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## Wilket Creek: urbanization, geomorphology, policy, and design

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Graduate Program in Geography

A thesis submitted in partial fulfillment of the requirements for the degree in Master of Science

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## Abstract

The understanding of the morphology of an urbanized channel is currently limited to a 'black box' understanding in that the main driving force of morphological change is hydrologic. This study aimed to expand our understanding of urbanized channels by conducting a socio-geomorphological investigation; that is, the natural and policy-driven events and processes leading to the current channel form. A fluvial audit including historical analysis and fieldwork was conducted in Wilket Creek, a southern Ontario urbanized channel, along with a review of provincial and municipal policy and reports. Overall, it was concluded that the current morphology of Wilket Creek is the result of a complex combination of urbanization, conservation policy, and channel reconstruction and design. This in-depth analysis provides the sequence of events and processes which took place in the catchment which has led to the current urban morphology.

## Keywords

Urbanization, fluvial audit, Wilket Creek, fluvial geomorphology, sociogeomorphology, natural channel design

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# Chapter One

## 1 Introduction

The central concern of the field of geomorphology is natural processes and landforms (Charlton, 2008). In most cases, the scope of geomorphology does not address the role of socio-political processes in landform analysis (Ashmore, 2015). While textbooks and research have long addressed the role of human impacts on landscapes and the recognition of human-constructed landforms (e.g., Gregory, 2006), this anthropo-geomorphic position sees humans as impacting a separate nature, and perturbing and damaging natural systems from the outside. This limits explanation of the role of humans in these systems (Ashmore, 2015).

To provide the socio-cultural and political stance that is missing from anthropo-geomorphic analysis, Ashmore (2015) uses the term socio-geomorphology; a distinct mode of enquiry that explicitly approaches rivers as socio-natures, a combined bio-physical and socio-political system. This fits with a research approach was recently labelled as critical physical geography (Lave et al., 2014). To conduct an analysis of this type in the context of fluvial geomorphology, historical background and a socio-political narrative is appropriate, as well as more conventional information on the channel morphology itself. This approach is particularly useful in the context of urbanized watersheds in which human agency has had direct effects on river morphology. This socio-geomorphic approach contrasts with previous urban river analyses, which treat urbanization as an external human impact on the natural system in which land-use change is a simple causal variable rather than as part of a socio-natural system (e.g., Rutherford & Ducatel, 1994; Leopold et al., 2005; Chin, 2006; Vietz et al., 2015). The socio-natural approach also makes it possible to incorporate explanations of river morphology related to direct human intervention, such as channel restoration. Analysis of designed and restored channels is largely absent from literature on effects of urbanization on river morphology

To provide a full explanation of the current state of an urban channel, knowledge of the direct human influences/interventions and fixes, along with the reasons and motivations for these direct human influences is required. Not all urban rivers undergo the same

morphological changes due to differences between local socio-political processes and in this local contingency and history are important considerations. Together with the physical attributes of the channel, this information can provide a detailed understanding of how urban river morphology is the outcome mutual interactions of ‘natural’ and socio-political circumstances.

To allow for an in-depth, socio-geomorphological investigation into the effect of urbanization on fluvial systems, this thesis is a case study. Located in Toronto, Ontario, Wilket Creek is a small, second order tributary of the West Don River, with a completely urbanized catchment. This study is related to a larger project “*Assessing and restoring the resilience of urban stream networks*”, which is focused on the effects of stormwater management on bedload transport in three creeks in the Toronto area. Wilket Creek is one of the previously-selected watersheds (representing older development with no storm water management). Wilket Creek is also typical of similar watercourses in the area, and in this way the case has broader relevance.

## 1.1 Objectives of this thesis

The in-depth, socio-geomorphological investigation into the effect of urbanization on Wilket Creek, Toronto completed in this thesis was fulfilled by two main objectives:

1. Characterize the current geomorphic characteristics of Wilket Creek by identifying:
  - a. Glacial geological setting
  - b. Channel morphology
  - c. Grain size and grain size distribution
2. Identify the sequence of events and processes which took place in the catchment starting with 19<sup>th</sup> century: land clearing through urbanization, conservation policy, re-engineering and restoration practices and other interventions to understand morphological changes in a socio-geomorphic context



## Chapter Two

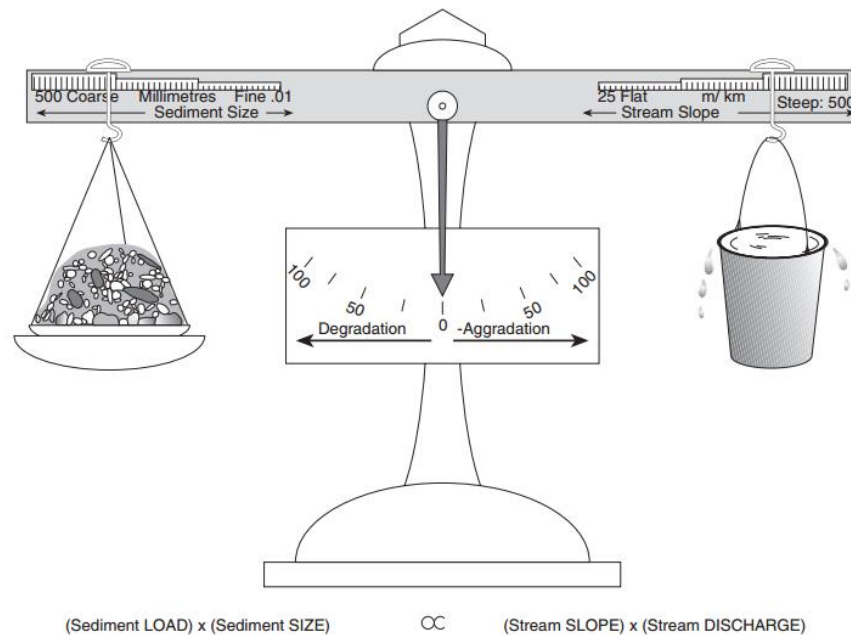
### 2 Channel morphology: urbanization effects and human influence

#### 2.1 Controls on channel morphology

River channel morphology is dependent on the type and intensity of fluvial processes, such as erosion, transport and deposition of material, incision/aggradation, and lateral migration, in the river (Knighton, 1998). These processes are governed by the hydrologic and sediment supply from upstream, as well as by the valley gradient, and bed and bank material (Knighton, 1998; Ashmore & Church, 2001). Secondary controls on channel morphology include riparian vegetation (Figure 2.1) (Knighton, 1998). Overall, these variables are responses to the catchment conditions including topography, geology, soils, vegetation, climate, and land use. Change in any one, or a combination of these controls may cause adjustment of the channel morphology to a new quasi-stable state (Wolman, 1967; Schumm, 1971; Knighton, 1998; Ashmore & Church, 2001; Emmett & Wolman, 2001). Rivers are subject to occasional disturbances, typically by flood events, where thresholds of the channel state are reached and exceeded (Knighton, 1998). River morphology is mostly controlled by these threshold exceedances; higher flows and occasionally single, large flow events may cause long-term changes to which the channel re-adjusts. This can change the morphology through lateral migration and incision, and is related to a particular range of channel forming discharge (flows) (Charlton, 2008).

The effects of channel forming discharge vary by the type of channel. Geomorphologists identify two fundamental classes of river: alluvial and bedrock (Charlton, 2008). Each of these types of channel adjusts differently; much of the literature to date concentrates on river process-form adjustment in alluvial channels, leaving analysis of other channel types less developed. There are two clear distinctions between the two classifications of rivers; morphological change in bedrock channels is uni-directional (rock cannot be replaced after erosion) and significant in-channel deposition converts the channel to an alluvial state, and that rates of change and adjustment in bedrock channels are slow (Turowski et al., 2008). It has been recognized that bedrock channels may be considered “semi-alluvial”, when

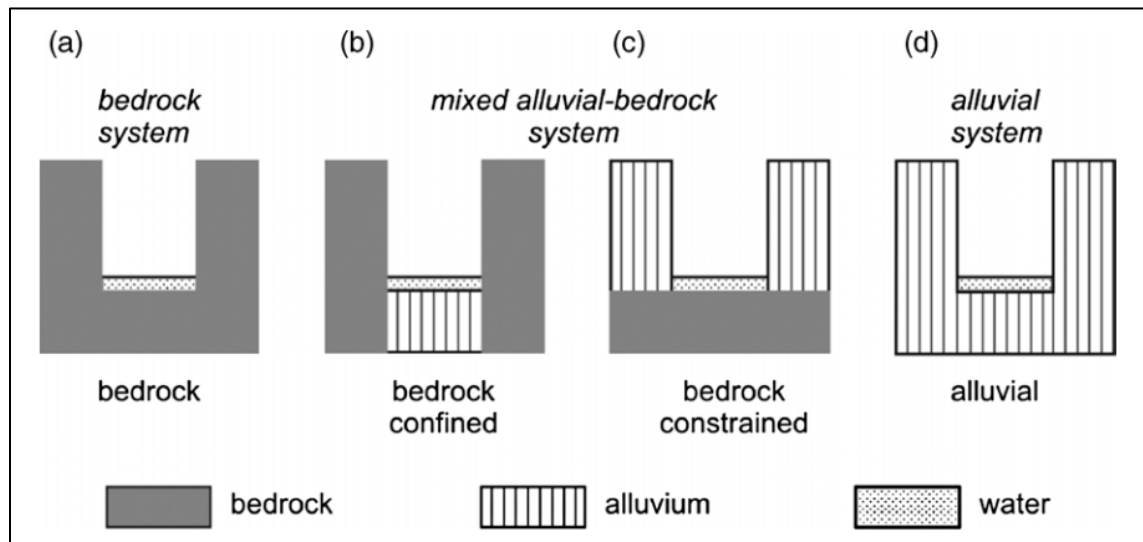
significant erosion has not occurred and the bedrock is locally or partially covered by alluvial deposits (Turowski, 2012). Some refer to these rivers as mixed alluvial-bedrock, leaving some confusion over the exact definition of a semi-alluvial river (Figure 2.2) (Howard, 1998).



**Figure 2.1: Illustration of the Lane balance between stream power (stream slope x discharge) and sediment supply (sediment load x sediment supply) (Charlton, 2008).**

In their paper, Ashmore & Church (2001), proposed a definition of the term semi-alluvial as channels which are “*not strictly alluvial but neither are they constrained in their adjustment to the same extent as bedrock channels. (They) flow through erodible material and show many of the characteristics of alluvial rivers but rapidity and completeness of adjustment may be limited....*” They relate this particularly to areas of Canada that are covered by glacial sediments into which rivers are eroded, rather than bedrock. Channels in these areas have also been termed glacially conditioned (Phillips & Desloges, 2013). The variation in type, composition, and thickness of glacial sediments have a substantial influence on the morphology, dynamics, and adjustment for the rivers, which erode into these materials (Phillips & Desloges, 2013). Specifically in southern Ontario, rivers run over low gradient till and glaciolacustrine plains, with post-glacial downcutting. The channel boundaries and valley sides of rivers in these areas typically have glacial (non-

alluvial) sediment exposed, while alluvial deposition and floodplain development occurs, and banks feature alluvial caps above non-alluvial materials. As well, the channel itself features alluvial cover (sand, gravel, cobble) in variable thicknesses and extent (Hrytsak, 2012; Thayer & Ashmore, 2016). The channel may behave like a bedrock channel, as channel incision, valley widening, and channel adjustment erode glacial sediments. However, there are characteristics causing these channels to differ from bedrock rivers, hence Ashmore & Church's (2001) usage of “semi-alluvial”. Glacial sediments (e.g., till) may be more erodible than the overlying gravel, and are much more erodible than most types of bedrock. The glacial sediments may provide a direct supply of readily transportable sediments, such as gravel and sand, forming much of the bed material cover. During erosion, cohesive clasts of glacial sediments may also be incorporated into the bed material, making the bedload composition different from that of alluvial systems. The morphology and mechanics of semi-alluvial channels are not well known, so prediction and understanding of their response to changes such as urbanization is in its preliminary phase. To further this understanding, the goal of this thesis is to describe this glacially-conditioned, semi-alluvial channel type in an urbanized setting.



**Figure 2.2: The variation of channel types (Hrytsak (2012) based on Meshkova et al., (2012)).**

## 2.2 Effects of urbanization on channel morphology

Rapid urban expansion, especially in the second half of the 20<sup>th</sup> century has had documented effects on watercourses in North America. The beginnings of these effects can be traced partly to initial stages of forest clearance, and direct modifications, such as water mills and dams, in the 19<sup>th</sup> century (Schenk & Hupp, 2009; Csiki & Rhoads, 2010; Walter & Merritts, 2015).

The dams built at this time, and generally those built in small catchments, are often run-of-river dams. Unlike impoundment dams, run-of-river dams have no mechanism to inhibit the discharge of water over the dam; any water held by the dam has a minimal residence time, which creates local backwater conditions for mills (Csiki & Rhoads, 2010; Walter & Merritts, 2015). While research on this specific type of dam is limited, with few studies investigating the effects of these dams on fluvial functioning, the effect of mills and their dams, whatever type they might be, has been investigated (Csiki & Rhoads, 2010). Walter & Merritts (2015) used historical photographs to locate mill dams throughout the eastern United States. They typically found a small wedge of fine grained sediment upstream of the dam, and an altered flood plain stratigraphy. Through coring and bank sampling, it was possible to identify these areas, showing the legacy which mills and other agricultural activities leave in the morphology (Walter & Merritts, 2015). Depending on the size of the dam and catchment, effects such as these on hydrology and sedimentary processes can be seen for several kilometers downstream. Urbanization may have further altered the channel form making this more important to morphological change (Csiki & Rhoads, 2010).

Analysis of the effects of urbanization on river morphology can be traced back to pioneering work by Wolman (1967), who suggested that rivers may go through three stages of changing sediment yield during urbanization: 1) the equilibrium condition when the landscape is dominated by agriculture or forest; 2) the construction period during which bare land is exposed to erosion; and 3) post-urbanization phase when the landscape is dominated by impervious surfaces, and sediment yield is limited. Subsequent geomorphologic analysis has tended to focus on the hydrological impacts of urbanized surfaces and their effects on stream flow and consequently on channel processes and morphology. These effects include increased peak flows, magnitude, and frequency.

Urbanization of all or part of a catchment has significant effects on the hydrologic and sediment regimes, including increased runoff, accelerated rate of delivery, increased size of flood peaks, and increases in the frequency of lower magnitude flood returns due to impervious surfaces (Burns et al., 2005; Niezgoda & Johnson, 2005; Chin, 2006). In urban areas, stormwater refers to rainwater and melted snow that flows over roads, parking lots, and other site. These sites are often referred to as impervious surfaces. Impervious surfaces are cover with materials which have no or little infiltration capacity or permeability for water (Brabec, Schulte, & Richards, 2002; Toronto and Region Conservation Authority, 2016b). During rainstorms, water runs rapidly into storm drains, municipal sewers, and drainage ditches, and flows directly into watercourses (Toronto and Region Conservation Authority, 2016b).

Urbanization can also transform the fluvial landscape, altering natural controls (Section 2.1) on channel geomorphology, and influencing ecological processes and their interaction (Gurnell, Lee, & Souch, 2007). Channel morphology adjusts either vertically or laterally, or both, in response to hydrologic and sediment regime changes in an attempt to reach a new state of equilibrium once more (Niezgoda & Johnson, 2005; Wolman, 1967). This leads to channel enlargement, alterations in channel planform, and further changes in sediment production (Wolman, 1967). While streamflow changes resulting from urbanization have been studied extensively, there has been relatively little analysis of the morphological response of river channels to specific changes in streamflow hydrology rather than more generally to the extent of urbanization. Changes in river morphology following urbanization have typically been done by comparing rivers with differing extent of urbanization and only occasionally using historical documents such a topographic maps, surveys, and air photos, or long-term monitoring. Therefore longitudinal (in time) studies of river response to urbanization are rare (e.g., Graf, 2000; Leopold et al., 2005; MacDonald, 2011)

Chin (2006) compiled research results from more than 100 studies, which were conducted across a range of areas to provide an in-depth analysis of the effects of urbanization on river landscapes. Of the studies which were selected, 58 specifically addressed morphological change. The conclusions from Chin (2006) were three fold:

1. Urban development has transformed watercourses across Earth's surface through changes in hydrology and sedimentology regimes, causing a range of morphological adjustments;
2. Although the impacts of urbanization are more easily summarized in terms of averages, considerable variability occurs among and within locales;
3. The persistence of urban-induced impacts can be conceptualized as time periods of adjustments for the various stages, characterized by the lag time, reaction time, and relaxation time.

Channel enlargement following urbanization was reported in approximately 75% of the studies recording channel morphological change, and channel cross-sectional areas generally increasing 2–3 times, with extremes as high as 15 times depending on the hydro-geomorphological conditions and extent of urban development within a watershed. Other changes in morphology have also been documented, including decreases in sinuosity and increases in bed material size, along with other chemical, biological, and ecological effects. Spatial variation in morphological responses results from differences in lithology, vegetation, slope, and urban structures, including road crossings and channelization. Between areas, regional trends are emerging for various environments. To date, most research on urbanization impacts on watercourses has emphasized temperate environments; data is now available for tropical settings which indicate a stronger sedimentological response in the tropics due to the intensity of precipitation and highly weathered soils. The lag time from the start of urban development to a sedimentological response could be as short as several months, however several years to decades seem necessary to clear construction-related sediments in some cases. The time required for rivers to complete the enlargement phase is variable, ranging from several years to systems that were still unstable 40–50 years following adjustment (Chin, 2006).

While the compilation by Chin (2006) was comprehensive, the cases that were selected can be thought of as primarily 'black box'; in the sense that they correlate channel changes with land-use change, usually using extent of percentage impervious watershed area as a surrogate for all flow and sediment delivery changes and without tracking causes and processes of adjustment. Along with the studies reviewed by Chin (2006) additional studies

(i.e. Hawley et al., 2013) were also reviewed. These studies can be divided into before-and-after channel studies, and paired channel studies. Before-and-after channel studies require long-term monitoring based on future urban planning as knowledge of the state of the morphology of the channel prior to urbanization is necessary. These studies are often limited to only comparing two time periods, often with decades between times, and do not monitor during the stages of adjustment. Alternatively, paired channel studies can be conducted in a short period of time as they draw comparisons between the current morphologies of multiple catchments with varying urban statuses. These studies have shorter timelines, where some only require one field season for data collection. While these are notable differences between the two study types, both types generally use similar data collection methodology, most commonly cross-section measurements. Due to the nature of the study type, as well as increasing awareness of the effects of urbanization on channel morphology, paired channel studies currently considerably outnumber before-and-after single channel studies. These examples provide an overall idea of the effects of urbanization on fluvial morphology, however they lack the in-depth, event-process analysis which is required to fully understand the evolution and morphological changes occurring in a channel (Chin, 2006). Further investigation into other urban effects assessment is necessary; this gap in the literature will be filled by this study.

Overall, the urban geomorphology papers to date have established three main things: urbanization causes change in rivers: most studies do not do longitudinal research through time on these rivers; and very few studies look directly at human intervention in the channel, focusing solely on the ‘natural’ responses. Only five of the selected studies mention direct human interventions on the channel morphology. In this case, direct human interventions are defined as any channel restoration or reengineering which may have taken place. Each of these three studies accounts for these interventions differently. Chronologically, Arnold et al. (1982) is the first paper to mention these interventions, noting portions of rip rap on the banks, as well as surveying a channelized portion of the river; this was used to demonstrate the longitudinal differences between the natural riffle-pool sequences and the channelized sections of the river, however the mention of these differences ended here. Next, Booth (1990) mentions that of the cross sections surveyed, at least one was confined in some way. These sections were placed in the stable category

along with ‘natural’ stable cross sections, instead of what could have been an urbanized category. Finally, Finkenbine et al. (2000) took a completely new approach, using the channelization or rip rap placement in the selected channel as a record of past erosion in that location. In Grable & Harden (2006), the term CRUD or ‘coarse riparian urban debris’ was used to describe any anthropogenically sourced material in or around the stream. The presence of CRUD was deemed reach specific, and considered to be part of the study creek; it was not noted that the presence of CRUD dictated anything about the history of the creek. Next, Booth & Fischenich (2015) investigated the classic channel evolution model (CEM) to determine the applicability to urban watersheds. Due to the variation in disturbances, the CEM typically used in literature inadequately describe the transitions an urban channel goes through. While these five papers begin to touch on the idea that humans have a direct intervention on the channel through restoration or reengineering, they do not appear to take these interventions under meaningful consideration. What is currently missing in these papers is the discussion as to why these direct interventions were put into place to begin with (i.e., infrastructure protection, public safety), and how one could go about categorizing these interventions as something other than stable or simply as past erosion. To expand our current knowledge of the effects of urbanization on channel morphology, further investigation and discussion of the direct interventions which humans have on the channel is required (Section 3.4 and Chapter 4)

While the studies to date have opened the field of urban geomorphology, they have so far only provided evidence of the consequences of urbanization on channel morphology without examining the history and processes of channel change. At the same time, they treat urbanization as a human impact external to the system and very few studies attempt to incorporate the effects, and processes, of policy and engineering intervention after urbanization. To understand these processes, detailed studies comparing pre-urbanization and post-urbanization channel morphology along with the influences of humans directly on the channel, over time, are needed.

To fill this research and knowledge gap, in-depth study on the specific events that change river morphology as a result of urbanization is required. This thesis is an example of how this approach can be implemented. This study tracks the history of the catchment from pre-



urbanization, including channel restoration and management, and describes the current state of the channel resulting from this history (Ashmore, 2015; Downs & Gregory, 2014). This will help answer the how, when, why, and who of the morphological change which is overlooked by the many previous studies of urban rivers.

## 2.3 Human intervention in urban channel morphology

Geomorphology primarily focuses on ‘natural’ process and landscapes. However the effects of humans on landscapes has not been completely ignored. Many textbooks and research articles often describe human impacts on landforms and landscape processes; in this instance ‘anthropogenic geomorphology’ is developing through a range of documentation, and categorization. Humans are seen as interfering with the natural order, where human-constructed landforms are artificial, and humans are disturbing equilibrium, changing boundary conditions, and creating harmful effects (Section 2.2) (Ashmore, 2015). In this instance, direct human intervention refers to any addition or change to the morphology of the channel, which is not caused naturally and could include gabions baskets, armour stone, hardlining, rip-rap, and channel realignment. Many urban channels have been modified in this way in order to protect surrounding infrastructure from morphological changes in the channel. This results in highly modified channels that are engineered for hydrological efficiency, with minimal geomorphological or ecological considerations. This creates many channels with long hardened sections, which may include concrete banks, or complete concrete channels. These channels are not dynamically stable morphologically, do not feature areas for aquatic habitat, and have little vegetation (Ministry of Natural Resources, 1994; Grable & Harden, 2006).

In order for a complete understanding of urban river morphology, an analysis beyond the norms of geomorphic research, which includes the social influences on the channel is required. Doyle et al. (2015) suggest that specific interventions and policies have effects on the reconstructed and restored morphology of urbanized channels. This may be considered another step in the evolution of urbanized channels not considered by Wolman, (1967) Using a term coined by Ashmore (2015), the socio-geomorphology of a channel extends beyond the ‘physical only’ account of urban channels, which views channels as a merely a product of the hydrological change due to urbanization in the catchment. This

type of analysis extends to include reports from provincial and local municipalities, conservation authorities, and consultant companies. The result will be a more complete understanding of geomorphology and of the role and consequences of geomorphologists' understanding of, and interventions in, these systems (Ashmore, 2015). Beyond the studies in Chin (2006), adequate documentation of the true nature of urban channels is rare. There are currently no papers using audits or descriptions to document urban channels. This study brings the urban geomorphology community one step closer to fully understanding and documenting what urban channels look like and why they look as they do.

This study aims to fill this research gap. An in-depth analysis of one case study will identify the current geomorphic characteristics of the channel as well as identify the sequence of events and processes such as urbanization, and reconstruction of the channel. This will aid in explaining how the channel became its current form, which could then be applied to other catchments in the area.

## Chapter Three

### 3 The case study of Wilket Creek

This study used a single case to provide a detailed and in-depth environmental history of an urbanizing catchment. This historical analysis of the morphology of Wilket Creek, located in Toronto, Ontario, provides background information for a larger project. The larger project, NSERC Strategic Project Grant “*Assessing and restoring the resilience of urban stream networks*”, is studying bedload transport in three creeks in the Toronto area. Wilket Creek is the most urbanized creek in the study; it has older development and no stormwater management in place. For comparison, there are two other creeks in this study; one features newer developments while the other is completely undeveloped.

In order to fulfill the holistic nature of the socio-geomorphic approach, this case study required the use of both primary and secondary data. Secondary data included reports, journal articles, aerial photographs, and Water Survey Canada data. Primary data used included analysis of aerial photographs, channel mapping, and various methods to obtain the grain size distribution of the channel (Table 3.1).

Wilket Creek is one of 11 river systems in 24 watersheds located within the Greater Toronto Area (GTA), Ontario, Canada (Trudeau & Richardson, 2016). These river systems flow into Lake Ontario. The climate in these areas is moderate humid continental (Koppen climate classification Dfa) with average precipitation of 831 mm/year, with daily average air temperatures from 3.7°C in January to 22.3°C in July (Trudeau & Richardson, 2015, 2016). Rainfall occurs in all months and snow from November to April; the frost free period typically occurs between April 13 and November 3. This region experienced heavy urbanization between 1969 and 2010; the population in the GTA has grown from 1,919,000 in 1961 to 3,893,000 in 1991 to 5,583,064 in 2011. The population density per square kilometer in 2011 was 945.4 (Trudeau & Richardson, 2016).

**Table 3.1: The types of data used by this thesis to conduct a fluvial audit on Wilket Creek, Toronto.**

Section	Data Type	Data Source
Geology	Secondary	Reports (e.g., TRCA, 2009a)
		Journal articles (e.g. Sharpe & Russell, 2016)
Land use	Secondary	Journal articles (e.g., Javed, 2009)
		Books (e.g., White, 2003)
		Aerial photographs and satellite imagery (e.g., City of Toronto, 1937)
	Primary	Analysis of aerial photographs (e.g., Figure 3.10)
Streamflow	Secondary	Journal articles (e.g., MacDonald, 2011; Trudeau & Richardson, 2016)
		Water Survey Canada (WSC)
	Primary	Analysis of WSC data and Wilket Creek gauge data (e.g., Figure 3.18: The discharge per unit drainage area (m <sup>3</sup> s-1km-2) of the West Don River and Highland Creek
Morphological change	Secondary	Reports (e.g., Parish Aquatic Services, 2013)
		Ground photographs (e.g., City of Toronto, 1937)
	Primary	Measurements of channel width change (Figure 3.30)
Current morphology	Secondary	Reports (Parish Aquatic Services, 2013)
		Channel mapping (Figure 3.33 & Figure 3.40)
	Primary	Grain size distribution analysis (Wolman Walks, Baseline, line-by-number)
		Bank stratigraphy and grain size distribution (Wolman Walk variation)

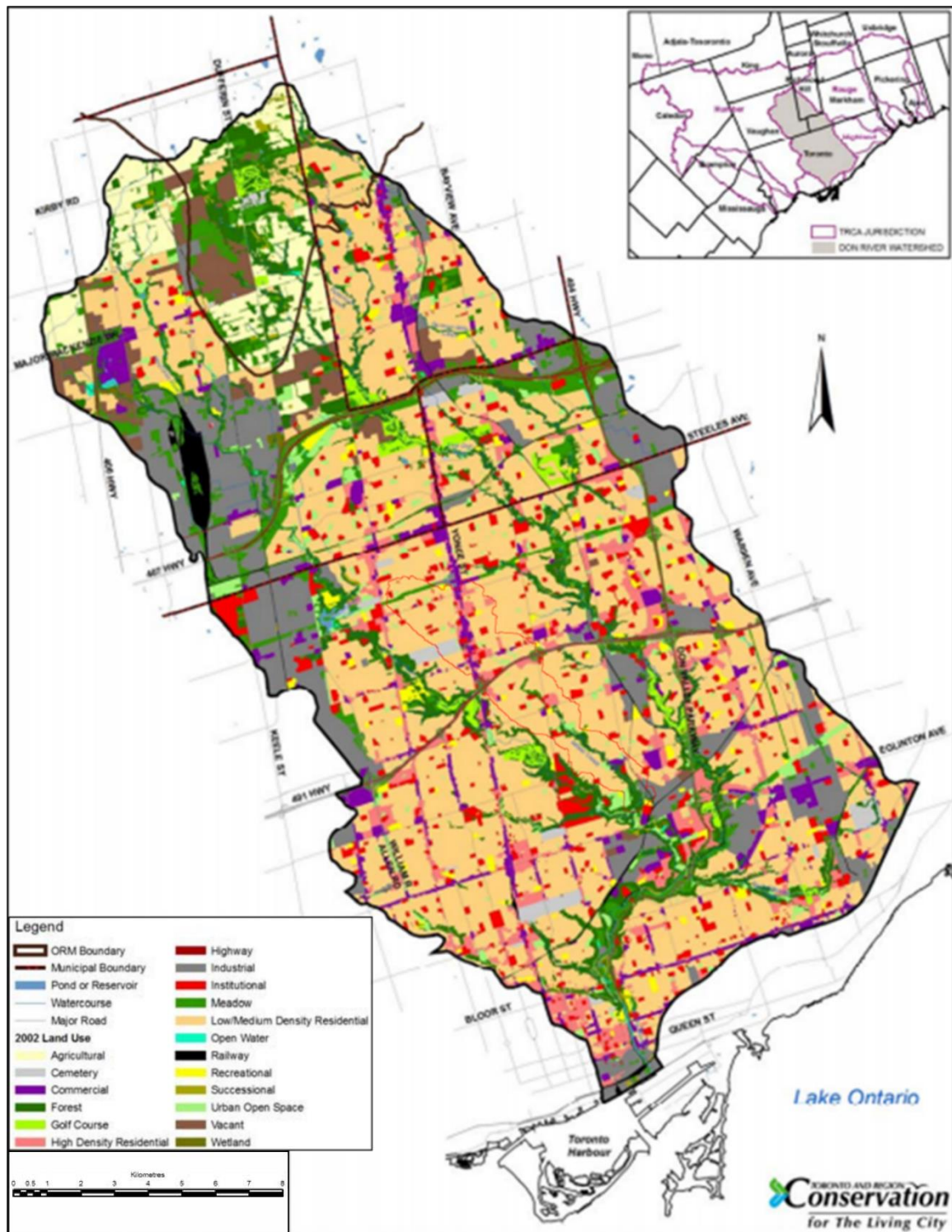
The City of Toronto became an industrializing city more than one hundred years ago, with increased rates of urbanization after World War II (City of Toronto, 2015). Development eventually extended the former boundaries of the City of Toronto (the Don River) further east in the early 1900s. Urban lands within the Toronto region, more specifically in the Don Valley watershed (Figure 3.1), include an historic urban core undergoing intensification, as well as multi-centered satellite communities comprising a variety of residential, commercial, industrial and institutional forms of land development (Trudeau & Richardson, 2016). These watersheds were predominantly serviced by conventional, separated sewer systems between 1969 and 2010, although the historic urban core of the City of Toronto had a combined sewer system. Runoff quantity control was only introduced in Ontario in the 1980s (Section 4.1), and in some recent satellite community subdivision, low-impact development (LID) after 2000 (Trudeau & Richardson, 2016). Trudeau & Richardson (2016) show that there has been a substantial change in hydrology in the Greater Toronto Area. These changes in hydrology also affect the channel morphology of the catchment into which they flow (Section 2.2). Because of the rapid rate and its recent history of urbanization, the Don River watershed (catchment) is a good example of the effects that rapid urbanization can have on a catchment and its channels (Don Mills Residents Incorporated, n.d.; Manwell, McGowan, & Rogers, 2009; Bonnell, 2014).

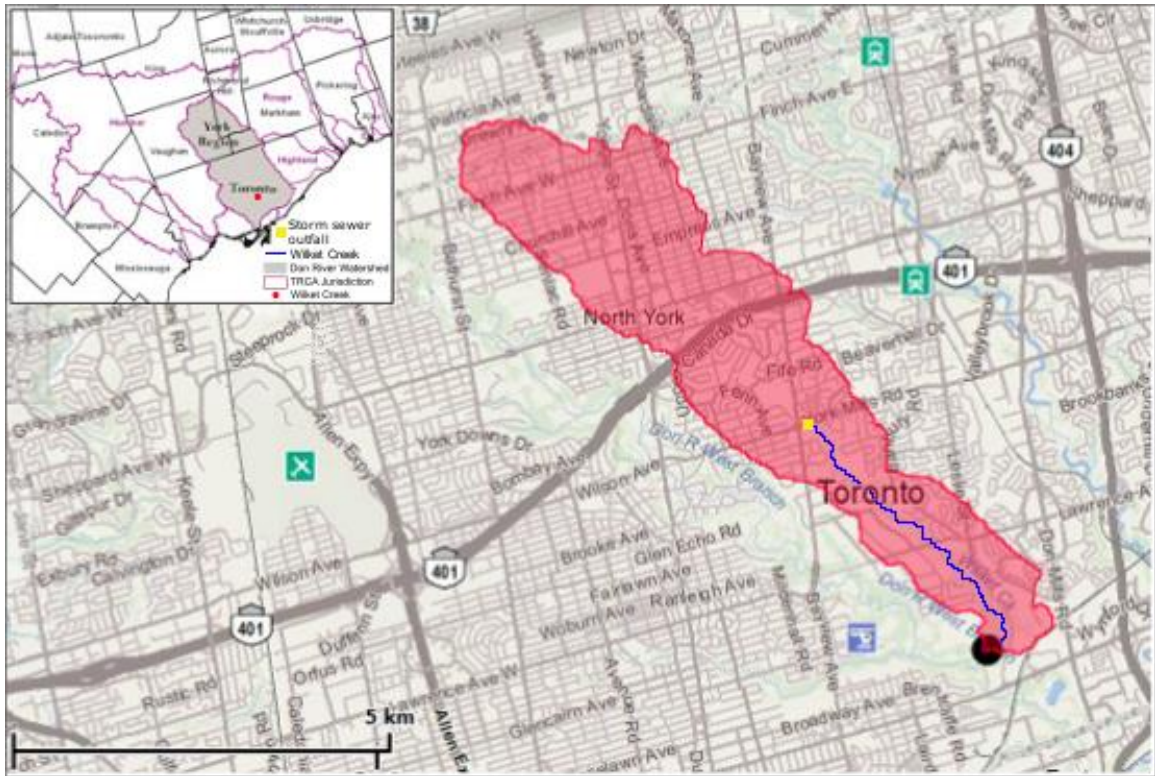
Wilket Creek is a small, second order tributary of the West Don River with a catchment area of 15.5km<sup>2</sup> (Figure 3.2) (Parish Aquatic, 2015; TRCA, 2015). The channel of Wilket Creek has been, and continues to be, heavily influenced by human activity through engineering intervention in several reaches (Parish Aquatic Services, 2013). Urbanization began in the 1950s, and the catchment was fully developed by the mid-1970s. The majority of construction within the catchment took place in the early 1960s when stormwater management was not a priority; as a result there are no stormwater management practices in the catchment (Figure 3.3) (Toronto and Region Conservation Authority, 2015).

Wilket Creek has a completely urbanized catchment, with no major tributaries. An additional input into the channel is from storm sewer outfalls along the valley. Within the catchment, approximately 93% of the land use is for community infrastructure, including residential housing, shopping centers and schools, and industrial land use. The remaining

7% land use in the catchment is treed, primarily along the riparian zone of the Wilket Creek channel (Parish Aquatic Services, 2013). The creek is bordered by the Bridle Path and Don Mill's developments, which also include three park areas along the valley (Figure 3.1): Wilket Creek Park, located at the confluence of Wilket Creek and the West Don River; Edwards Gardens located south of Lawrence Ave E.; and Windfields Park stretching from Post Rd to just south of Highway 401 (Figure 3.2). Windfields Park features sections of both open channel and buried channel. The buried section of the channel receives flow from local drainage and storm sewers along its course (Parish Aquatic Services, 2013). The headwaters were buried in 1972 in a 4m-wide stormwater conduit. The creek exits the conduit south of York Mills Road and east of Bayview Ave. Upstream of this point there are no surface channels (Figure 3.2). This study is concerned only with the open channel downstream of York Mills Road.

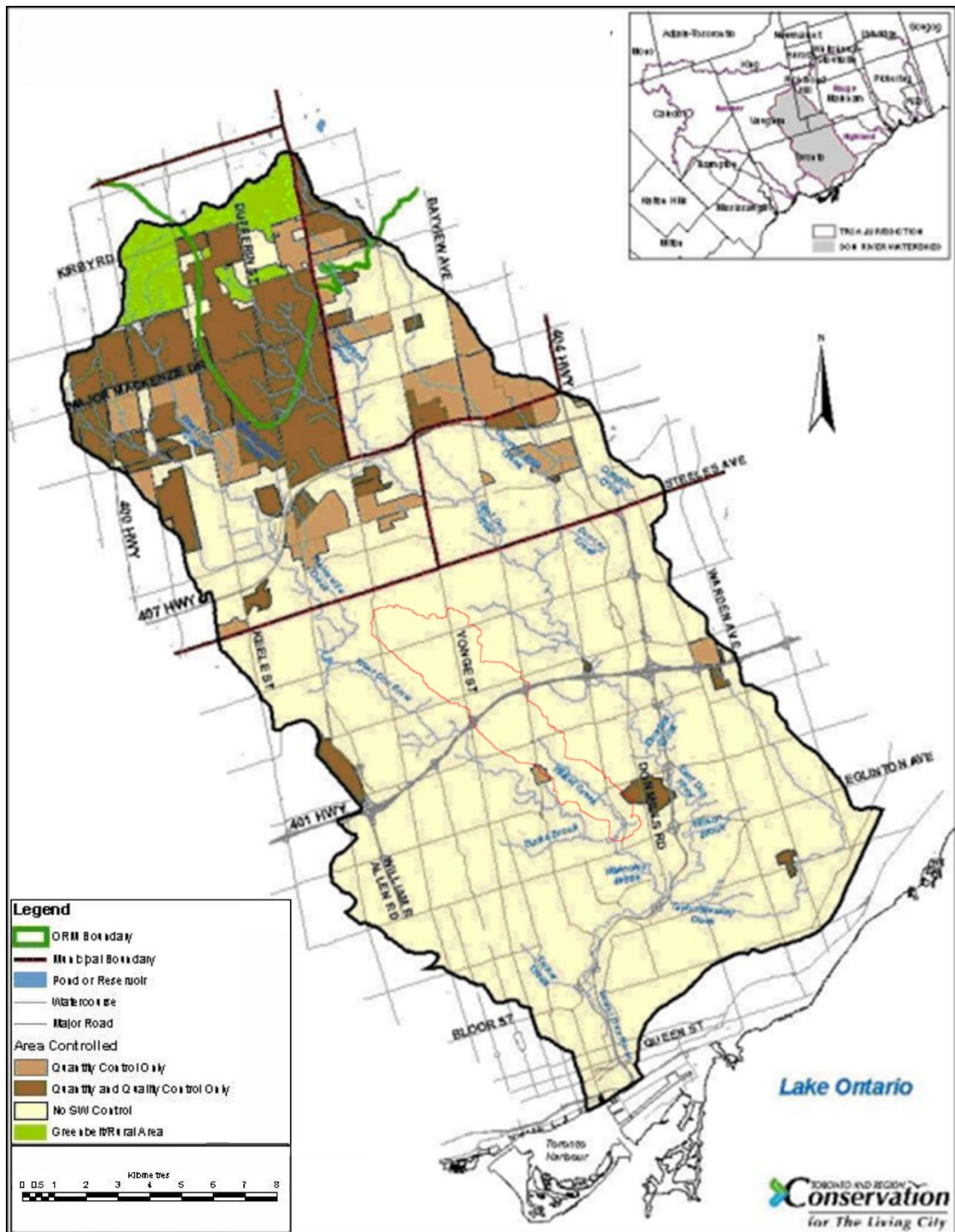
After extreme flood events and extensive channel erosion affected the catchment in 2005, 2008, and 2013, reconstruction of the channel took place as part of a Geomorphic Master Plan by the Toronto and Region Conservation Authority (TRCA) and the City of Toronto to protect the surrounding infrastructure (see below in Section 3.3 and Chapter 4 for more information) (Toronto and Region Conservation Authority, 2008; Toronto and Region Conservation Authority & City of Toronto, 2013). Many of the catchments in the Toronto area are similarly urbanized and have experienced urbanization and channel modifications similar to those discussed above. This makes Wilket Creek a good representative of a 'typical' small catchment in the Toronto area.





**Figure 3.2: The location of Wilket Creek topographical catchment in Toronto, Ontario. The channel north of York Mills Rd (the yellow square) was buried in 1972 in a trunk storm sewer. The open channel (highlighted in blue), flows from south of York Mills Rd to the confluence at the West Don River north of Eglinton Ave E.**





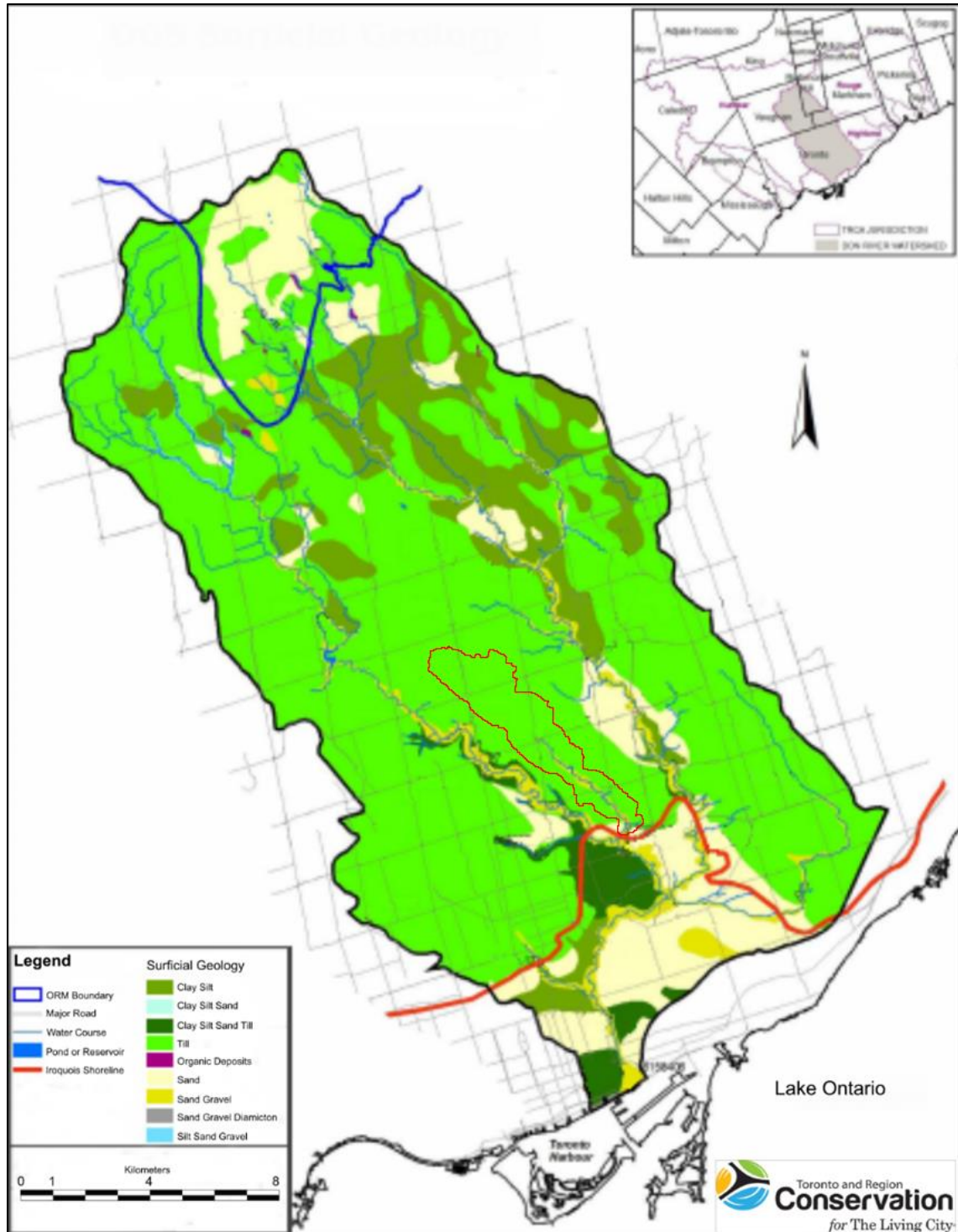
**Figure 3.3: The stormwater control measures in the Don River catchment. Wilket Creek (outlined in red), has no stormwater management controls in effect (Toronto and Region Conservation Authority, 2009b).**

### 3.1 The geological setting of Wilket Creek

Based on Ashmore & Church (2001), the Toronto and Region Conservation Authority & City of Toronto (2013) refer to Wilket Creek as a semi-alluvial channel. By their definition, Wilket Creek is partially alluvial channel, which is incised into cohesive glacial sediments in the bed and banks, which erode easily, causing the channel to adjust as an alluvial channel. To confirm into which glacial deposits Wilket Creek has been incised, documentation and surveys of the catchment, conducted by TRCA and the Ontario Geologic Survey were used.

The surficial geology of the Don River catchment is relatively uniform north of the Lake Iroquois Shoreline (Figure 3.4) (Sharpe, 2016). Between 12,500 and 12,000 years B.P., lake levels stabilized while the rest of the Ontario basin drained southeastward. This stabilization built sandy, pebbly spits or islands, which are similar to present day Toronto Islands, but at a higher elevation. A well-marked shoreline formed at the Lake Iroquois level, characterized by bluffs up to 15m in height which run east-west through the center of the City of Toronto. The Lake Iroquois shoreline crosses Wilket Creek close to its confluence with the West Don River. Due to post-glacial isostatic adjustment, the elevations for this shoreline range from 53m in the east to 61m (NAD83 / UTM Zone 17N) in the northwest of present day Lake Ontario. Other deposits attributed to Lake Iroquois include a general covering of sand, and a silty bottom cover in the former lake plain (Sharpe, 1980).

North (upstream) of the Iroquois Shoreline, the surficial geology of the Don River catchment is mainly glacial till (Newmarket till and/or Halton Till). The river valleys are incised through this surface layer into underlying Quaternary sediments that filled a pre-glacial fluvial valley system incised into a bedrock. This bedrock, currently at or below Lake Ontario level in this area, consists of shale of the Upper Ordovician Georgian Bay Formation (Figure 3.4 and Figure 3.5) (Toronto and Region Conservation Authority, 2009a). Above the bedrock is a sequence of glacial and interglacial (lacustrine/fluvial) units, which record the deposition over the last 135,000 years with more recent sediments at the surface (Figure 3.6) (Toronto and Region Conservation Authority, 2009a; Sharpe & Russell, 2016).



**Figure 3.4: The surficial geology map of the Don River catchment. Wilket Creek, outlined in dark red, is located south of the Oak Ridges Moraine (ORM) and north of the Iroquois Shoreline. The surficial geology of Wilket Creek is entirely till (adapted from Toronto and Region Conservation Authority, 2009).**

Figure 7: Don River watershed bedrock topography.

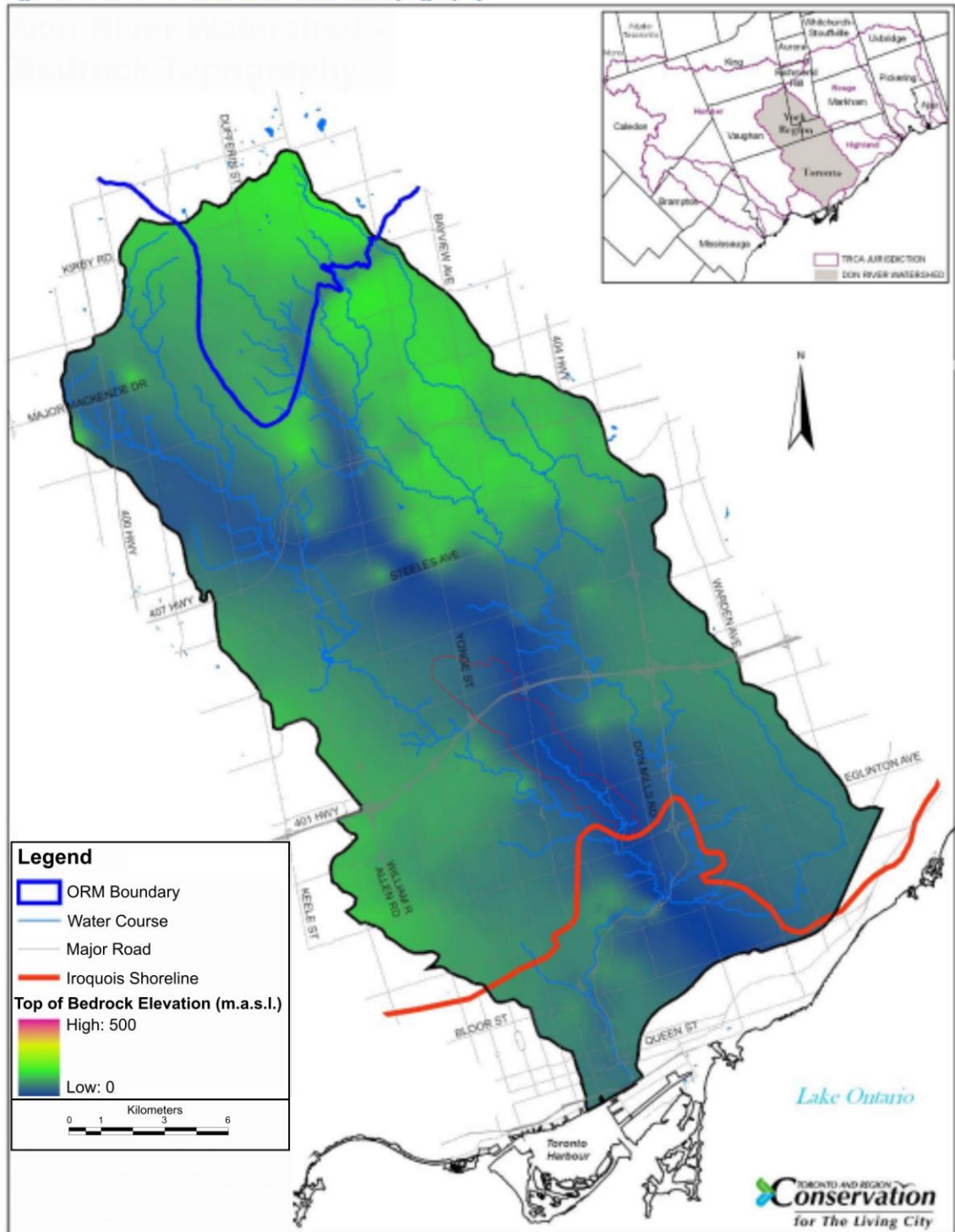
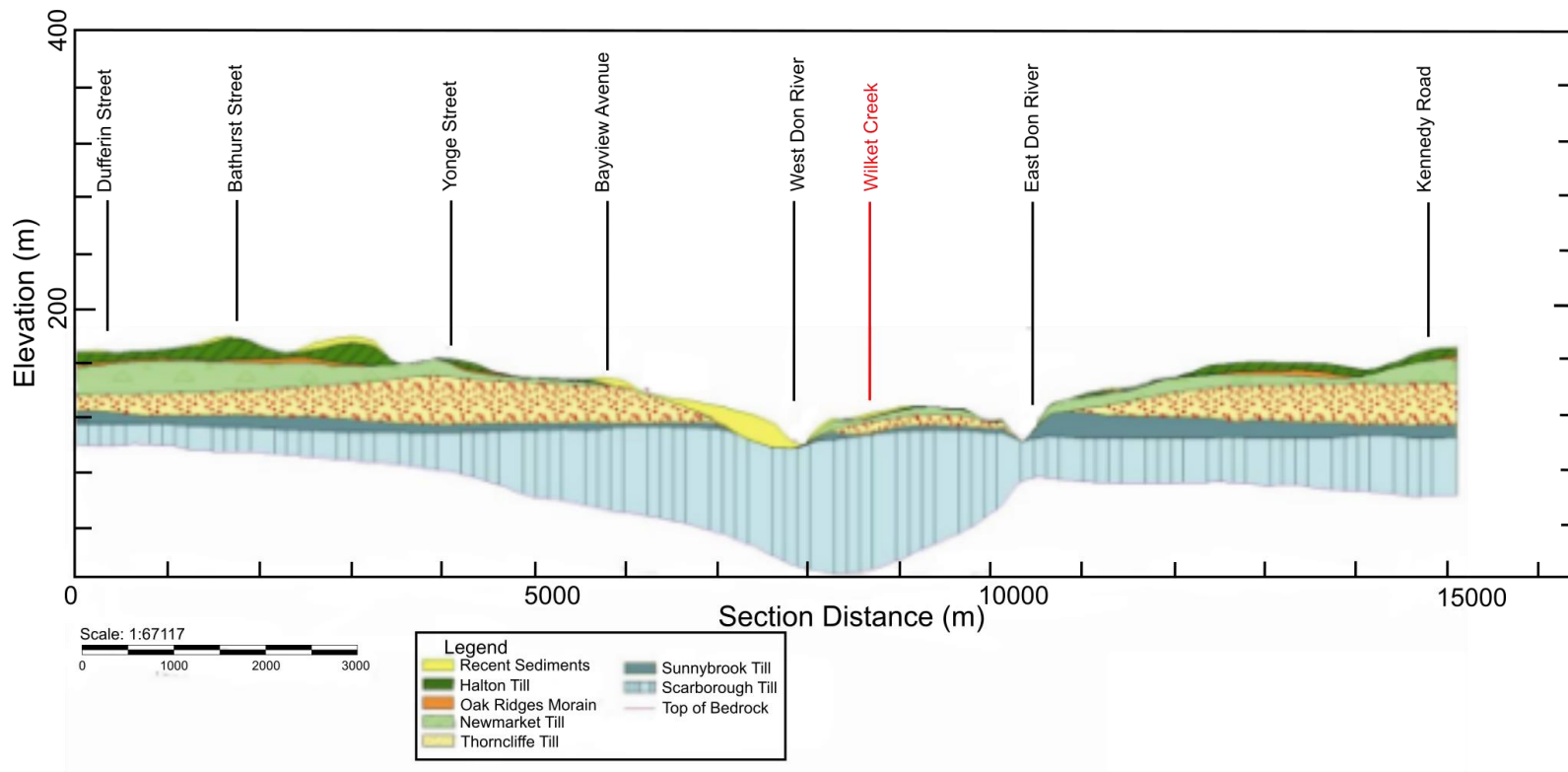


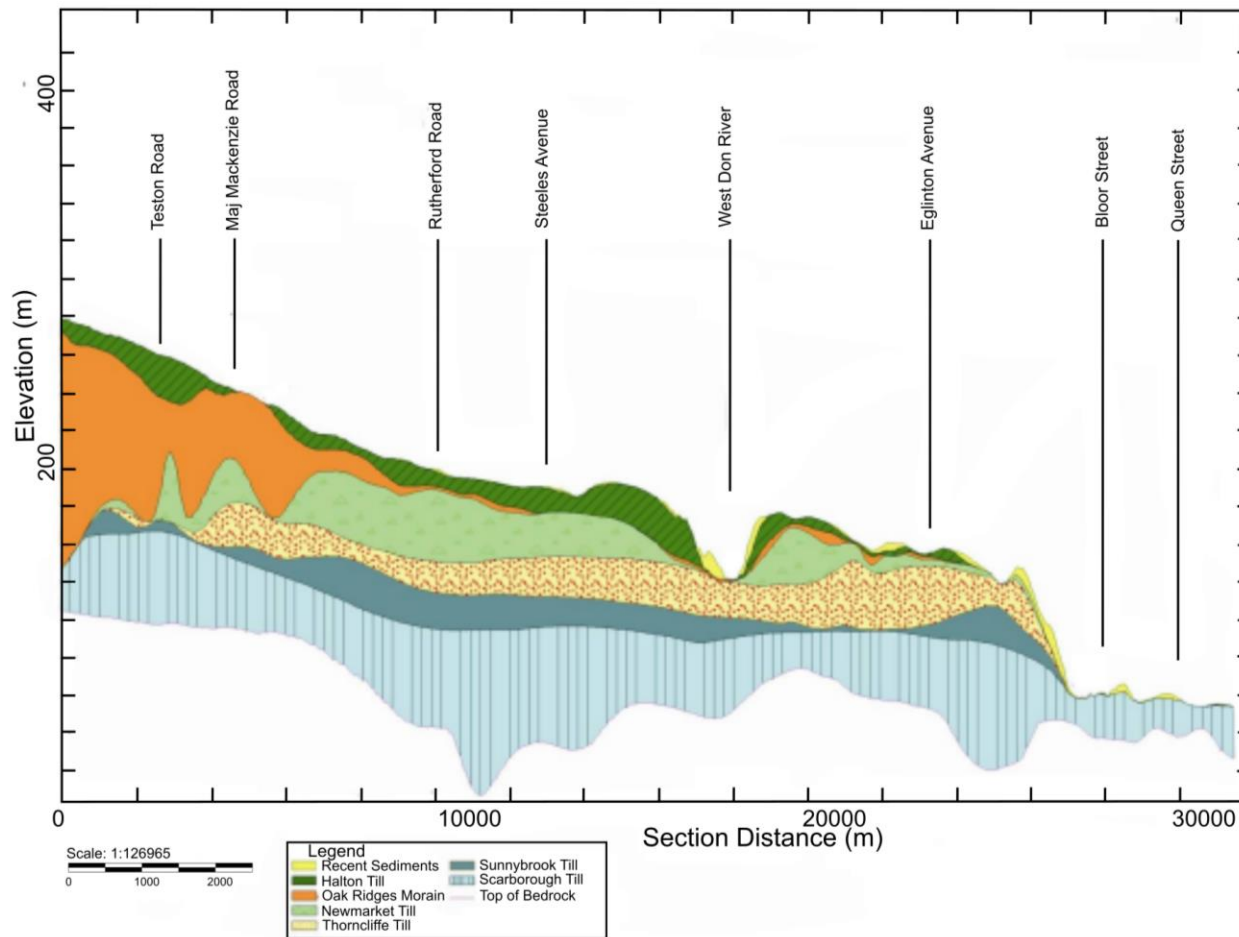
Figure 3.5: Bedrock elevation in the Don River catchment. Wilket Creek, outlined in dark red, is located south of the Oak Ridges Moraine (ORM) and north of the Iroquois Shoreline. Here, the bedrock elevation is close to present day lake level which is 75m. This elevation change is due to sediment overlay from glaciation. This figure is based on the report from *Toronto and Region Conservation Authority (2009)*.



The surficial geology of Wilket Creek was mapped in 2010 by the Ontario Geological Survey (OGS) (Toronto and Region Conservation Authority, 2009a). This mapping indicated that there are modern alluvial deposits along the creek with stone-poor, sandy silt to silty sand-textured till. In the downstream end of the creek undifferentiated older tills and coarse-textured foreshore and basinal glaciolacustrine deposits of sand, gravel minor silt, and clay are all present. Mapping conducted by OGS (Toronto and Region Conservation Authority, 2009a) of the Quarternary geology, (Parish Aquatic Services, 2013) concluded that Wilket Creek surficial sedimentology coincides with OGS' description of Halton Till. This till is predominantly silt to silty clay matrix, and clast poor, and includes glaciomarine deposits of sand, gravelly sand, and gravel. By contrast, at channel elevation, the creek appears to be within the Newmarket Till. This is based on Sharpe & Russell (2016), as well as based on two cross sections (Figure 3.6 and Figure 3.7) modified from Toronto and Region Conservation Authority (2009). Newmarket Till is approximately 50m thick and overlies the Thorncliffe Formation and underlies the Oak Ridge Moraine (ORM) and Halton Till (Sharpe & Russell, 2016). Newmarket Till consists regionally of dense, stony, sandy silt diamict. It extends from Peterborough north of the ORM, to west of Lake Simcoe, to the south side of the ORM, and to the area of Bowmanville bluffs on Lake Ontario (Sharpe & Russell, 2016). Using four points along the creek south of York Mills Rd, the elevations range from approximately 111m to 142m above sea level. These elevations place the channel of Wilket Creek in the Newmarket Till. This agrees with previous literature on the subject (Sharpe, 1980; Toronto and Region Conservation Authority, 2009a; Sharpe & Russell, 2016). Data on the composition of the sedimentology in the study reaches were limited. As a result, when referring to the glacial deposits into which Wilket Creek has incised, this study will identify it as diamict.



**Figure 3.6: A west-east cross section of the geology in Toronto. Based on the approximate location of Wilket Creek, it features recent sediments, and Halton Till. Wilket Creek flows into the West Don River, so it may also features some Thorncliffe Till and Sunnybrook Till(modified from Toronto and Region Conservation Authority, 2009).**



**Figure 3.7: A north-south cross section of the geology located west of Wilket Creek. The West Don River, into which Wilket Creek flows, features some recent sediments, Halton Till, and possibly some Thorncliffe Till. Wilket Creek likely follows a similar pattern, at least at its confluence (modified from Toronto and Region Conservation Authority, 2009).**

### 3.2 Land use change in Wilket Creek

Land use change in the catchment can be documented using a sequence of aerial photographs from 1947 to 2016. The land use of the Wilket Creek catchment changed from largely agricultural to nearly completely urbanized in this time period (Figure 3.8). While the urbanization history of the catchment began in the 1900s, events affecting the catchment began as early as the 1800s (Guthrie, 1986). The arrival of European settlers to the Don River Valley area in the 1800s initiated land clearance for agriculture and mill construction. This meant that the rivers in the area transitioned from being completely natural, to being used as irrigation and power sources. This land clearance and construction may have caused an initial sediment influx into the channel, and flow patterns may have changed (e.g., Crawford, Smith, Desloges, & Davies, 1998). Agriculture and the mills remained in the catchment until the 1920s when the building of the first residential area began in the lower catchment, and the upper catchment became a horse farm (White, 2003). The only evidence of a mill left in the catchment was the rockery in Edwards Garden, located just south of Lawrence Ave. By 1950, there were still more than 20 farms in the catchment. However, after Hurricane Hazel in 1954, the City of Toronto bought large tracts of land along the valley bottom, along with other valley lands and ravines in the city, to be used as parkland, and reduce flood hazards across the city. The horse farm, named Windfields Farm, was located on Bayview Ave, and owned by E.P. Taylor. While it downsized over the years, Windfields Farm remained as a functioning farm until 2009. Sections of the farm were preserved as parkland while the rest was sold for development. Residential land use in the catchment accelerated beginning in 1957 with the construction of two suburban communities, Bridle Path and Don Mills (Whiteson, 1982).

The Bridle Path and Don Mills developments both began at approximately the same time in the 1950s. However the infrastructure that was built differs greatly between the two. The Bridle Path development is located on the west side of the valley, while the Don Mills development borders the east side of Wilket Creek's channel. Construction of homes in the Bridle Path community began in 1929 with the construction of one home. The rest of the development was not built until after 1945, and was developed to be large, single family homes on acreages, leading to a low density housing development. By contrast, the Don



Mills development was the first development of its kind in Canada (Javed, 2009). The plan for the development was announced in 1953 by E.P. Taylor during the housing shortage following World War II. Centered on a town center and industry, housing radiated outwards. Housing types included lower-cost apartments, and both small and large houses (Javed, 2009). Green space was allowed for in both developments, but by 1975 nearly the entire southern half of the catchment was urbanized, likely with a large proportion of impervious surfaces from the Bridle Path and Don Mills developments (Figure 3.13). There has been little further development in the catchment since the 1970s, as the detailed aerial photos show (Figure 3.9 - Figure 3.17). The development that occurred in the catchment after this time is mainly commercial intensification. The catchment of present-day Wilket Creek is now completely urbanized, with only three parks in the catchment.

While the catchment was considered fully urbanized by the 1970s (Figure 3.13), the percentage of impervious surfaces may have changed since then. The development in the catchment has evolved over time, moving from residential to business centres in the upper catchment, and from farmland to residential in the lower catchment. The transition from farmland to residential areas has led to an increase in impervious surfaces. While it may seem contrary, the overall tree coverage in the catchment appears to also have increased in the catchment. This may be due to development adding trees as part of the beautification process, and natural woodland growth in the protected valley lands.

These trends can be seen in aerial photos taken from 1942 to 2016. These aerial photographs were acquired from the Toronto Archives (Figure 3.9 - Figure 3.15) and from satellite imagery (Figure 3.16 and Figure 3.17). Both satellite images came from Landsat 5 Copernicus. The earliest available aerial photos for the area are in 1942, with limited spatial coverage. The southern half of the catchment (Figure 3.9) shows the riparian area surrounding the creek as well as the farmland surrounding the creek in the catchment. It should also be noted that there is a left bank tributary, just upstream from the West Don River confluence at this time. With limited spatial coverage and image quality, it is not possible to see the creek channel in these photos, preventing a comparison of the channel morphology from 1942 to 2016.

Photo coverage is greater in 1947 (Figure 3.10) when the upper catchment shows the beginnings of residential land use. This area was known for some settlement prior to the 1940s. However, it seems likely that housing in this area increased post-WWII, with changes in government development policy and privatization of development. In the upper catchment, there is limited evidence of the channel. There is no riparian zone in the upper catchment, and the channel appears to be reduced to a drainage ditch. By contrast, the creek is open channel in both the middle and lower sections of the catchment. The land use in these sections of the catchment are still agricultural. The fields are mainly owned and operated by the Windfields horse farm, with the remainder farmed for cash crops in small holdings (White, 2003). Unfortunately due to the riparian forest in the valley, the creek channel itself is not visible in these photos.

The channel becomes more visible in the aerial photo from 1954 (Figure 3.11). It is likely that the photos were taken during the summer prior to Hurricane Hazel, which was in October of 1954. Hurricane Hazel is well known in Toronto for the extensive flooding it caused in the area; this flooding is expected to have occurred in Wilket Creek (see below in Section 3.3), and could have changed the morphology of the channel but the river is not clearly visible on the aerial photographs because of forest cover and low image quality. Residential land use in the upper sections of the catchment became denser, with new building in the area as well as extending further southeast in the catchment. Highway 401 was built from west to east, between the upper and middle sections of the catchment and can be seen in the 1954 photographs. North of Highway 401 the drainage ditch still existed, with some remnants of the ditch still extending northwest up to the cemetery on the west side of Yonge Street. By contrast, the creek is still an open channel downstream of Highway 401 to the confluence at the West Don River with the valley and riparian zone easily seen.

The residential land use in the catchment increased between 1954 and 1964 (Figure 3.12) with the construction of the previously mentioned Bridle Path and Don Mills subdivisions in the lower section of the catchment. The residential land use continues northwest, extending across the entire catchment north of Highway 401. Also during this time, the land use in the upper section of the catchment changed from residential to commercial and

possibly some industrial land use. The further development, as well as the evolution of the current land use, would have increased the percentage of impervious surface in the catchment. It is at this time that Wilket Creek is considered fully urbanized (Aquafor Beech Limited, Schollen & Company Inc., & Beak International Limited, 1999). With the evolution of land use, it appears that the catchment also begins to be more treed, and the valley and riparian zone southeast of Highway 401 to the confluence is still apparent.

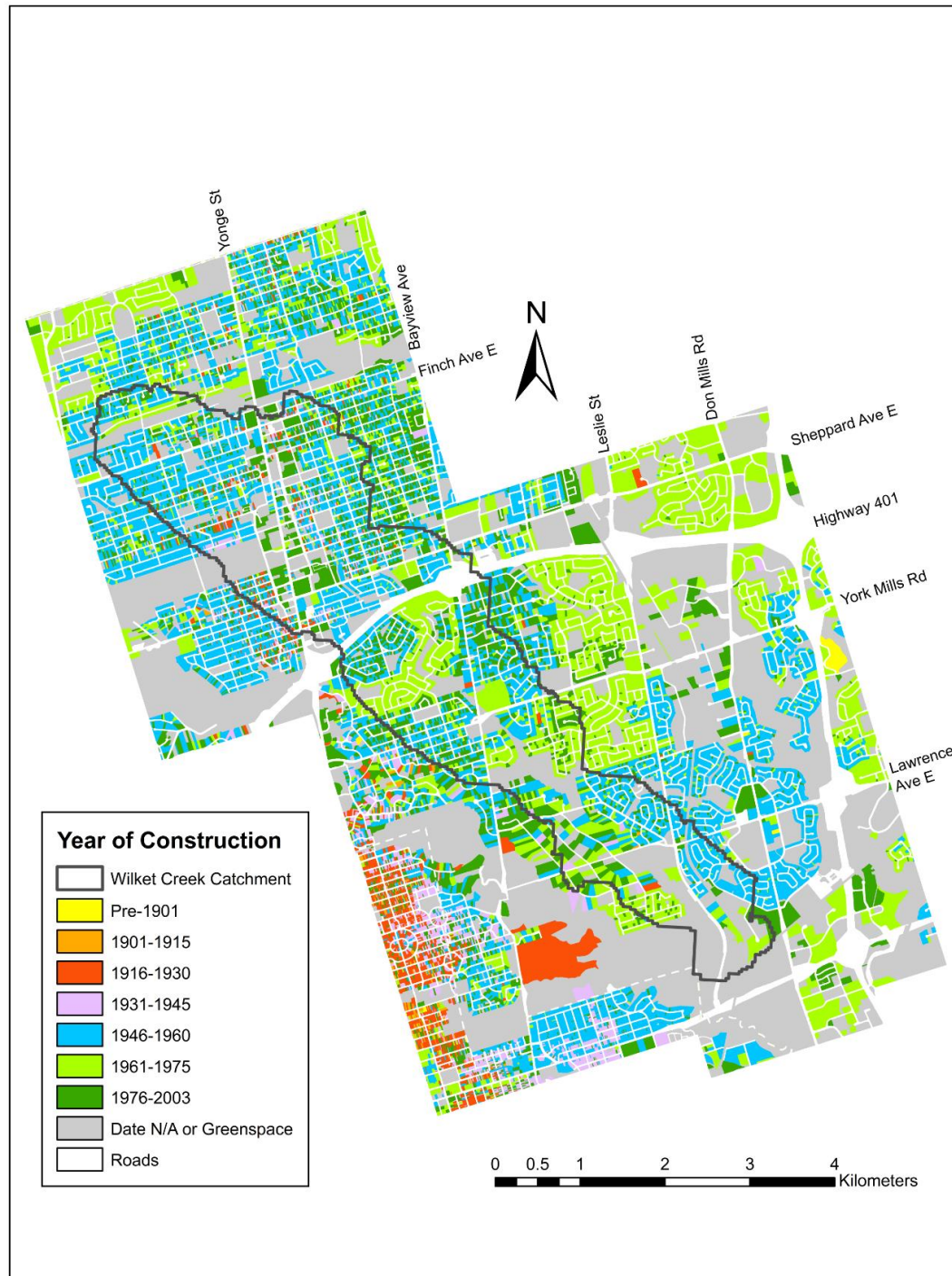
The open channel of Wilket Creek from Highway 401 southeast to York Mills Road was buried in a trunk storm sewer in 1971 (Cook, n.d.). As seen in Figure 3.13, the riparian areas located north and south of York Mills Road (the first major road south of Highway 401) became disconnected by this time. As a result, there is no evidence of the creek valley or riparian zone directly north of York Mills Road. Further north towards Highway 401, there is still evidence of the valley and some vegetation, which was preserved as a park. After the burying of the channel, the lower catchment, south of York Mills Road, remained the only open channel section of Wilket Creek. At this time, a footpath connecting Eglinton Ave East to Lawrence Ave East was built through the valley on the east side of the channel. Finally, urbanization continued throughout the catchment, with residential areas and a golf course, extending southward over the newly buried creek.

In the aerial photos from 1985 (Figure 3.14), land use of the catchment is becoming more complex. In the upper catchment, residential land use has evolved to more commercial usages. Yonge Street is now lined by high rises, and the percent impervious surfaces seems to have increased. However, it is hard to know the exact changes in percent impervious surfaces as it is too difficult to accurately measure based on the available aerial photographs. The drainage ditch which extended northwest of Highway 401 no longer appears to exist in 1985 (Figure 3.14), and no longer extends upstream (west) of Yonge Street. The middle section of the catchment remains much the same as in 1975. The residential land use in the lower section of the catchment is more obvious, and the entire catchment is undoubtedly urbanized, except for the valley south of York Mills Rd.

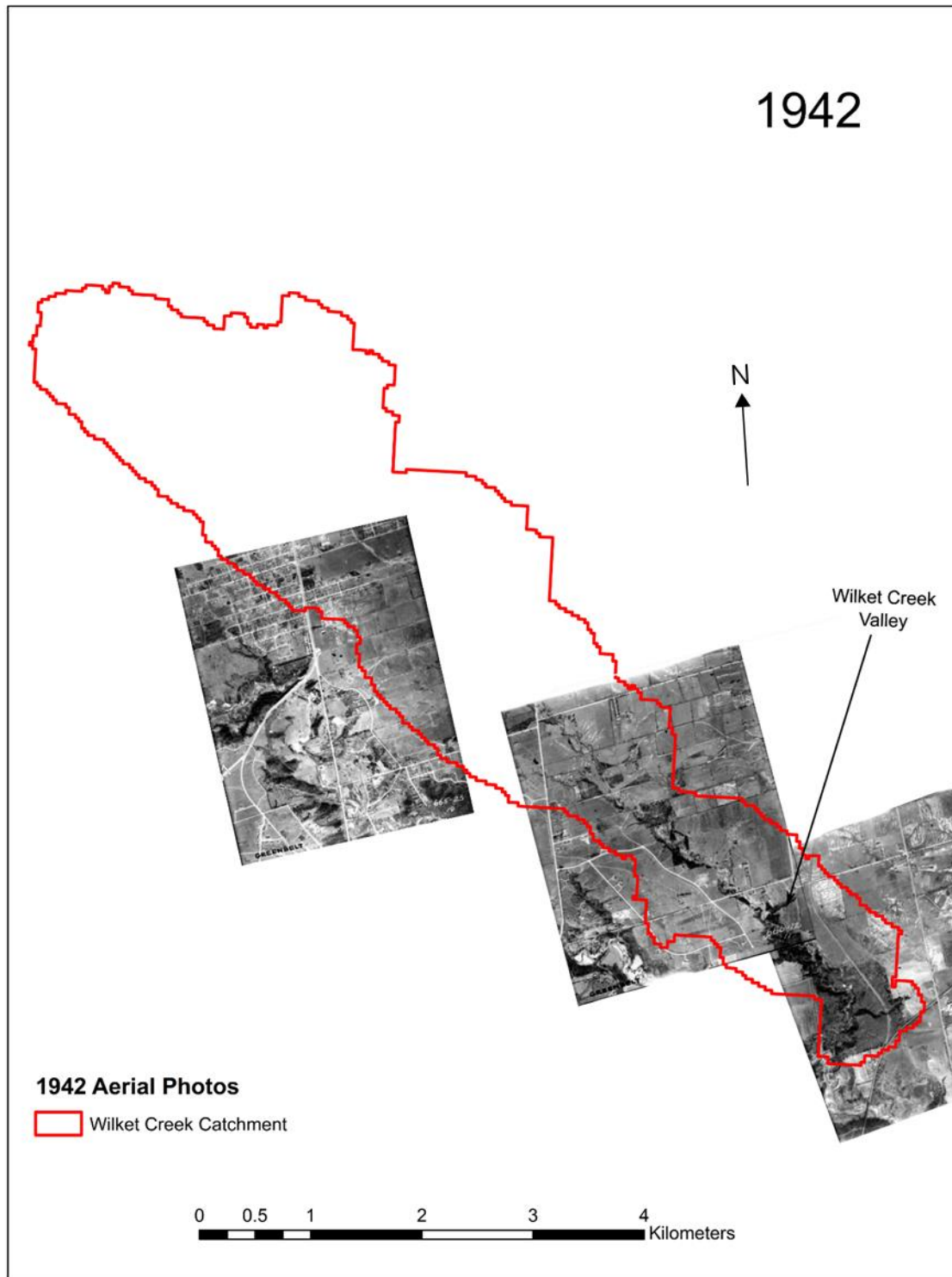
The evolution of development in the catchment continues through 1992 (Figure 3.15), and the catchment as a whole remains fully urbanized through 2002 (Figure 3.16) and 2016 (Figure 3.17). In the upper catchment, Yonge Street has more numerous high rises. The

middle catchment still has the remnants of the valley and riparian zone over the buried channel, while the lower catchment still has an open channel, valley and riparian zone.

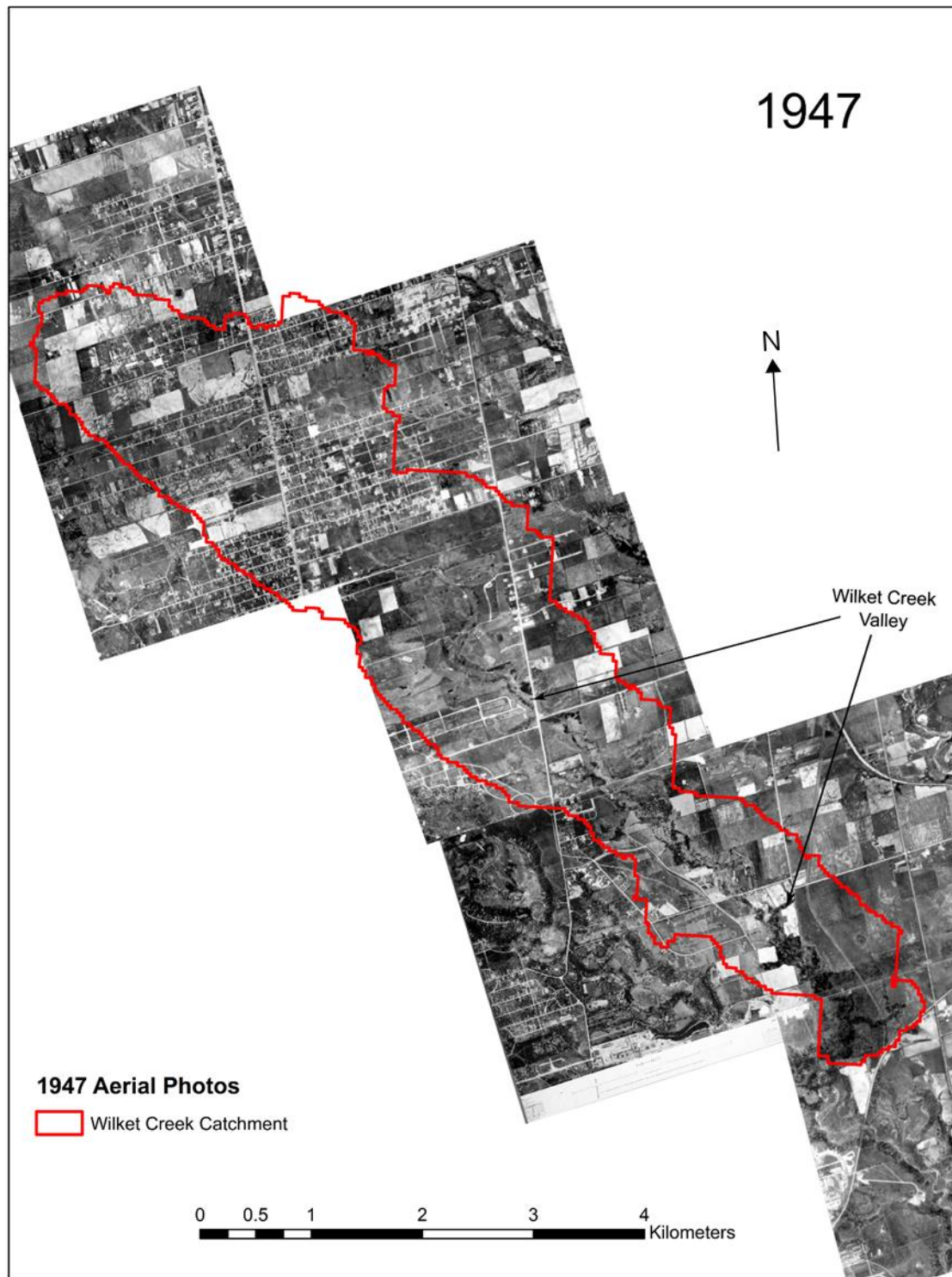
The historical air photos (Figure 3.9 - Figure 3.17), show extensive changes in land use and creek from 1942-2016. The catchment changed from agricultural with a small percentage of residential land use to being fully urbanized with residential, commercial, and industrial land use. The channel also changed from open channel to buried storm sewer downstream of York Mills Rd in the middle reach, leaving the only open channel in the lower catchment. Because of the intense urbanization in the catchment and the resulting hydrology change, the channel itself also changed in geomorphology. In order to protect the surrounding infrastructure, stream corridor policies, land acquisition, and reconstruction and reengineering of the channel began as early as the 1960s and the preservation of this corridor is apparent in the historical aerial photographs. This will be discussed further in Chapter 4.



**Figure 3.8: The date of construction for urban development in the Wilket Creek catchment and surrounding areas. The majority of construction occurred between 1946 and 1975. The land use changed in some areas after initial development, especially intensification of commercial land use in the upper catchment along the Yonge St corridor. Figure 3.9 - Figure 3.17 show changes from residential land use to commercial from 1942 to 2016.**



**Figure 3.9:** The aerial photos available for 1942 show the valley lands of the lower Wilket Creek catchment. The coverage of the riparian zone prevents any visibility of the channel itself.

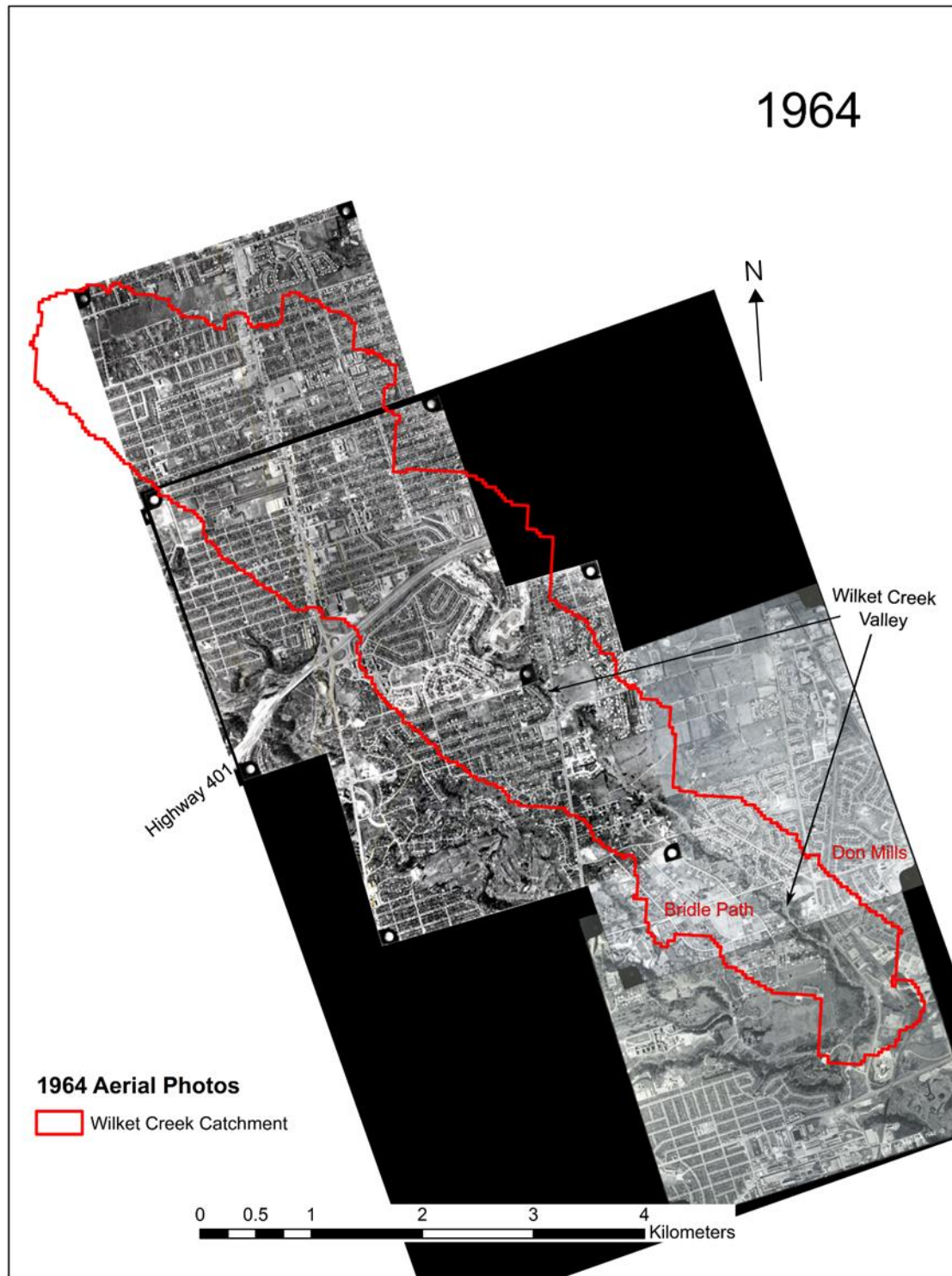


**Figure 3.10:** These aerial photos from 1947 cover the entire catchment area. It can be seen that there is only a drainage ditch in the upper catchment, while the middle and lower areas of the catchment are still open channel. Forest growth in the riparian zone prevents a clear view of the channel throughout the catchment.

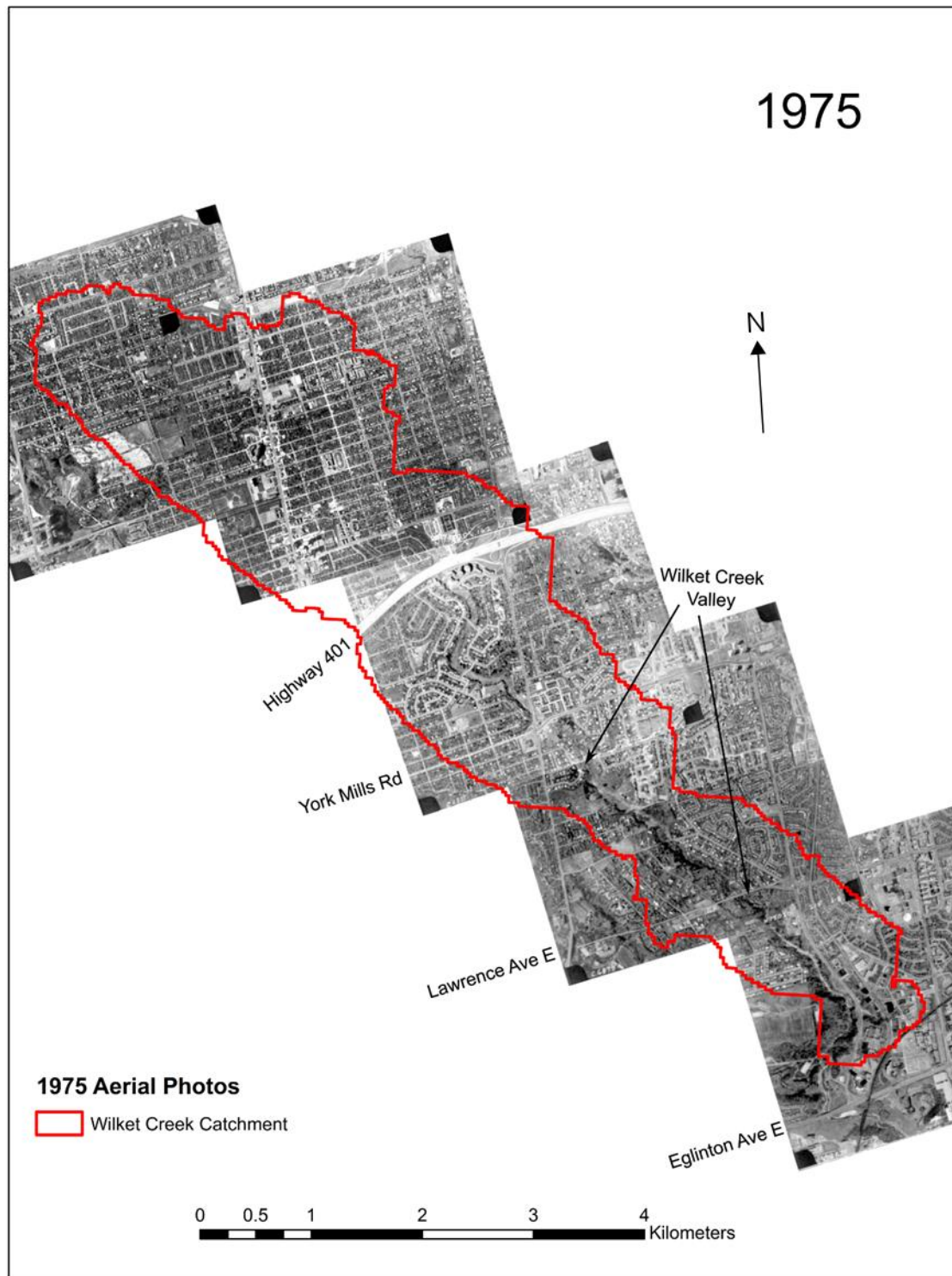




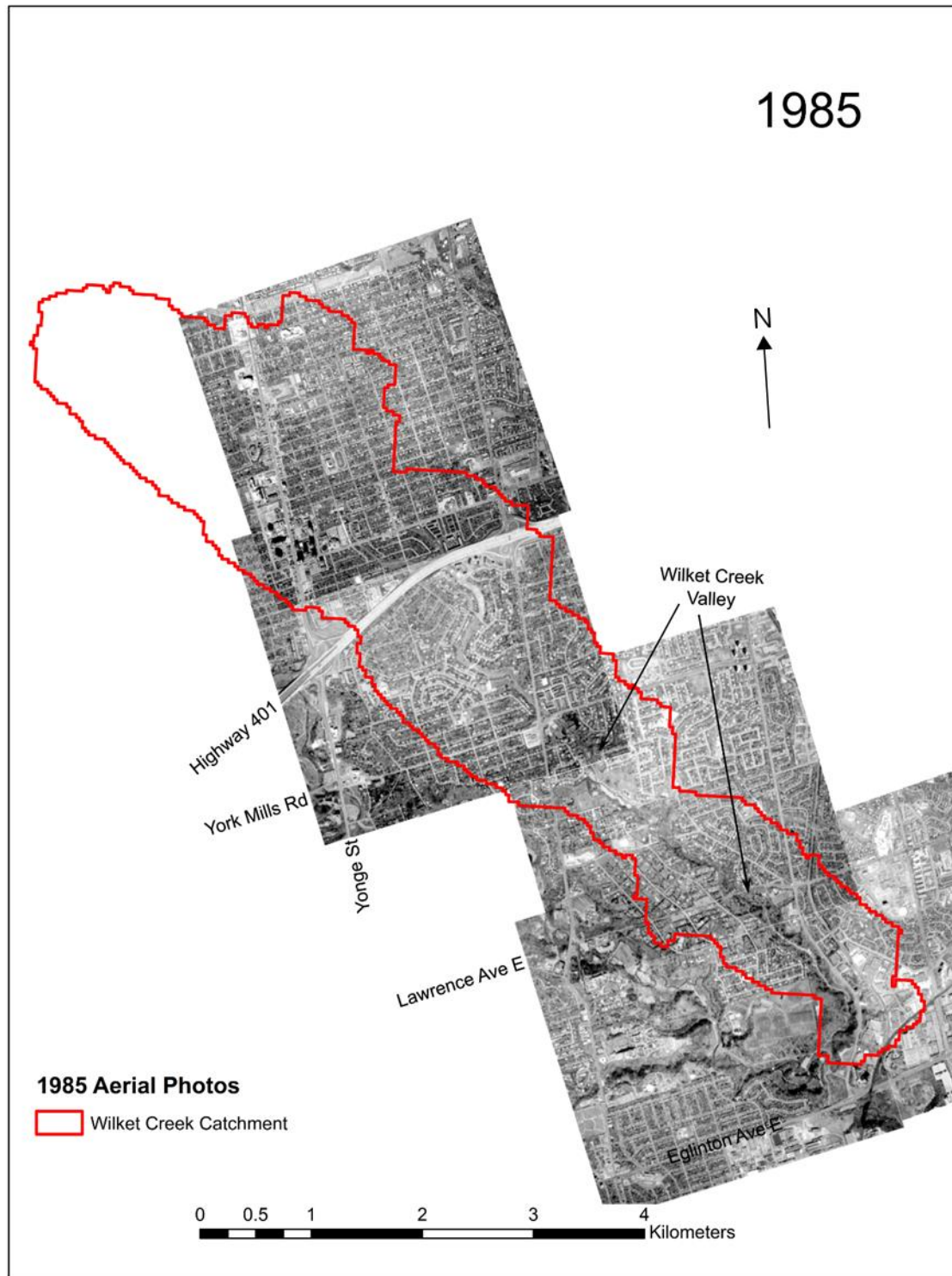




**Figure 3.12:** The aerial photos from 1964 show the accelerated land use change from agriculture to residential. The two main developments are the Bridle Path and the Don Mills developments in the middle to lower catchments. While the channel is still open south of Highway 401, the visibility of the channel is still reduced by vegetation in the riparian zone.

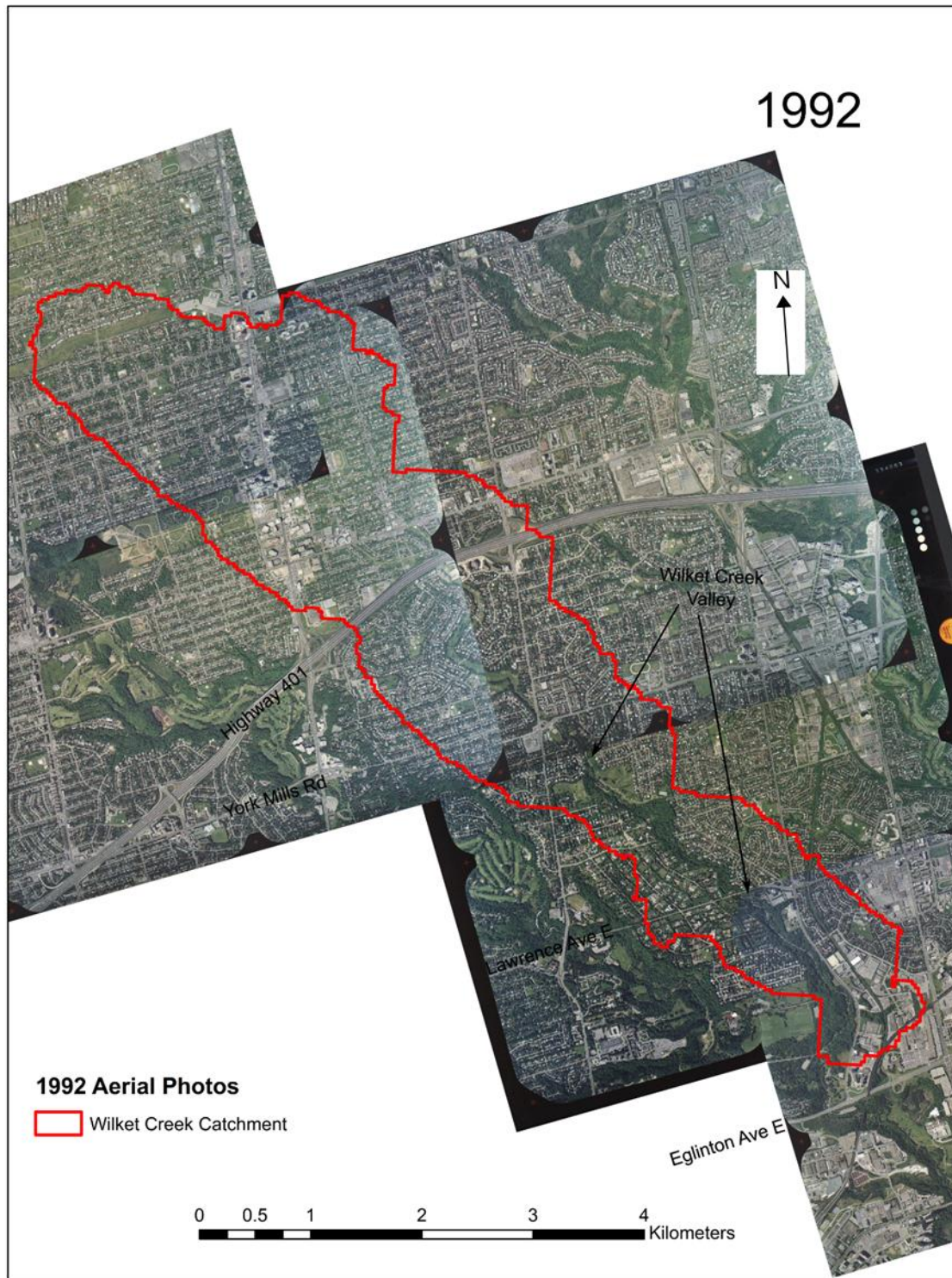


**Figure 3.13: The aerial photos from 1975 showing the change in the land use between Highway 401 and York Mills Rd. The creek was buried north of York Mills Rd in 1971. The footpath connecting Eglinton Ave E and Lawrence Ave E is easily seen in these photos, while the visibility of the channel is reduced by the riparian vegetation.**



**Figure 3.14:** The land use in the catchment is more complex by 1985, especially in the upper catchment. The drainage ditch north of Highway 401 has been covered, so only a few meters is visible close to Highway 401 by this time. The only open channel is south of York Mills Rd to the confluence with the West Don River just north of Eglinton Ave.





**Figure 3.15:** This aerial photo from 1992 shows that the catchment is fully urbanized, even though the land use continues to change. The channel is not visible in these photos due to the riparian coverage. North of York Mills Rd to Highway 401, the historic valley of Wilket Creek is seen where the channel is buried.



**Figure 3.16:** These satellite photos from 2002 show that the land use in the catchment continues to evolve. It is hard to see the channel in these photos due to the riparian coverage, while the footpath running between Eglinton Ave E and north to Lawrence Ave E is easily visible.





**Figure 3.17:** These aerial photos from 2016 show the fully urbanized catchment, in which the land use is still evolving. Some areas of the channel are visible.

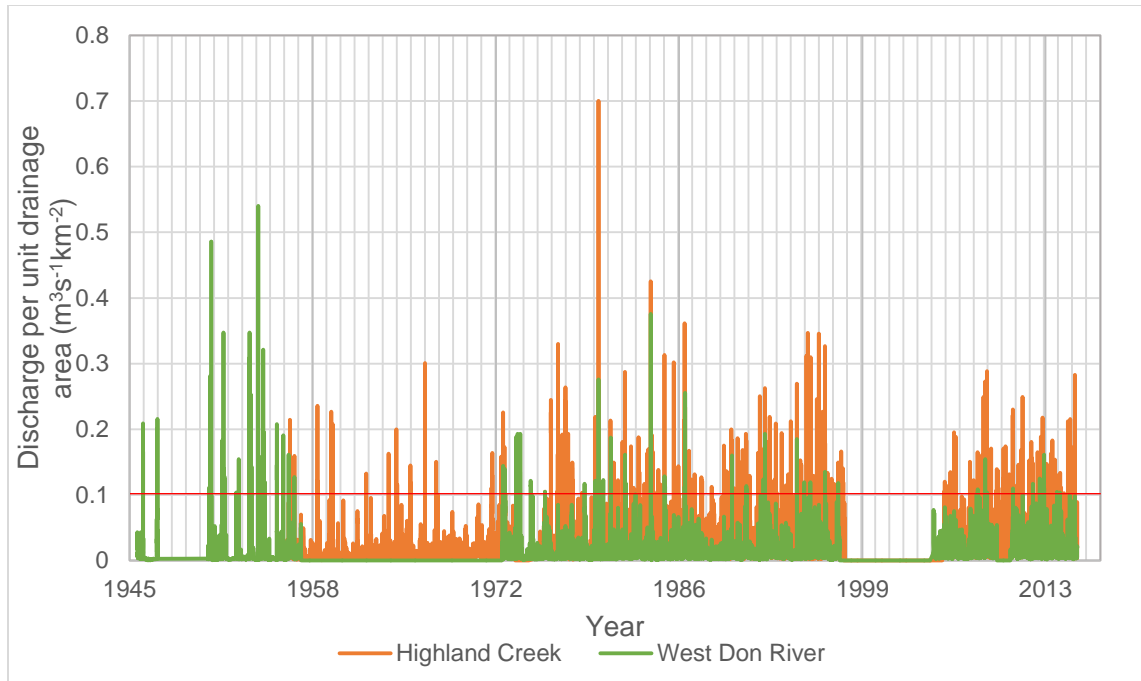
### 3.3 Streamflow changes and extreme events

As mentioned previously in Chapter 2, the hydrology of the system is the major control on channel form (Hollis, 1975). When urbanization occurs in a catchment, the streamflow regime changes, typically becoming more flashy, with higher peak and average flows (Hammer, 1972; Hollis, 1975; Trimble, 1997; Chin, 2006; Colosimo & Wilcock, 2007; Trudeau & Richardson, 2015). Since no streamflow monitoring has been done by Water Survey Canada (WSC) or TRCA on Wilket Creek, it is not possible to directly analyze historical changes in streamflow during and after urbanization. Recently, with the start of the larger research project, gauging started in the creek in 2014. While rating curve data are still being collected, the only streamflow data currently available for Wilket Creek is April-November water level data for this project. In order to approximate the hydrologic history expected in an urbanizing catchment such as Wilket Creek, streamflow records from neighbouring catchments were examined for peak flow events and changes following urbanization. These catchments have similar urbanization histories, and therefore similar hydrologic histories. The two catchments selected for long-term comparison to Wilket Creek were the West Don River at York Mills (Station: 02HC005; drainage area of 88km<sup>2</sup>) and Highland Creek near West Hill (Station: 02HC013; drainage area of 89km<sup>2</sup>). The gauging stations are located just south of York Mills/Ellesmere Road, directly west and east respectively of where Wilket Creek exits its underground conduit. The gauge on the West Don River at York Mills (02HC005) started in 1945 and continues to present day making it one of the longer records in GTA. The Highland Creek near West Hill gauge (02HC013) began in 1956 through present day, but the record is missing between 1995 and 2005. The combination of the two gauges provides a long-term estimate of flood event occurrence in the areas surrounding Wilket Creek since 1945. There are two gaps in the data set. The first gap in data is only in the West Don River from 1957 to 1975 while the second gap is in both gauges from 1998 to 2001. Even with these gaps in the data, the length of the data provided with these two gauges is substantial enough to provide a general context for possible changes in streamflow regime in Wilket Creek.

Urban catchments in the Greater Toronto Area show peak flows from two up to ten times the mean daily discharge (MacDonald, 2011). Based on these flow records (Figure 3.18),

there have been multiple flood events greater than 0.1 discharge per unit drainage area, in the Don River and Highland Creek respectively. For this study, discharge per unit drainage area ( $\text{m}^3\text{s}^{-1}\text{km}^{-2}$ ) is calculated as discharge ( $Q$ ,  $\text{m}^3\text{s}^{-1}$ ) divided by drainage area ( $DA$ ,  $\text{km}^2$ ) (Watt, 1989; Wohl et al., 2012). The discharge per unit drainage area of  $1.0\text{m}^3\text{s}^{-1}\text{km}^{-2}$  was chosen as it divides baseflow and small flood events from major flood events. Because this data is a daily average, it is not possible to quantitatively determine the value separating baseflow and major stormflow. These major flows would be considered channel forming (see below). There are two large gaps in data, so it is not possible to extract exact numbers of changes in peak values and changes in frequency due to urbanization. It is however possible to make strong inferences. For the West Don River, the peak discharges do not seem to have increased over time, however the frequency of larger flows has increased over time. Highland Creek also follows this same trend (MacDonald, 2011). The discharge of Highland Creek is at least double, if not more, than the discharge of the West Don, despite having very similar drainage area. This may be due to a variation in the rates of urbanization of the two catchments; however both Highland Creek and the West Don River began urbanizing in the early 1950s. Development of the lower Don (i.e. Don River at Todmorden) began earlier with industry in the 1850s (Guthrie, 1986). Trudeau & Richardson (2016) also noted that there is correlation between the percentage of urbanization in a catchment and changes in the total runoff and streamflow for several catchments in GTA. The number of peak flow events, or major flood events, noted above is also important to compare to Wilket Creek. Since the West Don River and Highland Creek border Wilket Creek, it can be assumed that some, or even all of the events that occurred in these two catchments would have also occurred in Wilket Creek. As well, these major flood events had the potential to alter channel morphology, based on estimates of ‘control’ discharge for mobilizing the  $D_{50}$  along the present day channel (Section 3.5.3). Recent major flood events stimulated emergency works and reconstruction of the channel (Section 4.2.2)



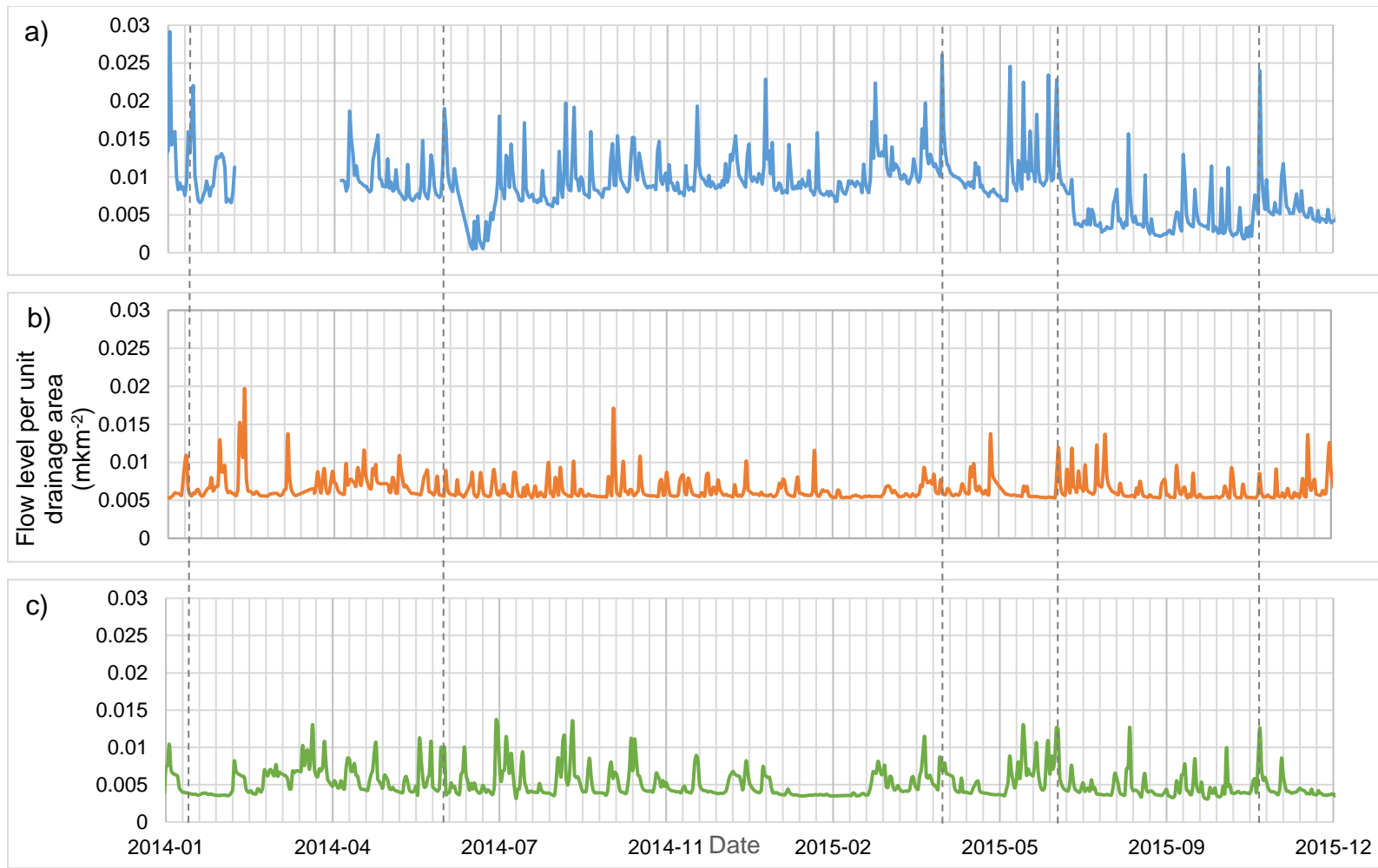


**Figure 3.18: The discharge per unit drainage area ( $\text{m}^3\text{s}^{-1}\text{km}^{-2}$ ) of the West Don River and Highland Creek catchments upstream of York Mills/Ellesmere Roads. These gauges are located approximately due east and west of where Wilket Creek appears on the surface (south of York Mills Rd), and can be used to approximate the timing of large flood events in Wilket Creek. Prominent flood years include 1954, 1980, and 1984; these floods will be more closely examined in Figure 3.21. As part of the NSERC Strategic Project Grant, gauging on Wilket Creek began in 2013 through to current day, with several gauges in both restored and unrestored sections of the channel. There are two gauges located upstream of Lawrence Ave E, while three more are located downstream of Lawrence Ave E. The longest record is from the gauge that was installed on September 13, 2013, and is used here. Figure 3.19 shows the comparison between flood events which were identified in the West Don River and Highland Creek and those that occurred in Wilket Creek based on flow level (stage).**

Figure 3.19 provides data for a two-year period from January 2014 to December 2015. Within this period, there are several flood events that coincide among the three catchments. Based on the three events selected for comparison (Figure 3.19), the events between Wilket Creek and the West Don River seem to be more similar in magnitude than between Wilket Creek and Highland Creek. The events in Wilket Creek are relatively larger than those seen in the other two catchments, this may be due to a greater percentage of urbanization in this

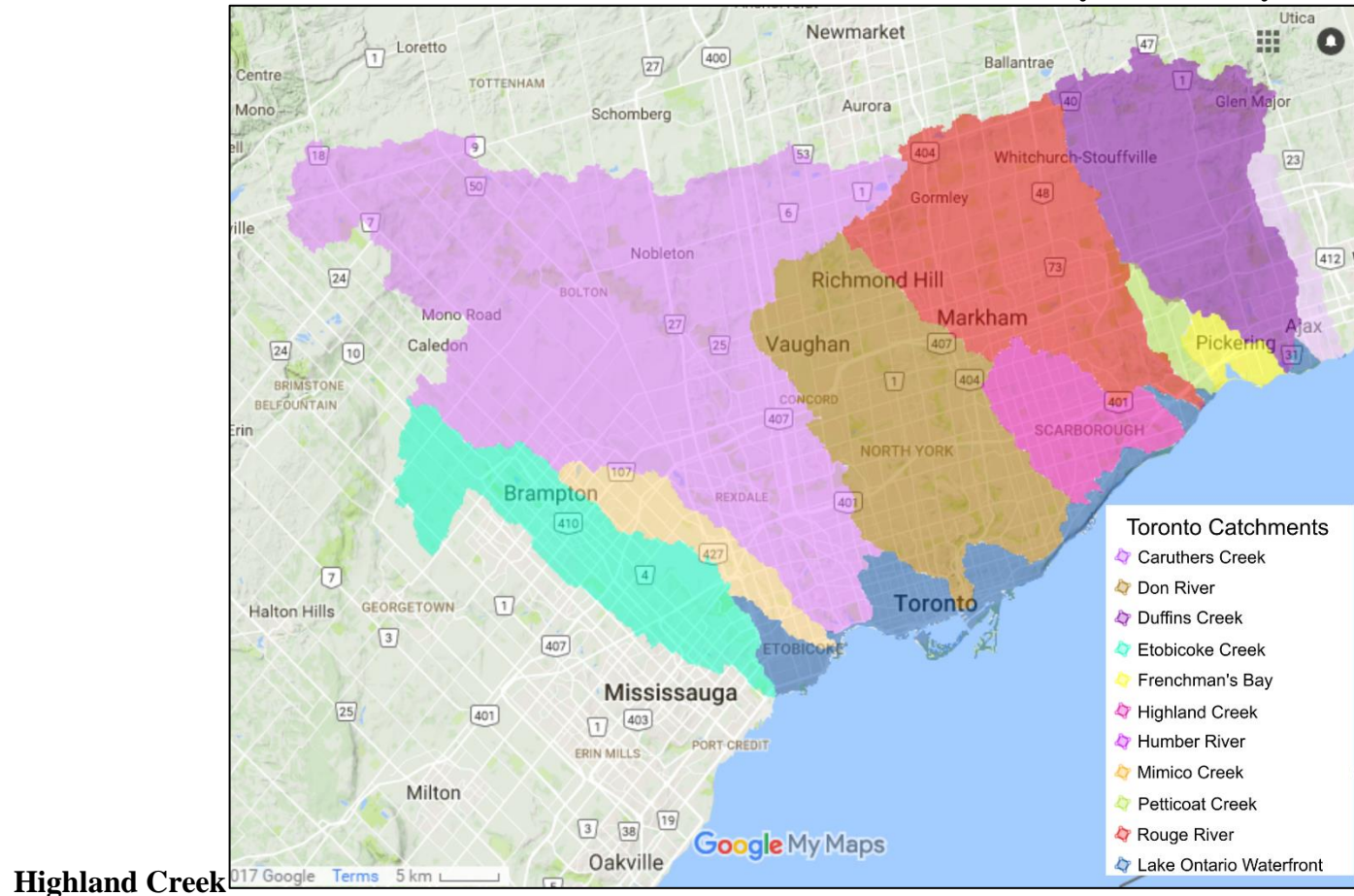
catchment. The drainage area of Wilket Creek is considerably smaller and more elongated than the drainage areas of the West Don River and Highland Creek. Overall, the comparison in Figure 3.19 shows that using catchments neighbouring the study catchments is potentially valid for looking at historical flood events of an ungauged catchment.

Based on the assumption that the West Don River and Highland Creek are suitable surrogates for historical major flow events, this was extended to another neighbouring catchment in order to investigate how the critical discharges for erosion found by Parish Aquatic Services (2013) relate to Wilket Creek flows. Figure 3.20 shows the three catchments, which are all similarly urbanized: Black Creek near Weston (Station: 02HC027; drainage area of 58km<sup>2</sup>), as well as Highland Creek near Westhill and the Don River at York Mills used above. The peak flow events (Figure 3.21) were converted to flow per unit drainage area, and the years with the highest flows as well as those years mentioned as having substantial peak flows were selected. The range of flow level is quite large between the three catchments. Based on Figure 3.19, Wilket Creek's flow level per unit drainage area, calculated (mkm<sup>-2</sup>) should be slightly higher than those of the West Don River at York Mills. That said, the flow level per unit drainage area selected in Figure 3.21 also show that the flow level per unit drainage area of Highland Creek should be lower than both Wilket Creek and the West Don River. As a result, the addition of three catchments in Figure 3.21 increases the range of possible flow levels which Wilket Creek would have experienced at any given time. Figure 3.21 also shows the years in the surrounding catchments that had the highest peak flows. In particular, major flood events took place in 1954 (Hurricane Hazel), 1980, 1984, 1986, 2000, 2005, and 2013. It is expected that Wilket Creek would have also experienced these flows, especially as documentation of the resulting damage to Wilket Creek in 2000, 2005, and 2013 is noted in many documents by the City of Toronto and the TRCA. These events, and the resulting policies and changes made to the morphology of the creek are discussed below in Chapter 4.

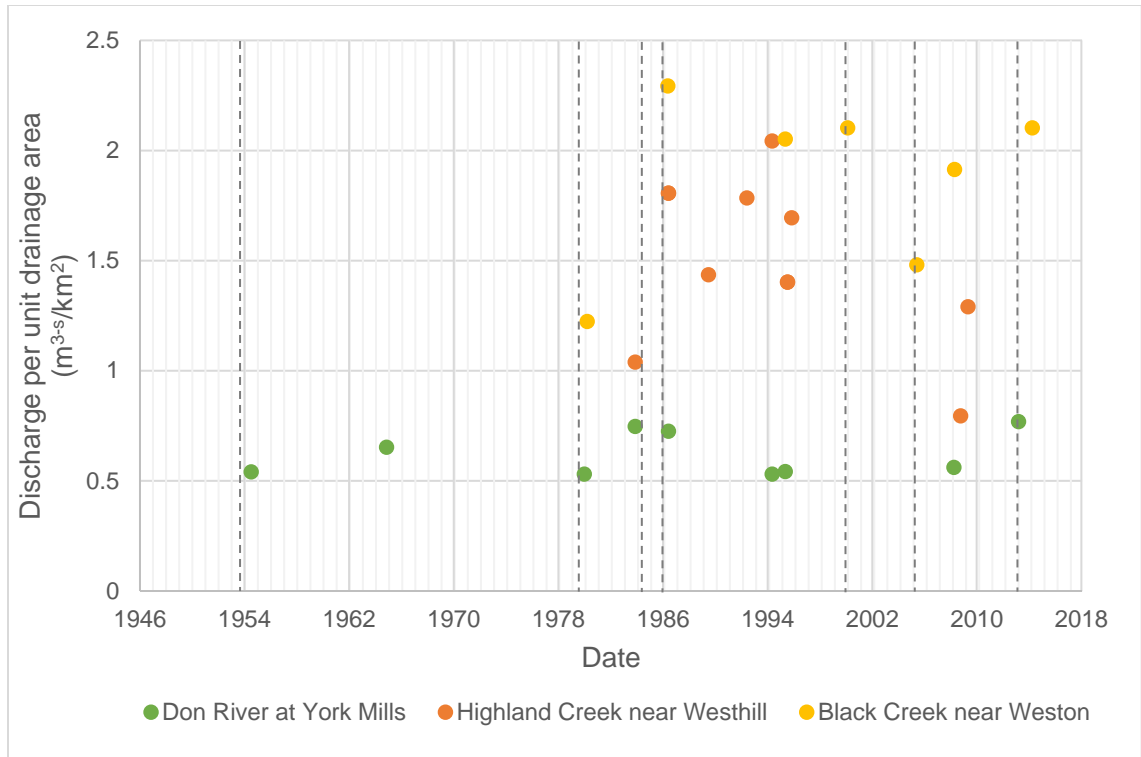


**Figure 3.19: A comparison of flow level per unit drainage area ( $\text{mkm}^{-2}$ ) between a) Wilket Creek, b) Highland Creek near Westhill, and c) the Don River at York Mills. The flow level in Wilket Creek is far greater than those seen in the**

other two catchments. The selected events in Wilket Creek are more similarly mirrored by the West Don than by



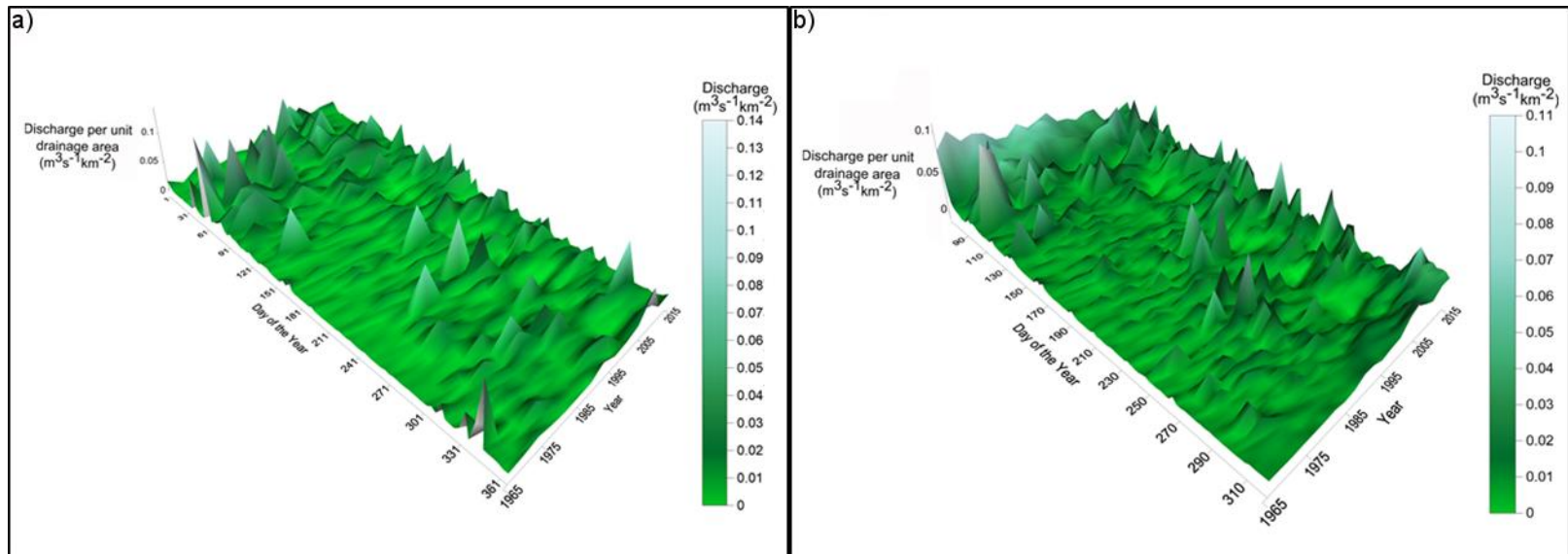
**Figure 3.20: Catchments in Toronto and the Greater Toronto Area. The streamflow data from the Don River (brown) into which Wilket Creek flows, along with the Humber River, into which Black Creek flows (purple), and Highland Creek (pink), were all used as surrogate streamflow data for Wilket Creek. The peak streamflow years are noted in Figure 3.21.**



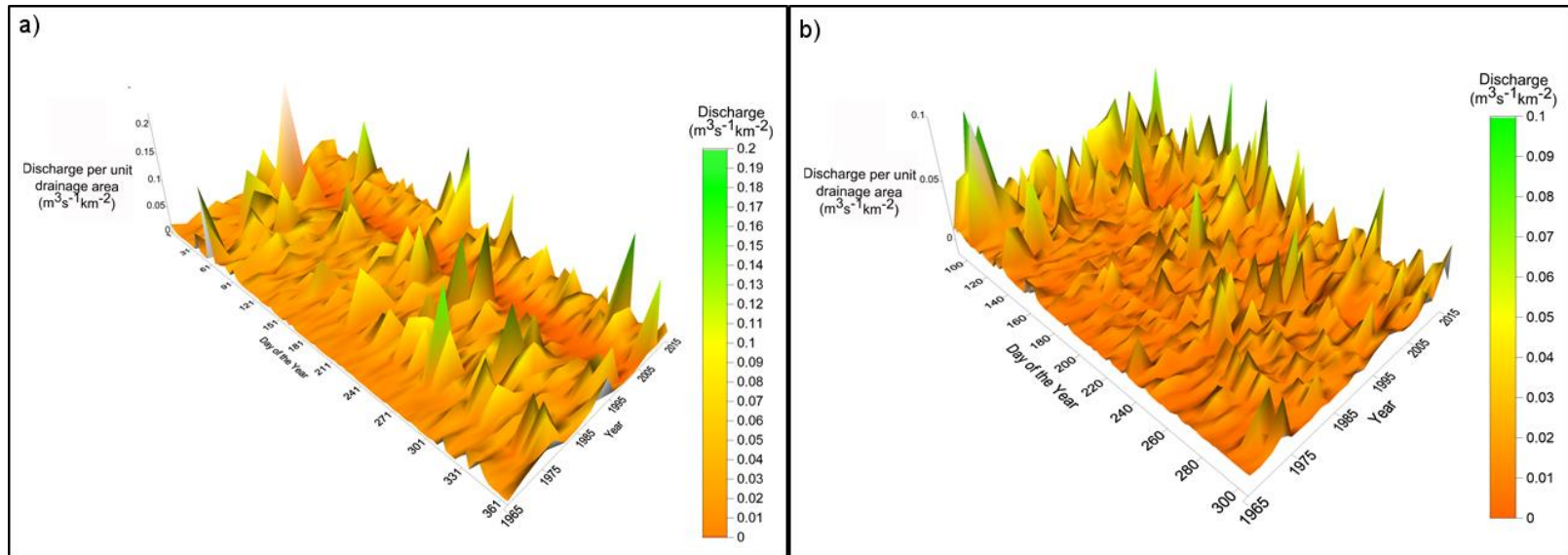
**Figure 3.21: The peak flow events in three neighbouring catchments to Wilket Creek. There is a large range of discharges between the three catchments; based on the above information, Wilket Creek would have also experienced these events, most likely within this range of discharges. These are the most extreme events in each of the catchments; it is expected that for each of these years (1954, 1980, 1984, 1986, 2000, 2005, and 2013) there would be an extreme event in Wilket Creek as well.**

While Figure 3.19 and Figure 3.21 show the peak events which may have occurred in Wilket Creek due to the proximity of the catchments, catchment size, and physiographic conditions, the overall trends in discharge should be examined. Gauging of the Don River at York Mills began in 1945, with a few gaps in data 1999 and 2006. While this gauge shows the flooding caused by Hurricane Hazel in 1954 (Figure 3.22), there are also several large flood events at other times in the late 1940s and early 1950s. Neither of the gauges on the other neighbouring catchments date back to this time period so there is limited information on whether these events also occurred in Wilket Creek. Highland Creek near Westhill began in 1956, although continuous gauging did not begin until 1958, and there is a large gap in the data between 1999 and 2006. Finally, the gauge on Black Creek at Weston began in 1966, and has no gaps in the data.

The discharge per unit drainage area was calculated over time for the neighbouring catchments. The daily discharge per unit drainage area of the Don River at York Mills (Figure 3.22) shows a decrease in spring snowmelt flows, and the traditional seasonal flow cycle is interrupted by summer rainfall flows. This becomes more obvious after about 1975, at approximately the same time as urbanization began to move northwards throughout the catchment. Over time, there is an increase in the frequency and magnitude of flashy summer flows. Highland Creek near Westhill follows a similar time trend in which snowmelt flows have depleted over time (Figure 3.23) while flashy summer flows start after urbanization began in 1974, increasing in frequency and magnitude over time. This pattern presumably increases with the increase of urbanization in the catchment. Finally, Black Creek at Weston (Figure 3.24) shows depleting winter snowmelt flows over time with little to no late fall flows. Flashy summer discharges are already occurring throughout the year at the time that gauging began (1966). This is most likely due to the early urbanization that occurred in this catchment. Given that this time trend is, in general, similar in surrounding catchments it is reasonable to infer a similar shift in annual flow regime in Wilket Creek over the same time period.

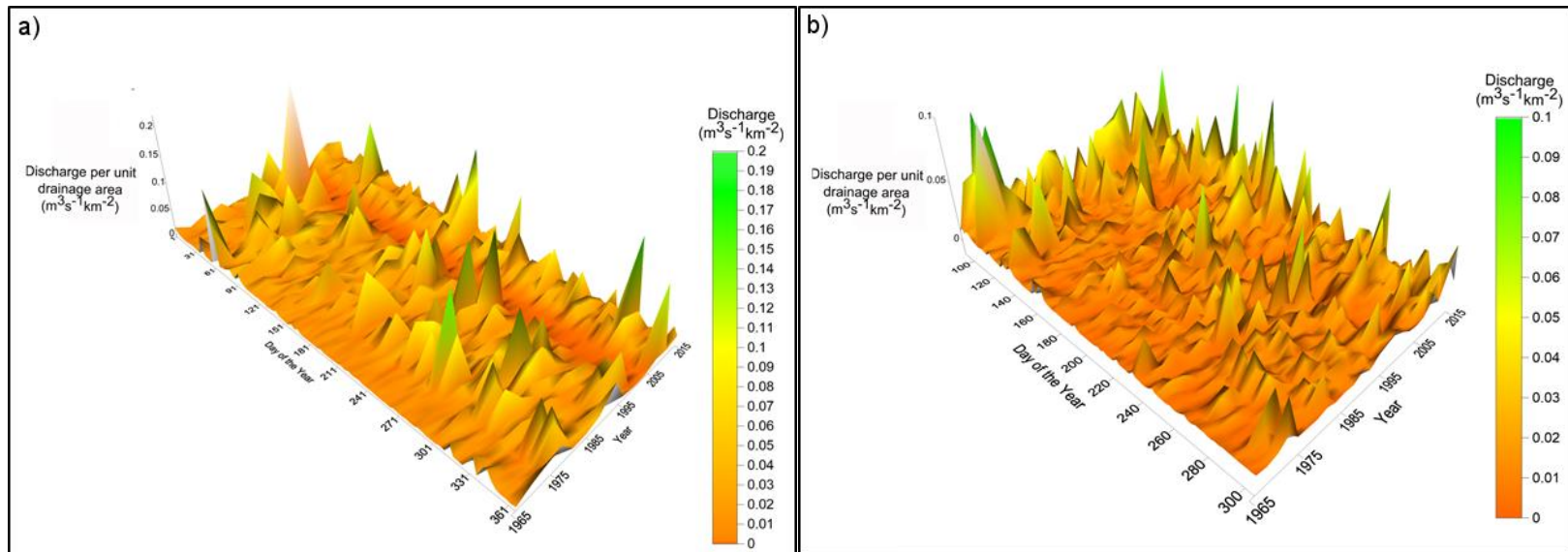


**Figure 3.22: The discharge per unit drainage area ( $\text{m}^3 \text{s}^{-1} / \text{km}^2$ ) of the Don River at York Mills from 1966 - 2015. a) Shows the entire year while b) shows the summer months between April 1 and October 31. The winter snowmelt flows have depleted from 1966 to 2015. Flashy summer flows begin in approximately 1975 at the same time as urbanization; these increase in frequency and magnitude over time as well. There is overall more spikes annually.**



**Figure 3.23: The daily discharge per unit drainage area ( $\text{m}^3\text{s}^{-1}/\text{km}^2$ ) of Highland Creek near Westhill starting in 1966. a) Shows the entire year while b) shows the summer months between April 1 and October 31. The winter snowmelt flows have depleted from 1966 to 2015. Flashy summer flows begin in approximately 1974 with urbanization, and increase in frequency and magnitude from this time. There is a gap in the data from 1999 to 2006.**

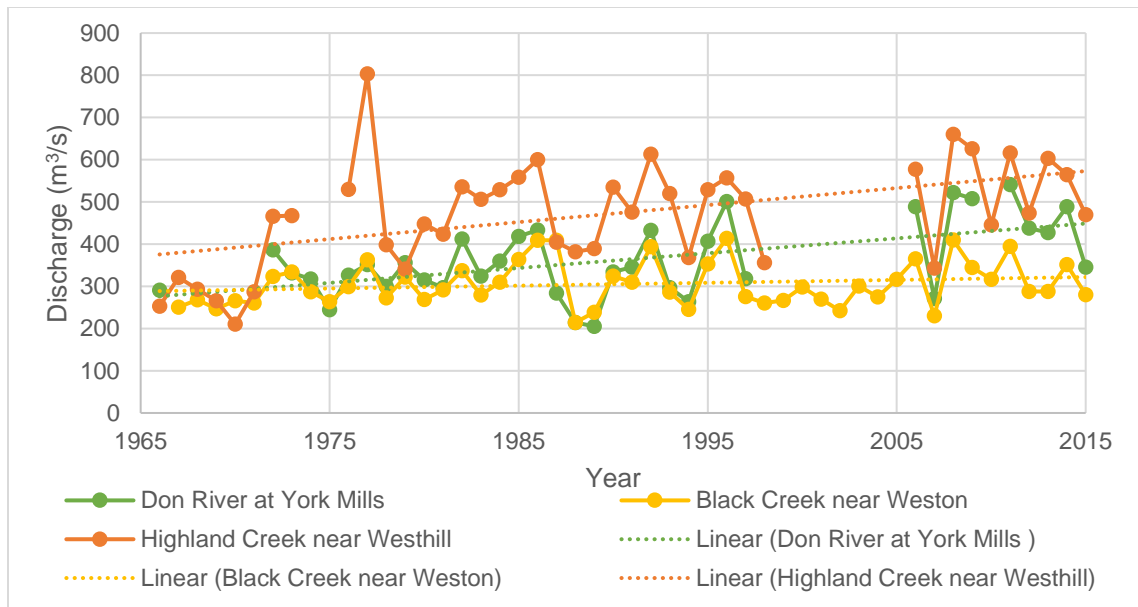




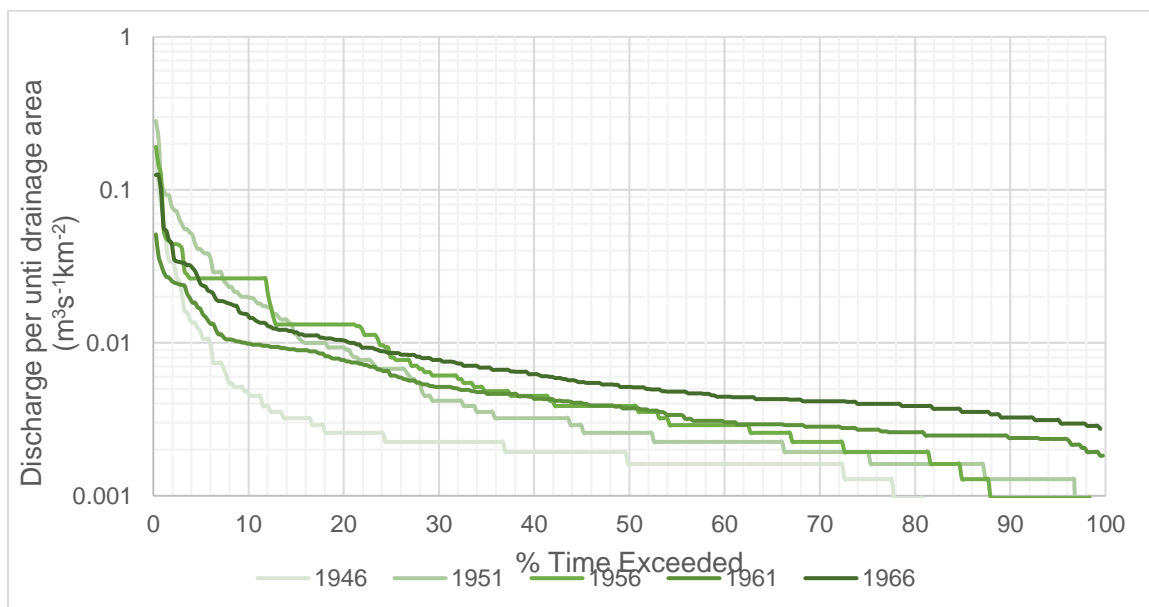
**Figure 3.24: The daily discharge per unit drainage area ( $\text{m}^3\text{s}^{-1}/\text{km}^2$ ) of Black Creek at Weston starting in 1966. a) shows the entire year while b) shows the summer months between April 1 and October 31. The winter snowmelt flows have depleted from 1966 to 2015. Flashy summer flows have already begun at the start of gauging in this catchment however, over time there is an increase in the frequency and magnitude of the flashy flows, presumably with the increase of urbanization.**

The total annual discharge for each of the three neighbouring catchments (Figure 3.25) shows an increase in annual discharge over time. This is most likely linked to the increase in urbanization in each of the catchments. Finally, the flow frequency curves were calculated for each of the catchments. Since the gauge on Black Creek began in 1966, major flood events in the early 1950s in the West Don River (Figure 3.18) are not accounted for in the comparisons among catchments. The flow duration curves for the West Don between 1946 and 1966 (Figure 3.26) show the peak flows are higher in some of the early years. However, the overall curve has shifted upwards from the 1940s to the 1960s for higher duration flows. The large flows in the 1950s are mostly affecting the top 10-20% of all flows. It is assumed that due to proximity to Wilket Creek, a similar thing must have occurred in this catchment as well.

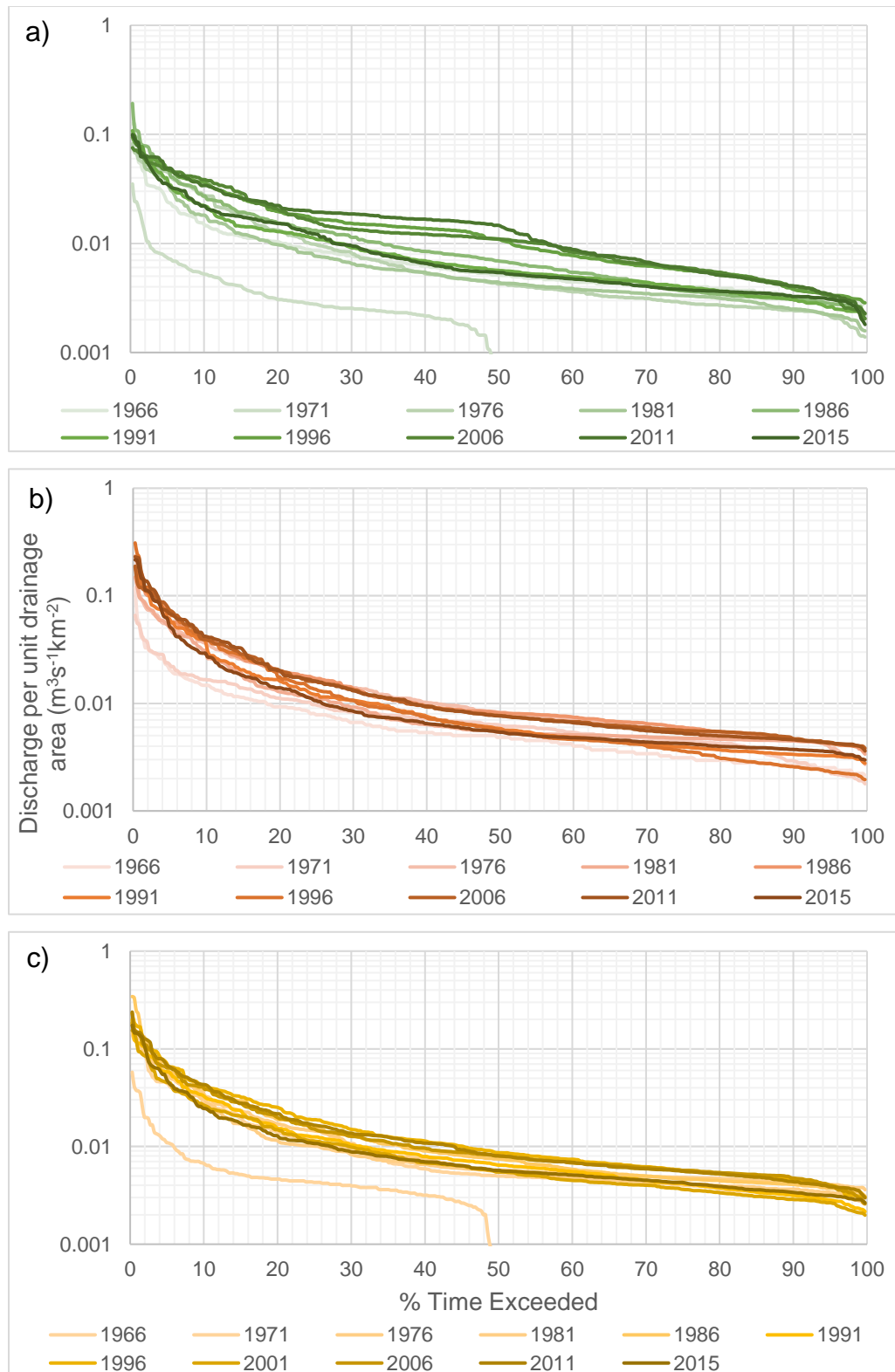
For the sake of comparison across the three neighbouring catchments, and to get an idea of what the flow shift may have been, Figure 3.27 shows the flow curves from 1966 to 2015. Figure 3.27a shows the rest of the flow curves for the West Don River. These curves follow the same pattern as those seen in Figure 3.26. The peak flows between 1966 and 2015 are not as high as those between 1946 and 1966, while the overall annual flow, including peak flows, has increased over time on average. The peak flows in Highland Creek (Figure 3.27b) have increased, while the overall annual flow over time has increased on average slightly. Finally, the flows in Black Creek may have increased since the 1966, however since the 1970s the overall average annual flow has not increased noticeably (Figure 3.27c). As these catchments share similar urbanization histories, physiographic characteristics, and catchments sizes, it can be assumed that Wilket Creek would have also experienced this same trend.



**Figure 3.25: The total annual discharge of the three neighbouring catchments; Don River at York Mills, Highland Creek near Westhill, and Black Creek at Weston. While there are gaps in records for both Don River at York Mills and Highland Creek near Westhill, the overall trend is an increase in annual discharge over time. This can be linked to the increase in urbanization in each of the catchments. As these catchments share similar urbanization histories, physiographic characteristics, and catchments sizes, it can be assumed that Wilket Creek would have also experienced this trend.**



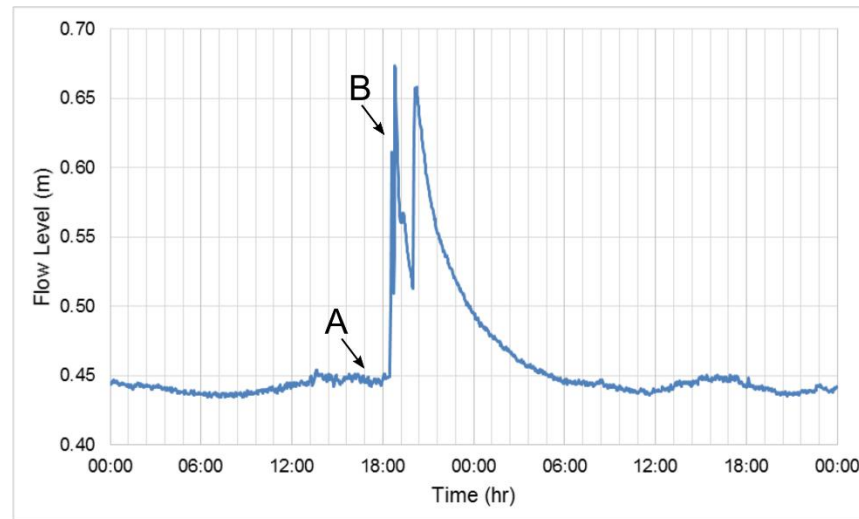
**Figure 3.26: The flow duration curve for the West Don River between 1946 and 1966.**



**Figure 3.27: Flow duration curves for a) the Don River at York Mills, b) Highland Creek at Westhill, and c) Black Creek near Weston.**

Figure 3.28 shows a peak flow event in Wilket Creek from July 27-28, 2016. This event is typical of peak flows for Wilket Creek; a very flashy event, lasting only a few hours. It is likely that the peak flows in this creek are flashier than those in the West Don River or Highland Creek, due to the small size, and the higher percentage of urbanization in the Wilket Creek catchment. Wilket Creek appears to follow the same pattern of flashiness that is seen in Black Creek throughout the year (Figure 3.24). The rising limb is rapid; there is less than 2 hours between the base flow level of the channel and the peak flow. This event also shows the initial influx of runoff from the surrounding as well as the second wave of flow from upstream. The standardized peak flow is 1.5 times higher than the base flow level. Overall, the event is only 12 hours long; short lived events such as the one in Figure 3.28 are frequent in the catchment (Figure 3.19).

In the above figures, the general trend of increased magnitude and frequency expected in an urbanizing catchment is seen in the West Don River, Highland Creek, and Black Creek. When Wilket Creek is compared to these two neighbouring catchments, several peak flow events line up; while it was not possible to have historic flow rates for Wilket Creek, the catchments neighbouring this creek provide a good surrogate for the historical hydrologic change due to urbanization and a range of magnitude of historic peak flow events, as well as the frequency with which critical discharge for bed material transport is exceeded.



**Figure 3.28:** The rise and fall of a peak flow event in Wilket Creek above base flow during a 48 hour flood period. The letters, A and B, correspond to the photographs showing the base flow and peak flow of this event. These photographs were taken slightly downstream of the gauge noted in the previous figures. The morphological history of Wilket Creek

The sequence of events and activities which took place within the Wilket Creek catchment were documented using historical photos, books, and documents from the Toronto Archives as well as university and public libraries, and secondary sources from TRCA and consultant reports. These provide a basis for a historical description of changes to channel geomorphology especially following urbanization.

Parish Aquatic Services (2013) investigated the historical planform over the last 150 years. While it is unclear where these data came from, it does provide a general idea of the morphological change that has occurred in the catchment. Figure 3.29 shows the most recent planform data. Figure 3.29 a) shows a portion of the creek from Lawrence Ave E and York Mills Rd, and includes the section investigated in this study. Based on this figure, there appear not to have been major changes in the planform morphology between 1965 and 2009. This may be because channel evolution due to urbanization had occurred before 1965, when the catchment was already considered fully urbanized. By contrast, Figure 3.29 b) shows the planform change from 1965 to 2009 in the creek from the confluence north to Lawrence Ave E. The planform morphology of this stretch of creek appears to have changed greatly during this time, including lateral migration of meander bends. This change may be due to two different influences; urbanization may have already changed the channel, but there is still a possibility that it continues to change the channel. Second, the morphological changes appear to have occurred mostly between 2003 and 2009. As noted above in Section 3.3, a severe rainstorm in August 2005 drastically altered the morphology of Wilket Creek. These alterations endangered the infrastructure within the channel valley, leading to reengineering/reconstruction of the channel. The greatest planform changes are most likely due to these direct human interventions on the channel following erosion from the 2005 flood. These influences decreased the sinuosity of the channel, and increased the size of the bend (Figure 3.29b), Chapter 4).

A comparison of channel widths between 1947 and 2016 using aerial photos was undertaken for this study. These two years were selected due to the lack of visibility of the channel in aerial photos in the intervening time periods seen in Section 3.2. Bevan (2014) did a similar analysis with similar results, partly based on ground survey of channel cross-sections. Figure 3.30 shows width measurements of the visible channel from aerial

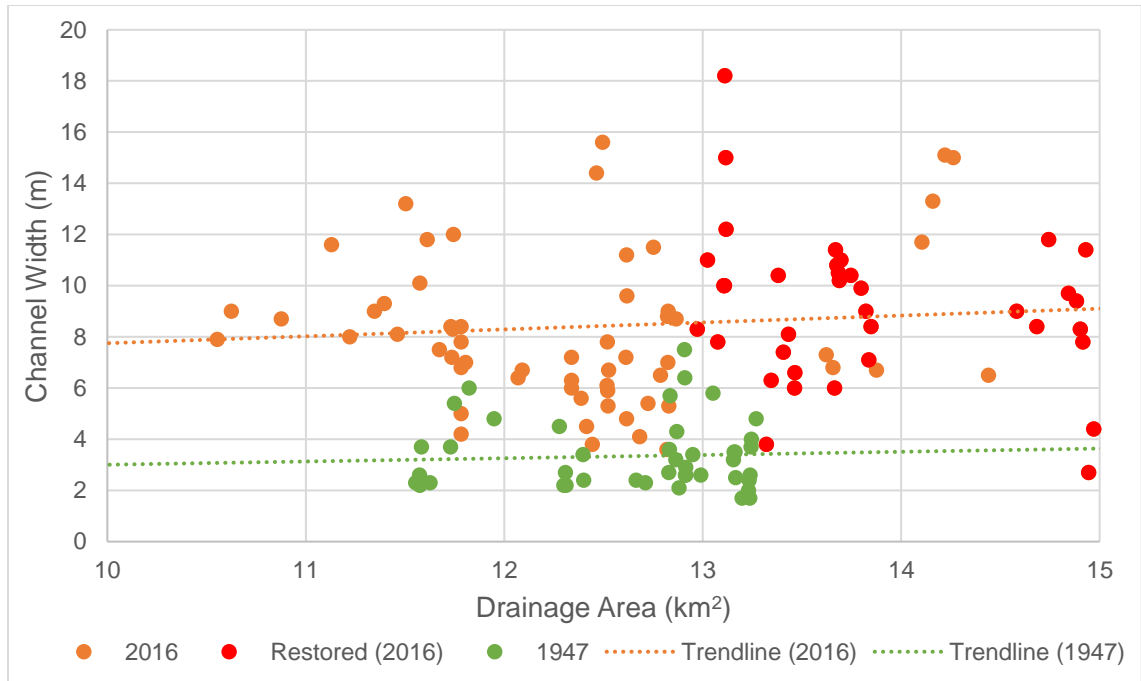
photographs. The aerial photograph from 1947 covers a limited length of the channel, however overall the channel has widened between these two time periods. In 1947, the channel width averaged between 3m and 8m, while in 2016 the channel width averaged between 4m and 16m. This finding is consistent with many previous papers on the effects of urbanization on river morphology (i.e. Arnold et al., 1982; Chin & Gregory, 2001; Wolman, 1967). With that in mind, it must also be noted that there have been processes or events occurring within the catchment other than urbanization that could affect the morphology of the channel. Some of these processes or events include the rainstorm events noted in Section 3.3, and the reengineering/reconstruction, which will be discussed in Chapter 4.

Ground photographs of the channel itself show the morphological changes between the 1960s and 2016. Figure 3.31 shows ground photos from the early 1960s and indicates that the channel is shallow in depth and not very wide. Unfortunately, there is no way to accurately measure these as there is no given or known scale. The grain size, which will be discussed below in Section 3.5.2 and 3.5.3, seems to range from sand to cobbles. As seen in several figures below, including Figure 3.37 and Figure 3.43, the depth of the channel has increased since the ground photos in Figure 3.31 were taken. In Figure 3.31 the depth seems to be less than 0.5m, while based on bank profiles in Section 3.5.3, the depth is now over 1.5m in many locations, showing the degree of incision in the channel, a common channel response to increased discharge from urbanization (Leopold, 1968; Brown, 2001; Chin & Gregory, 2001; Walsh et al., 2001).





**Figure 3.29: The planform alignment of a) the upstream reach and b) the downstream reach of Wilket Creek. The planform in b) begins before the beginning of urbanization while the planform in a) begins during urbanization. The greatest change in planform morphology is between 2009 and 2013. This may be due to further reconstruction after a flood event in 2005 (modified from Parish Aquatic Services, 2013).**



**Figure 3.30: The widening of Wilket Creek between 1947 and 2016. The widths from 1947 are less than half of those in 2016. The distribution also shows the widths of the restored sections channel which fall within the distribution of widths from 2016. It is likely that widening is the result of increased discharge but direct confirmation is difficult.**

There is some evidence of changes to the morphology of Wilket Creek during after urbanization but information and data are limited. Overall, the planform of Wilket may have changed over the last 70 years, but it is not possible to see the entirety of the channel in the aerial photos from the 1940s and planform mapping that has been done is may not be completely accurate. For the same reason, the historical width of the channel can only be estimated but some widening between 1947 and present is apparent. Changes in morphology in the past 15-20 years are better documented in reports and plans for restoration and these are described in detail in Chapter 4. There have been many processes and events in the catchment which have influenced the channel; the evidence points to hydrologic and morphologic change, however with limited data to show these changes, it is not possible to pinpoint one process or event that is the main cause, or the exact timeframe over which these events took place. Documentation of the current channel followed by an examination of the policies, programs and and channel restoration work that may have influenced the catchment and modified the channel, may allow for a better

estimation of the transformations Wilket Creek went through in order to reach its current morphology. The current channel morphology is documented in the following section of this Chapter, and the policy and restoration context and activities are described in Chapter 4.



**Figure 3.31: Historical ground photos of Wilket Creek from the early 1960s. While the locations of each of these ground photos is not known, each photo demonstrates what the mid-urbanization channel may have looked like. Each of these photos show a) a section of channel less than half a meter in depth and a width of approximately 1-2 meters; b) a section of channel varying in depth and with a varying channel width; c) a larger section of channel with a small boy for scale: this section is less than 0.5m in depth with a width of less than 2m; d) a section of channel exhibiting the beginning of erosion (Toronto Archives, 1965). Below, Figure 3.39, shows photographs of the current channel for comparison.**

### 3.5 The current morphology of Wilket Creek

The current morphology and bed material characteristics of the river were documented for two reaches in order to describe the major features of the more ‘natural’ sections of the channel with limited human interference and engineering. This follows principles established by Sear et al. (1995)

Sear et al. (1995) developed the term “fluvial audit” with the aim to answer fundamental questions such as: Is intervention necessary? If necessary, will the commitment be long- or short-term? Where and how should the regime be applied? What are the likely impacts of a particular regime? To conduct the analysis required, data are derived from historical sources, such as cross-sectional survey, aerial and ground photographs, and any existing field observations or public records (Table 3.2). These allow for an historical analysis of the channel, and help answer the questions posed by Sear et al. (1995), as well as providing the events and processes which created the current channel (Downs & Gregory, 2014). This study follows similar methodology to that proposed by Sear et al. (1995). This chapter will investigate the geology, land use change, hydrology, morphological change, and the current morphology of the current channel of Wilket Creek. The combination of these will provide the quantifiable aspects of how the current channel of Wilket Creek came to be (the ‘black box’ portion of the study), while Chapter 4 will attempt to qualify the reasoning behind its current morphology.

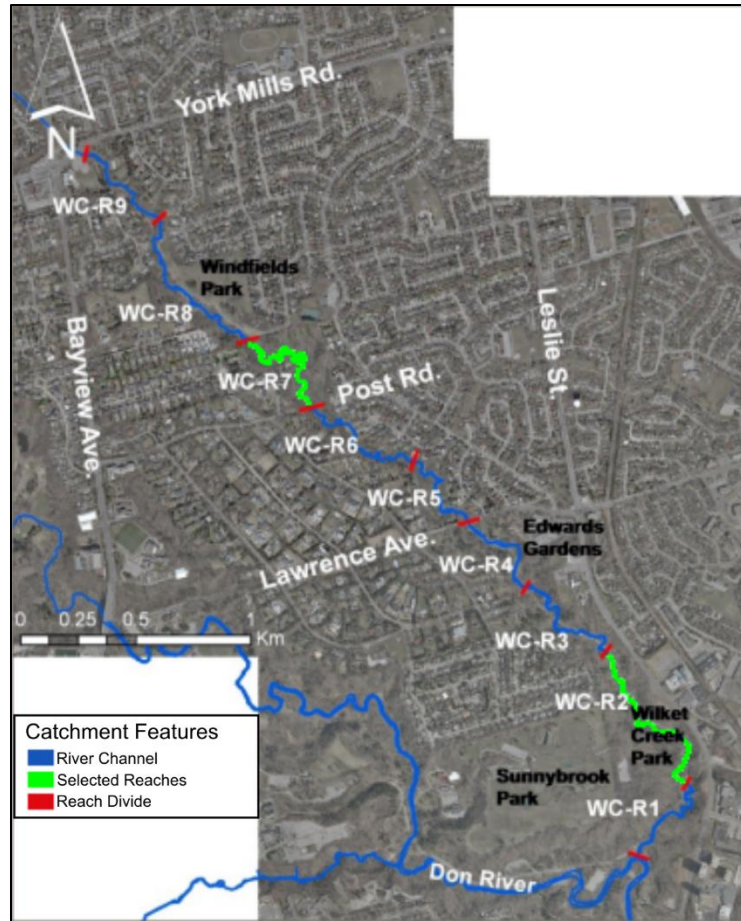
**Table 3.2: Potential components of a historical analysis of fluvial systems. Many of these components are used for fluvial audits (Downs & Gregory, 2014). Of these, aerial and ground photography, narrative accounts, and floodplain stratigraphy were examined in this study.**

Data source	Purpose
Flow records	Used to reconstruct a flood history of significant events, flood-frequency and flow-duration relationship for year-on-year flow indications and climate trends
Repeat editions of large-scale topographical maps	Commonly used to reveal quantitative changes in channel width and rates of bank erosion, and to document change in channel pattern and the approximate age of channel engineering work, bridges and other near-channel infrastructure
Aerial photographs	Used for the same purpose as large-scale maps, but additionally allowing interpretative analysis of the 'textual' quality of the image related to land use change, riparian and in-channel vegetation, and channel sediments. Channel depth analysis may be possible.
Remote-sensing images	For similar purposes as aerial photographs but especially suited for discerning amounts of erosion and sedimentation in large rivers
Ground photographs	Used for interpretative analysis of channel bank, cross-section and planform condition in time if the photographs can be referenced to a common point. Quantitative analyses through photogrammetry may be possible.
Repeat surveys of channel cross-sections	Allows quantitative and qualitative interpretations of channel changes, especially of channel depth, which may be difficult to achieve with maps and photographs
Narrative accounts	Can provide indications of past channel environments, including vegetation communities, but must be seen within the prevailing cultural attitude towards the environment
Floodplain stratigraphy	Uses floodplain and in-channel sedimentary evidence, probably in conjunction with techniques for dating organic or inorganic material, to reconstruct past geomorphological environments. For instance, absolute dates of floodplain stratigraphy may be indicated by carbon 14 dating of organic material while stratigraphy analysis of pollen records or heavy metal traces may be used if they can be correlated to a master sequence of ambient environmental conditions.
Vegetation composition and age	The expected progression in the composition of terrestrial vegetation on emergent bar and floodplain surfaces can be used to indicate the relative age of floodplain surfaces. Dendrochronology can be used to provide absolute dates of floodplain surfaces and rates of floodplain deposition.



### 3.5.1 Survey and data collection

For this study, field visits began in June 2015. The first field visit on June 26 was to identify the reaches which would be used for the study. Data collection place between July 7-10, 2015, and August 11-14, 2015. Due to safety concerns, no fieldwork took place during the winter months, and the channel was re-inspected visually on March 21, 2016 for any noticeable morphology changes over the winter months. The final field visit took place on June 14, 2016, when the banks were surveyed. Wilket Creek was divided into reaches by the TRCA as part of the Master Plan for channel restoration (Figure 3.32). Surveying the entire creek was too demanding given the field time available, so only two reaches were selected for this study to characterize the variation in morphology along the existing channel outside of any recently engineered and restored reaches. Due to construction at the confluence with the West Don River during the 2015 field season, and limited access due to private property in upper reaches, this study used sections of TRCA Reaches 2 (858m in length) and 7 (832m in length). These reaches are referred to as the downstream and upstream reaches respectively. The selection of these reaches allows this study to establish the ‘natural’ post-urban morphology distinct from the known reengineered areas. This selection also made for consistency between any TRCA studies and this study. These reaches were then divided further into subsections to allow for better organization and identification during field data collection. These reaches contrast each other providing a more full representation of the range of channel characteristics; the upstream reach is a sandy, highly sinuous, low slope reach while the downstream reach is gravelly, with a higher slope. Most recent engineering and channel restoration work has occurred along the channel in which the downstream reach is located.



**Figure 3.32: The TRCA defined reaches in Wilket Creek, Toronto. This study examined sections within WC-R2, and WC-R7 (highlighted in green). (Toronto and Region Conservation Authority & City of Toronto, 2013).**

To begin constructing a map of the channel, the location and form of the current channel was documented in the summer of 2015. The current channel form and location were documented with photographs, sketches and notes together with planform mapping using a Trimble GPS unit. Next, bed material grain size was collected by a combination of 15 Wolman Walks, one line by number, 6 Basegrain photograph sites, and 4 site locations for sediment sample collection followed by sieving (M. Gordan Wolman, 1954; Detert & Weitbrecht, 2013). BASEGRAIN is a MATLAB-based automatic object detection software tool for granulometric analysis of top-view photographs of fluvial non-cohesive gravel beds (Detert & Weitbrecht, 2013). Wolman Walks and line by number sampling were used for grain sizes gravel to boulders, while the sediment collection was used for sand, and mixed sand-gravel sediments. The locations of each of these samples were

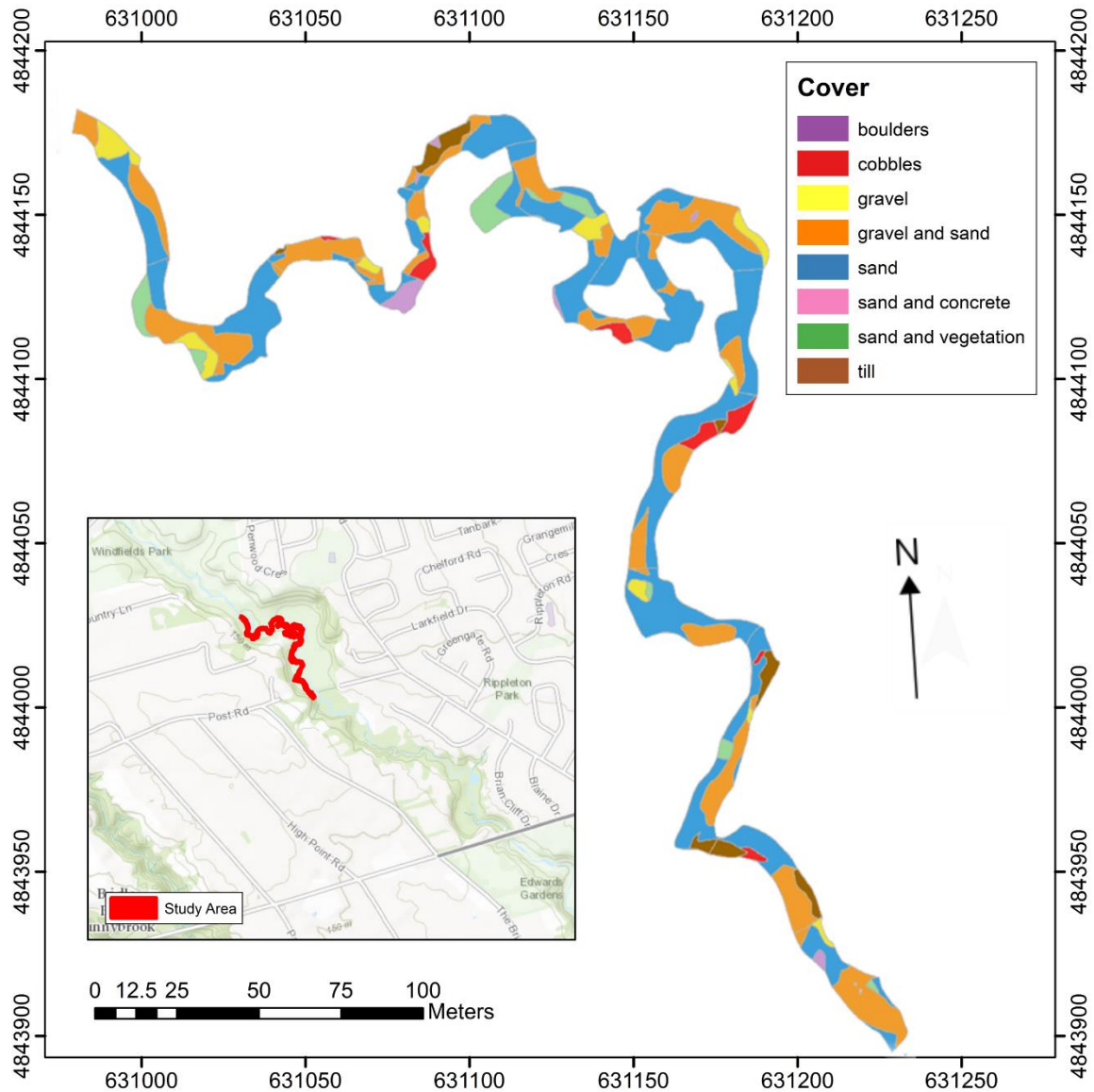
documented by both the Trimble GPS unit and in the sketches of the channel bed itself. Finally, these sand and sand-gravel samples were sieved in the laboratory to obtain grain size distributions for the two reaches.

Several bank profiles were measured in the downstream reach to estimate the grain size and grain size distribution for any location which showed evidence of the pre-urbanization channel in the banks and to document bank stratigraphy. Within the bank stratigraphy, grain size distributions were measured using a variation on the Wolman Walk (Wolman, 1967) to characterize the inferred pre-urbanization alluvial deposits. Finally, the overall extent of the semi-alluvial character of the current channel was interpreted from the grain size and grain size distribution data that was collected. With this collection of data, it was possible to build a final map of the major channel features within the two selected reaches.

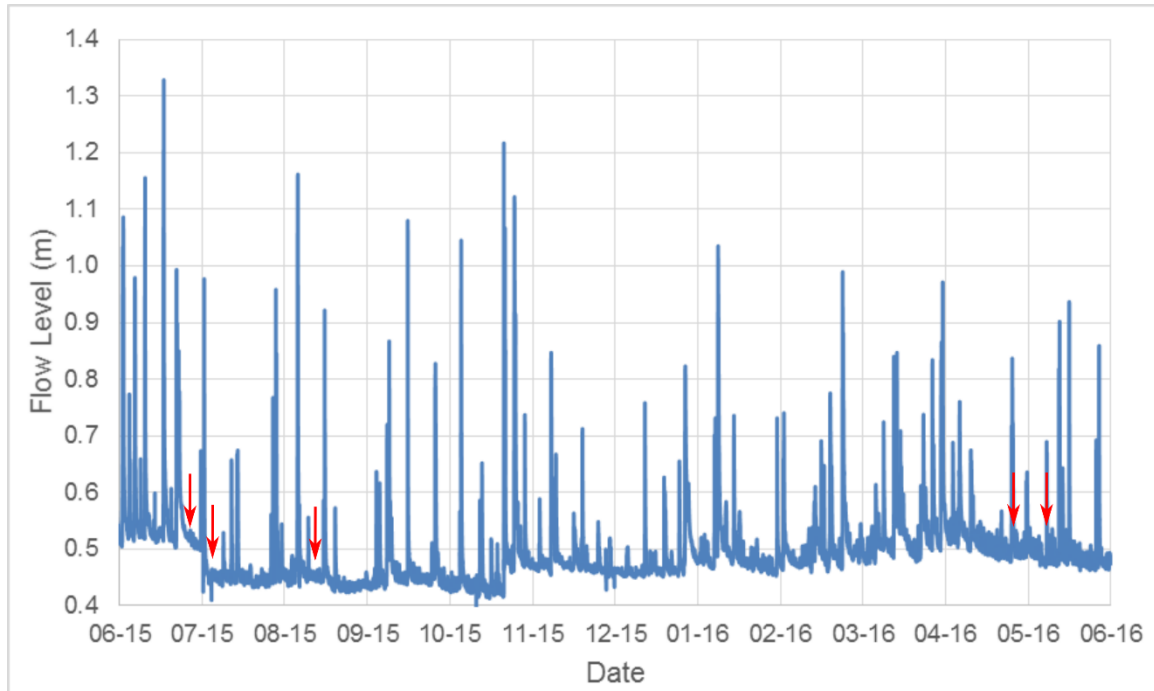
### 3.5.2 Upstream reach

The bed of the upstream reach is mostly sand or mixed sand-gravel, with minor occurrence of gravel, scattered cobbles and boulders, and occasional exposure of glacial diamict (Figure 3.33). Gravel and mixed sand-gravel patches are generally small shallow bars in the middle of the channel. With successive fieldwork trips, the areas of exposed diamict changed as these sand and sand-gravel areas shifted following high flow events (Figure 3.34). This migration ranges; the extent of migration depends on the frequency and magnitude of high flow events. Other than these areas, the channel bed is dominated by sand, which is associated with woody debris and vegetation.





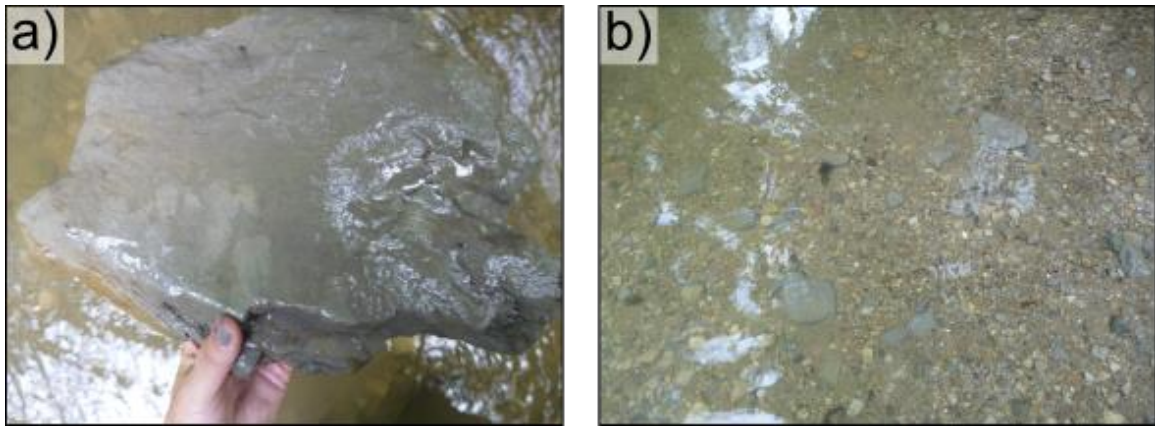
**Figure 3.33: The upstream study reach channel bed, showing the planform of the channel, and grain size and type. This reach is highly sinuous, and shows active meanders creating a meander neck cutoff. The diamict exposure in this area is easily seen as it appears at shallow depth. The alluvium is almost completely sand or sand-fine gavel. Map created July 8-10, 2015, with no flood events during this time (Figure 3.34).**



**Figure 3.34: The flow level (above base flow) of Wilket Creek, with the field visit highlighted by red arrows. Three of the five dates were single days (the first and the last two), while the middle two visits were four days in length. Between each of the five different field visits there is at least one peak flow. The stream flow data (from Section 3.3) is from a gauge located in TRCA defined Reach 3 as part of the larger research project.** The glacial sediment which is exposed in this reach is relatively smooth, containing small gravel clasts within it. This material is highly erodible and mainly exposed in deep pools in this reach. Downstream of these areas, clasts of the material are present, both in the channel and on bars (Figure 3.35). These clasts are presumably eroded during high flow events.

The areas of exposed glacial sediments shifted noticeably between field visits. The higher the flows or a longer time between visits, the more apparent were these shifts in sand-gravel cover layer over the glacial sediments. After winter months intervening between field visits, rearrangement of channel sediment and woody debris created many areas with bed material characteristics unrecognizable from previous visits despite being within clearly defined sections, indicating an active channel. Several trees which had been undercut during the summer 2015 field season, fell into the channel. These trees trapped sediment and smaller woody debris, creating a damming effect upstream. This leads to further alterations in the bed morphology through deposition, creating the extensive sand bars seen

in this reach. These sand bars grow up to 15m in length, 10m wide, and at least 1m thick (Figure 3.36). These sand bars are located through the reach, and do not migrate noticeably.

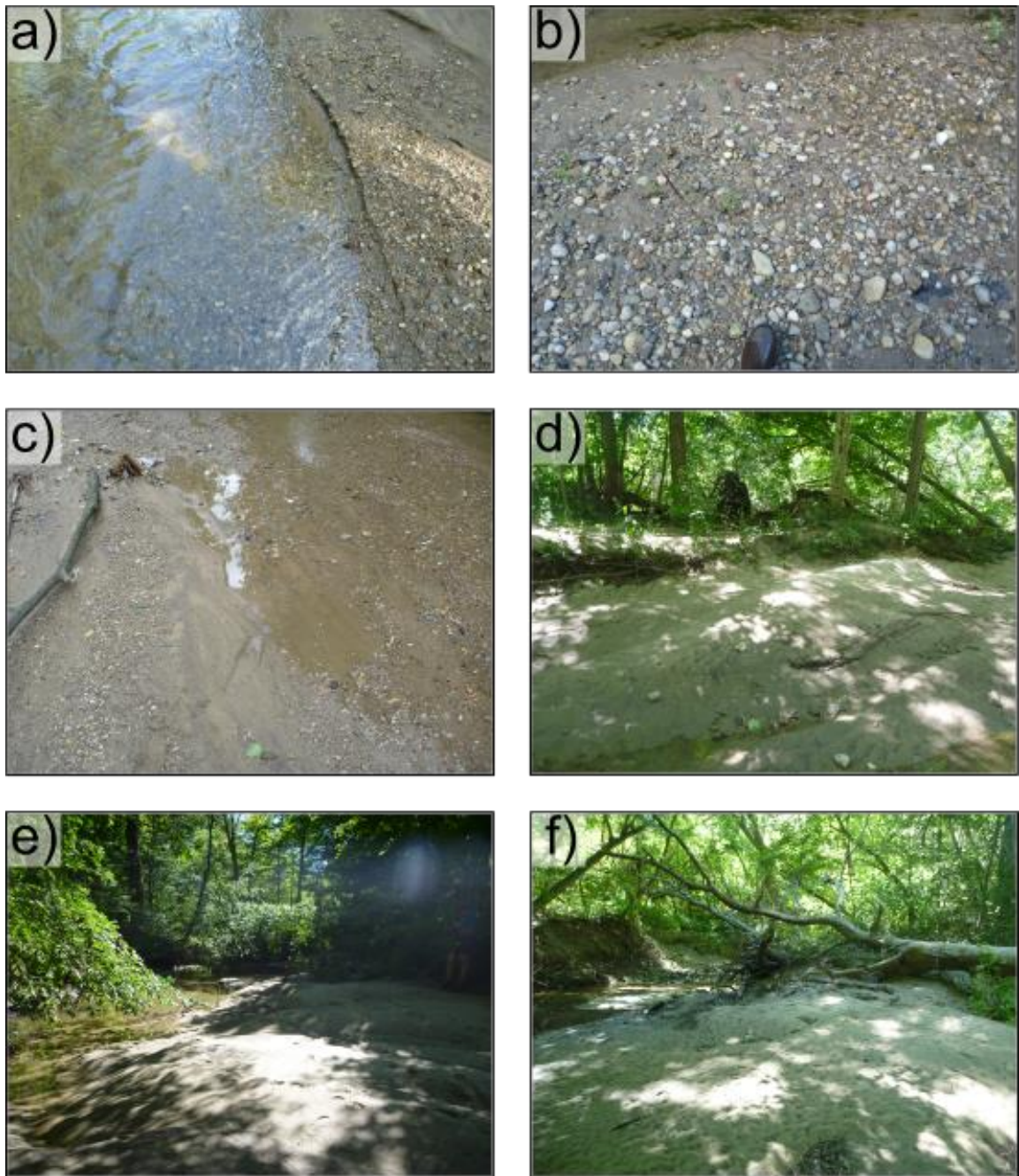


**Figure 3.35: Glacial diamict clasts located in the upstream reach of Wilket Creek. On the left, a) a close up photo of a till clast, and on the right b) depositional area of till clasts from upstream erosion. The till in this reach is smooth with few small clasts in it.**

The woody debris in the channel frequently extends from the banks of the channel as fallen trees (Figure 3.36). These trees span the channel width, and line the channel banks along with roots and vegetation. Generally, the root exposure is due to channel widening, undercutting trees, or erosion of the channel sides indicating active meandering. This destabilization leads to bank failure, which increases the sediment input to the channel. This could lead to the deposition of the aforementioned sand point bars, or it could lead to erosion of the downstream banks.

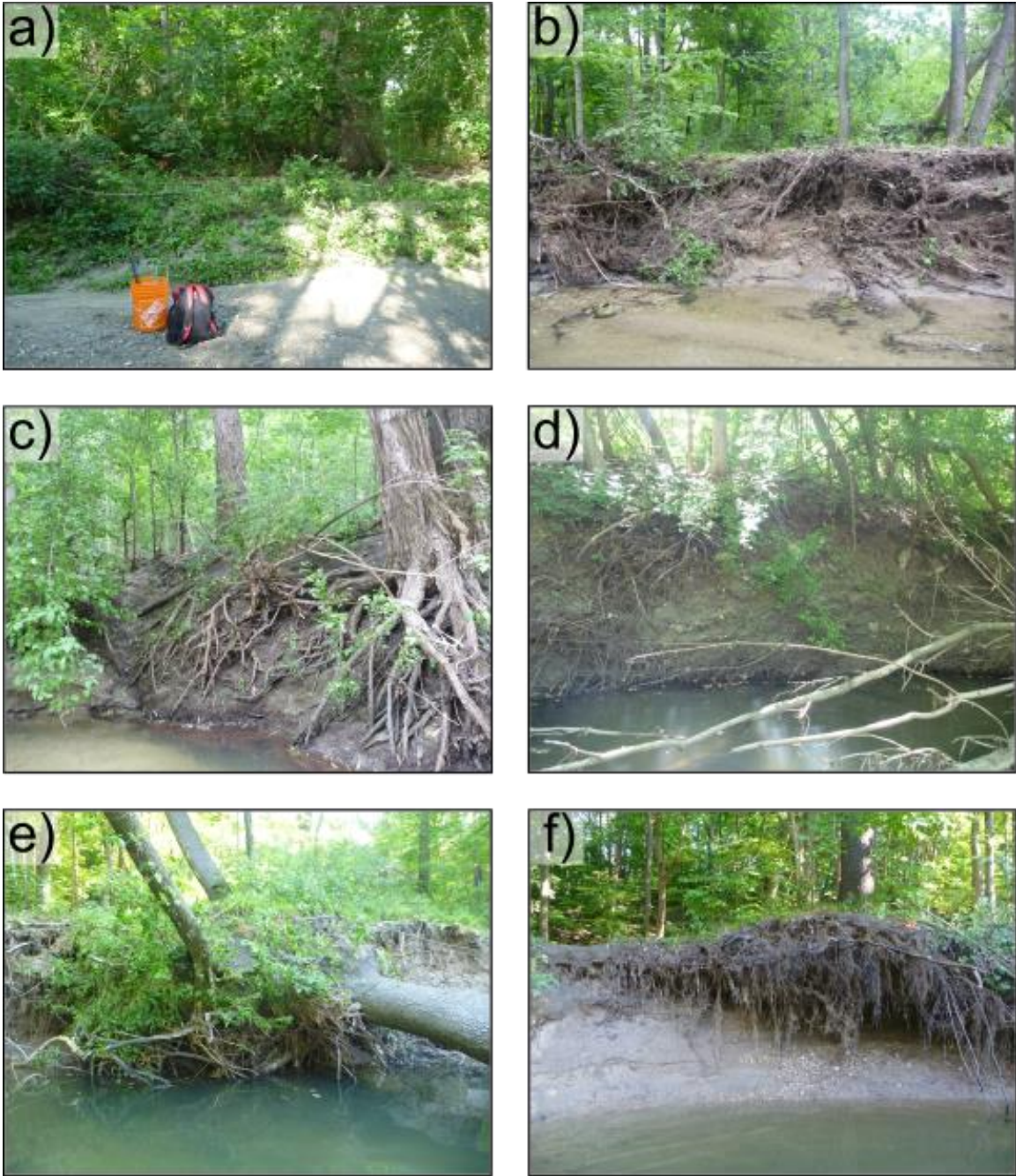
In Figure 3.33, the channel meanders back on itself in two locations; the overall sinuosity of this reach is 1.56. With the erosion occurring laterally, the meander bends become increasingly unstable. In one case, between two field visits, the channel cut through a meander neck, creating an oxbow bend and completely new morphology. There have been minimal protection measures taken to prevent further migration of the channel in parts of the channel that are adjacent to infrastructure (Figure 3.37). Where there is less vegetative cover, the exposed bank structure is mainly homogenous sand. In some areas, the glacial sediments extend upwards into the banks but this is not rare due to the amount of sand in this reach.





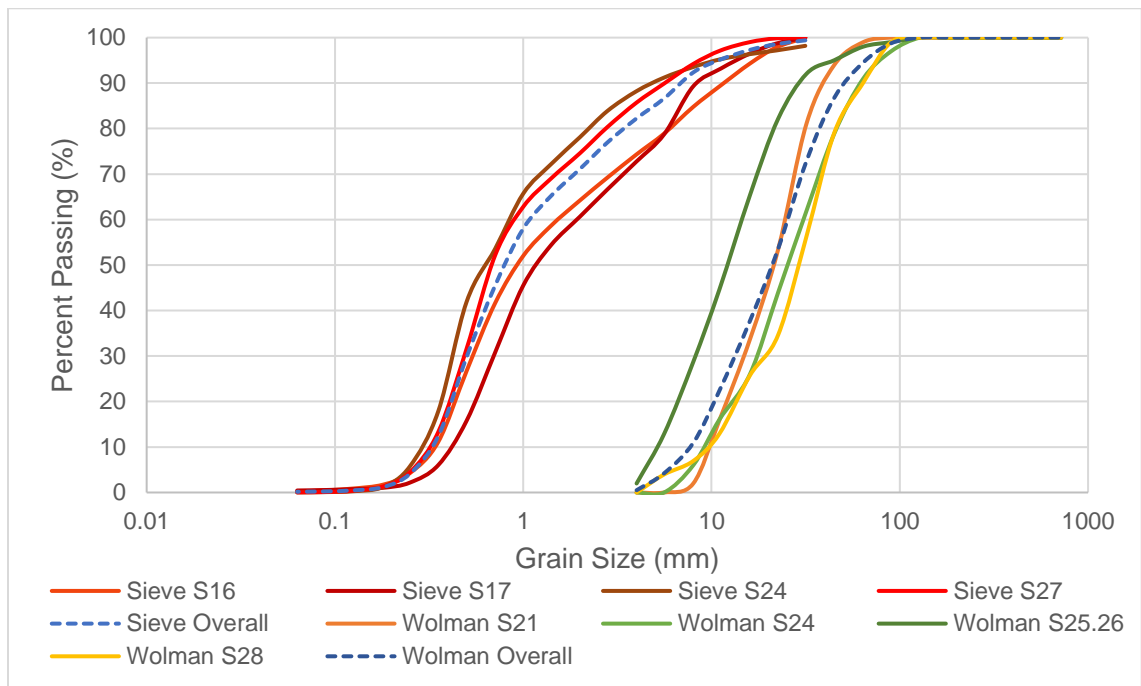
**Figure 3.36: The upstream reach channel bed showing sand and gravel areas, gravel dominated areas, and sand dominated areas. In a) a sand and gravel point bar, b) a gravel and sand bar, c) a sand and fine gravel bar, d) a sand bar on the inside of a meander bend, e) a sand bar on the outside of a meander bend, f) a sand bar created by woody debris downstream. The sand point bars are extensive, both laterally and vertically. Other areas of alluvial cover are gravel and sand and gravels areas lying in thin layers overlying Halton till.**





**Figure 3.37: Pictures of the upstream reach left and right banks. In a) a low bank with some vegetation cover, b) an eroded bank with roots of varying sizes helping with bank stability, c) an eroded bank with larger root mass helping with the stability of the bank, d) a bank with bar sediment at the base and roots and vegetation at the top, e) a group of trees which fell due to erosion undercutting the bank, and f) a bank eroding and undercutting a large tree. The tree in f) fell into the channel over the following winter months.**

The grain size distribution of the upstream reach was divided by the subsections (e.g. S16), and then an overall average distribution was calculated. As seen in Figure 3.38, the distribution for three of the four subsections are quite similar for both the Wolman Walk samples and the sieved samples. For the Wolman Walk samples, sections 21, 24, and 28 have a slightly coarser grain size than seen in Section 25/26, with a  $D_{50}$  of 11-12mm and a  $D_{50}$  of 10.3mm respectively. For the samples that were sieved, the distribution is narrow with a coarse tail in each of the sections sampled. The  $D_{50}$  ranges from 0.6 to 1.5mm. The distribution is evenly split with half between 0.1mm and 1mm, ranging from fine to coarse sand and fine gravel. This means that it is mixed sand and gravel with approximately 20-35% > 2mm and 5-15% > 8mm and a maximum size about 30mm.



**Figure 3.38: The grain size distribution of the upstream reach obtained through four Wolman Walks (gravel fraction), sediment collection and sieving (sand and fine gravel).**

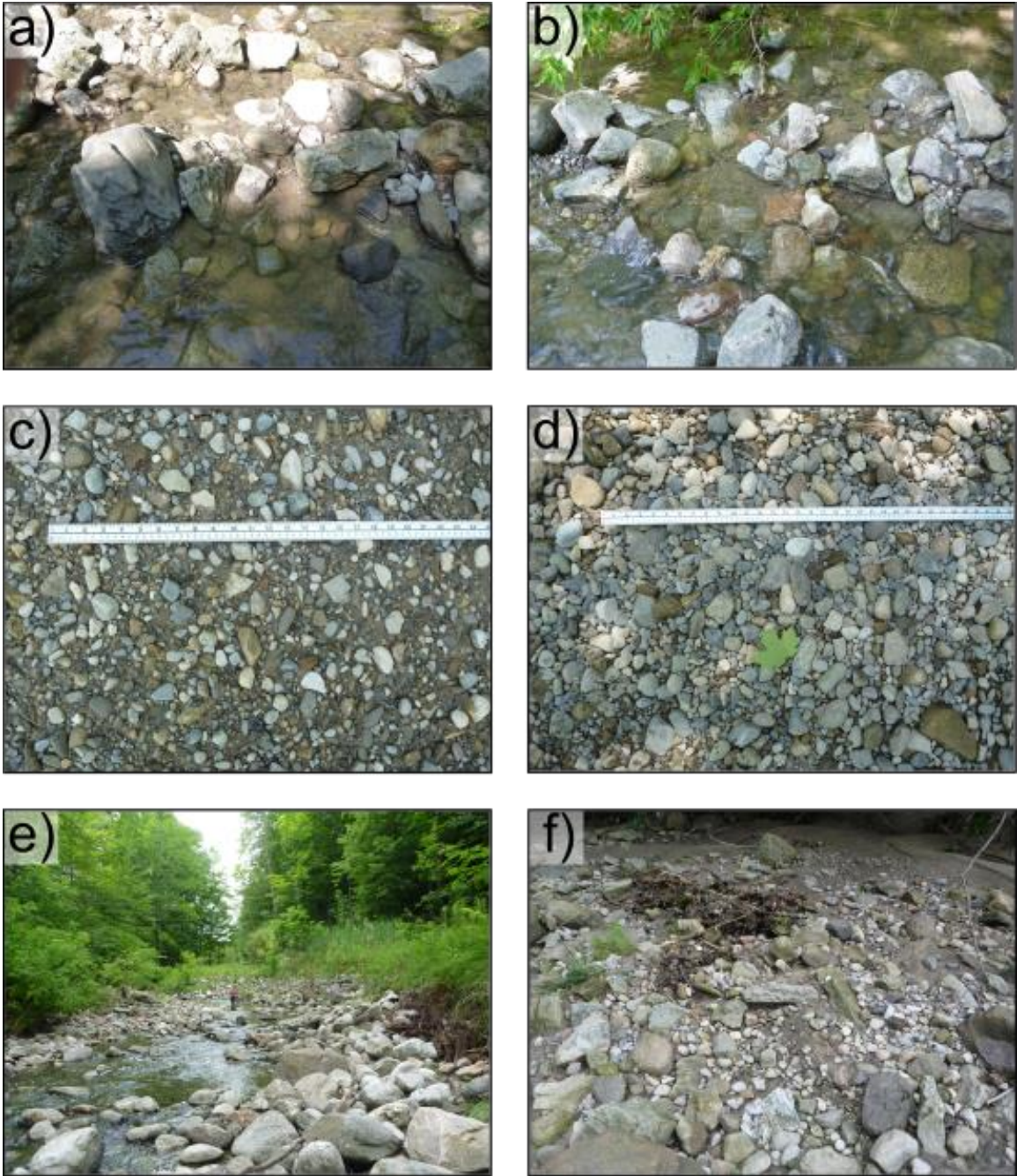
### 3.5.3 Downstream reach

The downstream study reach is very different from the upstream reach. The planform is much less sinuous (1.14), however the lower sinuosity may be due to channel straightening during reconstruction/reengineering. The slope of the downstream reach is 0.0082m (Parish Aquatic Services, 2013). As seen in Figure 3.40, the grain size of the channel is larger, dominated by gravel (2 – 60mm in diameter) and cobbles (60mm – 256mm in diameter) with areas of sand and diamict exposure (Figure 3.40) (Wentworth, 1922). Cobbles in this reach appear to dominate or appear in all subsections of this reach. The areas that are dominated by sand also have large woody debris, which may contribute to trapping the finer sediment.

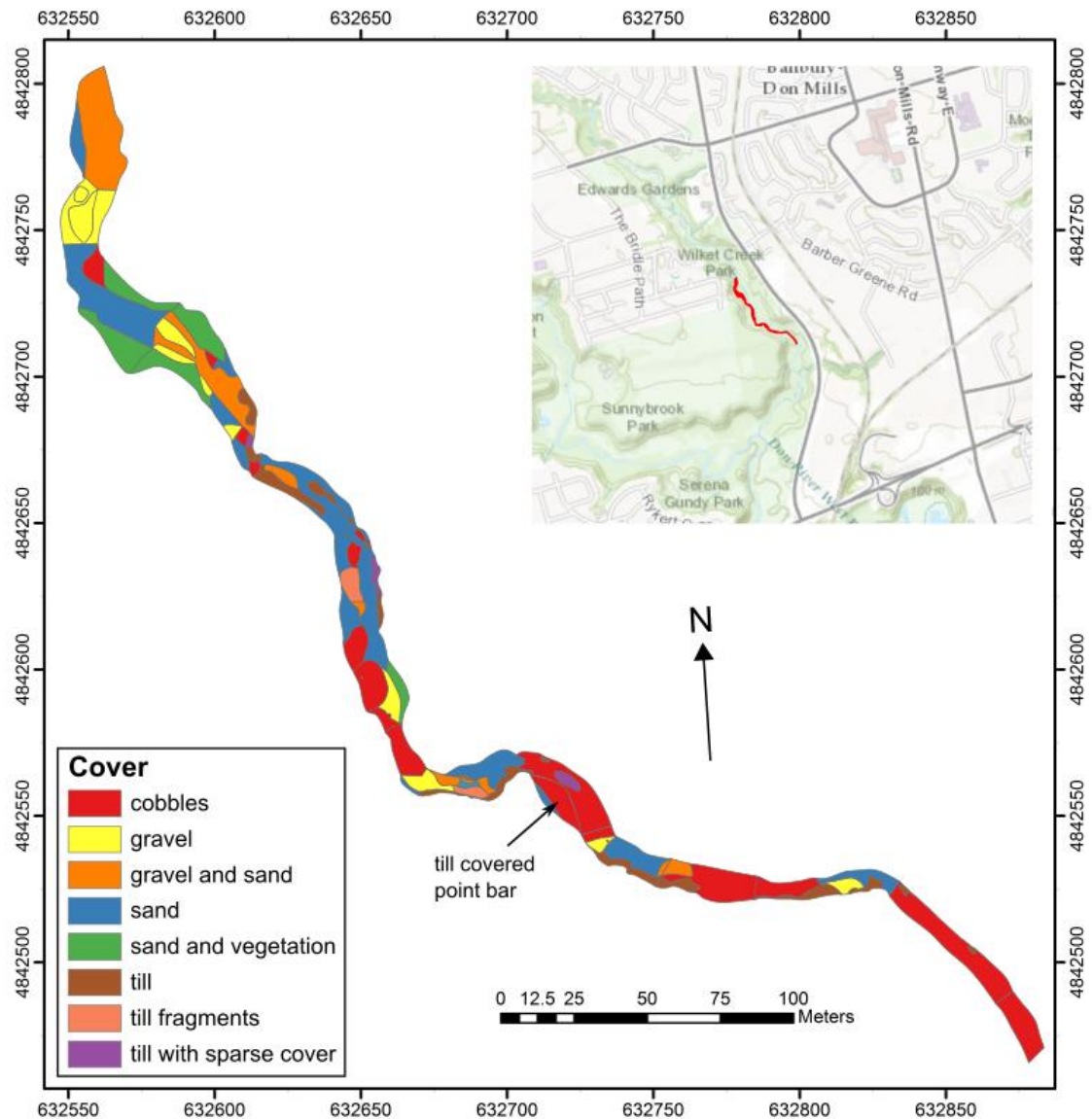
There is a larger range of grain sizes in this reach compared to the upstream reach. As seen in Figure 3.39, the sediment in the reach ranges from natural boulders to sand, with some areas containing natural and/or imported (for bank protection) cobbles and boulders. The distribution of the different grain types and sizes varies within the reach. Some areas are dominated by large boulders with little plant matter, while others are dominated by sand with large amounts of woody debris. The spread of the grain size distribution is discussed below.

The downstream reach also has areas of exposed glacial sediment in the bed, which extends noticeably up into the banks. The composition of the glacial sediment is similar to that seen in the upstream reach; smooth (fine matrix) while containing a larger number of clasts. The areas of exposed glacial sediment are more frequent and larger than those seen in the upstream reach. The glacial sediment occurs *in situ*, as glacial sediment with sparse cover, and as glacial sediment fragments. The exposed glacial sediment is blocky in nature, with the clasts occurring downstream of these areas (Figure 3.41b)). Downstream of the largest area of exposed diamict, fragments cover an entire point bar (Figure 3.40). Cover sediment is mainly gravel or mixed sand and gravel. Between field visits, the areas of till exposure in this reach remained consistent, unlike the upstream reach. This is most likely due to the overall larger grain size in this reach; higher flows are required to mobilize the larger grain size.





**Figure 3.39: Examples of grain size of the channel bed in the downstream reach. There is a larger range of grain size in this reach; a) natural cobbles and boulders, b) natural gravel, cobbles, and boulders ; c) natural gravel and sand; d) natural gravel; e) natural and/or historical reconstructed cobbles and boulders; f) natural sand to boulders along with woody debris.**



**Figure 3.40: The downstream study reach channel bed, showing the planform of the channel, as well as grain size and type. This reach has a different array of cover types than the upstream reach; the two additional cover types, diamict (till) fragments and diamict (till) with sparse cover, may be due to several reasons including more areas of diamict (till), river engineering (e.g. rip rap) in the reach, and a greater discharge passing through the reach.**

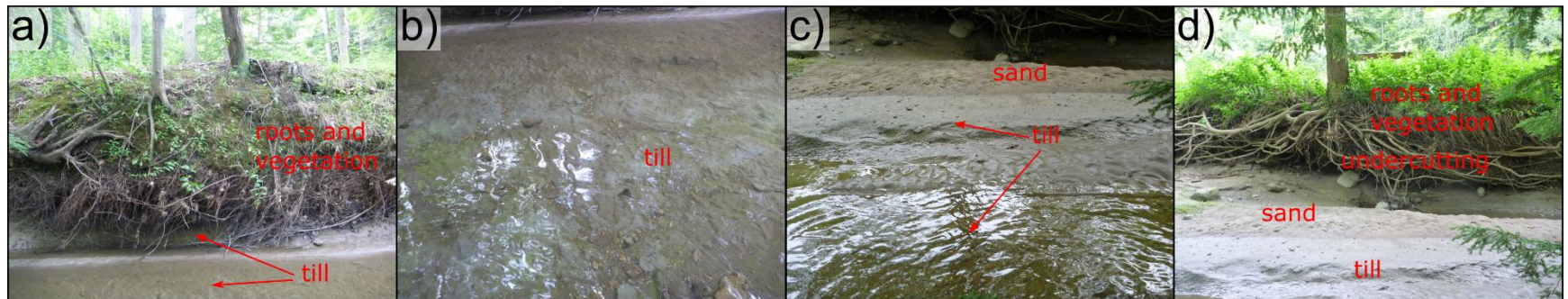
Based on the definition of semi-alluvial from Ashmore & Church (2001), Wilket Creek was classified by Parish Aquatic Services (2013) and Toronto and Region Conservation Authority & City of Toronto (2013) as semi-alluvial. The extent of the alluvial cover was not fully documented in those reports but mapping shown in Fig 3.41 indicates frequent exposure, especially at channel margins and in bends. Figure 3.39 and Figure 3.41 show

examples of sediment cover on the channel bed, highlighting the exposed diamicton. One area from the downstream reach was selected to be investigated for the extent and depth of the alluvial cover in the channel. Figure 3.41 shows the selected cross section. Moving from the right bank to the left bank, it is possible to see the diamict layer extending upwards into each bank. This cross section is in an area with very little alluvial cover; as seen in Figure 3.41 c and d, there is a small bar in this cross section. To provide insight into the depth of alluvial cover in the reach, two holes were augured into bars in the area seen in Figure 3.41. Due to backfill of water in each of the holes, it was hard to auger down to the diamict layer beneath the bars so no reliable data could be obtained.

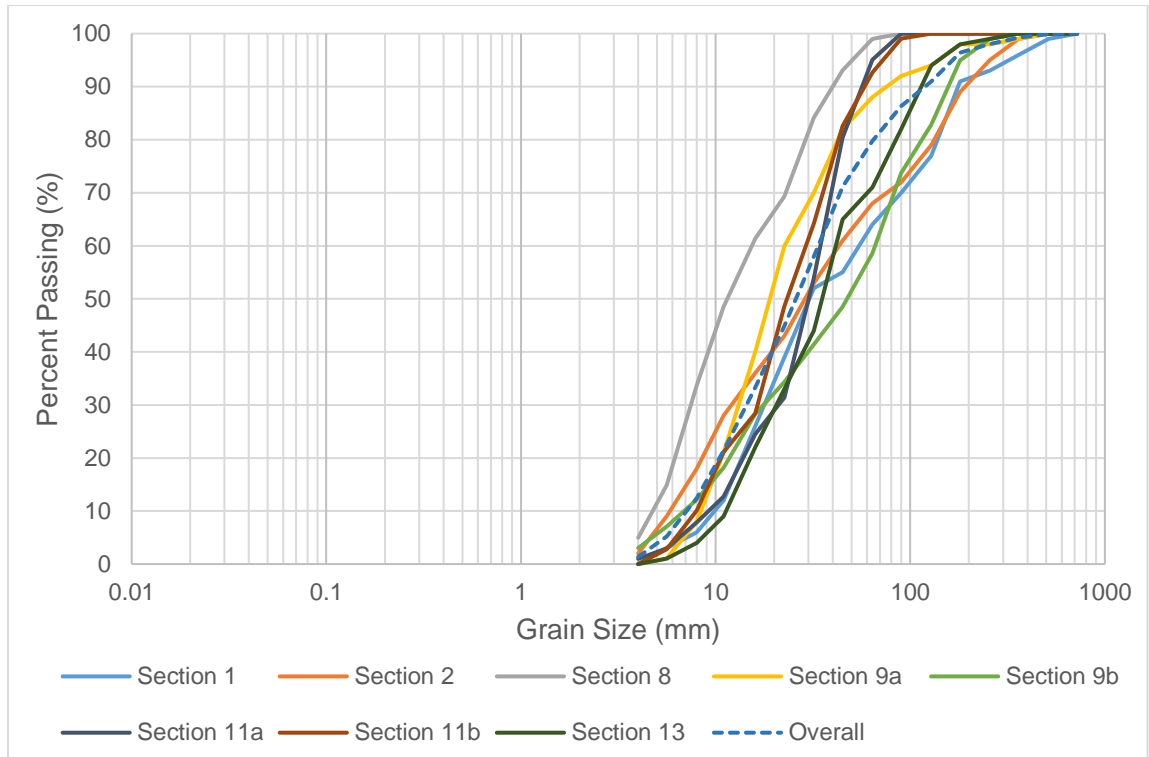
A grain size analysis was conducted for the downstream reach (Figure 3.42). The downstream reach grain size distribution was captured through Wolman Walks based on the initial visual inspection. . The distributions are highly variable and multimodal in some cases. This implies that there may be an outside influence of sediment on the system such as glacial sediment or input through channel reengineering and bank protection. The  $D_{50}$  is extremely wide ranging; the  $D_{50}$  ranges from 10mm to 60mm. The maximum grain size in this reach ranges from 300-400mm in some areas.

Figure 3.43 shows two left bank profiles from the upstream end and the middle of the downstream reach. The depth of these bank profiles also shows the degree to which the channel has incised, especially when looked at compared to Figure 3.31. The profiles are similar; b) and g) are lag layers that appear to be from the bed of a previous channel. Based on the position of this layer in the stratigraphy, this layer is most likely from Wilket Creek's channel pre-urbanization. This layer was investigated for its grain size distribution, which was then compared to the grain size distribution of the adjacent channel bed. Above this layer, a) and f), appears to be overbank fines or post-settlement alluvium. This layer may be sediment that was washed down the channel in the 1950s and 1960s, from the erosion during the development and construction boom in the catchment. It is also possible that this layer is even earlier from previous land clearance for agriculture (e.g. Crawford et al., 1998). The two bank profiles differ below the lag layers; beneath lag layer in the profile on the left of Figure 3.44 is a well sorted fine to medium sand layer with clear flow structures, while under the lag layer in the profile on the right of Figure 3.44 there is layered diamict.





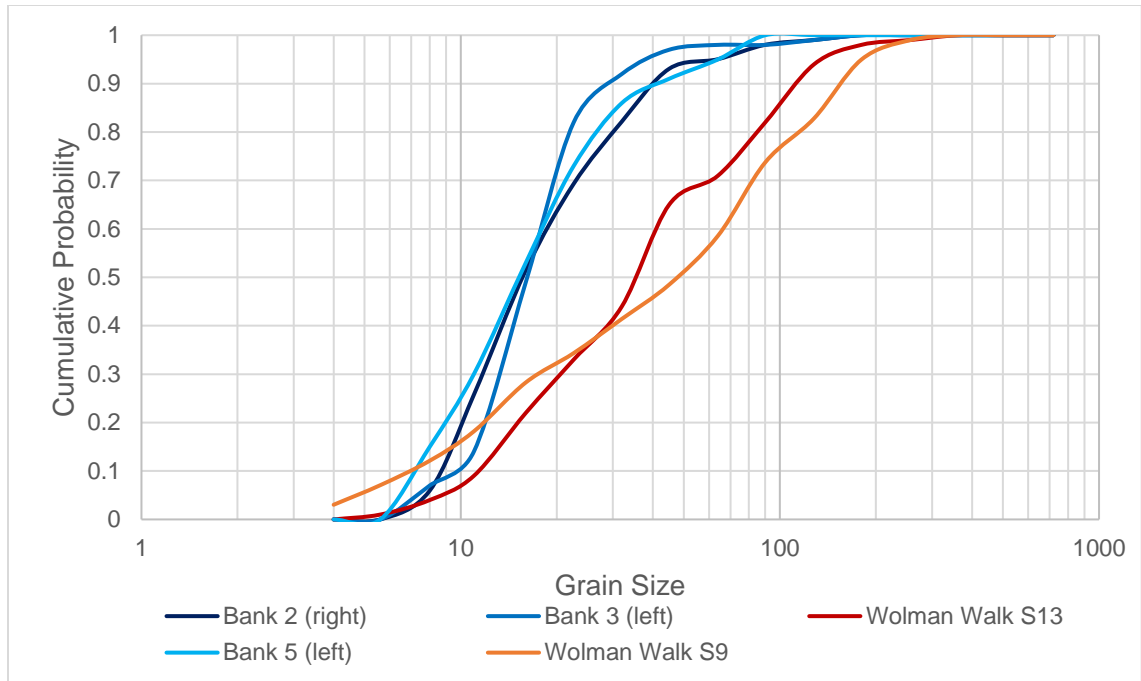
**Figure 3.41: A full view of a cross section in the downstream reach. Starting from a) the right bank featuring vegetation and roots on top of diamict (till) in the bank which extends downwards into the channel bed; b) blocky till in the channel bed abutting the right bank with minimal to no alluvial cover; c) till channel bed abutting the left bank featuring a silty/clay bar; d) the eroded right bank with roots and vegetation. The point bar featured in c) was used for the depth of alluvial cover in Figure 26.**



**Figure 3.42: The grain size distribution of the downstream reach obtained through Wolman Walks (Wolman, 1967).**



**Figure 3.43: Two left bank profiles in the downstream reach. Sampling each section revealed several layers with similar layers labelled in coordinating colours; a) a massive fine sand layer with organics and iron irregular layers intermixed, b) alluvial gravel layer with slight grading to smaller pieces; c) well sorted fine to medium sand with clear flow structures; d) post settlement layer; e) paleo soil; f) coarse sand fining upwards to medium to fine sand; g) gravel lag layer; h) layered diamict.**



**Figure 3.44: The grain size distribution of the bank and its adjacent channel bed in the downstream reach. There is a clear difference between the two distributions; the channel bed Wolman Walks show a much coarser distribution. This addition of coarse sediment may be due to the reconstruction occurring in the channel (Chapter 4).**

When the bank alluvium in three different locations through the downstream reach is compared to the adjacent channel bed, each has a distinctly different distribution (Figure 3.44). For the channel bed alluvium, the  $D_{50}$  ranges from 35mm to 50mm, making it medium to coarse gravel. The average  $D_{50}$  is 42.5mm. In contrast, the bank alluvium has a very narrow distribution with a  $D_{50}$  of 10mm. This means that the bank alluvium is medium gravel with a slightly coarse tail. As well, the channel bed distribution is slightly irregular, implying that it is not a unimodal distribution. This does not follow a ‘classic’ alluvial gravel size distribution. It would have been expected that the channel alluvial would generally have a similar distribution to that seen in the banks. This could mean that the channel bed is experiencing a new sediment input of coarser material that the pre-urbanization channel did not.

This sediment input may be from a natural sources or from historical reconstruction. If the sediment is from natural sources, the source may be from the banks or further upstream. Since the upstream reaches are finer in grain size (Section 3.5.2) it is unlikely that it came



from this source but from the banks or channel bed. As discussed above, the increased stream flow from urbanization leads to channel incision and widening. With high variability in geology, there may be pockets of large grain sizes released through these processes which may not have been accessed pre-urbanization. Alternatively, the sediment source may be from historical reconstruction. The history of reconstruction/reengineering of Wilket Creek prior to the 1990s, which will be discussed in Chapter 4, is not well known, although remnants of gabions and rip-rap are apparent in several places along the channel in both reaches. These may be a source of coarser material in the channels but there is no documentation to confirm this.

Parish Aquatic Services (2013), focused on TRCA defined reaches WC-R1, WC-R2 and WC-R3 for a threshold analysis for particle entrainment. WC-R2 coincides with the downstream reach of this study. Parish Aquatic Services (2013) used Fischenich (2001) model based on critical shear stress to describe the sediment entrainment ( $>D_{50}$ ) of these reaches (Table 2). The reach selected for this study, R2, was combined with R3. Based on their calculated  $D_{50}$  of 48mm, the resulting critical discharge would be  $4.71\text{m}^3/\text{s}$ . Parish Aquatic Services (2013) also investigated the erodibility of the Halton Till which is believed to be the underlying diamict substrate in the channel. As discussed above in Section 3.1, the complexity of the glacial history in this area allows for only an estimation of the glacial material type underlying the catchment. However, Parish Aquatic Services (2013) chose to use values from the Halton Till, as they believed it was most likely this till underlying the catchment. Using a value obtained by Khan & Kostaschuk (2011) for Halton Till of 5.4Pa, and Fischenich (2001)' equation, critical discharges in selected cross sections range from  $0.05\text{m}^3/\text{s}$  to  $0.19\text{m}^3/\text{s}$ , with an average of  $0.13\text{m}^3/\text{s}$ . These values represent increases from those determined using relationship for noncohesive sediment, they are relatively low and not realistic of the actual conditions found in the channel. It was estimated that the flow was  $1\text{m}^3/\text{s}$  during a field visit, and no apparent erosion was taking place; this is due to till being more erodible than gravel and the overlying gravel protects the till. This discrepancy underlies the need for further research on entrainment and erosion of cohesive sediments.

Overall, the current channel of Wilket Creek is complex. The parameters in each of the two reaches investigated vary greatly in their results (Table 3.3). The sediment in the upstream

reach is sandy to sandy-gravel and the channel is actively meandering. By contrast, the downstream reach is cobble-gravel-till dominated, with a low sinuosity. Both reaches however are semi-alluvial and contain ‘natural’ reaches which may also contain new material from channel construction efforts. Chapter 4 investigates the direct human interventions on the channel.

**Table 3.3: Summary of the parameters used to evaluate the two reaches in this study (select values from Parish Aquatic Services, 2013).**

Parameters	Upstream Reach	Downstream Reach
Sinuosity	1.56	1.14
Elevation Range	141m - 136m	116m – 111m
Alluvium Depth	>0.6m	>1.5m
Channel Alluvium D <sub>50</sub>	0.011m	0.035m
Bank Alluvium D <sub>50</sub>	n/a	0.01m
Channel Length	858m	832m
Average Channel Width	9.34m	7.85m

### 3.6 Summary of the current state of Wilket Creek

At the outset of this investigation, it was hoped that it would be possible to more fully document changes to Wilket Creek morphology during and after the urbanization phase. Wilket Creek has undergone complete urbanization since the 1950s. As noted in Section 3.3, there is currently limited long-term hydrologic data for Wilket Creek. This required hydrologic data from neighbouring catchments to be used as surrogates for the hydrological history. The three neighbouring catchments suggested that flow events and peaks increased along with urbanization. Wilket Creek’s channel has widened since 1947 (pre-urbanization) to present day (post-urbanization). The planform change over time is difficult to map due to riparian cover. It appears to be less sinuous, however this may be due to reconstruction/reengineering in the channel. Topographic data with which the current valley and channel morphology could have been documented was also limited by the availability of DEM data at only 10m resolution. Archival sources also yielded very little information or historical photographs.

This semi-alluvial channel is sandy in the upstream reach, gravel-cobble in the downstream reach. This may also be effected by incision. The grain size distributions for the downstream reach may be due to artificial inputs from the aforementioned reconstruction/reengineering. Since many of the attributes of Wilket Creek documented in this chapter will be affected by reconstruction/reengineering in the future. Because of this, an investigation into what has been done in terms of reconstruction/reengineering, and how this is driven by the policy environment and practices is necessary.

## Chapter Four

### 4 Policy, regulatory, and design influences on the morphological design of Wilket Creek

In order to fully understand how the hydro-morphology of Wilket Creek became what it is today, it is important to understand the societal impacts creating change in the catchment (Doyle et al., 2015). As discussed in Section 3.3, the stream flow change associated with urbanization causes morphological change in the channel (Trimble, 1997). These changes threaten the surrounding infrastructure, leading to reconstruction of the channel (Parish Aquatic Services, 2013). The social processes influencing the reconstruction of Wilket Creek can be roughly grouped into scientific practice, and policy creation and execution. Scientists and engineers are required to design watercourses that meet political and regulatory demands, which in turn have to meet agency goals. To evaluate if the agency goals have been achieved, the system must be designed so that non-scientist stakeholders are capable of assessing it. As a result of the demands and policies imposed on channel reconstruction and design, the systems that are created may not be the most ecologically or economically desirable; more importantly, these designs have a particular morphological effect on the watercourse and it is not known if these designs are the most suitable for the given system. The constructed morphologies tend to be substantially different from the unrestored reaches and what these unrestored reaches would adjust to given time.

To understand the current physical landscape of Wilket Creek, the demands and policies that shape that landscape need to be discussed and understood. A timeline of the policies and programs which were implemented in Ontario was made to draw comparisons between these initiatives and the direct effects on Wilket Creek. Due to the nature of this analysis, the data used is secondary; documents from the Toronto Regional Conservation Authority and consultancy agencies associated with the projects, were used to develop a timeline of restoration/channel re-engineering. The timeline of these policies and projects could then be compared to the restoration/channel reengineering which took place in Wilket Creek to look at the direct impact these policies had on Wilket Creek specifically.

## 4.1 The evolution of environmental policy in Ontario from 1946 to 1980

The most important early environmental policy in Ontario affecting rivers and watersheds is the Conservation Authorities Act in 1946. This Act was legislated in a response to the concern expressed by agricultural, naturalist and sportsmen's groups that much of the renewable natural resources of the province were in an 'unhealthy state' due to poor land, water and forestry practices during the 1930s and 1940s (Shrubsole, 1990; McLean, 2004; Sandberg, 2013). This Act also provided jobs for servicemen returning from World War II (Shrubsole, 1990). Prior to the Conservation Authorities Act, and throughout the Depression and World War II, organizations such as the Ontario Conservation and Reforestation Association, the Federation of Ontario Naturalists and individuals writing for *The Farmer's Advocate*, pressed the case for conservation and wise resource management. The Conservation Authorities Act allowed the province and municipalities to form a Conservation Authority within a specified area (a catchment) which would undertake programs for natural resource management (Conservation Ontario, 2013). This gave specific mandates and powers to the Ministry of Natural Resources and Conservation Authorities, and therefore municipalities, which had not been in place before. In the Toronto area, four conservation authorities were created: Etobicoke-Mimico Creek Conservation Authority, the Humber River Conservation Authority, the Don River Conservation Authority, and the Rouge-Duffins-Highland-Petticoat Conservation Authority. These conservation authorities were eventually amalgamated into the Toronto and Region Conservation Authority studied in this project.

Shortly after the formation of these Conservation Authorities, Hurricane Hazel hit Toronto in October of 1954 (Desfor & Keil, 2000). Between October 15<sup>th</sup> and 16<sup>th</sup> 1954, 210 millimetres of rain fell within 12 hours (McLean, 2004; Manwell et al., 2009; Bonnell, 2011). Previous rainfall saturated the soil in the area, funneling an estimated 90% of the rainfall directly into the watercourses featuring steep slopes with little or no natural water storage capacity. Hurricane Hazel was the most severe flood in the Toronto area in recorded history; the hurricane was particularly damaging along the Humber River, and west end of Toronto where 81 lives were lost and thousands were left homeless. Following the storm,

steps were taken towards flood control planning in Toronto and the Greater Toronto Area (GTA) (Toronto and Region Conservation Authority, 2000).

In 1957, Etobicoke-Mimico Creek Conservation Authority, the Humber River Conservation Authority, the Don River Conservation Authority, and the Rouge-Duffins-Highland-Petticoat Conservation Authority were amalgamated into the Metropolitan Toronto and Region Conservation Authority (MTRCA) (Desfor & Keil, 2000). In 1959, The Plan for Flood Control and Water Conservation was finalized; 15 large control dams were proposed, 4 major flood control channels, the initiation of an erosion control program, and acquisition of valley lands (Metropolitan Toronto and Region Conservation Authority, 1959). The ownership of the valley lands allowed for uniform implementation of policies in the future. At the same time, the provincial government initiated an eleven year process to develop and implement a floodplain planning policy. This prevented any further development in flood hazard areas (Toronto and Region Conservation Authority, 2000).

Over the next 30 years, two other major programs were implemented to enhance the flood control plan in Toronto: flood forecasting and warning program and the stormwater management program. The flood forecasting and warning program was designed to monitor watershed conditions including snow, precipitation, and flows. It also issues flood messages to municipalities when the situation warrants it. As part of the Watersheds Plan in 1980, the stormwater management program was initiated to help mitigate the effects of urbanization on runoff and erosion (Toronto and Region Conservation Authority, 2000). From here, the program has evolved to include water quality and temperature impacts, source control, and retrofitting of facilities (Toronto and Region Conservation Authority, 2000, 2013). All of these policies have had a direct impact on Wilket Creek, and other watercourses under the control of the TRCA.

#### 4.1.1 The early years of reconstruction of Wilket Creek

The Plan for Flood Control and Water Conservation allowed the MTRCA to purchase the valley lands of Toronto watercourses including Wilket Creek in 1959 (Metropolitan Toronto and Region Conservation Authority, 1959; Desfor & Keil, 2000). At the same time, (Section 3.4), the morphological change had already beginning in the channel by the

early 1960s. It was shortly before this (1958) that a footpath was built through the downstream reaches, extending from Eglinton Ave E north to Lawrence Ave E, and connecting Wilket Creek from Edwards Gardens to its confluence at Wilket Creek Park. This pathway increased the pedestrian activity and other activities in the valley. With the longevity of the parks and footpath, citizens in the surrounding neighbourhood came accustomed to a particular look and feel of Wilket Creek channel; this influenced the reconstruction which later took place in the channel (Section 4.2.1)

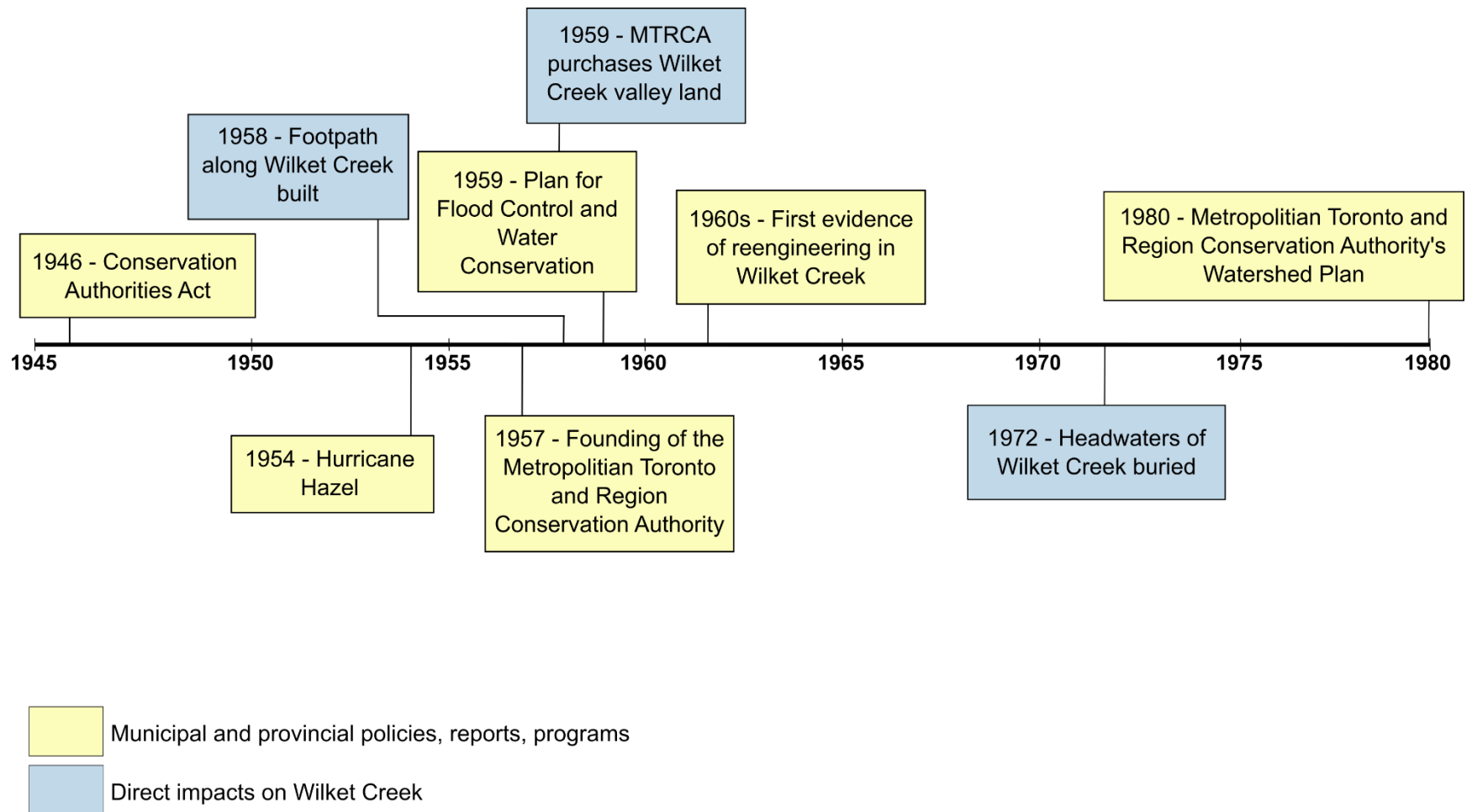
Through the Toronto Archives, ground photographs from activities in the valley were collected, showing the early reconstruction in Wilket Creek (Barr, 2015). The ground photos (Figure 4.1) show the early construction and reconstruction in Wilket Creek in the early 1960s. Three of the photographs are in black and white, making it more difficult to see some of the construction and reconstruction. Figure 4.1 a) shows the beginning of construction in Edwards Gardens. The lower portion of the photograph shows the tread marks from construction vehicles. Figure 4.1 b) shows the retaining wall in Edwards Garden which was under construction in Figure 4.1a). Figure 4.1 c) shows reconstruction (bank hardening) left bank while looking upstream; Figure 4.1 d) shows further bank hardening of the left bank while looking downstream. Based on this limited data, it seems that the first attempts of reconstruction in Wilket Creek channel was bank hardening.

The headwaters of Wilket Creek were buried in 1972 (Section 3.2) (Cook, n.d.). There is no documentation that reveals the reasoning behind the burial of Wilket Creek through the construction of the storm sewer. It may have been as part of stormwater management from Highway 401, or from housing developments within the catchment; this may have also been a measure for erosion control or to create a place for Saint Andrews Park. The source of the water exiting the storm sewer is not known for this study; overall it is believed that the headwaters source is the upper catchment, and some runoff from Highway 401.





**Figure 4.1: Evidence of early bank armouring and reconstructing. a) construction in Edwards Gardens; b) retaining wall in Edwards Garden July, 1961; c) hardening of the left bank looking upstream; d) hardening of the left bank looking downstream. Each were taken in the early 1960s however the exact dates are not known (Toronto Archives, 1961).**



**Figure 4.2: Timeline of the policies, initiatives, and programs from 1945 to 1980 which directly affecting the management of fluvial systems in Ontario, Toronto and Wilket Creek.**

## 4.2 Provincial and municipal environmental policies from 1990 to present

The provincial and municipal environmental policies continue from the Watershed Plan (1980) to present day. In the early 1990s, the type of reconstruction of the channel dictated by these policies changed from hard lining urbanized channels with concrete towards a new type of reconstruction known as Natural Channel Design (NCD) (Metropolitan Toronto and Region Conservation Authority, 1994b; Ministry of Natural Resources, 1994; Toronto and Region Conservation Authority, 2008; Vietz et al., 2015). This influence of Rosgen-type, grass-roots, and local design new to the experts at the Ministry of Natural Resources (MNR) (Rosgen, 1996). In Toronto specifically, this change may have been in part initiated by the Task Force to Bring Back the Don in 1991 (Helfield & Diamond, 1997). This was mainly due to the degraded condition that the Don River was in at this time. Since the formation of the Task Force to Bring Back the Don, and the introduction of NCD, the policies affecting channels in Ontario has evolved, producing particular design features and morphologies.

There were four different policies and programs which began in 1994: The Task Force to Bring Back the Don, the Royal Commission on the Future of the Toronto Waterfront, the Valley and Stream Corridor Management Program, and the first Natural Channel Design conference and manual. The Task Force to Bring Back the Don was established in 1989, with a broad mandate ‘to undertake initiatives that will contribute to the ultimate restoration of the entire watershed by focusing on rehabilitation efforts within the jurisdiction of the City of Toronto’ (Luste, 1994; Desfor & Keil, 2000). This is a shift away from engineering and flood/erosion control towards a conservation and ecology. Consequently, this shifted how the valleys and rivers were viewed, used, and restored. The Task Force managed to create its own niche within both the city administration and civil society (Desfor & Keil, 2000). Together with the Royal Commission on the Future of the Toronto Waterfront (1992), the Task Force to Bring Back the Don (1991) brought in grassroots-community influence and engagement into the decision-making process; then, they proposed more comprehensive and preventative measures to help restore the marshland at the Don River’s confluence at Lake Ontario (e.g. upstream riparian plantings, a shift towards recreation

values of the greenways, and other Best Management Practices to reduce effects of urbanization, pesticides, etc.) (Helfield & Diamond, 1997). From here, the Task Force to Bring Back the Don put forth recommendations to achieve these goals with a forty step proposal (Metropolitan Toronto and Region Conservation Authority, 1994a). The Forty Steps to Bring Back the Don were divided into four different categories: Caring for Water, Caring for Nature, Caring for Community, and Getting It Done (Metropolitan Toronto and Region Conservation Authority, 1994a). The success of these steps were reviewed in 2009 as part of the Don River Watershed Plan: Beyond 40 Steps discussed below (Metropolitan Toronto and Region Conservation Authority, 2009).

In the same year, the Metropolitan Toronto and Region Conservation Authority (MTRCA) initiated the Valley and Stream Corridor Management Program. This program had four main purposes:

1. To integrate MTRCA's public safety responsibilities with its commitment to ecosystem planning and management;
2. To define and identify the valley and stream corridors within the MTRCA's jurisdiction to which its policy and regulations will apply;
3. To update and establish new MTRCA policies and procedures for valley and stream corridor protection and rehabilitation
4. To foster recognition and commitment by provincial and municipal agencies and the private sector for integrated valley and stream corridor management at the watershed, subwatershed, and local level (Metropolitan Toronto and Region Conservation Authority, 1994b).

The vision of this program was to treat MTRCA's greenspace system as 'green and blue' infrastructure by retaining watercourses and valley and stream corridors as open natural landforms from the headwaters to the river mouth marshes throughout their jurisdiction. This was a key point for the way watercourses are treated in Toronto. This set the stage for Natural Channel Design in the Valley and Stream Corridor Management Program and Wet Weather Flow Master Plan that follows (Metropolitan Toronto and Region Conservation Authority, 1994b; Toronto and Region Conservation Authority, 2013).

At approximately the same time, the first Natural Channel Design conference was held in June 1994 (Ministry of Natural Resources, 1994). Of the policies and programs which began in the early 1990s, this conference and the following report may be the most influential through to present day, as it has been used in most design policies since this time. Along with the Watersheds Plan (1980), the Natural Channel Design contributed to an evolution of the type of channel restoration; hardlining channels with concrete, gabions, or armour stone to convey water more efficiently became an out-of-date protocol. Environmental concerns, as well as shifts in other policies, made it necessary for channel design to evolve into multi-functional systems again; making these channels more ‘natural’ through bioengineering. This report dictated that a natural system should exhibit two key characteristics:

1. Physically (geomorphologically) the channel should be dynamically stable, exhibiting self-regulatory mechanisms which accommodate change in flows and sediment loads, and
2. Biologically the channel should exhibit healthy ecological functions, manifested by productive vegetative communities and the valley and healthy aquatic and terrestrial communities.

This was the first time in policy, report, and design history that geomorphology was included in the reconstruction of urban channels. With this in mind, the report provides information and a process which consultants, conservation authorities, and local government can use to incorporate geomorphological and ecological considerations into stream and valley management and design. Now, almost 25 years later, this report has left many notable effects on channel design including the riffle-pool construction, and reconnection of channels to their floodplain; while it is widely used, the riffle-pool restoration method is currently ahead of science and it is not known if the construction is proper for a long-term viability (Ministry of Natural Resources, 1994; Chapuis, Bevan, & Macvicar, 2015)

In 1998, the Metropolitan Toronto and Region Conservation Authority (MTRCA) became the Toronto and Region Conservation Authority (TRCA) following the amalgamation of the City of Toronto (Toronto and Region Conservation Authority, 2013). The following

year, the TRCA initiated *The Living City Strategic Plan*. This plan aimed to engage agencies, industries, and communities in collaborating for the sustainability of all life within the TRCA's nine watersheds as well as Lake Ontario. While the Don River has its own Task Force, this plan brought other communities and agencies to a similar level of engagement (Toronto and Region Conservation Authority, 2013).

The TRCA initiated a long-term geomorphology study as part of the Ministry of Natural Resources Valley and Stream Corridor Management Program in 2002. The TRCA was finally prompted to start monitoring geomorphology following promotion from NCD and Rosgen; it was seen as something that should be considered in addition to engineering, and hydrological and ecological monitoring (Ministry of Natural Resources, 1994; Rosgen, 1996). As part of a wider geomorphological monitoring program, the TRCA outsourced this monitoring to Parish Geomorphic Limited who installed one erosion pin, and completed a few cross-sectional analyses mainly in Edwards Gardens. This study was not extensive or intensive in nature, leaving many questions about the overall morphology of this channel unanswered.

In 2003, the City of Toronto initiated the development of the Wet Weather Flow Master Plan (WWFMP) to address the impacts of wet weather flow (WWF), including issues related to controlling and reducing the impacts of combined sewer overflows (CSOs), stormwater discharges, and inflow/infiltration on the watercourses in Toronto. The overall goal of the WWFMP as a long term (100-year) plan is to reduce and eventually eliminate the adverse impacts of wet weather flow on the built and natural environment leading to measurable improvement in the ecosystem health of the watershed. This goes back to the 'protect and mitigate' mandate from the Conservation Authority Act (1946).

The WWFMP also includes provisions for water quality, and natural areas and wildlife. Targets for improvements to the existing conditions were established for twenty locations in the Don River catchment. This includes assistance in the development of the Wilket Creek Geomorphic Systems Master Plan (Section 4.2.1) (City of Toronto & Livegreen Toronto, 2003; Parish Aquatic Services, 2013). The WWFMP states that the proposed source control, conveyance control, and end-of-pipe facilities will assist in restoring part of the balance in the flow and sediment regimes that were altered due to urbanization.

Typically, the proposed works may include construction of pool/riffle sequences (from NCD), protection of stream banks, realignment of the low flow channel, and protection of steep slopes. These measures still place erosion control at the centre of the issues with the urban watercourses in Toronto.

It is acknowledged in City of Toronto and TRCA documents that for a considerable number of stream reaches, restoration will be required if the objectives relating to protection of property, restoration of healthy aquatic communities and protection of infrastructure are to be met. In many instances, the TRCA identifies its projects as restoration with the idea that their work is to return watercourses to a state which they were in prior to the damaging event (Toronto and Region Conservation Authority, 2016a). These damaging events are large flows highlighted in Section 3.3, including 2000, 2005, and 2013. Unfortunately, the damaging event is usually hydrologic in nature, stemming from urbanization as discussed below, in order to repair the channel the new hydrologic regime must be taken into account. This means that the channel is rarely returned to its original state (which may also be unknown), and is instead repaired to a new state (Doyle et al., 2015). Based on this, these repairs should be called reconstruction or re-engineering rather than restoration.

Within the Don River watershed, there are a number of sections where restoration of degraded sections of the streams use natural channel design techniques, removal/modification of a number of fish barriers, protection/ reconstruction of municipal infrastructure located within the valley lands; and restoration of riparian vegetation. Although throughout the Don River watershed approximately 18km of stream are to be restored, Wilket Creek was not specifically identified to be reconstructed using natural channel design (Metropolitan Toronto and Region Conservation Authority, 2009).

In 2009, the Don River Watershed Plan reviewed and built on the Forty Steps to a New Don (Metropolitan Toronto and Region Conservation Authority, 2009). The Watershed Plan is intended to inform and guide municipalities, provincial and federal governments, the TRCA, non-government organizations and private landowners as they update their policies and best management practices for environmental stewardship. The Plan was also created to allow for the community to respond to a number of recent policy and planning initiatives, including the City of Toronto's Wet Weather Flow Management Master Plan,



stormwater retrofit studies of other municipalities, and TRCA's vision for The Living City. Shortly after this plan, Toronto updated *The Living City Strategic Plan*. The aim of this plan was to guide the implementation of TRCA's legislated and delegated roles and responsibilities in the planning and development approvals process over the next 10 years (Toronto and Region Conservation Authority, 2013).

Finally, in early 2015, the City of Toronto, and Parks, Forestry and Recreation began developing a Toronto Ravine Strategy. While Toronto's ravines were once seen as disposable and unsafe, the city aims to change this, making them desirable and easily accessible nature sites throughout the city. Now, along with the TRCA and a wide range of stakeholders, the Toronto Ravine Strategy will consider improvements such as better gateways into the ravine, navigation throughout the ravines, and publicize historic places. This strategy will help balance the fine line between protection and use. This strategy is currently in draft form and is expected to be completed by the end of April 2017.

#### 4.2.1 Emergency works in Wilket Creek from 2000 to present

The provincial and municipal policies in Ontario and Toronto continue after the *Watershed Plan* in 1980; information specific to the effects that these policies may have had on Wilket Creek is not known between 1980 and 1999. The Wilket-Milne Creek Regeneration Concept Plan was completed in 1999. The following year, a major rainstorm hit Toronto and the Wilket Creek Geomorphic and Habitat Systems Master Plan was created. Both of these plans were created due to the flood damage, erosion and water quality degradation occurring in the catchment during all magnitudes of rainstorms (Aquafor Beech Limited et al., 1999; Toronto and Region Conservation Authority & City of Toronto, 2013). However, before these works began, a particularly severe rainstorm in 2005, initiated emergency works to protect surrounding infrastructure from compromise (Section 3.3).

In August 1999, the Wilket-Milne Creek Regeneration Concept Plan was created as part of the 'Forty Steps to a New Don' with the Don Watershed Task Force. This Wilket Creek-specific plan consists of two major components: development of stormwater management alternatives and development of possible channel restoration approaches. As well, the plan asks for public input into the project, while suggesting two demonstration projects, with

continued monitoring and additional studies to implement any further recommendations (Parish Aquatic Services, 2013).

Due to the age of development in Wilket Creek catchment (Section 3.3), Wilket Creek has no stormwater management systems in place. To help prevent further instream erosion due to hydrologic issues in the catchment (Section 3.3) a combination of centralized and source control measures were recommended by the Concept Plan as the best solution for Wilket Creek. These measures include centralized control measures such as flow control devices in storm sewers with surcharge to off-line ponds, and source control measures such as rain barrels. While these measures were recommended, at the time of the report there were no existing targets for retrofitting a catchment such as Wilket Creek with stormwater management measures (Aquafor Beech Limited et al., 1999). Today, Wilket Creek still has no known stormwater management control (Figure 3.3).

Channel restoration, the second component of the Wilket-Milne Creek Regeneration Concept Plan, was considered due to the channel entrenchment in Wilket Creek leading to a disconnection between the channel and the floodplain. It was decided that the best option was to elevate the bed above the sanitary sewer to re-connect the active channel to its floodplain through: 1) construction of a rock ramp at existing riffle segments and self-adjustment of the channel, 2) the use of NCD concepts, and 3) the use of traditional river engineering hard lining approach. These techniques were to be applied through Wilket Creek and Windfields Parks (Aquafor Beech Limited et al., 1999).

The community response to this Plan was low; however, the respondents reflected the general idea that the contrived landscape of Edward's Garden should be similarly applied to Wilket Creek and Windfields Parks. While this could not be achieved with the type of channel restoration proposed for the channel, with public input it was agreed that the recommended Concept Plan would integrate the riparian corridor into the vision of Wilket Creek to maintain the sense of place which makes Edward's Gardens special to the community. It is at this time that the idea of morphology as a combination of science, social, and political becomes apparent (Lave et al., 2014; Doyle et al., 2015).

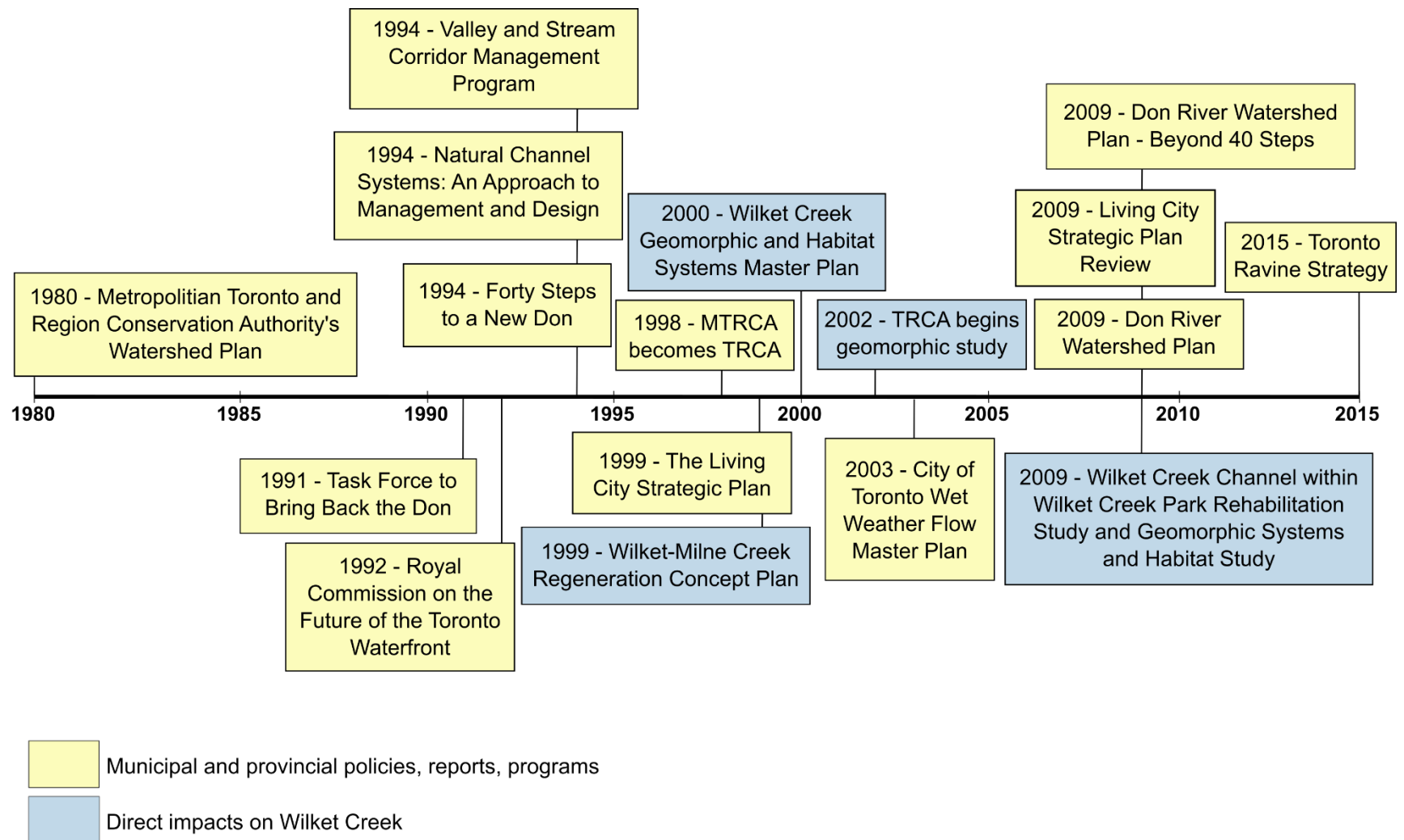
Following the Concept Plan, a large storm event in May 2000 lead the City of Toronto to commission a geomorphological study by Parish Geomorph Ltd. This study concentrated

on the portion of Wilket Creek which flows from Lawrence Ave E to the confluence. Several areas of concern were reported where channel protection methods such as gabion baskets have met minimal success. Through Rapid Geomorphic Assessment, the channel was deemed “unstable”, which was attributed to the altered (urbanized) flow in the channel and requiring mitigation (Ontario Ministry of the Environment, 2003) . It was concluded that the large storm event of May 2000 exacerbated existing issues of erosion in the channel. This study was re-visited in 2003, along with the 2002 TRCA geomorphic monitoring site. The monitoring site, an erosion pin, showed change in the channel and as a result, further geomorphic monitoring and hydraulic analyses were recommended (Parish Aquatic Services, 2013).

Since the significant storm events in May 2000, several other significant storm events to June 2008, took place in the Wilket Creek catchment (Toronto and Region Conservation Authority, 2008). The most notable storm event was the rainstorm on August 19, 2005 (Section 3.3). After this event, the City of Toronto and TRCA took an inventory of the damage; this damage was concentrated in Edwards Gardens and Wilket Creek Park (Toronto and Region Conservation Authority, 2008). There were 26 areas of concern due to damaged and ‘at risk’ infrastructure (e.g. bridges, pathways, manholes, sanitary sewer) (Toronto and Region Conservation Authority, 2008). Ten repair projects were completed and implemented as part of Emergency work (defined by TRCA) in 2007. Overall, these sites required repair due to erosion issues, however specifically at three sites repairs were required because of exposure of the underlying sewer (Toronto and Region Conservation Authority, 2008). Unfortunately, on June 23, 2008, 3 of these repaired sites were re-damaged in another rainstorm (Toronto and Region Conservation Authority, 2015).

At the same time in 2007, the City of Toronto began to seek support and funding from City Council to conduct a larger, long-term study of the creek (Toronto and Region Conservation Authority, 2008). Finally, in 2009, Toronto Parks, Forestry and Recreation (PFR) and Toronto Water identified multi-year funding to commence in 2010. This funding provided for the "Wilket Creek Channel within Wilket Creek Park Rehabilitation Study and Geomorphic Systems and Habitat Study," with TRCA to manage the project (Parish Aquatic Services, 2013). The Master Plan is a large-scale project which can maintain the

long-term management required for the issues of erosion and degradation seen in Wilket Creek. It falls under the planning and approvals of the Ontario Environmental Assessment Act, which ensures all possible effects of the project are considered during the planning stages (Toronto and Region Conservation Authority, 2008).



**Figure 4.3: Timeline of the policies, initiatives, and programs from 1980 to 2015 which directly effecting the management of fluvial systems in Ontario, Toronto and Wilket Creek.**

Three areas within Wilket Creek Park were identified as requiring immediate attention due to the risk to municipal infrastructure and/or public safety by Parish Aquatic Services, A Division of Matrix Solutions Inc. (PARISH; formerly Parish Geomorphic Limited; PGL). These sites are collectively referred to as Site 3, Site 6 and Site 7 (Figure 4.4) by TRCA and the City of Toronto (Toronto and Region Conservation Authority, 2008, 2013) (Toronto and Region Conservation Authority & City of Toronto, 2013). The project milestones are outlined below:

- Notice of Study Commencement and Public Information Center #1 – Present the objectives of the study and the proposed designs for the Emergency Works at the first two priority sites in Wilket Creek (June 2011)
- Phase I Emergency Works: Protection of exposed sanitary trunk sewer crossing and bank stabilization at Sites 6 and 7; emergency works in Site 3 (April to May 2011).
- Phase II Emergency Works: Realignment of the existing trail away from the channel, re-align and widening of the channel, and installation of two new bridge crossings to protect the sanitary sewer at Sites 6 and 7 (repaired in Phase I) (July 2011 to May 2012).
- Phase III Emergency Works: At Site 3.1, move channel away from eroding valley wall, install a new 30m long free span bridge, install protection for the sanitary sewer that crosses the river immediately downstream of the bridge (November 2012 to May 2013)
- Public Information Center #2: Presentation of alternatives (December 2013)
- Consultation meeting #1 with Friends of Wilket Creek (FOWC) community group (February 2014)
- Consultation meeting #2 with Friends of Wilket Creek community group (April 2014)
- Public Information Center #3: Presentation of preferred alternatives (June 2014)
- Phase IV: Site 3.2 & Site 2 channel re-alignment to bring the channel away from sanitary infrastructure, protect the sewers with concrete encasements and armour stone retaining walls; channel widening, habitat enhancement, trail re-alignment and bank protection works. (Completed fall 2015) (Parish Aquatic Services, 2013)

Following the Wilket-Milne Creek Regeneration Concept Plan, the Wilket Creek Channel within Wilket Creek Park Rehabilitation Study and Geomorphic Systems and Habitat Study aims to reconstruct the channel of Wilket Creek to protect the surrounding

infrastructure. The reconstruction/reengineering of the channel used techniques of NCD such as riffle-pool design (above); the specifics of Phase II will be discussed below. The policies above dictate the plans for this reconstruction/reengineering to occur; next, the TRCA commissioned consultants to design the plan for the reconstruction. The interplay and interdependence of between policies and conservation authorities stems from the original Conservation Authorities Act, while the designs are taken from the ever evolving science of geomorphological design.





**Figure 4.4: The restoration sites as defined by the Wilket Creek Channel within Wilket Creek Park Rehabilitation Study and Geomorphic Systems and Habitat Study. Emergency works to reconstruct the channel and protect surrounding infrastructure at project sites 2, 3.1, 3.2, and 7 was completed between April 2011 and fall 2015. The two reaches highlighted are the two discussed above in Section 3.5 (modified from Parish Aquatic Services, 2014)**

## 4.2.2 Reconstruction of Site 3 Phase II in Wilket Creek

The reconstruction and channel realignment of Wilket Creek was made more complicated by the dimensions of the valley and the surrounding infrastructure. The meanders empirically designed to allow for the urbanized hydrology of the channel would not accommodate for the infrastructure also within the valley (Figure 4.5) (Parish Aquatic Services, 2014). In order to accommodate for both the new hydrology and the infrastructure in the valley, another realigned planform of Wilket Creek was proposed (Figure 4.6). This planform design helps stabilize the channel while accommodating the infrastructure in the valley. This proposed planform design shows the section of Wilket Creek downstream of Lawrence Ave E. Figure 4.7 shows two examples of proposed planform in a reach upstream of Lawrence Ave E. These two examples show how varied and invasive the reconstruction/reengineering is in Wilket Creek.

The objectives of the Master Plan and the proposed designs for the Emergency Works at the first two priority sites in Wilket Creek were first presented to the public in June 2011. Presentation of alternative strategies as well as detailed plans for the open channel south of Lawrence Ave E were presented in December 2013. It is not known how much the initial proposals were updated before the alternatives were presented. The plan proposals presented were divided into three different maps covering Sites 1 through 10 (Figure 4.8 - Figure 4.10). Each of these maps detail the channel realignment, the riffle-pool sequences, and the vegetation and rip-rap placement on the banks. These alternatives were put into action based on severity of the damage.



**Figure 4.5: The current planform of Wilket Creek's watercourse (blue) south of Lawrence Ave E. This is compared to the empirically designed proposed planform**



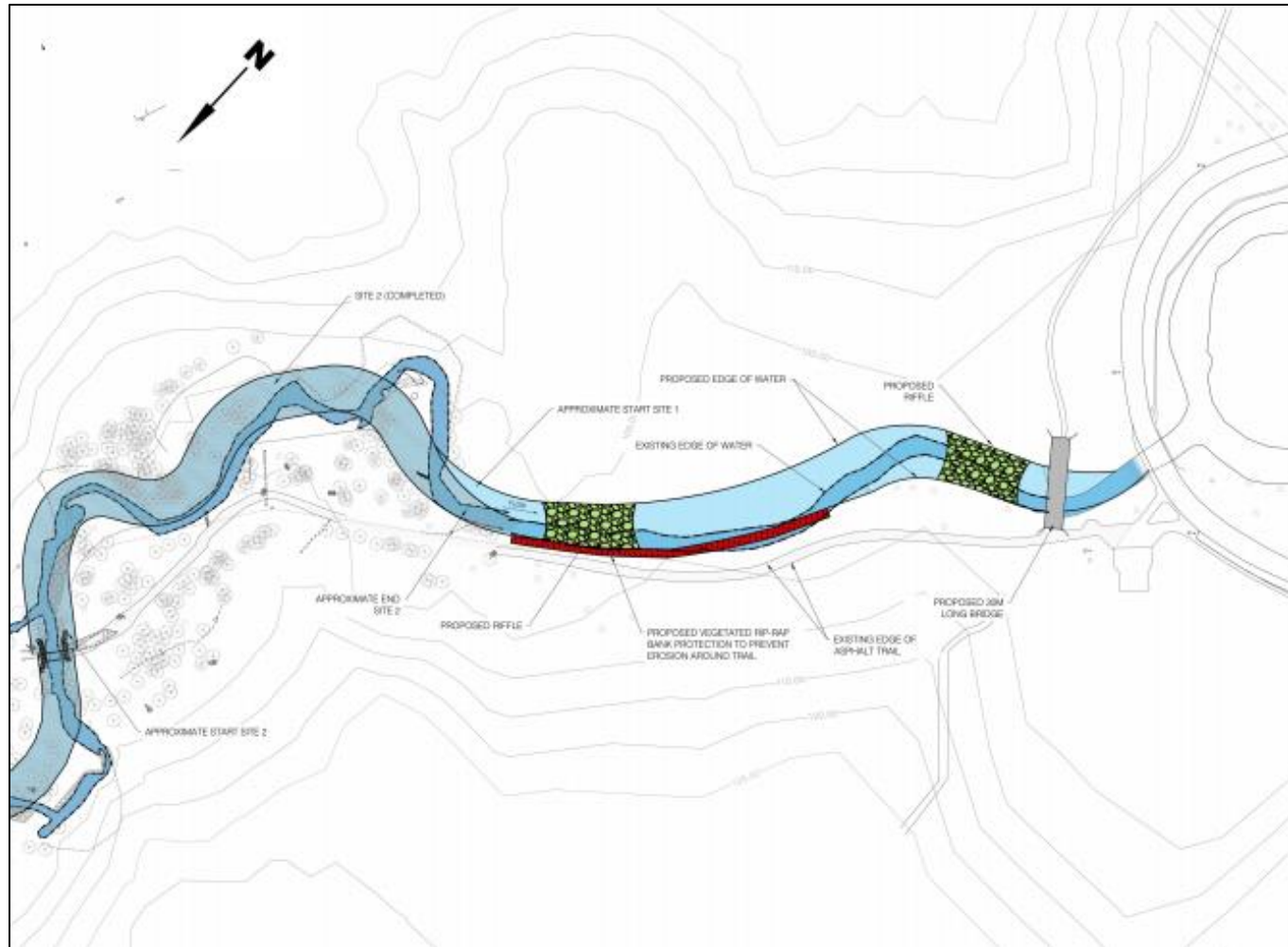
for the reconstruction/reengineering of the channel. (Parish Aquatic Services, 2014).



**Figure 4.6: The proposed realigned planform of Wilket Creek south of Lawrence Ave E. This planform design helps stabilize the channel while accommodating the infrastructure in the valley (Parish Aquatic Services, 2014).**

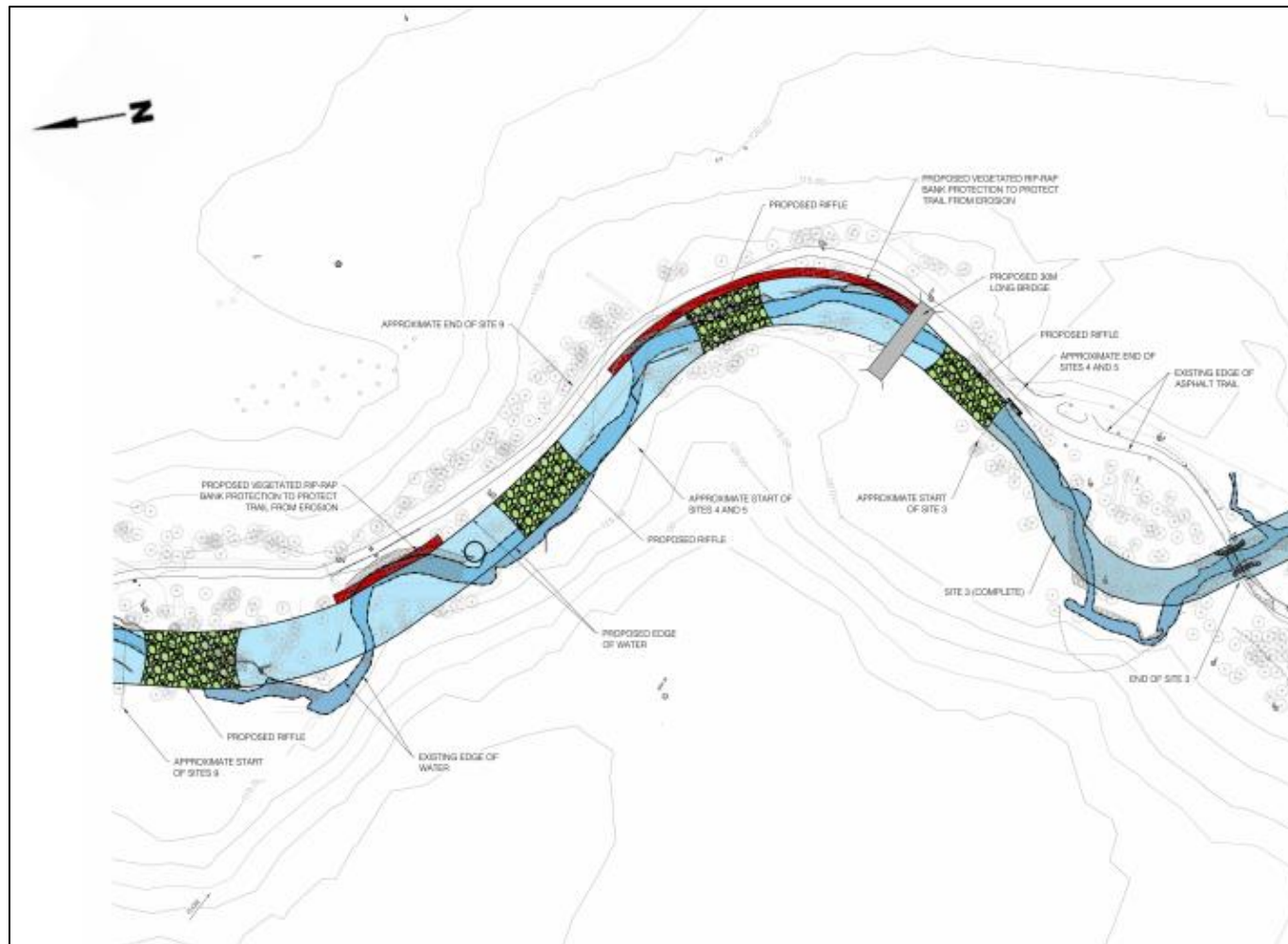


**Figure 4.7: The two proposed planform designs for TRCA defined Reach 7. The high sinuosity of the channel combined with the new urbanized hydrology has led to an unstable channel; the proposed planform designs aims to stabilize this section of Wilket Creek (Toronto and Region Conservation Authority & City of Toronto, 2013).**

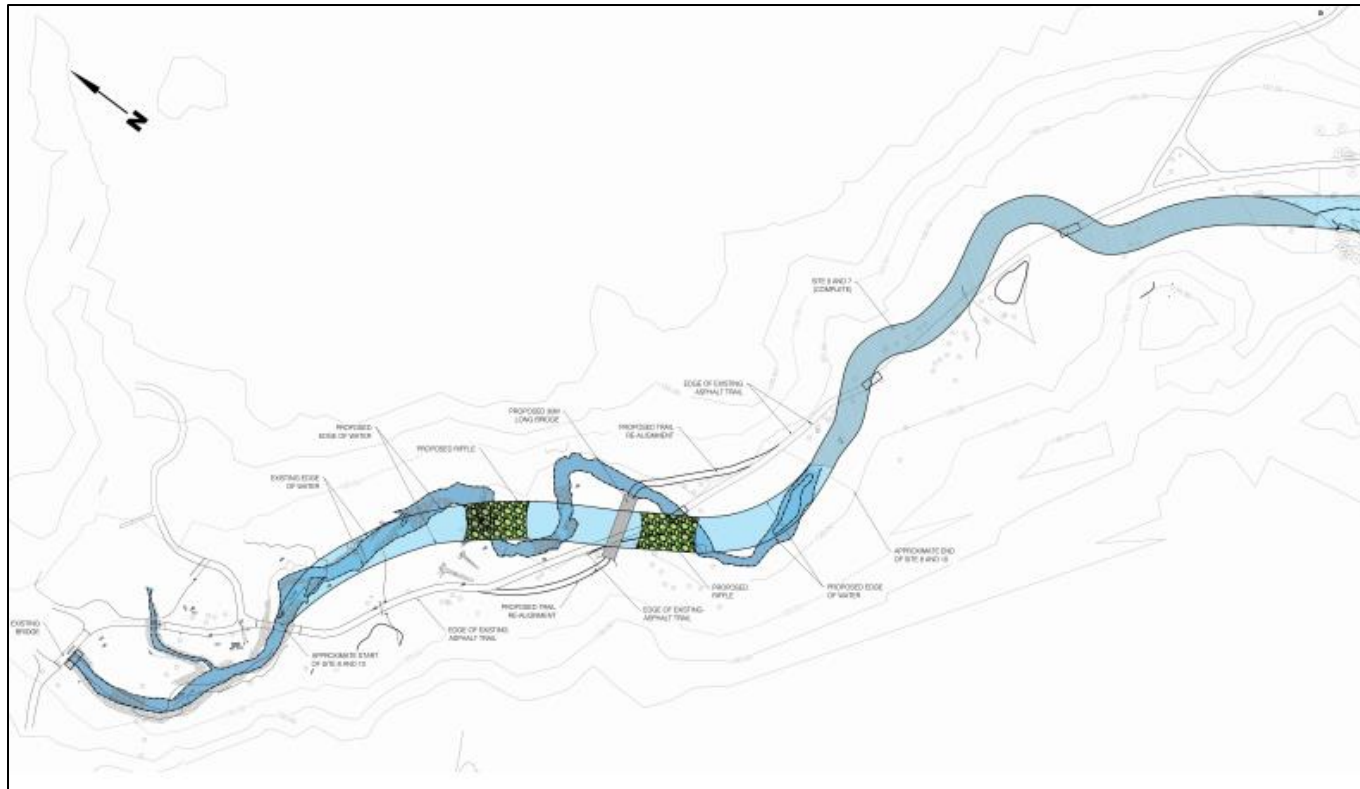


**Figure 4.8: The alternative plan for Site 1 and 2 presented at Public Information Center #2. This map provides an overview of reconstruction plans; more detailed plans were provided for this study (Toronto and Region Conservation Authority & City of Toronto, 2013).**





**Figure 4.9: The alternative plan for Sites 3-9 presented at Public Information Center #2. This map provides an overview of reconstruction plans; more detailed plans were provided for this study (Toronto and Region Conservation Authority & City of Toronto, 2013).**



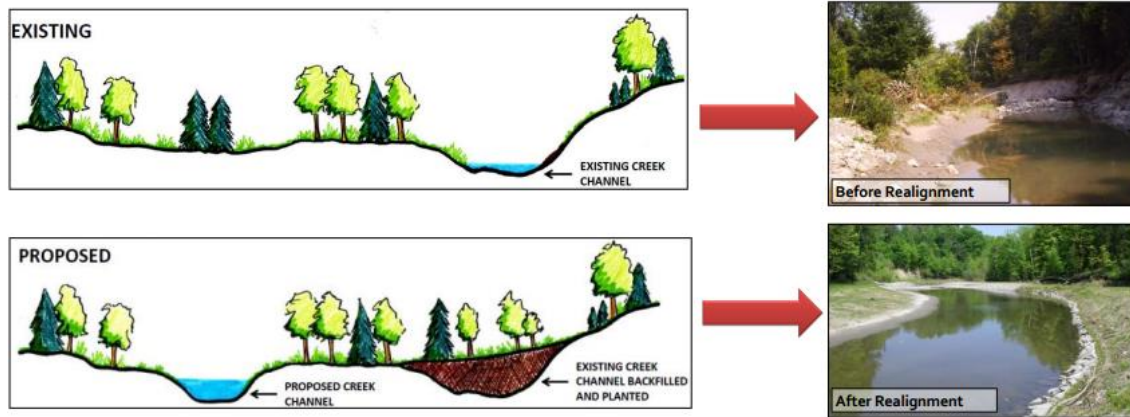
**Figure 4.10: The alternative plan for Sites 6-10 presented at Public Information Center #2. This map provides an overview of reconstruction plans; more detailed plans were provided for this study (Toronto and Region Conservation Authority & City of Toronto, 2013).**

Chronologically, the restoration of Site 3 in Wilket Creek as part of Phase II followed emergency works in Phase I Sites 3, 6, and 7 (Figure 4.4). The Phase I emergency works in Sites 6 and 7 involved encasement of the existing sanitary sewer where it crosses under the creek, realignment of the existing trail away from the watercourse, two new bridge crossings, and modification to the watercourse. The channel was also widened to connect the channel to the floodplain. At the same time, works were underway in Site 3 where the channel was realigned away from the valley wall contact (Figure 4.11), with a vegetated buttress treatment used to stabilize the bank (Figure 4.12). This site was designed with a bankfull width of 15m and depths from 0.75-1.7m, with two riffles and a large pool. A new 30m bridge was installed to accommodate the proposed channel footprint. The reconstruction of these sites have been deemed relatively successful; some natural and unintended adjustment occurred at Site 3 Phase I which was recommended to be improved in future works.

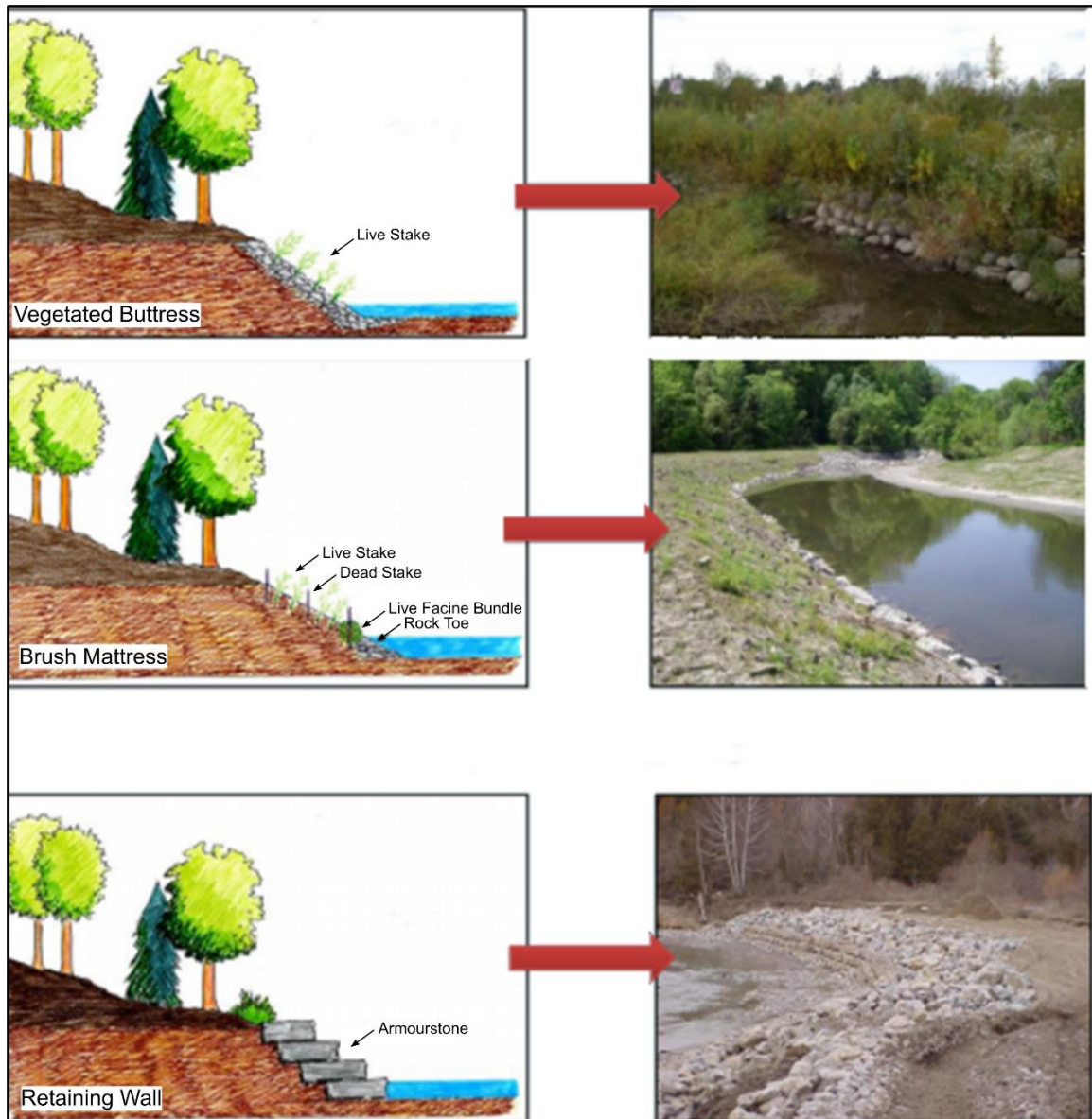
Following these two works, channel restoration began in Site 3 as part of Phase II. The main objectives for this site was to repair eroded areas of the creek while protecting the underlying and adjacent sanitary sewer, pedestrian crossings, and multi-use trail. There were several considerations and constraints taken into account before construction: 1) evidence (undercut banks, exposed till, large quantities of woody debris) in the existing channel was undersized for the urban flow regime, 2) evidence (high bank angles, exposed length of sanitary sewer and bridge footings) of channel cross-sectional area had increased via incision, 3) rates of widening and incision were facilitated by a relatively steep channel gradient and a lack of upstream sediment inputs, 4) the channel contacts the valley walls in several locations, including along the outside of meander bends at Site 3 Phase II (also a constraint on channel design), 5) extremely high energy, urbanized flows acting on channel boundary require a limited selection of appropriate bank protection treatment, 6) the multi-use trail running along the creek, and 7) the sanitary trunk sewer line running along and crossing under the channel at the upstream extent of Site 3 Phase II (Parish Aquatic Services, 2014).

The design parameters for Site 3 include the design discharge, planform and profile, cross sections, stone sizing, bank treatment, and restoration planting plan. The design discharge

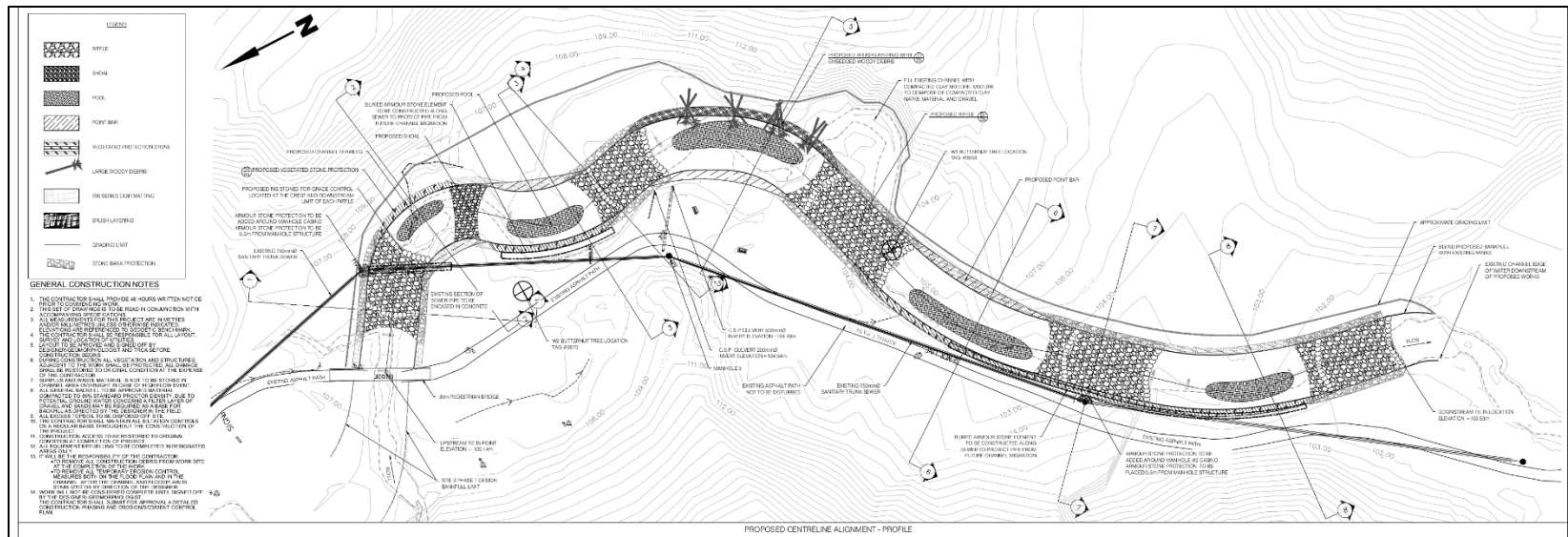
for Site 3 Phase II is the same as was used for Site 3, 6, and 7 in Phase II. The discharge was determined to be  $38\text{m}^3/\text{s}$ , and is based on a detailed geomorphic field investigation conducted for Phase I sites. This roughly correlates to the 10-year storm events as indicated through the hydraulic analysis for the study area (Parish Aquatic Services, 2012). The overall bankfull gradient is 1.3%; planform adjustment to decrease the bankfull gradient for Site 3 Phase II is restricted by the local infrastructure and valley walls. The sinuosity of the planform along this site is reduced slightly as the channel is pulled away from two major valley wall contacts and the sanitary sewer. The profile design consists of three riffle features, one shoal feature, and three pools of varying length. The riffle slopes range from 2.5% to 2.9%; the first riffle is located over where the sanitary sewer crosses under the channel (Figure 4.13) (Parish Aquatic Services, 2014).



**Figure 4.11: Sketches and photographs of realignment in Wilket Creek. This type of realignment took place at many of the reconstruction sites including Site 3 Phase II (Toronto and Region Conservation Authority & City of Toronto, 2013).**



**Figure 4.12: Examples of bank stabilization measures undertaken in Wilket Creek. In Site 3 Phase II, vegetation was used extensively to provide stability to the bank which had been moved off valley walls (Toronto and Region Conservation Authority & City of Toronto, 2013).**



**Figure 4.13: Detailed plans of the reconstruction of Site 3 (upstream) and Site 2 (downstream) (Parish Aquatic Services, 2014).**

The final design will incorporate a channel width that is consistent with, or larger than, the existing cross-section in order to increase the capacity of the system, and reduce flooding on the adjacent footpath and trails. To avoid entrenchment, the design ensured that the creek is well-connected to the floodplain. The cross-section dimensions are similar to those used for Site 3 Phase I for continuity (Table 4.1). Cross sections at riffle crests are 15m wide with a maximum bankfull depth of 0.75m, while pools have a maximum bankfull depth of 1.8 and range in width between 15.0 and 18.0m. The width of a pool depends on whether a point bar has been designated to be established during construction. For Site 3 Phase II, point bars are included in the design at the pools and have been incorporated into the cross-sectional design on the inside of two bends that are adjacent to valley wall contacts. This design element allows higher flows to spill out onto the floodplain bench, dissipating energy and erosive forces and improving flow around the bend (Parish Aquatic Services, 2014).

**Table 4.1: Cross sectional characteristics of Wilket Creek at Site 3 Phase II (*Parish Aquatic Services, 2014*).**

Design Element (m)	Riffle	Transition/ Shoal	Pool (no constructed point bar)	Pool (with constructed point bar)
Bankfull Width	15.0	15.0	15.0	18.0
Max Bankfull Depth	0.75	1.05	1.8	1.8

The stone sizing for the reconstruction of Site 3 Phase II was designed to provide channel stability over a range of flows. These stones were purposefully over-sized to provide this stability, as well as minimize potential risk to the underlying sewer. (Table 4.2) provides the riffle-boulder mix gradation for the proposed design. The robustness of the riffle stone is partially a function of how well the stone is interlocked during construction. The largest diameter stones (the keystones) range from 1250-1300mm and are used to create ribs at the crest and toe of the riffles. The boulder mix has a  $D_{84}$  of 1200mm, a  $D_{50}$  of 700mm, and a  $D_{16}$  of 300mm. This is substantially larger than the grain sizes noted in Sections 3.5.2 and 3.5.3, in the ‘natural’ sections of the channel. The shoal design (which does not include ribs) will not experience the same magnitude of velocities as on the riffles, however the



shoal boulder mix is similar to that of the riffle to allow for ease of construction. Voids between boulders were filled with a matrix mix consisting of native materials and pit-run gravel. The pools between riffles consist of natural substrate.

**Table 4.2: Riffle and shoal boulder mix gradation for Site 3 Phase II (*Parish Aquatic Services, 2014*).**

Size Class (mm)	Riffle Stone Size (mm)
D <sub>95</sub> – keystone	1250 – 1300
D <sub>84</sub>	1200
D <sub>50</sub>	700
D <sub>16</sub>	300
Size Class (mm)	Shoal Stone Size (mm)
D <sub>84</sub>	1200
D <sub>50</sub>	700
D <sub>16</sub>	300

A variety of bank treatments are included in the design for Site 3 Phase II including vegetated stone protection along sections of the channel which are in close proximity to the sanitary sewer line. Due to high velocities and erosive forces, the toe stabilization at the upstream extent of Site 3 Phase II will have vegetated stone protection due to its robustness. Table 4.3 provides bank treatment stone gradation for the proposed design. The recommended stone is angular in nature in order to maximize the degree of internal friction and interlocking between particles. Brush layering is used at the second location where the channel has been pulled back from the valley wall contact and will include embedded woody debris to provide roughness and enhance aquatic habitat opportunities. The remainder of the banks will be stabilized using a combination of coir cloth and live stakes to stabilize the disturbed native materials along the channel banks. Additionally, the two manholes which are located directly adjacent to the channel are to be protected using armour stone. Finally, restoration planting is used to provide vegetative stabilization in the riparian zone and floodplain. In addition, any areas disturbed during construction activities will require plantings for restoration purposes (Table 4.4).

While the designs for Site 3 Phase II stabilized the channel, there may continue to be some adjustment to natural flows. Some adjustments of sediment transport from reaches upstream, siltation in pools ‘flushed’ during bankfull and higher flows, subtle planform adjustments, and some bar formation are anticipated. Photographs of the finished site from March 2016 can be seen in (Figure 4.14).

**Table 4.3: Bank treatment stone size gradation for Wilket Creek (*Parish Aquatic Services, 2014*).**

Size Class (mm)	Stone Size (mm)
D <sub>95</sub> - keystone	1300
D <sub>50</sub>	900
D <sub>15</sub>	600

**Table 4.4: Restoration planting list for Site 3 Phase II (*modified from Parish Aquatic Services, 2014*) .**

Trees		
Common Name	Scientific Name	Quantity
American beech	<i>Fagus grandifolia</i>	2
White pine	<i>Pinus strobus</i>	5
White oak	<i>Quercus alba</i>	3
Shrubs		
Common Name	Scientific Name	Quantity
Speckled alder	<i>Alnus incana</i>	21
Smooth service berry	<i>Amelanchierlaevis</i>	28
Alternate leaf dogwood	<i>Cornus alternifolia</i>	50
Redbud	<i>Cercis canadensis</i>	130
Grey dogwood	<i>Cornus racemosa</i>	80
Common ninebark	<i>Physocarpus opulifolius</i>	150
American elderberry	<i>Sambucus canadensis</i>	170
Pussy willow	<i>Salix discolor</i>	55
Nannyberry	<i>Viburnum lentago</i>	80



**Figure 4.14: Photographs of the completed reconstruction of Wilket Creek in March 2016.**

### 4.3 Summary

It is the urban nature of Wilket Creek that prompted the need for the channel and valley to be safe for multi-use activities (e.g. pedestrian pathway, parks). In order to ensure the safety and stability of the channel and valley, policies and channel reconstruction were put into place, beginning with the Conservation Authorities Act (1946). As the creek changes morphology in a particular way over time, both hydrologic and policy/science ‘events’ initiate further reconstruction and alterations to the channel. These policies allow for external science to drive the ideas about what morphology of the river should be. The knowledge from experts in particular technical groups, such as the TRCA, translated into a narrow idea of what channels ‘should’ look like (i.e. tables, pools and riffles, etc.). The community which uses the pathway and parks, also influences the channel morphology; the community has expressed preferences for the creek form and function to remain as it has been historically to retain their sense of place.

Unfortunately, this may not be what it would look like either before or after urbanization without direct human interventions. The channel design is explicitly related to the technical knowledge of agency, and steered by policy that favours or requires NCD. The culmination of these effects means that the current channel of Wilket Creek is socio-natural: policy, politics, Natural Channel Design science, and community. Together these combine and interact to produce the “reconstructed” channel morphology, contrary to the ‘traditional’ effects of urbanization on river morphology of the type previously undertaken (e.g., Chin, (2006)).

## Chapter Five

### 5 Summary and conclusions of this study

The goal of this thesis was to describe a glacially-conditioned, semi-alluvial channel in an urbanized setting, with an examination of the human influences and interventions in the creek. This study examined how the current morphology of Wilket Creek was created as a product of its geologic history, urbanization, provincial and municipal policies and regulations, scientific and community views of the river, and changing approaches to river engineering and design.

The morphology of Wilket Creek is partly related to the geological setting. This resulted in its semi-alluvial character, and effects the local glacial history, landforms and sediments. The glacial sediments into which it has incised, Newmarket Till, behaves similarly to bedrock, though more erodible in nature; overlying alluvial cover protects the till from erosion. This has produced a distinctive morphology and a particular response to urbanization, and also vulnerability to the effects of urbanization with eventual consequences for river engineering and design and its current morphology.

Urbanization took place in Wilket Creek's catchment in the 1900s, starting with the construction of the first house in the Bridle Path development in 1929. Since then, rapid residential, commercial, and industrial development began in the late 1940s in the catchment; becoming fully urbanized by the mid-1970s. The types of development have evolved over time (Figure 3.9 - Figure 3.17). Based on the hydrologic history of three neighbouring catchments, this urbanization caused the hydrology of Wilket Creek to have large, flashy summer flows, as well as higher annual flow. Based on the literature (Hammer, 1972; Hollis, 1975; Rutherford & Ducatel, 1994; Trimble, 1997; Chin, 2006; Colosimo & Wilcock, 2007a; Trudeau & Richardson, 2015), hydrologic change due to urbanization would have had an effect on channel morphology. Many features of the current morphology of Wilket Creek can be attributed to hydrologic change. The planform pattern has changed between 1965 and 2009; width measurements between 1947 and 2016 show that the channel has widened over the course of urbanization. Additionally, when compared

to historical ground photos from the 1960s, the current channel has incised by approximately 1m, exposing the Newmarket Till on the channel bed.

The current morphology is further complicated by reconstruction in the channel. While the TRCA has labelled works in the channel as restoration, it is not possible to know what the channel was prior to urbanization based on the current data. As previously mentioned, the channel size no longer accommodates the urbanized flow. Therefore, instead of restoration, the channel has actually experienced reconstruction and reengineering to accommodate for the new flow regime.

Previous urban geomorphology papers view channels as a merely a product of the hydrological change due to urbanization in the catchment. The socio-geomorphology of a channel extends beyond the ‘physical only’ account of urban channels. This type of analysis extends to include reports from provincial and local municipalities, conservation authorities, and consultant companies. Hurricane Hazel jump-started conservation authorities in the Toronto area into making policies which regulate the city’s watercourses to protect citizens and surrounding infrastructure. Policies such as the Forty Steps to a New Don, the Royal Commission on the Future of the Toronto Waterfront, and Natural Channel System set the recommendations for watershed management implementation. The effects of these policies and reports is still seen in the current catchments. This type of analysis results in a more complete understanding of geomorphology and of the role and consequences of geomorphologists’ understanding of, and interventions in, these systems (Ashmore, 2015).

Intervention measures were discussed in detail in Section 4.2.2, for a site located at the confluence of Wilket Creek and the West Don River. Located upstream of this site, the two reaches documented in Chapter 3 are scheduled for reconstruction in the next two years. Unfortunately, this means that the physical characteristics of these reaches – mainly its semi-alluvial nature – will no longer be visible after this time. These reaches will become the same homogenous riffle-pool reconstruction as seen in Site 3 Phase II (Section 4.2.2), decreasing the heterogeneous, and ‘natural’ state of the channel. This study does however bring the urban geomorphology community one step closer to fully understanding and documenting what urban channels look like and why they look as they do; these are

complex systems involving natural controls on channel form as well as human influences and interventions.

## 5.1 Future research

There were some limitations to this study (Section 3.6), however it also opened several different avenues of research. First, this study is not a unique case in Toronto; there are many applications of this kind of reflective study in Toronto, and other areas with semi-alluvial systems. It is possible to use a socio-geomorphologic approach in urban channels outside of Toronto. Unfortunately, a direct application of the approach used in this case study is not possible, partly due to different policies and policy creators in each catchment investigated outside of Toronto.

Interview data behind the thinking, arguments, and rationale of the policy creation and implementation would aid the social aspects in a study of urban riverscapes, following work by Lave (2012) and Lave et al. (2014). Second, as noted by Chapuis et al. (2015), an investigation into the success and longevity of the riffle-pool system used primarily in Natural Channel Design should also be undertaken. As well, an analysis of the vague language which is used by the TRCA and other conservation authorities would prove useful. Since much of sociogeomorphology relies on reports from conservation authorities, the philosophy and language of these groups would allow for a more in-depth analysis of the influence that these policies and reports have on catchments under the control of conservation authorities.



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