



Don River Watershed Plan

Fluvial Geomorphology – Report on Current Conditions

2009

Prepared by: Toronto and Region Conservation

Toronto and Region Conservation for The Living City

Member of Conservation Ontario Natural Champions

the Don

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1.0 Introduction

The Toronto and Region Conservation Authority (TRCA), in consultation with the multi-stakeholder Don Watershed Regeneration Council and watershed municipalities, is developing a watershed plan for the Don River. This watershed planning process has been initiated in response to a number of recent policy and planning developments, including the need to fulfill York Region's watershed planning requirements under the Oak Ridges Moraine Conservation Plan (ORMCP, Ontario Regulation 140/02) and to update the original management strategy outlined in *Forty Steps to a New Don* (Metropolitan Toronto and Region Conservation Authority (MTRCA), 1994).

The goal of the watershed planning study is to recommend updated management strategies that will guide land and water use decisions, such that the overall ecological health of the Don River watershed is protected and improved. The aim is to build on the *Forty Steps'* principles to protect what is healthy, regenerate what is degraded, and take responsibility for the Don. Recognizing the significant watershed planning work that has already been completed, and given that there are limited undeveloped lands remaining on the Oak Ridges Moraine within the watershed boundary, this study will focus mainly on filling information gaps, guiding land use planning and approval decisions, and providing direction to advance implementation of regeneration priorities.

This report has been prepared as part of the scoping and characterization phase of the watershed planning process, in which current watershed conditions are presented in the form of technical reports covering a range of subject areas, including groundwater quality and quantity, surface water quantity, low flows and water use, fluvial geomorphology, surface water quality, aquatic systems, terrestrial systems, nature-based experiences, cultural heritage, land and resource use and air quality.

This report summarizes existing fluvial geomorphology conditions in the Don River watershed. Section 2 describes fluvial geomorphic processes and the impacts of urbanization. Section 3 describes the data and methods used to evaluate channel stability and form. Section 4 presents existing watershed conditions based on regional fluvial geomorphological monitoring data and reconnaissance level surveys conducted throughout the Don River watershed in 2007. Section 5 presents indicators, measures and targets for evaluating fluvial geomorphology conditions, as per sections 24 and 25 of the ORMCP. Management considerations are summarized in Section 6.

2.0 Understanding Fluvial Geomorphology

Fluvial geomorphology is a study of the processes responsible for the shape and form, or morphology, of watercourses. In simple terms, fluvial geomorphology describes the processes whereby sediment (e.g., silt, sand, gravel, stones) and water are transported from the headwaters of a watershed to its mouth. These processes determine and constantly change the form of river and stream channels and determine the shape, or *morphology*, of the channel. Fluvial geomorphology studies identify and quantify these processes, which are dependent on climate, land use, topography, geology, vegetation and other natural and anthropogenic influences.

A watercourse, by its very nature, is a dynamic system responding to a constant change in flow and sediment supply. The amount of flow in a natural watercourse is determined primarily by climate and geology. Climate controls the amount of water delivered to the surface of the watercourse and how and when it arrives. Geology exerts a fundamental control on what happens to the water once it arrives at the ground surface. Through its effect on infiltration and the use of water by vegetation, geology establishes the volume and proportion of groundwater and surface water available to flow through a drainage basin. Geology also determines the volume and properties of sediment supplied to the channel, and the strength and erodibility of the surficial material through which the watercourse flows. A complex underlying geology and topography can result in considerable variation in channel character, as well as changing sensitivity to potential impacts, within the same drainage system.

Watercourses respond to changes in flow and sediment supply with frequent adjustments in channel position and shape accomplished through erosion and deposition. This self-regulating ability is an inherent characteristic of natural watercourses that allows the average channel morphology to remain relatively constant over time. The state in which flow and sediment supply are balanced to achieve this stable channel form is often referred to as *dynamic equilibrium*. In a condition of dynamic equilibrium, channel morphology is stable but not static, since it changes gradually as sediment is deposited and re-mobilized throughout the watercourse. For example, in many natural watercourses the outsides of channel bends tend to erode, but there is corresponding deposition of material on the insides of bends. This gives the channel the appearance of 'migrating' across the floodplain or in a downstream direction. This kind of erosion and deposition is natural and is essential to maintaining the balance between flow and sediment supply in the system. Dynamic equilibrium is also critical for riparian and aquatic biota, which are adapted to the habitat provided by this constantly evolving but stable condition.

2.1 Geomorphic Processes and the Human Landscape

Over periods of centuries or even decades, human activities can affect geomorphic processes on a scale that transcends natural impacts with an effect likened to a major global climate change (Knighton, 1998). Deforestation reduces evapo-transpiration and infiltration and increases runoff and sediment supply to watercourses. Farming introduces tile drainage and watercourse re-direction through ditches, which reduces stream length and alters flow and habitat potential. Urban development typically results in the extensive compression and paving of land surfaces, which can significantly reduce infiltration and dramatically increase runoff to watercourses. When changes in flow regime and sediment supply from land clearing and urbanization exceed the thresholds for self-regulation in affected watercourses, the dynamic equilibrium will be upset, causing the channel to become unstable. In such circumstances the watercourse adjusts with physical changes that occur much more rapidly than the controlled adjustments of the natural dynamic equilibrium. These changes are rapid, extensive and often catastrophic and may include severe bank erosion, a lowering of the bed level of the stream, or major changes to the path of the channel itself. Such changes can result in destruction of aquatic and riparian habitat, damage to infrastructure and property, and risks to public safety.

Research into the effects of urbanization on watercourses has indicated that the critical threshold, at which channel destabilization begins, typically corresponds to a total drainage basin imperviousness of three to five percent (Hammer, 1972; Booth, 1990). Significant enlargement of the channel cross-section begins once the drainage basin reaches five to ten percent imperviousness. It is estimated that the channel will continue to enlarge, in response to urbanization, for a period of 35 to 65 years after the end of development in the watershed.

Once adjustment of the channel to urbanization is complete, the cross-sectional area may be up to 6 times greater than that of the channel prior to disturbance (e.g., Hammer, 1972). This enlargement can occur by erosion of the channel banks and incision of the channel bed, the degree of each being determined by their relative resistance to erosion. In addition to cross section enlargement, urban watercourses also experience adjustment of their plan form as the channel attempts to evolve a new meander pattern that is compatible with the new hydrologic and sediment regime. This adjustment process is thought to take an order of magnitude longer than cross-section change, resulting in a total period of instability as a result of urbanization that may be measured in centuries. It is theorized that urban watercourses will eventually achieve a new form of dynamic equilibrium through these adjustments, but even if this should occur, experience suggests that the ultimate form of an urban watercourse will bear little resemblance to a pristine river or stream and will not possess the stability or structure required to support diverse aquatic ecosystems (Booth and Jackson, 1997; Fuerstenberg, 1997).

In addition to the effects of land use change, human induced change can also include activities that result in direct modification to watercourse channels themselves. Agricultural practices can sometimes result in the realignment and channelization of watercourses resulting in loss of natural channel forms and habitats. Tillage immediately adjacent to watercourses causes channel instability as bank vegetation that would normally control erosion rates is lost. In the past, channels were realigned and straightened to facilitate development, changing aquatic habitat and intensifying channel instability as the resulting artificial channel forms lacked natural adjustment mechanisms. Furthermore, historic approaches to urban flood control have emphasized the rapid removal of water from the landscape, generally via the realignment, enlargement, and hardening of river and stream networks. The resultant increase in flow velocities and reduction in flow attenuation from the disconnection of channelized watercourses from their floodplain has amplified the increase in flows caused by urban land uses and exacerbated the resultant erosion.

Historically, the management of channel instability and increased erosion in impacted urban watercourses has been addressed using engineered erosion protection. This has involved a variety of modifications to river and stream channels including hardening of bed and/or banks with concrete, riprap, gabion baskets or armour stone as well as the installation of weirs and other grade control measures. However, in many cases such works have failed because they are undermined or circumvented by the watercourse channel as it adjusts either to maintain its natural evolutionary path or to respond to continued urbanization. Such works also affect aquatic and riparian habitat within and adjacent to the watercourse. Hardening of the channel increases velocities and decreases natural attenuation of flows, exaggerating the urban land use impacts on physical channel form described above. As a result, these conventional engineering approaches have typically resulted in a cycle of failure of the installed protection and ongoing channel degradation, leading to regular repair and extension of existing works and to the need for constructing new protection works elsewhere.

In recognition of the negative outcomes of past erosion management approaches, current practices include consideration of geomorphic and ecological processes, as well as potential impacts on upstream and downstream areas when designing and constructing erosion protection works. In some cases, large sections of watercourse are reconstructed in an attempt to restore equilibrium conditions through a practice referred to as “natural channel design”. However, the complexity of geomorphic processes in urban systems and the constraints created by infrastructure and private property make it difficult to truly recreate natural channels, and the performance of such projects in restoring natural physical and ecological function of watercourses is still being assessed. Further, conventional erosion protection works continue to be constructed for sites or areas immediately at risk where there is insufficient time, space or funding to examine more comprehensive process-based solutions.

Over the past two decades, development has increasingly incorporated stormwater management measures to attempt to mitigate the unbalance between the urban hydrologic regime and the natural channel form. By far the most popular and widely-used approach is the design of end-of-pipe stormwater ponds or wetlands to detain the excess runoff from urban developments and release it slowly at a rate that is considered to be safe to the stability of the receiving watercourse. The design of such facilities is typically predicated on the assumption that flows in the watercourse below the level required to initiate sediment transport of the median substrate particle size will not result in erosion. Currently, there is increasing evidence that these facilities may not be protecting receiving watercourses downstream of new developments (Booth and Jackson, 1997). It is speculated that this may be due an oversimplification of complex mechanisms of erosion and sediment transport in current design practices in that the release of flows at low rates may not be sufficient to mitigate their impacts (Aquafor Beech Limited, 2007). In addition, there is evidence that these facilities may not perform to detain flows in real-world conditions even to the degree for which they are designed (Bengtsson and Westerstrom, 1992). Such results suggest that stormwater management approaches based on detention may not be sufficient to manage the watercourse impacts from increases in runoff and flow volume in urban areas.

The Don River watershed has been rapidly and extensively urbanized and the river system is reacting to this change. There are many reaches where the stream channel is no longer stable and is adjusting to a changed pattern of stream flow, largely due to increased surface runoff from impervious surfaces associated with urban developments. Traditional engineering practices employed to deal with storm flows have exacerbated these conditions. Through enhanced understanding of natural systems, efforts are being made to restore natural function to impacted watercourses but this is made challenging and in some cases impossible because of the degree of watershed alteration that has taken place.

3.0 Data Sources and Methods

Measurement of fluvial geomorphology and geomorphic process involves both examination of channel morphology and investigation of the flow regime and sediment supply that drive geomorphic processes in the watershed. The combined information resulting from these measurements allows the geomorphic condition of a watershed to be determined, and repeated measurements over a period of time allow for natural rates of change to be quantified and for the impacts of land use change and urbanization on geomorphic processes to be evaluated.

Measuring channel morphology involves an examination of the complex three-dimensional geometry of a watercourse: plan form (the form of the channel when viewed from above); longitudinal profile (the elevation and gradient of the bed in a lengthwise direction); and cross-section (the size and shape of the channel in cross-profile). Measurements in these planes are taken using topographic survey equipment and then transferred into two-dimensional representations that can be interpreted and compared with subsequent surveys. The rate of erosion and morphological change is also monitored using erosion pins that are driven into the channel banks. Another fundamental aspect of channel morphology is the bed material, or substrate, which is an important factor in forming the channel geometry. The composition of the bed material may also provide insight into the watershed sediment supply. Bed material is characterized by sampling the substrate and analyzing the particle size distribution of the sampled material.

Flow regime can be measured directly by gauging flow in a watercourse at discrete locations. However, as the installation and calibration of stream gauges is time consuming and expensive, the flow regime is often predicted using hydrologic computer models. This method also allows the effects of land use changes on flow regime to be predicted by modifying the input parameters of the model. Empirical stream flow data from gauges or modeled flow data can be related to geomorphic conditions using various indicators to relate the effect, or potential effect, of changes in flow to sediment transport and erosion. One type of indicator used is an erosion index, which is an indicator of the length of time that flow in the creek exceeds a rate at which erosion is assumed to occur (i.e. critical discharge), and the magnitude of flow during that time. In theoretical terms, an erosion index can be used comparatively to examine the change in erosion potential as a result of different flow conditions. However, the results of such analyses must be used with caution as complex erosive processes cannot be described through the designation of a simple erosion threshold, and therefore the amount of erosion or channel instability that will actually occur may not relate directly to the calculated erosion index.

The degree of disturbance to river and stream channels and corridors within a watershed can provide a measure of their resilience and ability to self-regulate. Where river and stream channels have been disturbed through artificial confinement, straightening or hardening, they are unable or less able to modify their form in a controlled manner in response to changes in flow regime or sediment supply and as a result often erode catastrophically or transfer erosion problems to downstream areas. Further, where river valleys and stream corridors are constricted by infrastructure or development, the watercourse channel may not be able to migrate naturally across its floodplain and is typically hardened or altered to prevent this from occurring. While watercourses may still be impacted by flow changes from urbanization, where channels and corridors remain undisturbed the resultant changes are more contained and controlled, and present less of a threat to life, infrastructure and property when they occur.

A watershed-wide assessment of riparian vegetation conditions was completed for the Don River through application of a method that uses a Geographic Information System (GIS). Riparian areas were delineated around all Don River watercourses based on a buffer on both sides of the stream centerline of 30 meters plus the average stream channel width by stream order (as determined through sampling of 2002 aerial photography). Land use and land cover mapping derived through interpretation of 2002 aerial photography was then overlaid with the riparian areas using the GIS. Those portions of the riparian area lacking natural land cover (forest, meadow, wetland or successional land cover types) were identified and quantified.

Characterization of conditions in a large area with respect to fluvial geomorphology is made difficult by limitations in the ability to collect information. As there are hundreds of kilometers of defined rivers and streams in the Don River watershed, it is not practical or economically possible to maintain current data describing the condition of each segment of watercourse within the system. However, TRCA has initiated long-term geomorphic monitoring as part of its Regional Watershed Monitoring Program (RWMP), focusing on a limited number of sites that were selected to be representative of the broader range of conditions within each watershed. In the Don River watershed 17 geomorphic monitoring stations have been established, as shown in Figure 1. Monitoring was initiated on all sites in 2001, using standard fluvial geomorphology documentation and measurement techniques to characterize channel form, sediment characteristics and the surrounding setting (Parish Geomorphic Limited, 2003a). Reference points were set up to allow TRCA to monitor changes of some parameters over the course of repeated measurements, which are planned on a three-year cycle. In addition to geomorphic measurements, upon initiation of the geomorphic monitoring, all sites were subject to rapid assessments which provide a qualitative measure of watercourse condition, as well as basic historic air photo analysis to provide some measure of the types of change that have occurred at that location over the past several decades. This information is contained in the document *Regional Monitoring Program Fluvial Geomorphology Component: Don River, Rouge River, and Highland Creek Watersheds* report (Parish Geomorphic Limited, 2003a).

In addition to the assessment and monitoring work completed for the 17 RWMP sites, fluvial geomorphology assessments have also been completed for portions of the stream network in support of municipal studies in the Town of Markham (Aquafor Beech Limited, 1996, 2001, 2007) and the City of Toronto (Marshall Macklin Monaghan (MMM), 2003). Furthermore, reach walks were conducted by TRCA staff throughout the Don River in 2007 to provide a high level, qualitative overview of geomorphological conditions in the Don.

4.0 Existing Conditions in the Don River Watershed

4.1 Regional Watershed Monitoring Program Sites

The total length of river and streams in the Don River watershed is approximately 272.2 kilometers. This estimate of stream length is based on TRCA's watercourse layer, which may not accurately represent the length of streams in newly developed and developing areas. Therefore, the estimate is a rough guideline. The majority (78%) of the stream length is composed of small tributary streams, classified as either first, second, or third order. Stream order is a measure of the degree of stream branching within a watershed; a first-order stream is an unbranched tributary, a second-order stream is a tributary formed by the connection of two or more first-order streams, a third-order stream is a tributary formed by two or more second-order streams and so on. The principal stream order of a watershed is the largest stream order present within it, and therefore the Don River watershed is a fifth order system due to the order of the main branch of the river. This is typical of many of the watersheds in southern Ontario that drain to the north shore of Lake Ontario. Table 1 and Figure 1 illustrate the channel length associated with each stream order in the Don River watershed, and in the primary subwatersheds.

Figure 1: Don River Watershed Stream Order and Geomorphic Monitoring Station Locations.

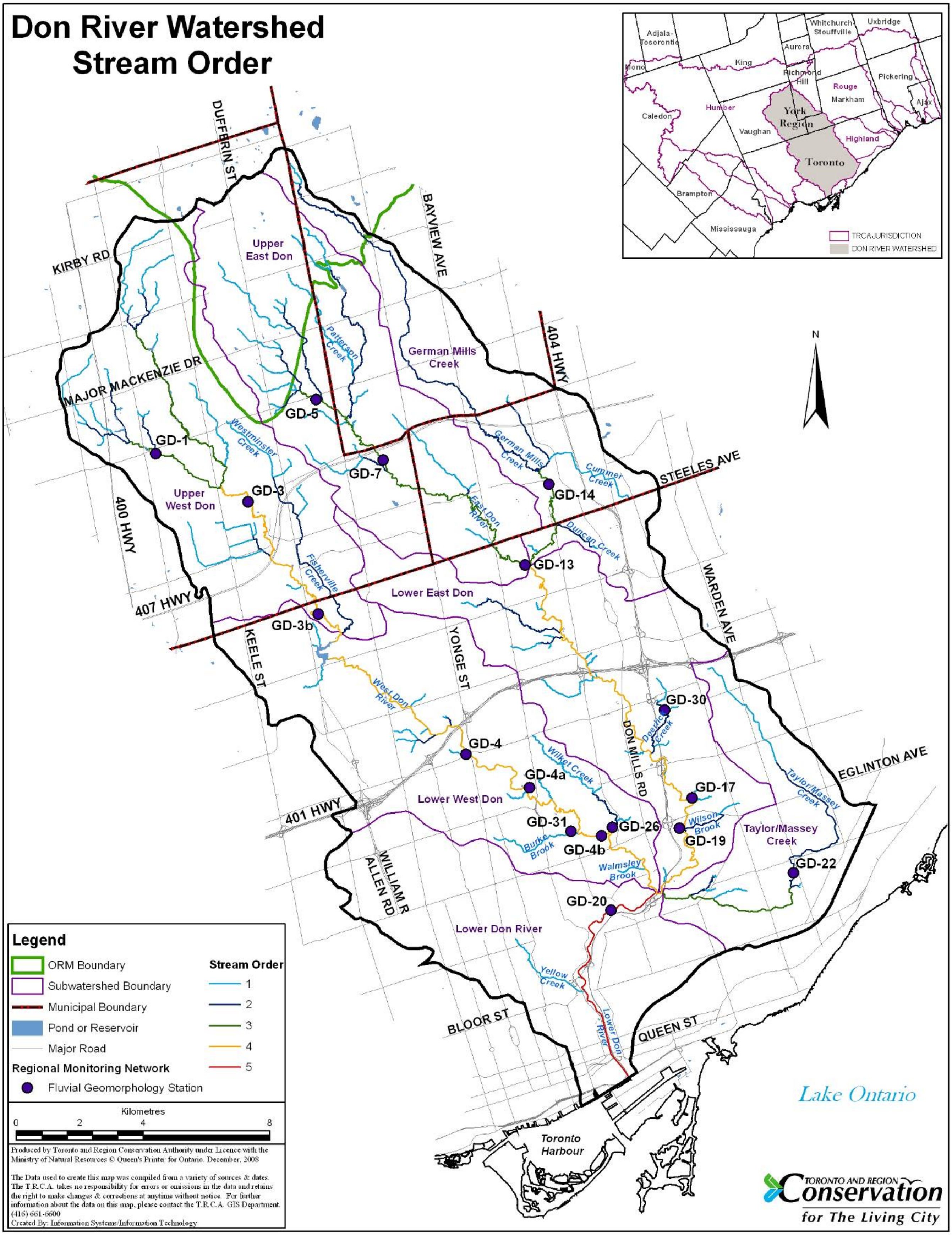


Table 1: Don River watershed stream length by stream order.

Subwatershed	Stream Length (km) by Stream Order[1]					
	1	2	3	4	5	Total
Upper West Don River	30.6	15.4	12.8	9.6		68.4
Upper East Don River	21.4	14.8	13.7	0.0		49.9
German Mills Creek	6.2	20.6	4.7			31.5
Lower West Don River	17.3	3.2		20.7		41.2
Lower East Don River	11.7	9.0		18.8		39.5
Taylor/Massey Creek	6.2	8.1	5.4			19.7
Lower Don River	3.3			0.2	8.5	12
Don River watershed	*106.8*	*71.1*	*36.6*	*49.3*	*8.5*	*272.3*

[1] Stream length has been estimated based on TRCA's watercourse layer and may not accurately represent actual stream length in newly developed and developing areas.

Bifurcation ratio is a measure of the degree of branching of tributaries within a watershed and is defined as the average ratio of stream length of a particular order to the length of streams of the next greatest order. The average bifurcation ratio for the Don River watershed is 2.5, which is higher than that of nearby watersheds but is largely the result of the relatively short length of the 5th order section of the main Don downstream of the confluence of the East and West Don Rivers. Without considering the 5th order relationship, the bifurcation ratio is a more typical 1.4.

The drainage density of the Don River watershed, which is the ratio of the total length of river and stream channels to the overall watershed area, is 0.76. This is a very low value compared to undisturbed watersheds with the physiographic setting of the Don River, and reflects the historic elimination of many tributary streams, particularly in the southern two thirds of the watershed, as a result of urban development practices. This is clearly visible in Figure 1.

Like most fluvial systems in southern Ontario, the Don River and its tributaries are 'semi alluvial' in nature (Ashmore and Church, 2001). A purely alluvial watercourse is one in which the form of the channel and surrounding floodplain are entirely the consequence of the transport and deposition of sediment, or alluvium, supplied to the watercourse channel and valley by erosion from the surrounding landscape. In southern Ontario, streams are relatively young in geologic terms and most were created at or after the end of the Wisconsin glaciation around 10,000 BC. As a result, in addition to the characteristics of alluvium transported from upstream, the morphology of stream channels is at least partially controlled by the properties of the glacial deposits through which they flow. In the case of the Don River watershed, this controlling material includes glacial till, glacial lake and pond deposits and glacial outwash material. Further, the large and well-defined valleys of the main Don River and its major tributaries were likely formed by glacial outwash rather than the current rivers and streams that reside in them, and therefore the development and evolution of these watercourses in the present age is often controlled or restricted by the much larger outwash channel. While the morphology of semi-alluvial streams can superficially appear similar to alluvial streams, their channels often consist of a relatively thin layer of alluvium on top of a highly resistant base material such as glacial till. In these cases steams may not develop morphological features such as pools and riffles with the same regularity or predictable form as alluvial streams (Foster, 1999). This is important as the majority of research in theoretical and applied fluvial geomorphology has been conducted on alluvial streams, and, therefore, conventional models, theories and methods must be applied with caution to semi-alluvial situations.

In addition to glacial influences, the variable topography (Figure 2), geology and land use of the Don River watershed result in highly diverse morphology in the river and its tributaries between the headwaters and the outlet to Lake Ontario. The highest elevation areas occur above the Oak Ridges Moraine, in the extreme northwestern portion of the watershed (blue areas on Figure 2), with the steepest slopes occurring on the escarpment while much of the remainder of the watershed is characterized by gentle slopes. Table 2 summarizes some of the morphologic characteristics of river and stream channels measured at Regional Watershed Monitoring (RWM) Program stations throughout the watershed (refer to Figure 1 for locations).

Detailed geomorphic surveys were conducted at all of the RWM stations in 2002 and repeat measurements of erosion pins, one control cross-section, and bed substrate were conducted in 2005. Preliminary analysis of the 2002-2005 data for evidence of channel change related to urbanization was not conclusive, and there were no trends identified that can relate specific types of channel change with land use impacts. However, as noted previously, the physical configuration of virtually all watercourses, natural or otherwise, is in constant flux and the impacts of land use change require decades to be manifested. As such, it can be expected that these effects will be reflected in long-term monitoring data, but that it may require two or three more cycles of monitoring (i.e. 10 to 15 years) to detect. However, the evidence of urban stream instability in the RWM data may be less obvious in watercourses downstream of older development, as many of the more dramatic morphologic changes associated with channel instability would already have taken place. Further, the repeat measurements conducted at the three-year repeat monitoring intervals are limited in scope and not all areas are subject to measurement; more extensive monitoring is likely required to capture the true extent of morphologic change occurring in the Don River watershed.

Based on this analysis, in 2002, it was estimated that only 63% of riparian areas in the Don River watershed contained natural riparian vegetation. This suggests that a significant proportion (37%) of Don River stream banks still lack the stabilizing influence and protection that natural riparian vegetation can provide. A more detailed breakdown of findings from this work on a subwatershed basis can be found in the *Aquatic System – Report on Current Conditions* (TRCA, 2009).

Figure 2: Elevation Map of Don River Watershed.

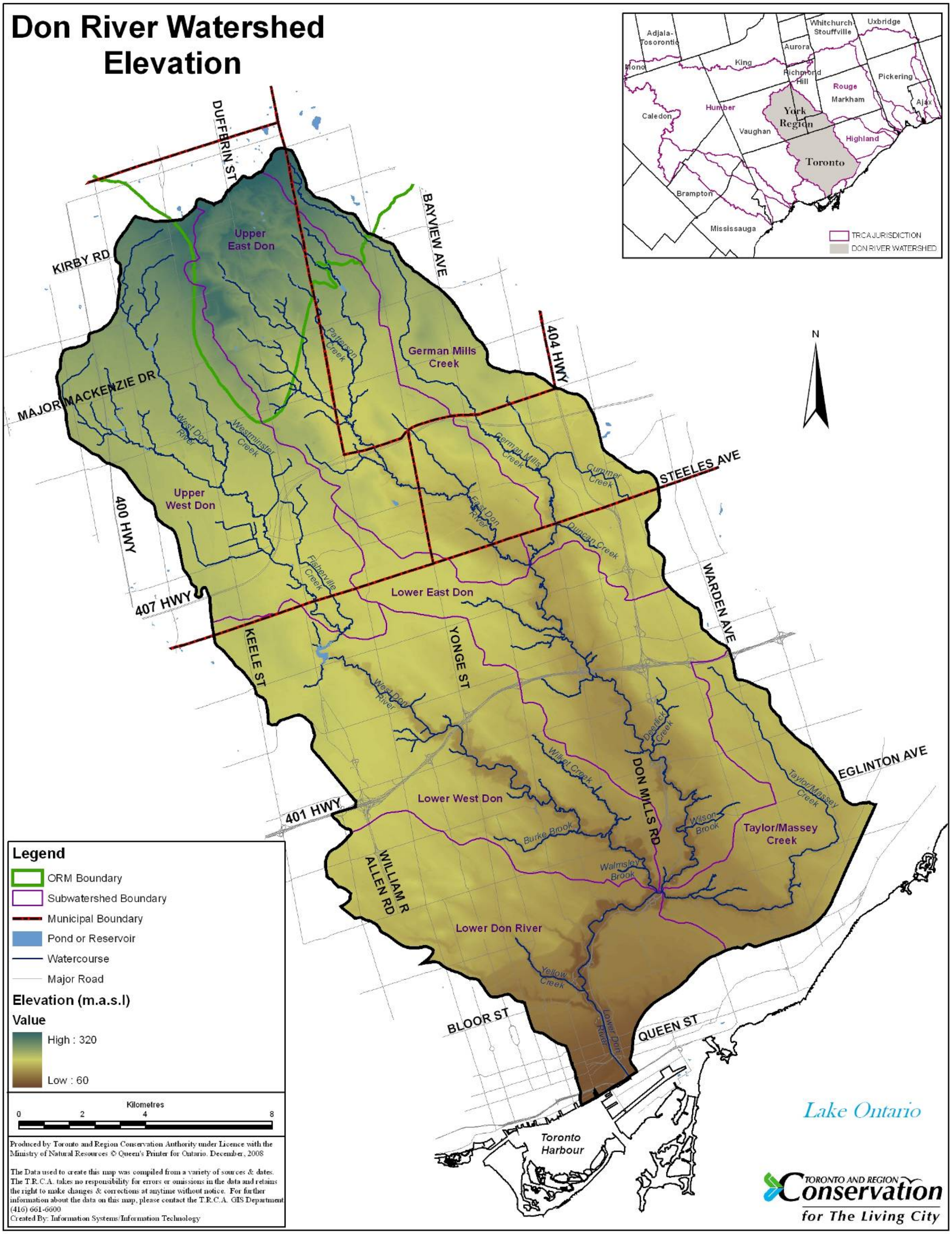


Table 2: Morphological characteristics and stability ratings at regional monitoring sites in the Don River and tributaries.

Subwatershed	ID #	Drainage area (km^2)	Avg. bankfull width (m)	Avg. bankfull depth (m)	Bankfull gradient (%)	Median substrate (cm)	Critical discharge (m^3/s)	Avg. bank height (m)	Stability index*
Upper West Don River	GD-1	6.8	7.66	0.57	0.18	0.046	1.06	1.3	Moderate
	GD-3	32.6	5.31	0.72	0.33	1.02	0.70	1.3	Moderate
	GD-3b	51.8	9.76	0.76	0.54	5.0	1.74	4.7	Low
Lower West Don River	GD-4	77.4	10.56	0.72	0.35	2.87	0.73	2.1	Moderate
	GD-4a	83.9	10.35	0.73	0.14	1.65	4.08	2.2	Moderate
	GD-4b	98.2	13.57	0.95	0.11	2.9	2.16	2.6	Moderate
	GD-26	15.2	9.38	0.51	1.52	2.66	1.39	1.5	Low
	GD-31	12.9	9.21	0.58	0.81	2.88	1.42	1.3	Moderate
Upper East Don River	GD-5	7.5	4.67	0.43	0.99	0.53	0.24	1.1	Moderate
	GD-7	37.2	7.99	0.62	0.41	0.81	0.70	1.4	Moderate
	GD-13	60.6	10.22	0.73	0.54	1.19	1.027	1.6	Moderate
German Mills Creek	GD-14	33.2	7.49	0.71	0.38	4.95	1.50	2.0	Moderate
Lower East Don River	GD-19	153.8	16.36	0.92	0.36	4.66	1.56	2.2	Moderate
	GD-30	3.6	7.89	0.56	1.57	5.31	1.52	1.3	Low
	GD-17	148.4	18.98	0.95	0.32	6.64	2.67		Moderate
Taylor/Massey Creek	GD-22	18.2	10.21	0.71	1.94	1.07	0.82	2.4	Low
Lower Don River	GD-20	316.0	22.04	1.10	0.14	1.62	9.34	2.9	Moderate

Source: Parish Geomorphic Limited, 2003a.

* Note: stability index reflects natural stability/instability and does not necessarily indicate human impacts

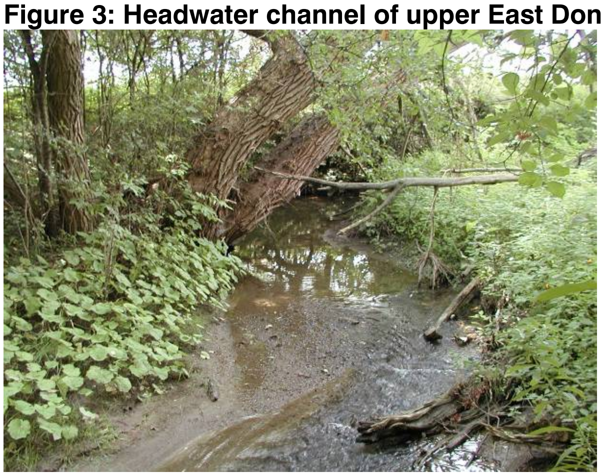
To obtain more detailed information, TRCA staff conducted extensive field reconnaissance surveys of the Don River watershed in 2007. These surveys encompassed approximately 140 km of channel throughout the Don River watershed, including all 7 subwatersheds. In advance of the site walks, staff conducted desk top measurements of reach length, valley length, channel sinuosity, and slope. In the field, staff conducted high-level observations of the following indicators of stream and corridor condition:

- General geomorphological observations
- The presence of past channelization including type and general condition
- Document visual evidence of channel stability or instability
- Areas at risk due to failure of channel banks and valley slopes
- Whether flows were ephemeral or perennial
- The presence of fish barriers
- The presence of obvious groundwater discharge within the channel, river bank or adjacent floodplain
- Areas of good riparian habitat conditions
- Opportunities for habitat enhancement
- Obvious enforcement related issues
- The presence of interesting fauna (fish, bird, etc); and
- The presence of cultural heritage features.

The data collected provided extremely detailed and useful information regarding the condition of the surveyed watercourses. The complete survey results are presented in *Don River Watershed Reach Walk Summaries – 2007* (TRCA, 2008). They are also used, in addition to the available Regional Monitoring Network data, to summarize the condition of stream channels and corridors below.

In the upper headwaters of the Don River watershed, small tributaries are generally underlain by thick sand deposits of the Oak Ridges Moraine and flows are largely ephemeral given that this is a zone of infiltration. Towards the transition zone at the southern end of the Moraine (south of Major MacKenzie Drive), it is possible to watch groundwater seeping to the surface of the bed and begin continuous flow. Further downstream, the headwater watercourses take on a low gradient, meandering channel form when permitted with deeper, narrower channels in the open field sections, and wider channel conditions in forested sections (Figure 3).

Figure 3: Headwater channel of upper East Don River.



The direct and indirect impacts of urbanization are apparent in the headwater areas. Many streams located within or downstream of older urban development have been altered through channelization and installation of engineered bed and bank stabilization techniques to facilitate development or protect private property, altering or eliminating natural morphologic features (Figure 4). Field reconnaissance indicates that very little "natural" river channel remains except in some headwater sections of the Upper West Don River, Upper East Don River and German Mills Creek. In these areas, streams in or downstream of newer developments exhibit less direct physical impact but are beginning to exhibit widening and instability in response to an altered hydrologic regime. It appears that in the open sections of the floodplain, dense grassy rooting masses help maintain channel stability despite the changes in hydrology that have occurred. When the river flows through the more shady, vegetated wooded areas, undergrowth and surficial rooting mass becomes more limited, which seems to have contributed to the much more unstable channel conditions in these areas in response to the changes in hydrology.

Figure 4: Channelized section of upper German Mills Creek.

Throughout the headwater areas, including portions of the upper West Don River subwatershed, historical agricultural influences of channel instability are present, including the impacts of tile drains, old mill ponds, small private stream crossings and agricultural land uses. There are a significant number of abandoned agricultural ponds across the headwaters; at least one of these has had the impoundment structure fail resulting in channel and floodplain impacts downstream. With these ponds, there is significant potential for extensive ecological impacts not only as a result of the disturbance to the downstream channel and floodplain due to the sudden failure of these impoundments, but also due to the loss of swamp and marsh habitat that will occur upstream of the impoundment as water levels recede permanently. These impoundments are also usually associated with significant volumes of sediment that have been stored within the reservoirs over a period of 100 or more years. With the failure of these ponds, this accumulated sediment also becomes highly mobile, further degrading what are typically coldwater habitat conditions downstream.

Further south, through the older developed areas of the Town of Richmond Hill, City of Vaughan, and Town of Markham, the corridors of the of the East and West Don rivers, as well as major tributaries such as Fisherville and German Mills creeks, become increasingly well defined and flow through shallow valleys (Figure 5). The direct physical impact of human activity becomes increasingly apparent in these areas, as many stream channels and corridors were realigned and engineered to facilitate development of infrastructure and housing, and to improve flood conveyance. A large proportion of the total stream length of the watershed from this point south has been straightened, hardened, buried, dammed, diverted and/or otherwise modified. Watercourses that have not been completely hardened show signs of instability including channel widening. This has resulted in the construction of stream bank protection works in many areas to prevent impacts to buildings and infrastructure constructed adjacent to watercourses. However, this effect is not as pronounced as it is further downstream in the City of Toronto, likely in part because of the relatively erosion resistant underlying glacial till in this area.

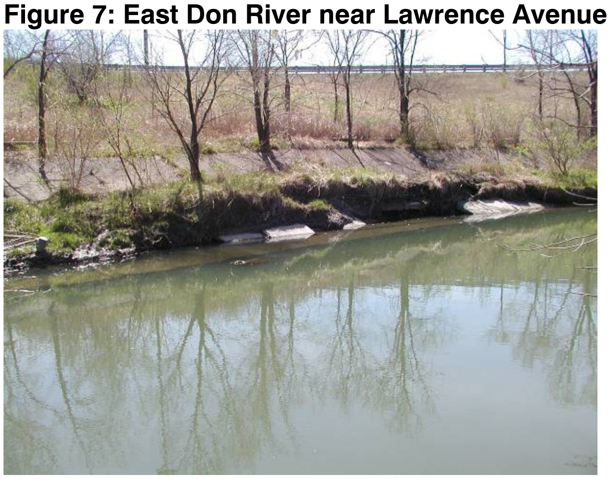
Figure 5: East Don River near Carrville Road, Richmond Hill.

Approaching Steeles Avenue, the corridors of the East and West Don rivers become increasingly defined in the form of deep incised valleys (Figure 6). These are the remnants of glacial outwash rivers that cut valleys down to a lake level significantly lower than today's, after the draining of the glacial Lake Iroquois. The bottom substrate of these valleys consists largely of sand and gravel deposited in the remnant glacial outwash channels as the water level of Lake Ontario slowly rebounded and advanced into these deep valleys in the post-glacial period. This material is much less resistant to erosion than the glacial tills through which watercourses flow further north in the watershed, and the rate of movement of the East and West Don rivers, both natural and otherwise, is greater in this area. As a result, the impacts of upstream development and the associated hydrologic change are much more pronounced in the City of Toronto than they are further upstream.

Stream bank erosion and channel widening are widespread in the East and West Don river valleys, and without the control on bed level elevation created by glacial tills in upstream areas, the river channels have also downcut a significant degree. This tendency to downcut has resulted in the failure of many bank protection works that have been installed over the past century (Figure 7), resulting in the need for constant maintenance and replacement by the City of Toronto and TRCA. Increased lateral erosion rates within the river channels, caused by the urban hydrologic regime, and irregular patterns of channel migration, caused by bank protection works, have also increased erosion of valley walls, as seen in Figure 6, particularly on the East Don River where the river valley is narrower. While some erosion of valley walls is inevitable when modern rivers are confined within large, remnant glacial channels, the increased rate of erosion due to urbanization in the watershed is much larger than would be expected in a natural system, resulting in loss of property on tableland above the unstable valley slopes, loss of forest cover on valley slopes, and safety risks.

Figure 6: East Don River south of Lawrence Ave.

Figure 7: East Don River near Lawrence Avenue and Don Valley Parkway.



Despite the widespread historic elimination and enclosure of watercourses associated with development in the City of Toronto, there remain a number of significant tributary watercourses to the East and West Don rivers that originate within City boundaries, such as Taylor/Massey Creek, Wilket Creek, and Burke Brooke. These tributaries are the steepest watercourses in the Don River watershed, steeper even than those flowing over the southern slopes of the Oak Ridges Moraine, as they flow over a relatively short distance from the tableland of the City into the deep valleys of the East, West or Lower Don rivers. These watercourses have experienced perhaps the most dramatic and longest-lasting hydrologic changes from urbanization anywhere Southern Ontario, as their upstream catchment areas consist almost entirely of older, high-density development with virtually no stormwater management controls. In addition, the networks of small tributaries that regulate the rate of flow into the main watercourse channels have been largely replaced by pipes and engineered conduits in this older development that discharge stormwater runoff much more rapidly. These hydrologic impacts, combined with the high flow energy associated with steep gradients and the highly erodible substrates where these watercourses flow into the main valley systems, have resulted in some of the most extreme examples of channel degradation and resulting impacts to infrastructure and property found in TRCA jurisdiction. Extensive erosion protection works have been constructed over the past half-century or more in response, which fail frequently due to the extreme conditions and require constant effort to maintain and replace (Figures 8 and 9).

Figure 8: Failed Erosion Protection Works on Taylor/Massey Creek near Warden Ave. and St. Clair Ave.

Figure 9: Channel reconstruction work on Wilket Creek near Lawrence Ave. and Leslie St.

The Lower Don River originates at the confluence of the West and East Don River branches, near the Don Mills Road ramp to the Don Valley Parkway. For most of its length, the Lower Don is a low-gradient channel that conveys flow out of the remnant glacial valley over the historic Lake Iroquois shoreline deposits and into Lake Ontario. The Lower Don River has been entirely channelized and hardened over the last 150 years, to allow for and prevent undermining of critical infrastructure such as the Don Valley Parkway (DVP), railway tracks, Bayview Avenue, and various other utilities running parallel and adjacent to the river throughout its entire length. Between the confluence of the three tributaries (Lower East Don River, Lower West Don River and Taylor/Massey Creek) and the Don Narrows, the river has a moderately sinuous form that meanders across a deep, moderately vegetated floodplain. Superficially, the river channel appears to possess a relatively natural form, but a wide range of bank and channel works including concrete trapezoidal channels, boulder rip rap banks, armourstone revetments, erosion control weirs, sheet piles and wooden piles, have almost completely fixed the channel in place (Figure 10). As in other portions of the Lower East and West Don rivers, bank protection has caused downcutting of the river channel and irregular channel migration patterns, resulting in failure and need for reconstruction and new works elsewhere. Due to the low gradient of this section of the river, sediment from ongoing degradation and erosion in the upstream watershed is deposited, creating irregular accumulation patterns in the channel.

Figure 10: Bank protection on Lower Don River north of Bloor Street.

The Don Narrows is the nearly straight reach of the river from Riverdale Park to the CN Railway north of Keating Channel (Figure 11). The Narrows resulted from realignment of the river over a century ago, when the Port Lands industrial area was created and the wetlands at Ashbridge's Bay (the original mouth of the Don) were drained. At that time, the river was straightened and widened using vertical cedar piles placed side-by-side to form a sheer, hardened river bank. Later in the mid-1950s, the original cedar piles were replaced with steel sheetpiles to provide a foundation to construct the DVP on the east side of the river, and to reinforce the railway bed and Bayview extension on the west side of the river. The channel within the Don Narrows is relatively uniform with low-bed relief features and substrate consisting primarily of sand and coarse silt. There is essentially almost no hydraulic gradient to the channel, and water levels in low flow conditions are governed by the Lake Ontario backwater south of Gerrard Street.

Figure 11: Don Narrows upstream of CN rail line and Gardiner Expressway.

The Keating Channel makes a 90-degree bend south of the Gardiner Expressway into the inner Toronto Harbour. This bend, and the sheltered location of the Keating Channel, result in deposition and rapid accumulation of sediment, which is produced in large volumes in the watershed due to the destabilization of the watercourse channel network as noted above. The channel requires annual dredging to maintain the capacity of the channel and prevent a hydraulic constriction that would significantly increase the risk of flooding in the Lower Don River and the surrounding flood-prone areas.

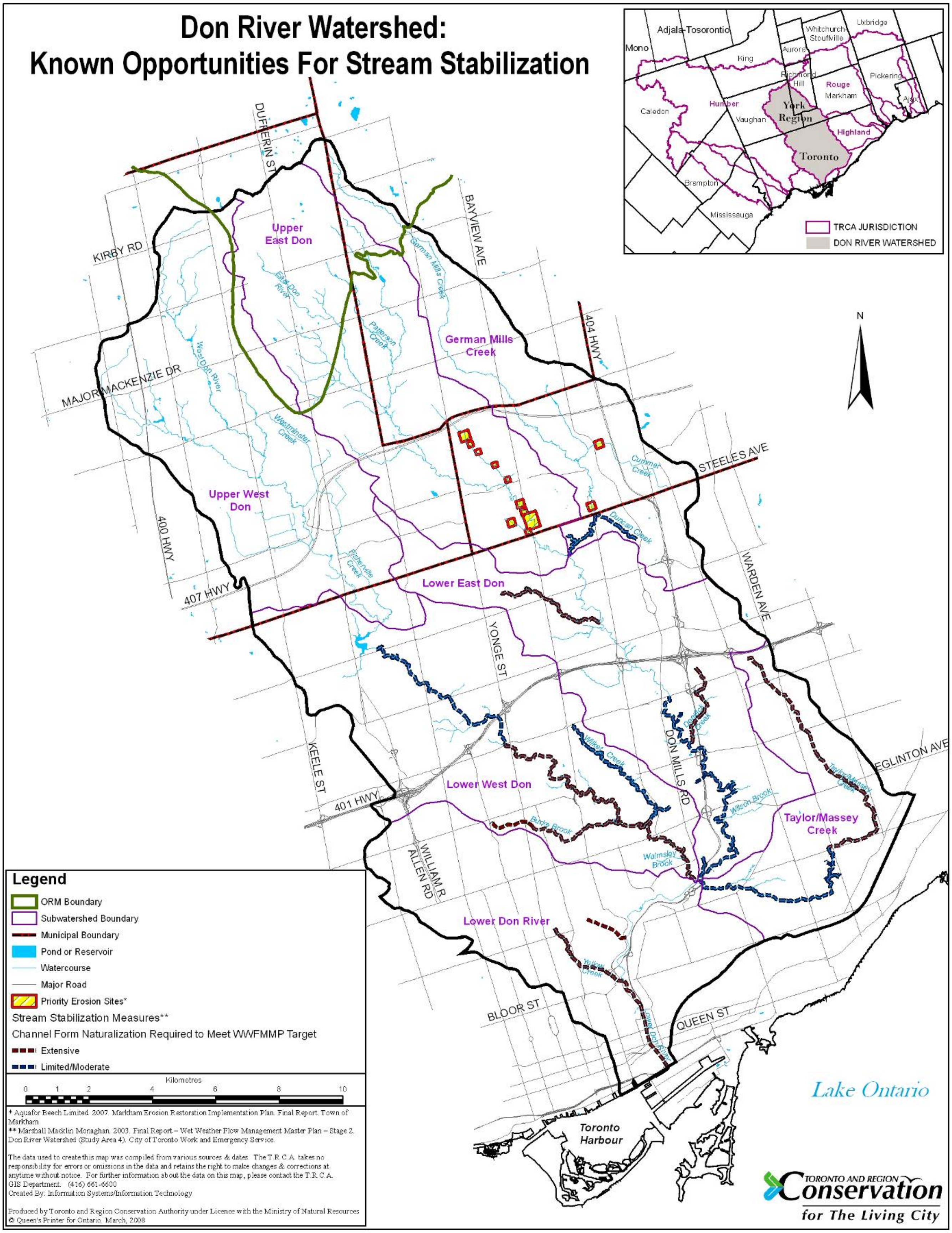
4.2 Other Sources of Information

4.2.1 Markham Erosion and Restoration Studies

Geomorphic processes and channel condition were assessed for watercourses within the Town of Markham in the determination of development charges for stormwater management and erosion (Aquafor Beech Limited, 1996). The study determined that under existing (1996) conditions, 30% of the length of watercourse channels within the Town of Markham (the majority of which are located in the Rouge River watershed) were either unstable or only moderately stable in response to impacts from urbanization. However, this percentage is much higher in the portion of the Don River watershed in Markham, where most streams were determined to be degraded. Further, it was also predicted that this figure would increase to 90% in response to proposed future development if current stormwater management practices were continued, as watercourse impacts were found to be related to the increase in runoff volume from upstream development which is not addressed in by current stormwater management practices. The study concluded that the cost to the Town would be to restore these unstable watercourses would be approximately $50 million. An update to this study was conducted in 2001 (Aquafor Beech Limited, 2001) to account for new information regarding existing and future development. The update determined that there would be greater degradation to Markham watercourses than originally estimated, resulting in a future cost to the town of approximately $80 million. It is important to note that the costs determined through these studies are based on the costs of reconstructing the impacted watercourse channels using ‘natural’ channel design techniques. However, in urban settings, additional costs may be incurred by the Town in repairing and maintaining these channels in perpetuity.

Subsequent to its development charges studies, the Town of Markham prepared an Erosion Restoration Implementation Plan (Aquafor Beech Limited, 2007) that was intended to identify priority restoration sites in Markham watercourses and to develop a system for prioritizing sites and guiding capital expenditures for erosion remediation. Within the 20 km of the East Don River, German Mills Creek, and tributaries in Markham, the study identified 106 locations where erosion was either acutely exacerbated by the hydrologic impacts of development, where infrastructure or private property were placed without regard to future channel migration and therefore impacted by erosion, or both. In addition, 31 locations were identified where the above conditions had created barriers within watercourses to fish movement and migration. Of these sites, 12 were identified as priority projects requiring intervention within a 10-year period to remove unacceptable risks to health and safety, at an estimated cost of $5.2 million (Figure 12).

Figure 12: Known opportunities for stream stabilization in the Don River watershed as identified from the Town of Markham Erosion Site Study and City of Toronto WWFMMP Study.



Markham is developing a plan to identify restoration solutions for Pomona Creek, through a class environmental assessment process. The main objectives of the study are to:

- Identify the causes of erosion in the watercourse
- Improve fish habitat and linkages
- Protect public infrastructure
- Reduce impact of storm runoff
- Improve wildlife habitat and species diversity
- Involve the community in assessing issues and developing solutions

When the project is completed, the Pomona Mills Creek will have minimum bank erosion, improved water quality, improved access for fish and wild life habitat and safer public infrastructures within the creek valley.

The Town of Markham has initiated a class environmental assessment study to examine the existing flood capacity issues associated with the Don Mills Ditch extending from Steeles Avenue, north to the confluence with German Mills Creek within the Town of Markham. The study involves a review and confirmation of current flood capacity issues, development and assessment of various flood mitigation alternatives and a recommended preferred strategy to address existing flooding of lands located adjacent to the watercourse.

4.2.2 City of Toronto Wet Weather Flow Management Master Plan

In support of the City of Toronto's Wet Weather Flow Management Master Plan, a reconnaissance level survey 22 reaches was carried out along City of Toronto portions of the Don River and its tributaries during the fall of 2000. Detailed evaluations of erosion and stream bank stability were carried out at six (6) of the 22 sites. This information was used to recommend stream restoration works along selected reaches as part of the preferred management strategy (Marshall Macklin Monaghan (MMM), 2003).

Through this preliminary assessment, general conclusions were drawn on the stability of the reaches. In general, small tributaries of the Don River were found to be extremely unstable, due to widespread imperviousness, lack of stormwater control, and channel modifications, despite the moderating influence of favourable surficial geology (glacial outwash material in the valley bottoms). Widespread hardening of the banks has exacerbated the erosion problems in unprotected sections and bank failures in protected and unprotected areas are common. Sections of larger tributaries, such as Taylor/Massey Creek, were found to be more stable as a result of lower slope and stream power, and extensive stabilization. The West Don River was found to be moderately entrenched, with enlarged meanders that are progressing downstream, due to a combination of natural factors (e.g., till soils) and human influences (e.g., G. Ross Lord Dam restricts sediment supply, channel modifications, stormwater control upstream). The West Don was determined to be stable during moderate storm events, but "sudden and catastrophic" changes in the channel form could result from large events (>10 year events). The East Don River was found to be moderately stable, although local instabilities exist where the river has been straightened or where lateral migration is eroding valley walls. The Main Branch of the Don River is the most controlled by human-made structures, and it was concluded that these will need to be maintained to continue to control downcutting and lateral erosion.

To help address observed instances of channel instability and erosion damage to the valley system and improve the quality of aquatic habitat, stream stabilization works were recommended for several reaches within the City of Toronto including portions of the West Don and East Don rivers, as well as large and small tributaries. Stream stabilization works that are proposed to be implemented over a 25 year timeframe include:

- stabilization of degraded sections of the streams using, utilizing limited natural channel design features where possible (Figure 12);
- removal/modification of a number of fish barriers;
- protection/reconstruction of municipal infrastructure in the valleylands; and
- restoration of riparian vegetation.

A total of 18 kilometers of stream were proposed for stabilization, 41 fish barriers were identified for removal or modification, and a number of exposed sewer pipes and water mains were to be protected.

5.0 Ratings for Fluvial Geomorphology Indicators

In evaluating current conditions in the Don River watershed, a rating system was adopted based on standard letter grades. Each of these categories corresponds with "poor", "fair", "good" and "excellent" levels of condition as shown in the table below. Where the measures and targets were quantitative and data permitted, ratings were assigned, in part, to reflect the percent satisfaction of the target. Comparisons to conditions in other watersheds under TRCA jurisdiction were made and informed evaluations where data were available, to reflect relative conditions. Where measures and targets were qualitative, or data were lacking, evaluations were based on professional judgment. The management objectives, indicators, measures, targets, and current conditions ratings for fluvial geomorphology are presented below.

Grade	Rank	Percent of Target Achieved
A	Excellent	Better than 80
B	Good	Between 70 and 79
C	Fair	Between 60 and 69
D	Poor	Between 50 and 59
F	Fail	Below 50
TBD	To be determined	Further study required; baseline data not available

Objective: Protect and regenerate the natural form and function of the Don's valley and stream corridors		**Overall Rating**	
		Fail	
Indicator	**Measure**	**Target**	**Rating**
Channel morphology	Channel geomorphic surveys at RWMP sites	Maintain or restore natural channel structure	N/A
Erosion potential	Erosion indices and flow regime at stream gauge locations	Maintain baseline erosion potential where stream banks are stable and decrease where stream banks are unstable	N/A
	Rates of channel change at RWMP sites	Maintain or restore natural rates of morphologic change	N/A

N/A = sufficient information is not available to assign a rating for this measure. Baseline conditions (2002) have been established and will be used for future evaluations.

Sufficient data to assign a rating regarding the channel morphology indicator is not available at this time. Information from more recent assessments (limited data collected in 2005) of channel cross-sections and substrate at Regional Watershed Monitoring Program sites is not available to be compared to findings from the 2002 assessment, so a rating cannot be assigned according to this measure. Furthermore, it is premature to attempt to calculate stream bank erosion rates (erosion potential indicator) using the erosion pins installed in 2002, as changes over the intervening three years have likely been too small to accurately measure. It is proposed that baseline stream bank erosion rates be calculated based on future assessments of fluvial geomorphology monitoring sites.

Once information regarding additional measures becomes available, future watershed report card ratings will be based on an average of ratings assigned for each indicator. Ratings for each indicator will be based on consideration of ratings for each measure associated with the indicator.

An overall grade of 'Fail' has been assigned to the fluvial geomorphology objective for the Don River watershed, despite a lack of data. This grade reflects the highly degraded physical condition of the channel network observed throughout the watershed, both from the direct effects of human alteration of channels and from the indirect effects of land use change on watershed hydrology. There are essentially no river and stream channels remaining in the watershed that possess both natural form and function and the equilibrium of geomorphic process in the watershed has been destabilized, resulting in degradation of aquatic and riparian habitats and erosion damage to infrastructure and property. Efforts to date to counteract these effects in the watershed, such as erosion protection works, have been largely ineffective and in many cases have exacerbated impacts. The degree of impact to the fluvial geomorphology of the Don River watershed is as great as or greater than any other watershed in Canada, which presents major challenges to any current or future restoration efforts.

6.0 Management Considerations

6.1 General Discussion

Watercourses are complex, dynamic systems that evolve over long periods to achieve a balance between climatic and geologic processes in a watershed. Human development and alteration of watercourses can disrupt this sensitive balance, resulting in instability and extreme conditions which impact natural systems and humans alike. The process of channel adjustment to these disruptions can continue for decades or centuries, prolonging impacts and causing the loss of species that rely on the impacted watercourses for habitat. Respecting the complexity of geomorphic processes and the potential for disruption of these process following changes in land use or direct physical alteration of watercourses, is a key management principle for protecting the form and function of stream channels and to maintain watercourses and their valley corridors in a natural state. Once these impacts have occurred, restoration of watercourses is extremely difficult, and many past initiatives have proven to be to be complicated, long-term efforts that are very costly and only partially effective.

The Don River differs from most of the other watersheds in the TRCA jurisdiction in that it has been almost entirely urbanized and the destabilizing effects of land use change have either already occurred or have been set in motion throughout the watershed. As such, the protection of fluvial geomorphology in the watershed cannot rely on recommendations for future urban growth areas and associated stormwater controls to preserve the reaches of the river that have not yet been impacted. Further, the degree of existing impact in the watershed is extreme, with direct modification of river and stream channels, encroachment and constriction of stream corridors and valleys, and alteration of the hydrologic regime at a massive scale. As such, it is unlikely or even impossible that the natural form and function of the Don River and its tributaries can ever be restored, as the costs and resources associated with acquiring sufficient land and controlling stormwater flows from developed areas to achieve this goal would be staggering. Therefore, there should be a focus on opportunistic efforts for limited, local improvements through initiatives such as improving channel and valley form and management of stormwater runoff through restoration and redevelopment projects.

Future restoration projects must set goals and objectives that are realistic given the challenging conditions of extreme hydrology, extensive channel alteration, and corridors that are constrained by development and infrastructure. Restoration projects will not be able to rely on practices such as 'natural channel design' and will universally require hard engineered elements to accommodate these conditions. As a result, it cannot be expected that restoration will be successful after a single intervention; engineered restoration works will need to be monitored and maintained in perpetuity in the Don River watershed if long-term objectives are to be achieved.

Throughout the Don River watershed, property and infrastructure adjacent to watercourses and watercourse corridors are being impacted or are at risk from erosion, either because they were originally located without consideration for natural channel evolution or because urbanization and channel network alteration have cause watercourse to migrate more rapidly and erratically than under natural conditions. Additional erosion impacts will result over the next decades as the effects of more recent development in the upper portions of the watershed are manifested. As experience has demonstrated in the Don, the use of engineered bank protection to address this issue has exacerbates problems elsewhere and creates a perpetual cycle of maintenance and reconstruction of protection measures. To eliminate risks without incurring the costs and consequences of continued expansion of bank protection, efforts should be made to remove infrastructure, buildings and private properties from watercourse corridors and adjacent areas. When necessary, initiatives to stabilize channels to prevent erosion into infrastructure should no longer be conducted in isolation but should consider the watershed context of the project area and the potential negative outcomes of stabilization works.

6.2 Subwatershed Considerations

Management recommendations specific to individual watersheds, from a fluvial geomorphologic perspective, vary by geographic location within the watershed, and by the extent of and age of the surrounding urbanized landscape in proximity to any given tributary within the Don.

The Lower Don River represents the section of river with the longest period of urban occupation and the highest degree of channelization of all subwatersheds. Opportunities for direct modifications to the structure of the main channel in this subwatershed are highly constrained by infrastructure located within the corridor, with the exception of the proposed work being developed by TRCA and Waterfront Toronto through the Don Mouth Naturalization and Port Lands Flood Protection Project. However, there are opportunities to improve the hydraulic and water quality conditions in this section of the river as part of Toronto Water's implementation of the Wet Weather Flow Management Master Plan which will examine opportunities to divert sanitary, storm flows and possibly treatment plant discharge away from the river. TRCA will work closely with Toronto Water through the development and implementation of this project, which will contribute to the process of delisting Toronto as an Area of Concern. Another key recommendation for the Lower Don would be to look for additional opportunities to create offline wetland and fluvial habitats along portions of the floodplain upstream from the Bloor Street Viaduct, similar to Chester Springs Marsh and the Todmorden Mills Oxbow.

A key feature of the lower subwatersheds is the steep forested ravine system that contains numerous feeder tributaries from the adjoining tablelands, many of which have permanent baseflows from groundwater discharge. A number of these tributaries had previously been entirely buried within combined sewer systems and no longer function as an open channel system. Others have major storm sewer systems diverted into the channel at the top of the ravine, which has resulted in severe channel instability of these systems resulting in highly degraded ecological function, while contributing large volumes of sediment into the main branches of the various subwatersheds. There are opportunities on these systems to work with the City of Toronto to divert stormwater flows away from these ravine tributary systems as part of Toronto Water's long-term sewer upgrade and maintenance program. This could help establish a more natural hydrological regime in these ravines and enable the stabilization of these channels.

Taylor/Massey Creek is one of the most, if not most: fragmented, flashy, sediment deprived, unstable and polluted tributaries (due to combined sewer discharges) within the entire Don watershed. TRCA will be working with Toronto Water on their plans to divert combined sewer discharges away from the river as part of Toronto Water's Wet Weather Flow Management Master Plan, as well as a geomorphological master plan focused on the Warden Woods area of Taylor/Massey Park, with plans to eventually extend that study to the entire subwatershed. In the headwaters of Taylor/Massey Creek there may be opportunities to create naturalized channel systems and offline wetlands in the large hydro corridors in the Ellesmere Road and Lawrence Avenue areas. For the remainder of Taylor/Massey Creek, regular monitoring and maintenance of bank protection works are recommended, as is the relocation or protection of some pathway currently at risk of erosion.

In the Lower West Don and Lower East Don subwatersheds, there may be opportunities to enhance coldwater stream and wetland habitat conditions in small tributaries upstream of Bayview in the Lower West Don and in Charles Sauriol Conservation Area on the Lower East Don. The Lower East Don also possesses a number of large heavily eroding valley wall sections which are providing extensive volumes of bedload in a bedload starved system. It is recommended that these valley walls be permitted to continue to erode, though regular monitoring of these sections is recommended to ensure buildings and infrastructure on the adjacent tablelands are not at risk to failure.

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