historical assessment for this study was based on a review of aerial photographs spanning the period from 1926 to 1991. Available background reports and satellite imagery were also reviewed to gain further insight into historic conditions and/or changes in the study area. Current land use within the study area can be observed in Figure 5.

4.1 Land use

Prior to 1945, land use was predominantly agricultural. Buildings and vegetation were sparse. Urban development began around 1950, likely in conjunction with construction of the highway and accelerated after 1973, progressing outward from Old Montreal Road in Orleans. Historic photographs were not available for the Gloucester area, however, it is reasonable to presume a similar temporal progression of development. At present, the western portion of the study area is densely urbanized. Details based on review of available background information and imagery for specific subwatersheds are presented in Table 4-1**.**

4.2 Drainage Network

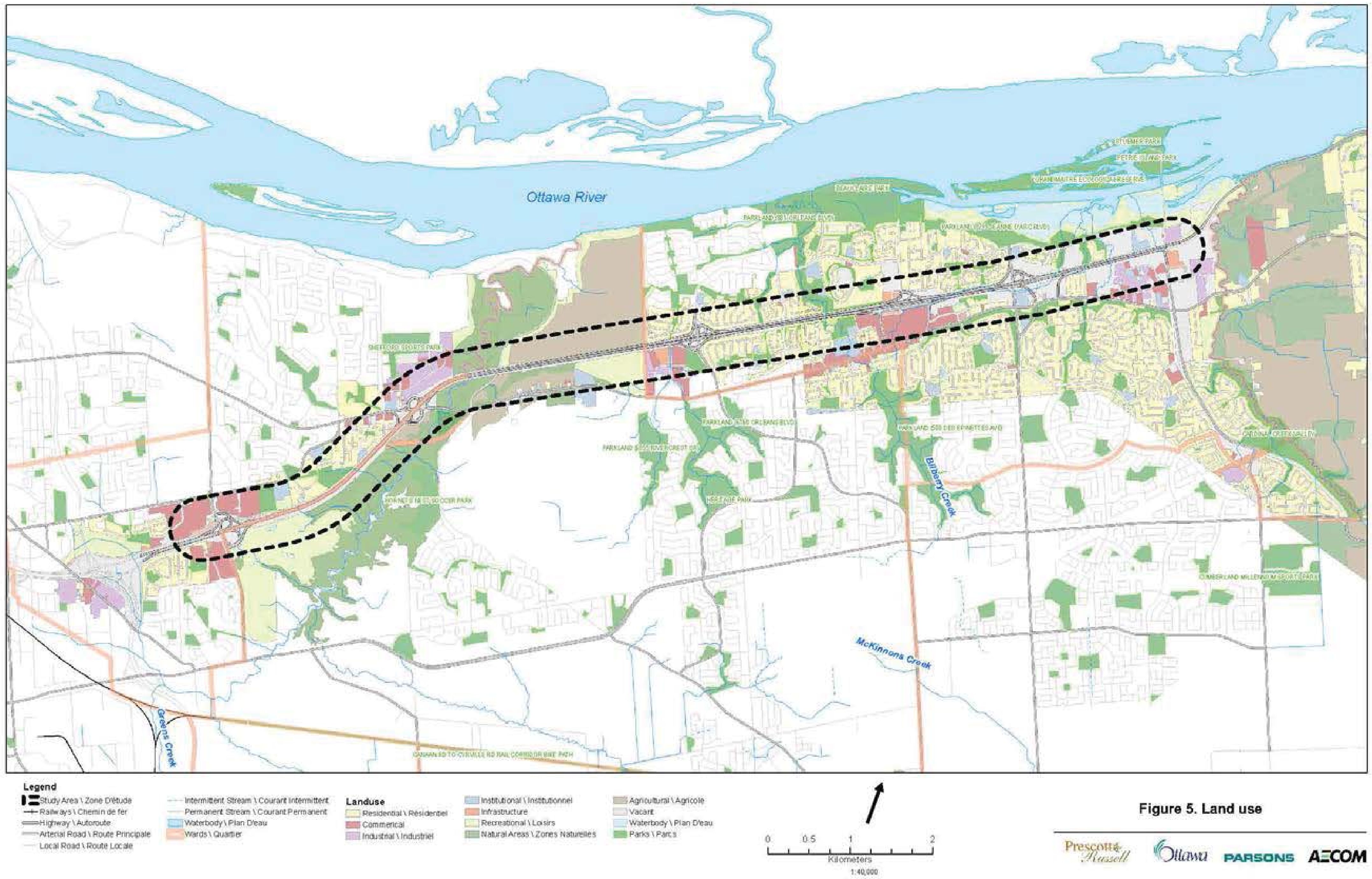
Changes to the drainage network often occur in conjunction with landuse alterations. These drainage network changes may include loss of surficial drainage channels (e.g., swales which are replaced by tile drains in agricultural fields, or replacement of small watercourses with a storm drainage network) which alters the hydrologic characteristics of the watershed. When flows are altered (e.g., increase in peak flows, duration of flows in the creek), then the channel will respond. Further, when a loss in channel length occurs, then an increase in stream energy occurs, which requires a channel response and thus has implications to in-stream processes and channel stability.

The review of historic background information and aerial photographs/ satellite imagery revealed that many watercourse reaches had been realigned and straightened to accommodate agricultural activities prior to 1926. Urbanization in densely developed portions of the study area resulted in further realignments, diversions, piping, and loss of headwater channels and an overall reduction in channel length. Although the natural silt/clay substrate was noted to provide some resistance to change, these watercourses show signs of impacts from urbanization, such as general straightening, widening, bed degradation, and downcutting (Geomorphic Solutions, 2007). In general, watercourse reaches in subwatersheds containing urbanized areas show more evidence of alteration than those impacted only by agricultural activities.

Table 4-1. Overview of historical changes in land use and drainage network within the study area

Subwatershed	Primary Land Use	Historic Channel Changes		Historic Loss of Channel Length
		Study Area	Upstream	
Cyrville Drain	Urban	Realignment and channelization suspected	Likely channelization around residential area	Assumed loss due to modifications
Green's Creek	Conservation Area / Urban / Golf Course	Tributaries north of highway piped	Modification in urbanized areas, e.g., concrete wall lining bank at Innes Road	Limited channel loss suspected in urbanized areas
Voyager Creek	Urban / Agricultural	Straightened and channelized, piped reaches	Possible modification in urban area	Limited loss of headwater channels suspected
East Bilberry Creek	Urban	Bank Armouring	Substantial channel straightening, bank armouring, and diverted / piped tributaries; one major tributary diverted	Substantial loss of headwater channels due to urbanization upstream of study area
Taylor Creek	Urban	Brisebois Creek Straightened, channelized; Taylor Creek Armoured	Taylor Creek channelized and concrete-lined; piped	Assumed due to modifications

Figure 5. Current land use



5. Existing Conditions

A review of background materials was completed to gain insight into the existing conditions of watercourses within the study area. The review focused specifically on identification of existing areas of erosion or instability concern and general characterization that are directly relevant to the study area and objectives of the study. A review of current aerial photography and mapping along each watercourse to identify modifying influences of channel form.

Findings from the background review are described in each subsection of this chapter, beginning from west to east within the study area. Results are further summarized in Table 5-1.

5.1 Cyrville Drain

The Cyrville Drain subwatershed is located at the western limit of the study area. Within the study area, the subwatershed extends from the Aviation Parkway to the Blair Road interchanges along the length of the highway. The watercourses are completely channelized and appear to have been realigned to accommodate the highway interchange. Headwaters are located in the residential area to the north and the Cyrville Drain outlets to Green's Creek. The Cyrville Drain subwatershed contains three watercourse crossings along Ottawa Road 174.

5.2 Green's Creek

The Green's Creek subwatershed is located near the western limit of the study area and extends from Blair Road to approximately 1 km east of Rockliffe Parkway. The creek has several tributaries including Borthwick Creek, Mud Creek, Black Creek and Ramsay Creek and flows northeast, under Ottawa Road 174 to the Ottawa River.

South of the highway, the subwatershed is located entirely within National Capital Commission (NCC) Greenbelt Lands and includes the Green's Creek Conservation Area. Land use in this area is a mix of forest, golf course, and agriculture. Land use varies in all directions in relation to the highway: north – residential, west – commercial, east - agricultural. In the majority of the subwatershed (upstream of the study area), land use is an approximately even mix of forested park land, golf course, residential and aggregate. Through the study area, Green's Creek, flows in a northeasterly direction from Highway 174 (where the main branch splits) to the outlet at the Ottawa River and has several watercourse crossings.

Much of the Green River valley has been identified as a Life Science Area of Scientific Interest (ANSI), containing a diverse flora and fauna and as an important link between the Mer Bleue Bog and the Ottawa River (RVCA, 2010). Instream substrate is predominantly clay and silt. Natural pool-riffle sequences are present but spaced far apart. Bank vegetation is dense and forested, overall, along the main branch and tributaries. RVCA (2010) reported approximately 35% of the banks as "unstable" and that issues of erosion have been identified, particularly between Innes Road and St. Joseph Boulevard (upstream of the study area).

During the 2010 RVCA assessment, Green's Creek was surveyed from the mouth of the creek to 13.5 kilometers south which encompasses the study area. The stream morphology of Green's Creek is described as mostly runs with areas of pools and riffles. Substrates are described as mostly clay, sand, muck, gravel and silt. Cobble and boulder were identified in smaller percentages.

A large portion of the stream is classified as 'not altered'; however 20% of the 13.5 km's surveyed are classified as 'highly altered' and may be straightened, armoured, have little to no buffer and are mostly located near road crossings. Rapid Geomorphic Assessments completed within the study area JTBES (2011) indicate that the main

branch of Green's Creek and its tributaries are either in 'adjustment' or 'in transition' and is sensitive to land use change.

Within the study area, steep bank slopes are evident in satellite imagery at meander bends. Instances of erosion and or slope failure are visible both upstream and downstream of Highway 174. Native clay substrate has been linked with stability and land slide issues. Observation of satellite imagery shows that tributaries originating north of the highway crossing appear piped and likely convey storm water to the system. RVCA (2010) indicated that numerous stormwater outlets contribute to increased storm peaks, erosion, and poor water quality. Development in the upstream watershed may further exacerbate the system.

5.3 Voyager Creek (West Bilberry Creek)

Voyager Creek, also referred to as West Bilberry Creek, is situated to the east of Green's Creek. Voyager Creek flows in a northerly direction to the Ottawa River through a variety of different land uses including natural areas, commercial (south of highway) residential areas (upstream of study area), agriculture (north of highway), recreational areas and has several road crossings.

Within the study area, Voyager Creek has been straightened and channelized. Review of satellite imagery suggests that the creek is piped through some reaches. The creek follows a natural sinuous path in the headwaters and is channelized north of St. Joseph Boulevard.

5.4 (East) Bilberry Creek

The Bilberry Creek subwatershed is located towards the west end of the study area, and is adjacent (east) to Voyager Creek. Within the study area, the main branch of East Bilberry Creak follows northward, sinuous path through park/residential land to the Ottawa River. The channel, which has a relatively narrow vegetative buffer, has few tributaries within the study area. Land use within the study area and watershed consist primarily of urban development; natural and recreational areas are also present. Several road crossings occur along the creek.

During 2009, the City Stream Watch completed an assessment of Bilberry Creek which found that the majority of the watercourses are considered natural with no major alterations. Review of other background materials however, revealed that, between Ottawa Road 174 and Notre Dame Street, alteration of the channel has occurred, which included bank armouring, channel straightening, and addition of fill.

Within the general study area, Bilberry Creek shows characteristics typical of watercourses impacted by urbanized settings: generally straight planform, high width to depth ratio, and degradation of bed and banks due to high energy storm flows. Riffle-pool sequences are developed but are spaced widely and likely altered by in channel modifications. Geomorphic Solutions (2007) note that the natural silt and clay bed and bank material provide some resistance to erosion (Geomorphic Solutions, 2007).

Bedrock is exposed along the channel in the vicinity of the Ottawa Road 174 crossing. Here, bed and banks are lined with riprap as erosion protection. Basal scour in unprotected stream bed and a knickpoint in the bedrock section show downcutting. Eroding cutbanks bordering private property are also present in this reach. Downstream of the highway, the watercourse is more sinuous. Bank slumping and slope failure are prominent erosive features identified within the study area both upstream and downstream of the highway. Further downstream, the gabion baskets have been applied to protect stream banks. Erosion protection (i.e., rip rap, gabion baskets, crib walls) installed within the study area and greater subwatershed appeared to be functioning as intended (Geomorphic Solutions, 2007). RVCA (2009) classified approximately 45% of the watercourse banks as "unstable".

Within the watershed, channel modifications have taken place in relation to historic agricultural land use and subsequent land development (e.g., straightening, realignments, diversion and piping) resulting in a loss of channel length in the subwatershed. Most notably, many headwater swales and gullies were lost during land development. In addition, an entire branch was diverted at the western end of the subwatershed. The resultant loss channel length is that most reaches are in transition with adjustment concentrated in higher gradient reaches (Geomorphic Solutions, 2007). Erosion (deep scour pools) has been found concentrated in areas associated with storm water outfalls. Channel adjustments resulting in slope instability prompted efforts to protect some reaches against accelerated erosion. Several erosive features were noted during fieldwork completed by Geomorphic Solutions (2007).

5.5 Taylor Creek

The Taylor Creek subwatershed is located at the east end of the study area. In addition to Taylor Creek, the Taylor Creek subwatershed contains three other creeks all of which cross under Ottawa Road 174. From west to east, the creek crossings are Brisebois Creek, Bellevue Creek, Taylor Creek and an unnamed creek.

Brisebois Creek flows west to east, along the southern border of the highway through commercial property. It is a highly modified, straightened channel draining commercial and residential lands and passing through several culverts in the vicinity of the highway, Tenth Line Road and associated ramps. The main branch of Brisebois Creek crosses the highway just west of the Tenth Line Road eastbound onramp. North of the highway crossing, the creek passes through a stormwater management pond before entering the Ottawa River. Brisebois Creek is intermittent in nature and dries up partially in the summer (R. V. Anderson Associates Limited, 2007).

Bellevue Creek is a short sinuous drainage feature located east of Brisebois creek. The banks are forested and the creek is partially confined. No information regarding channel conditions was found in the literature.

Taylor Creek is located to the east of Bellevue Creek and crosses Ottawa Road 174 between Tenth Line Road and Trim Road. The creek originates from a stormwater retention pond located at the top of the Orleans escarpment. Immediately upstream of the study area, the creek emerges from an upstream, entombed reach (from Princess Louise Drive) and flows through a concrete-lined channel. Taylor Creek flows through residential, commercial and agricultural development and is divided by Ottawa Road 174. Taylor Creek then flows through a ravine towards the Ottawa River consisting of mixed upland forest and lowland forest (Stantec, 2007).

Geomorphic data regarding Taylor Creek were found in the Stantec Consulting (2007) and RCVA (2007) background reports. Within the study area, the creek is quite sinuous and natural in form. Watershed urbanization has resulted in an increase of storm flows which is held accountable for the minor to severe erosion observed within the study area. Upstream of the highway crossing, there is evidence of frequent scour to the bed and banks, clay deposits in pools, compaction to the bed, low vegetation in the watercourse and fallen trees and other debris in the channel. The water his highly turbid and riffles are poorly-developed. Downstream of the highway crossing, the watercourse is deeply incised. Localized scour, slumps, and debris accumulation are present. Erosion is concentrated on the outsides of meander bends. At the highway crossing, gabion baskets and riprap have been placed as erosion control and downstream of the highway crossing, a riffle-pool sequence has been constructed. In the immediate vicinity of the highway, the watercourse is relatively straight and does not appear to pose immediate constraints. It was noted by RVCA (2007) that approximately 55% of the banks were considered “unstable” and rehabilitation would be taking place in 2008.

Table 5-1. Overview of channel conditions by watershed, from west to east along the study area

Subwatershed	Background reports	Key findings for Study Area	Upstream land use	Current landuse along watercourse	Channel Planform	Valley setting)	Stream Orders
Cyrville Drain	No	n/a	Urban	Urban	Altered	Unconfined	2
Green's Creek	Yes	Channel is in adjustment or in transition Channel is sensitive to landuse change Erosion concerns present	25% Agricultural 25% Forest 25% Urban 25% Aggregate	30% Agricultural 40% Urban 25% Forest 5% Golf Course	Natural	Partially Confined	3
Voyager Creek/ West Bilberry Creek	No	Some urban impacts	100% Urban	50% Agricultural 45% Urban 5% Golf Course	Straightened	Partially Confined	4
East Bilberry Creek	Yes	In Transition; Impacted by Urbanization Bedrock exposure Bank erosion and scour Exposed foundation of pedestrian bridges	95% Urban 5% Agricultural	100% Urban	Altered - min. 50% Straightened	Partially Confined	3
Taylor Creek	Yes	Minor to severe erosion (scour, slump), meander bend erosion Historic channel modification	100% Urban	75% Urban 25% Agricultural	Natural	Partially Confined	2

6. Field Reconnaissance

Field reconnaissance focused on permanently flowing watercourses with existing crossing spans greater than 3 m. As a result, Green's Creek, Bilberry Creek, and Taylor Creek were assessed within the vicinity of the Highway 174 crossings. Further information regarding each structure, taken from the structural database of the City of Ottawa is detailed in Table 6-1. Chainages are taken from the functional ELRT and highway widening plan by Parsons for the ELRT project.

Table 6-1. Culverts subjected to field reconnaissance

Crossing	Approximate Chainage	Span (m)	Length (m)	Materials	Year Installed/ Extended
Green's Creek	303+935	32.7	66.5	4 Structural Plate Corrugated Steel Culverts	1958/1979
Bilberry Creek	308+340	3.4	100.3	Concrete Reinforced Box	1960/2009
Taylor Creek	311+865	3.5	110	Concrete Reinforced Box	1994

The geomorphological field investigation involved the following components:

- Geomorphological Reach Characterization
- Rapid Geomorphological Assessment
- Watercourse Crossing Assessments

- Photographic Record

6.1 Geomorphological Reach Characterization

As part of the reconnaissance field work, basic geomorphological reach data was identified and recorded. This included recording typical bankfull dimensions, noting bed and bank materials, land use, the influence of vegetation, locations of confinement by valley slopes, degree of channel-floodplain connectivity, and location of channel erosion and modification. Reaches can be defined as lengths of channel that display similar physical characteristics and have a setting that remains nearly constant along their length. Thus, in a reach, the controlling and modifying influences on the channel are similar, and are reflected in similar geomorphological form, function and processes within the reach. Due to land access constraints, reaches for this assessment were defined as the area immediately (within ~200 m) upstream and downstream of each of the crossings

6.2 Rapid Geomorphological Assessment

The Rapid Geomorphic Assessment (RGA) was designed by the Ontario Ministry of Environment (1999) to assess reaches in urban channels. This technique uses visual indicators to document evidence of channel instability using a presence/absence methodology. Stability is determined by adjustments in slope, either an increase (aggradation) due to sediment deposition or a decrease (degradation) due to bed erosion. It also considers an increase in the bank to bank width (widening) and by any evidence indicating adjustment in the planimetric form regime. Each of the geomorphic indicators is documented throughout the reach and upon completion, is tallied by category. This data is then used to calculate an overall reach stability index which classifies the reach as 'stable', 'transitional', or 'in-adjustment' which correspond to their relative sensitivity to altered sediment and flow regimes (Table 6-2).

Table 6-2: RGA Classification (Source: Ontario Ministry of Environment, 2003)

Factor Value	Classification	Interpretation
≤0.20	In Regime or Stable (Least Sensitive)	Channel morphology is within a range of variance for streams of similar hydrographic characteristics – evidence of instability is isolated or associated with normal river meander propagation processes
0.21-0.40	Transitional or Stressed (Moderately Sensitive)	Channel morphology is within the range of variance for streams of similar hydrographic characteristics but the evidence of instability is frequent
≥0.41	In Adjustment (Most Sensitive)	Channel morphology is not within the range of variance and evidence of instability is wide spread

6.3 Watercourse Crossing Assessment

Data relating specifically to the existing crossings were collected and documented. Information recorded included:

- Hydraulic characteristics
- Morphological characteristics immediately upstream and downstream as well as within the crossing
- Assessment of potential issues relating to the crossing (e.g. bank erosion, bed scour, debris trapping, and fish passage)

6.4 Photographic Record

A photographic record was completed along the channel reaches and at the crossing locations to document channel dimensions, bank and bed materials, riparian vegetation, valley walls, and floodplain dynamics. Locations of

geomorphological importance were also photographed and included bank erosion sites, channel modifications, and large woody debris (LWD) jams.

6.5 Results

6.5.1 Green's Creek (303+935)

Green's Creek flows within a large, defined valley. The four separate CSP culverts are outdated and are poorly placed (meander bend). The channel is entrenched and has poorly-defined bed morphology. There is large depositional feature on the left bank (defined looking downstream) immediately upstream of the crossing. A photographic record of Green's Creek and the Highway 174 crossing can be observed in **Appendix A**.

Results of the RGA are presented in Table 6-3. The dominant morphological process at Green's Creek within the vicinity of the crossing is degradation which has caused the channel to become entrenched and have a low bed relief form. Degradation (along with channel widening) often occurs following watershed urbanization as the sediment supply is decreased and the channel enlarges its cross-sectional area to accommodate larger peak flows.

Table 6-3. RGA results at Green's Creek

Reach	Factor Value				Stability Index	Condition	Dominant Process
	Aggradation	Degradation	Widening	Planform Adjustment			
Upstream	0.14	0.38	0.22	0.14	0.22	In-Transition	Degradation
Downstream	0.29	0.33	0.22	0.00	0.17	In-Transition	Degradation

Further detail regarding reach-scale morphological features and processes are presented in Table 6-4. Bank characterization is detailed in Table 6-5.

Table 6-4. Reach scale morphological characteristics of Green's Creek

Indicator	Upstream	Downstream
Channel Form (natural, modified)	Natural, bank modifications	Natural
Bankfull Depth (m)	1.1	1.0
Bankfull Width (m)	12.0	12.5
Bed Morphology	Poorly defined	Poorly defined
Boundary Materials	Alluvial, engineered (rip-rap)	Alluvial, engineered (rip-rap)
D_{50} Estimate	Coarse Sand	Coarse Sand
Excess sedimentation?	Left bank	Between outlets
Excess scour?	Right bank	No
Floodplain Connectivity	Poor (entrenched)	Poor (entrenched)
Valley Setting	Confined to the east	Confined to the east
Surrounding Land Use	Forest, highway corridor	Forest, highway corridor
Woody Debris	Yes – at inlet	Minor accumulations on banks
Riparian Vegetation	Shrubs, herbs, tall grasess	Deciduous trees, shrubs, tall grasses

Table 6-5. Bank characterization at Green's Creek

Bank Measure	Upstream	Downstream
Approximate Bank Height (m)	1.5	1.5
Approximate Rooting Depth (m)	0.5	0.5
Approximate Bank Angle (°)	45-60	45-60
Bank Face Protected by Vegetation (%)	50	50
Dominate Bank Materials	Silt and clay	Silt and clay
Modifications	Right bank – gabion baskets (failing) Left bank – rip-rap	No

The following should be considered during the detailed design of the proposed Green's Creek crossing:

- Gabion baskets on the right bank upstream of the inlets are failing
- Groundwater discharge was observed on the right bank upstream of the inlets
- The channel is entrenched and has poor connectivity with the floodplain which will result in further bed degradation and bank slumping
- The four separate culverts are disrupting the sediment transport regime and resulting in areas of excess sedimentation and scour
- The furthest west culvert is not accessible during base flow conditions
- Notable deposition on the upstream left (inside) bank and scour on right (outer) bank
- Debris accumulation at inlets

6.5.2 Bilberry Creek (308+340)

Bilberry Creek is a meandering channel that contains both alluvial and bedrock controlled sections within the vicinity of the Highway 174 crossing. Upstream of the crossing there is a series of bedrock steps. Downstream the channel is incised and is actively scouring the bed and bank. A photographic record of Bilberry Creek and the Highway 174 crossing is provided in **Appendix A**.

Results of the RGA at Bilberry Creek are presented in Table 6-6. The dominant morphological process upstream of the crossing is degradation as the channel has worn into bedrock. Downstream of the crossing, the channel is undergoing planform adjustment and degradation which is likely attributed to higher peak flows as a result of upstream development (two significant stormwater outlet were observed near the crossing). As well, failed gabion baskets and the subsequent deposition of the gabion material downstream of the outlet has caused multiple channels to form and has led to excess bed and bank erosion.

Table 6-6. RGA results at Bilberry Creek

Reach	Factor Value				Stability Index	Condition	Dominant Process
	Aggradation	Degradation	Widening	Planform Adjustment			
Upstream	0.00	0.38	0.11	0.00	0.12	In-Regime	Degradation
Downstream	0.42	0.67	0.33	0.71	0.53	In-Adjustment	Planform Adjustment

Further detail regarding reach-scale morphological features and processes are presented in Table 6-7. Bank characterization is detailed in Table 6-8.

Table 6-7. Reach scale morphological characteristics of Bilberry Creek

Indicator	Upstream	Downstream
Channel Form (natural, modified)	Natural and modified (armourstone)	Natural and modified (gabion baskets)
Bankfull Depth (m)	0.8	1.0
Bankfull Width (m)	5.0	6.0
Bed Morphology	Step-pool	Pool-riffle, multiple channels
Boundary Materials	Bedrock, alluvial, engineered	Alluvial, engineered
D_{50} Estimate	Course Pebbles	Fine Cobbles
Excess sedimentation?	No	No
Excess scour?	No	Yes – bed and bank scour
Floodplain Connectivity	Moderately entrenched	Moderately entrenched
Valley Setting	Confined	Confined
Surrounding Land Use	Forest, recreational	Forest, residential
Woody Debris	Minor accumulations on banks	No
Riparian Vegetation	Deciduous trees, shrubs, tall grasses	Deciduous trees, shrubs, tall grasses

Table 6-8. Bank characterization at Bilberry Creek

Bank Measure	Upstream	Downstream
Approximate Bank Height (m)	1.1	0.9
Approximate Rooting Depth (m)	0.4	0.5
Approximate Bank Angle (°)	45 - 90	<30
Bank Face Protected by Vegetation (%)	40	50
Dominate Bank Materials	Silt and clay	Silt and clay
Modifications	Right bank – gabion baskets (failing) at outlet, rip-rap and armourstone >100 m upstream of outlet	Both banks – gabion baskets (failing)

The following should be considered during the detailed design of the proposed Bilberry Creek crossing:

- Failed gabion on right bank at inlet
- Entrenched drainage channel confluences with main channel immediately upstream of culvert
- Failed gabion on both banks at outlet
- Failed gabion material has accumulated ~20 m downstream of the outlet
    - Multiple channels have formed
    - Diverting flows in the left bank valley wall causing excess scour
- Cut-off channels have formed at the meander upstream of the crossing
- Downstream of the crossing the channel is very incised and unstable
    - Consider removing failed engineering material (gabion, rip rap) and applying principles of natural channel design

6.5.3 Taylor Creek (311+865)

Taylor Creek is a meandering channel within a defined valley system. Approximately 20 m upstream of the crossing a beaver dam has caused backwater conditions to form and has disrupted sediment and debris transport. Review of ortho-imagery suggests the dam is less than 2 years old. Downstream the channel is actively scouring the bed and bank. A photographic record of Taylor Creek and the Highway 174 crossing can be observed in **Appendix A**.

Results of the RGA at Taylor Creek are presented in Table 6-9. The dominant morphological process upstream of the crossing is aggradation as backwater conditions has led to sediment deposition and an overall increase in bed elevation. Downstream of the crossing, the channel is undergoing planform adjustment which is likely attributed to higher peak flows as a result of upstream development. As well, similar to Bilberry Creek, failed gabion baskets and the subsequent deposition of the material downstream of the outlet has caused multiple channels to form and has led to excess bed and bank erosion.

Table 6-9. RGA results at Taylor Creek

Reach	Factor Value				Stability Index	Condition	Dominant Process
	Aggradation	Degradation	Widening	Planform Adjustment			
Upstream	0.29	0.00	0.00	0.14	0.11	In-Regime	Aggradation
Downstream	0.71	0.83	0.63	0.86	0.76	In-Adjustment	Planform Adjustment

Further detail regarding reach-scale morphological features and processes are presented in Table 6-10. Bank characterization is detailed in Table 6-11.

Table 6-10. Reach scale morphological characteristics of Taylor Creek

Indicator	Upstream	Downstream
Channel Form (natural, modified)	Natural and modified (gabion baskets)	Natural and modified (gabion baskets)
Bankfull Depth (m)	0.6	0.8
Bankfull Width (m)	5	6
Bed Morphology	Backwatered	Pool-riffle
Boundary Materials	Alluvial, engineered	Alluvial, engineered
D_{50} Estimate	Fine sand	Pebbles
Excess sedimentation?	Upstream of beaver dam	Deposition of gabion material ~10 m downstream of outlet
Excess scour?	No	Yes - bed and bank scour
Floodplain Connectivity	Good	Poor (entrenched)
Valley Setting	Confined	Confined
Surrounding Land Use	Forested, industrial	Forested, residential
Woody Debris	Beaver Dam 20 m upstream of inlet	Fallen trees >50 m downstream of outlet
Riparian Vegetation	Deciduous trees, shrubs, tall grasses	Deciduous trees, shrubs, tall grasses

Table 6-11. Bank characterization at Taylor Creek

Bank Measure	Upstream	Downstream
Approximate Bank Height (m)	0.8	1.2
Approximate Rooting Depth (m)	0.4	0.4
Approximate Bank Angle (°)	15-30	30-45
Bank Face Protected by Vegetation (%)	80	60
Dominate Bank Materials	Silt and clay	Silt and clay
Modifications	Right bank – rip-rap upstream of dam, gabion at outlet	Both banks – gabion baskets (failing)

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The following should be considered during the detailed design of the proposed Taylor Creek crossing:

- The beaver dam is disrupting natural sediment transport dynamics
- A dam failure or breach would result in a large release or water, debris, and sediment
- Gabion basket on the right bank at inlet has failed and material has accumulated in culvert
- Gabion baskets downstream of outlet have failed material has accumulated ~10 m downstream
  - Multiple channels have formed
  - Diverting flows causing excess bank and bed scour
- Meanders downstream of the outlet are unstable
- Downstream of the crossing the channel is very incised and unstable
  - Consider removing failed engineering material (gabion, rip rap) and applying principles of natural channel design

7. Watercourse Considerations and Constraints

7.1 Overview

When crossings are placed over a watercourse without due consideration of the processes that are occurring within the watercourse, then risks to the crossing structure and/or channel form and function may occur. Such risks could lead to the need for continual or emergency maintenance of the bridge or culvert and/or could adversely affect channel stability and both fish passage potential and aquatic habitat. This chapter is intended to provide an overview of common impacts associated with watercourse crossings and to identify specific considerations and constraints within the general study area to inform the generation of alternatives and detailed design for the Ottawa East LRT.

7.2 Risk to Crossings

Crossings placed over a watercourse may be at risk of failure due to channel processes occurring along the channel, both in proximity to the crossing location, and also along the drainage network. The extent of the risk will depend on the crossing type (e.g., bridge vs culvert), the type and extent of engineering countermeasures in proximity to the crossing, and the nature of channel processes that are occurring which could interfere with the crossing structure. Some channel processes that could contribute to risk of a bridge or culvert structure include:

- Channel bed degradation/lowering – this can lead to undercutting of bridge/culvert abutments/footings.
- Channel migration – movement of meanders could cause erosion of culvert/bridge embankments.
- Channel expansion – enlargement of cross-section areas (e.g., in response to urban hydromodification may lead to increased stress around culvert entrance leading to outflanking of a culvert and flow constriction.
- Knickpoint regression along the channel bed profile.

In many situations, risk to the crossing structure can be avoided by ensuring that the span is sufficiently wide to minimize impacts to channel functions. Similarly, risk can be avoided by ensuring that the location of the crossing structure considers the existing and anticipated future planform configuration and position on the floodplain. The crossing type (open or closed) may also influence the risk from fluvial processes on structural integrity.

7.3 Crossing Risk to Watercourse and Aquatic Habitat

Crossings situated along a watercourse interact with, and exert an influence on, channel processes. The scientific literature has identified common impacts of watercourse crossings both on channel functions and on aquatic species. Common impacts include destabilization of channel form and function, impediments to fish migration, and destruction of aquatic habitat. In some situations, impacts of a crossing on the channel result in a risk to the crossing. Typical adverse effects attributed to crossings include:

- Scour of banks at culvert inlet/outlet – due to flow contraction/expansion
- Establishment of a local base level control point (e.g., closed bottom culvert) that affects channel bed profile development
- Perched culvert – affecting channel profile and fish passage
- Sediment deposition – due to a loss in sediment transport capacity upstream or within the culvert
- Sediment loading – at road crossings due to the wash of road based sediment into the channel
- Channel bed degradation
- Channel bed Instability

Reduction in potential impacts of crossing structures can be accomplished by minimizing the number of crossings that occur along a watercourse. Further reductions in potential risk to the watercourses and aquatic habitat can occur through proper design and placement of crossing structures along the watercourse. This requires consideration of channel sensitivity and processes at each proposed crossing location.

7.4 Considerations and Constraints for Design

The following general considerations should be included when selecting design components:

- Minimize the number of stream crossings that occur along any proposed routes to reduce impacts to the watercourses.
- Minimize the length of channel enclosure (i.e., new culverts/bridges or culvert/bridge extensions).
- Avoid, where possible, the need for substantial channel realignment.
- Place any watercourse crossings perpendicular to flow over relatively straight sections of channel planform, away from meander bends.
- Ensure that crossing structures are properly sized not only from a hydraulic perspective, but also to ensure minimal impact to channel form and function.
- Maintain continuity of channel form and function through the crossing wherever possible (e.g., Bed morphology under open-bottom crossings; embedment in closed-bottom crossings etc.)

8. Summary

The proposed Ottawa East LRT route passes through five subwatersheds, all of which drain to the Ottawa River.

At the three major crossing locations, desktop review and field observations indicate an opportunity to make improvements during LRT and/or highway widening to watercourses through the removal of failed engineering material (such as gabion baskets and rip rap) and implementation of natural channel design principles upstream and/or downstream. For Green's Creek, there is ongoing bank scour, channel degradation, sedimentation and accumulation of woody debris. For Bilberry Creek, failed gabion baskets and subsequent accumulation of gabion material has diverted the channel and caused extensive bed and bank scour downstream of the crossing. At Taylor

Creek, a relatively new beaver dam upstream of OR 174 is disrupting sediment transport and failure would release accumulated water and sediment downstream. Gabion baskets have also failed.

In general, the design of any changes to watercourse crossings should consider, where possible, avoiding any new crossings, minimizing the length of the channel enclosure, avoiding channel realignment, avoiding meander bends, maintaining channel form and function through the crossing.

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Appendix A– Photograph Record

Green's Creek

Photograph 1. ↑
Looking upstream, upstream of crossing

Photograph 2. ↑
Looking downstream through most eastern culvert

Photograph 3. ↑
Left bank and inlet

Photograph 4. ↑
Looking downstream from outlet

Photograph 5. ↑
Looking at exposed till on right bank, downstream of crossing

Photograph 6. ↑
Outlet

Bilberry Creek

Photograph 7. ↑
Inlet

Photograph 8. ↑
Looking upstream at bedrock channel from inlet

Photograph 9. ↑
Left bank, upstream of crossing

Photograph 10. ↑
Outlet

Photograph 11. ↑
Looking downstream from outlet

Photograph 12. ↑
Scour on left bank, downstream of crossing

Taylor Creek

Photograph 13. ↑
Inlet

Photograph 14. ↑
Looking upstream at beaver dam from inlet

Photograph 15. ↑
Looking downstream, upstream of crossing

Photograph 16. ↑
Outlet

Photograph 17. ↑
Looking downstream from outlet

Photograph 18. ↑
Looking downstream at bed and bank scour, downstream of crossing