# IMPACT OF URBANIZATION ON MCVICAR CREEK, THUNDER BAY

BY

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## ABSTRACT

Urbanization has significantly altered natural ecosystems, particularly impacting waterbodies like streams and creeks. In Thunder Bay, Ontario, the urbanization of McVicar Creek has led to increased impermeable surfaces and reduced riparian shading, resulting in changes to stream characteristics and water temperature dynamics. This thesis investigates the adverse effects of urbanization on McVicar Creek, with a focus on water temperature variations as a key indicator. Through the collection and analysis of water temperature data from urban and non-urban study sites, this research aims to assess the impact of urbanization on stream thermal regimes.

Results indicate elevated water temperatures in urbanized segments of McVicar Creek compared to rural areas, suggesting the influence of an urban heat island within the city of Thunder Bay. Additionally, the study reveals significant differences in stream depth and width between urban and non-urban sites, highlighting the morphological alterations induced by urbanization. These findings underscore the importance of stream restoration projects and long-term monitoring to mitigate the adverse effects of urbanization on stream ecosystems. By understanding the impacts of urbanization on waterbodies, policymakers and environmental managers can develop effective strategies to protect and rehabilitate urban streams, ensuring the health and sustainability of aquatic ecosystems in urban environments.

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# Chapter One

## INTRODUCTION

Urbanization in the city of Thunder Bay has led to an increase in impermeable surfaces and a decrease in riparian shading. Streams subject to urbanization are experiencing hydrologic changes, causing alterations to the water chemistry, stream characteristics, and water temperature (LeBlanc, 1997). This is directly caused by the urban heat island effect. Human activity incorporates a high degree of heat-generating systems and devices, leading to a rise in the temperature of the local environment. This is also referred to as thermal pollution. Thermal pollution causes an increased number of stressors in the environment. One is the compromise of water quality. As water temperature increases, oxygen levels decrease. This occurs at a much faster rate in smaller watersheds such as streams. Thermal pollution can also compromise the health of aquatic organisms. Aquatic organisms, such as fish, rely on specific temperatures as warmer water temperatures can impact their growth and fecundity.

An urban environment also contributes to the increase in impermeable surfaces. Stormwater runoff can easily carry pollutants into watersheds as there are many stormwater drainage networks in an urban environment. There is also a lack of soil within cities that would normally absorb the stormwater (Ketabchy et al., 2019). Instead, this water tends to increase in temperature as impermeable surfaces hold more thermal energy compared to permeable surfaces, and it collects pollutants as it flows over urban surfaces (Ketabchy et al., 2019). The amount of riparian shading in a city is also compromised, leading to more solar radiation directly heating a watershed (Beganskas & Toran, 2021). These are all factors associated with how an urban heat island can increase the water temperature of an urban stream.

### 1.1 History of McVicar Creek

Urbanization is altering our environment at an extremely fast rate which is a reason for stream restoration projects being developed. Human health is dependent on water quality, so protecting our watersheds is becoming a very common practice. McVicar Creek, located in Thunder Bay, Ontario, is one example of a stream that has been affected by urbanization and has undergone multiple stream restoration projects. The lower half of the watershed is located in an area that has been heavily developed from the mid 1950's to the mid 1970's. This development was done within the floodplain of McVicar Creek and was completed before any floodplain management was conducted. In 1974, the Lakehead Region Conservation Authority (LCRA) began to regulate the floodplain and prohibited any new development in the area.

In 1987, the shorelines of Thunder Bay were recognized as an Area of Concern under the Great Lakes Water Quality Agreement by the Lakehead Region Conservation Authority (McVicar Creek Protection & Rehabilitation Plan, 2014). This includes McVicar Creek, as this area has suffered from environmental degradation due to urban development. It has affected the overall water quality of the stream as well as the biggest lake in Canada, Lake Superior (Marshall, 2015). In 2014, the city of Thunder Bay created the McVicar Creek Protection and Rehabilitation Plan to prioritize the health of streams in the Lakehead Region. This plan was established to create more green infrastructure spaces and to manage the stormwater runoff and pollution in the McVicar Creek watershed (McVicar Creek Protection & Rehabilitation Plan, 2014). There has been no further published work done on this project since its establishment in 2014. As well, there were no plans surrounding the long-term monitoring of this creek post-completion of the project.

### 1.2 Study Area

McVicar Creek is the smallest of five major watercourses in the city of Thunder Bay. Smaller streams, with their reduced water volumes, exhibit more fluctuations in temperature (Moore & Miner, 1997). The selection of this creek was influenced by its status as the smallest watershed in the area, indicating it would experience the most temperature variations. Therefore, McVicar Creek could be considered the most vulnerable to the effects of an urban heat island. Ketabchy et al. (2019) suggest choosing a stream that accurately represents both urban and non-urban areas under study. They also base their decision of a study site on land use and ease of access, focusing on the convenience of accessing the non-urban areas of the stream. McVicar Creek is easily accessible throughout its urban and non-urban environment. The creek is also not too deep to sample in chest waders and is not so small that the risk of the creek drying up in the summer would be of concern (Ketabchy et al., 2019). McVicar Creek remains disturbed due to its proximity to impervious surfaces and industrial areas, rendering the water flowing through it a subject of interest. All these factors make McVicar Creek an ideal area to study.

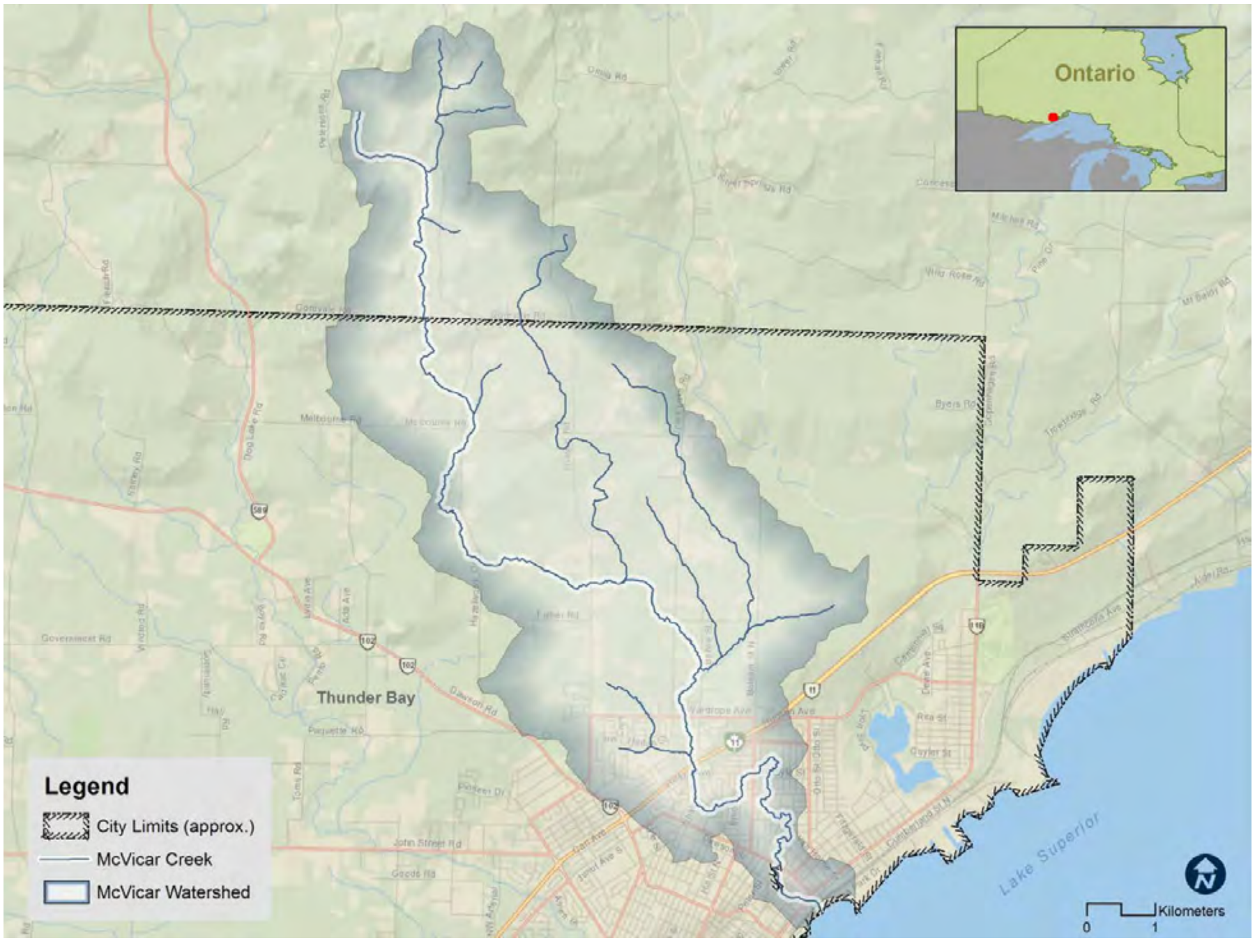


Figure 1.1 Location of McVicar Creek Floodplain, Thunder Bay, Ontario

### 1.3 Purpose and Objectives of the Research

The primary purpose of this thesis is to investigate the effects of urbanization on McVicar Creek in Thunder Bay, with a specific focus on how urbanization impacts water temperature dynamics and stream morphology. This will be accomplished by gathering water temperature data to assess whether the creek's overall water temperature is higher compared to that of a natural stream. While the data will provide insights into temperature variations, it may not be conclusive in attributing the increase solely to urbanization; however, this is the underlying hypothesis. Through observation of the land use changes, riparian vegetation, and stream characteristics, this thesis will show how urbanization has negatively impacted McVicar Creek within the urban areas of the watershed. The research emphasizes the role of urban heat islands and the modification of natural environments in elevating water temperatures, thereby affecting the ecological health of the creek. The research will also highlight the importance of keeping our streams clean through restoration projects and long-term monitoring. The results and conclusions of this thesis will aid in the implementation of management strategies for stream restoration projects aimed at protecting watersheds from the effects of urbanization.

# Chapter Two

# LITERATURE REVIEW

This literature review is an overview of the current literature that supports the research and data collection of this thesis. It will serve as a comprehensive exploration of the key themes presented in this thesis by understanding and addressing the multifaceted challenges posed by urbanization. It explores research on the urban heat island phenomenon, the effects that urbanization has on small urban streams, and the interconnected dynamics of water and air temperature within an urban setting. This literature review aims to synthesize existing knowledge and establish the contextual framework that is necessary for investigating the direct repercussions of the urban heat island on the health and resilience of McVicar Creek.

## 2.1 Urban Heat Island

An urban area is defined as a city with a population of at least 50,000 people (Danielson & Keles, 1985). Cities are now home to more than half of the world's population. With most human beings living in large urban areas, land use has changed drastically. Urban sprawl accounts for only 2% of the Earth's land surface, but the environmental impact this small percentage has is great. For example, urban centres produce 78% of global greenhouse gases (Meyer et al., 2005). The urban heat island effect is evident when the local ambient temperature is warmer within a city compared to nearby rural areas. This is becoming a more common issue that is beginning to affect the operation and habitability of urban environments.

This phenomenon is caused when urbanization occurs, reducing the amount of vegetation and evapotranspiration, and increasing the size of impervious surfaces. Studies have revealed that the urban heat island effect can increase air temperature by between 2 and 8 °C (Mohajerani et al., 2017). As global populations increase and cities expand, the urban heat island phenomenon intensifies. Extensive research has explored this effect in various climates, ranging from northern regions like Alaska to warmer and drier areas such as Spain (Adamowski & Prokoph, 2013). The urban heat island effect is a significant field of study, with ongoing investigations extending to Canada. Current research is particularly focused on understanding the adverse consequences resulting from the heightened intensity of the urban heat island, with studies underway in major cities such as Toronto and Regina (Adamowski & Prokoph, 2013).

A significant body of research focuses on studying local microclimates to better understand the urban heat island effect, aiming to support the creation of more sustainable urban spaces. The most common practice brought forward from the literature is the expansion of vegetation and green spaces within city centres (Hathway & Sharples, 2012). Research has shown that both large and even small parks can provide cooling effects. Several published studies have also highlighted how rivers and streams within urban areas can provide a cooling effect (Hathway & Sharples, 2012). The abundance of heat produced by cities is absorbed by the water and carried downstream (Hathway & Sharples, 2012). Streams can be used within cities as an integral mitigation effect for cooling the local ambient temperatures. Urban streams are very important to understanding the urban heat island. With their natural benefits, they can serve as a crucial countermeasure in mitigating the escalating urban heat island effect (Tsakaldimi & Tsitsoni, 2015). This can only be done if urban streams start becoming protected from the relentless spread of urbanization.

## 2.2 Urban Streams

Urban streams are now a popular area of research as increasing urbanization across the world is changing urban land use practices. Studies are investigating the dynamics between urban environments and urban development, focusing on how increased land use influences native ecosystems (Grimm et al., 2000). This research is at the forefront of urban ecological studies as streams that run through urban environments are particularly vulnerable to the impacts associated with landcover change. Streams need specific conditions including riparian vegetation and stable temperatures to thrive. Human disturbance is the leading cause for altering the environment where these streams flow and the reason why so many urban streams have lost their ability to recover and maintain ecological function (Walsh et al., 2005). Streams play an important part in urban ecosystems as they act as a habitat for productive biota, a carrier of water, and processors of the materials in that water, and a social and cultural space for human inhabitants, making it critical in bringing the resilience back to urban streams (Walsh et al., 2005).

Urban streams are exhibiting signs that have never been seen before due to the rapid advancements of civilization. Many studies have concluded with the fact that urban streams are ecologically degraded. Meyer et al. (2005) created the term “urban stream syndrome” to categorize the effects that urban streams are facing. This term was used to summarize the symptoms presented within urban streams that show consistent trends across geographic regions (Meyer et al., 2005). The list of symptoms that many urban streams are facing include increased concentrations of nutrients and contaminants, increased variability in streamflow, changes in channel morphology and stability, and reduced amount of biotic richness (Meyer et al., 2005). This study expanded the success of research around urban streams, as it became evident that cities all over the world were experiencing devastating effects to urban streams.

The literature shares an abundance of research focused on what urbanization will do to natural ecosystems. Studies have shown how a stream will change completely when the land around it is changing (Klein, 1979). The biological composition of urban streams is becoming more and more different as compared to the natural streams. One reason being the increased storm water runoff in urban areas which increases the severity of flooding causing channel erosion and changes within the stream bed composition (Klein, 1979). Several studies have focused on the relationship between watersheds and land use and conclude that the health of a stream ecosystem is lost when there is a modification to the stream characteristics (LeBlanc, 1997). These studies have also documented the impacts of urbanization on water temperature within an urban stream. Most results have concluded that urbanization can increase the water temperature of a watershed by several degrees Celsius (LeBlanc, 1997). This shows that watersheds in an urban environment would have a different water temperature compared to a natural watershed. Urban streams are continuously becoming degraded by the pressures of urbanization. This alone is causing urban streams to be the most disturbed aquatic ecosystems in the world (Tsakaldimi & Tsitsoni, 2015).

**2.3 Stream Temperature**

The study of how urbanization affects stream temperatures is rapidly expanding as cities reach unprecedented sizes. The ecological consequences of larger populations and sprawling landscapes are becoming more apparent as there is a heightened demand for living in a city. The increase in air temperature that is produced by the urban heat island effect is reflected in urban streams (Watson & Chang, 2017). Higher temperatures and large developed areas lead to higher baseflow temperatures within streams. Stream temperature, from the perspective of heat dynamics, is the process where heat energy is exchanged throughout the stream (Watson &

Chang, 2017). This process is critical for many aquatic species as they rely on consistency in water temperature (McBean et al., 2022). Many aquatic organisms cannot regulate their own body temperature and therefore rely on water temperature to efficiently regulate their internal temperatures. High temperatures in watersheds will also lead to the spread of aquatic diseases, as certain pathogens can survive and spread more readily in warmer waters (Watson & Chang, 2017). Aquatic organisms and the overall health of a stream can become devastated due to an increase in temperature (Somers et al., 2013). This is also referred to as thermal pollution. Thermal pollution is directly caused by hydrologic connections to impervious surfaces, a decrease in riparian vegetation leading to less shading from solar radiation, a decreased amount of vegetation within the watershed, and warmer water directly entering a stream through stormwater infrastructure (Somers et al., 2013).

Within the existing body of research, studies are being conducted on the effects of small-scale variations in water temperature on fish populations such as salmon and trout. These studies share insights into how dams and the loss of forested buffers can increase the water temperature of a stream and directly impact the health of these fish (Johnson, 2004). Some of these studies also use deterministic models that use averages of local ambient temperatures to predict future water temperatures of a stream. This methodology proves particularly valuable within the existing research, as it contributes to safeguarding aquatic species from the adverse effects associated with elevated temperatures (Kelleher et al. 2012). New research is looking into whether cities are affecting urban streams in a similar way to how dams and less vegetation impact natural streams (Kelleher et al. 2012).

The growth, metabolism, and reproduction of aquatic species are dependent on stable stream temperatures. If thermal regimes become too warm, the loss of aquatic fauna will be devastating to the ecosystem (Hester & Doyle, 2011). Higher temperatures within streams can also increase the activity levels of microorganisms which results in altered respiration and organic matter decomposition. These changes influence the overall functioning of the ecosystem and impact the way energy and nutrients move through the stream (Imberger et al., 2008). Therefore, understanding and addressing the factors that contribute to temperature changes in urban streams is crucial for preserving their ecological integrity and ensuring the sustainability of aquatic life.

One study presented in North Carolina, conducted a synoptic survey on 70 different streams with a range of different land covers to better understand how urbanization affects stream temperature. Stream temperature, canopy cover, stream channel depth, and width were all measured as these variables best represented the paths by which the urban heat island might affect stream water temperatures (Somers et al., 2013). The results focused on the 10 most-developed watersheds and the 10 most-forested watersheds and showed that the streams located in more developed areas had higher baseflow temperatures compared to the streams in forested areas (Somers et al., 2013). Other studies have created similar methods with the data collection being conducted on one stream that flows through both urban and rural areas. Hathway and Sharples (2012) found that the stream's water temperature increased by 2 °C as it flowed through a developed area (Hathway & Sharples, 2012). Another study following the same methodology found the stream to have a 3.7% increase in the water temperature downstream of Suceava City. On average the stream had a 0.99 °C increase in water temperatures within city limits compared to where the stream flowed outside of the city (Briciu et al., 2020). The studies presented within the literature all share a common goal: to attempt to mitigate the effects produced by urban heat islands to save the health of urban streams. Stream health can depend on various factors, but water temperature is arguably the most critical for in-stream processes. This is because water temperatures have the largest relation to water quality as it governs the most amounts of abiotic and biotic processes within a stream (Nelson et al., 2007).

### 2.4 Air Temperature Effects on Water Temperature

The rise of ambient air temperatures within cities has been predominantly researched compared to water temperature. The emphasis on air temperature studies is primarily attributed to the visible and immediate consequences that the urban heat island effect has on human health. A variety of studies have also given attention to the relationship between air temperature and water temperature (Gu et al., 2014). Water temperatures within a stream are strongly correlated with the climate. Long-term data analysis has shown that air temperature is a good way to project future water temperature. As air temperature has a pronounced influence on water temperature it is therefore likely that as air temperature increases so does water temperature (Null et al., 2012). The effects of climate change on stream health can be predicted by finding future water temperatures and their impact on different organisms. For example, if stream temperatures exceed the temperature tolerance for a specific fish species, then it is likely that the species will no longer be able to survive in that given stream (Mohseni et al., 1998).

Another popular method to find the relationship between air and water temperature is through linear regression models. Air temperature data is a widely used independent variable that is used in regression models. This is done to predict water temperature as the independent variable acts as a surrogate for the net energy balance that affects the surface of the water (Mohseni & Stefan, 1999). Other studies use different modelling approaches, such as the deterministic model and the stochastic model, to predict water temperatures of a given watershed only using air temperature (Caissie et al., 2001).

Models to predict stream temperatures can be very useful to understand and anticipate changes in aquatic environments. Researchers can observe the surrounding weather patterns that affect water temperature to address potential challenges in urban streams (Arisméndi et al., 2014). Understanding the relationship between air and water temperature is critical for understanding the future health of urban streams. The absence of long-term data, which refers to continuous observations over at least 10 to 20 years, on stream temperatures in the existing literature presents a significant limitation (Webb et al., 2008). This is impeding the comprehensive understanding of thermal regimes within small streams.

### 2.5 Riparian Vegetation Effects on Water Temperature

Riparian vegetation is an essential component of the health of stream ecosystems. The literature shows that riparian vegetation is one of the most efficient ways to regulate stream water temperatures. One way in which riparian vegetation can regulate water temperature is through the shading along a watershed (Timm et al., 2021). The amount of shading produced by trees affects the amount of solar radiation that is being distributed along the surface water. The more solar radiation that is blocked by riparian trees and plants, the fewer heat fluxes and water temperature variations within a watershed (Timm et al., 2021). The regulation of water temperature can also be seen when riparian vegetation produces a cooling effect through evapotranspiration of shallow groundwater and soil water (Sinokrot & Stefan, 1993). Evapotranspiration involves the evaporation of water and transpiration from plants and is the most effective when more vegetation is present. When the collective surface area of leaves is greater, more water vapour is released into the atmosphere, having an overall cooling effect on the surrounding area (Tabacchi et al., 1998).

Riparian vegetation has the effect of slowing down the flow of water. This process allows for the water in a stream to have more time in contact with the streambed and the stream banks, which dissipates heat and reduces the overall water temperature (Marsh, 2005). Research has also shown that riparian vegetation can create humid microclimates over streams which stabilizes the water temperature variability (Timm et al., 2021). When a lack of vegetation is present within a stream, detrimental effects can occur, including the loss of water quality and aquatic species due to the increase in water temperature.

Numerous studies have explored the relationship between riparian vegetation and water temperature. Garner et al. (2017) looked at water temperature dynamics over multiple different locations of one stream where the riparian vegetation density varied. They were able to show the increase in water temperature in the areas with less riparian vegetation. Trimmel et al. (2018) followed a similar procedure but included the risk of climate change on rising water temperatures. They gathered water temperature data during extreme heat waves to understand how riparian vegetation plays the role of cooling down rivers. The results also showed that the shading produced by riparian vegetation can significantly mitigate the effects of climate change on water temperature (Trimmel et al., 2018). Kupilas et al. (2021) have also found that a lack of riparian vegetation can reduce fish populations within the watershed. The buffer zones that sustain riparian vegetation help regulate water temperatures which maintains a stable condition for fish to thrive in.

Riparian zones are critical for stream ecosystems to properly function (Ward, 1989). Riparian vegetation is emerging as a fundamental strategy for the preservation and restoration of urban streams. The incorporation of wild plant communities has emerged as a prominent conservation strategy for fostering the health of urban aquatic ecosystems (Hu et al., 2019). Studies emphasize the importance of understanding the local conditions of riparian vegetation to help cities create conservation areas by increasing the amount of vegetation within their riparian buffer zones. This is an affordable and manageable practice that will help mitigate the effects of the urban heat island. One study has emphasized the importance of using native plants when completing these projects. Invasive plants can cause changes to both the structure and the functioning of an ecosystem (Richardson, 2007). The strategic augmentation of vegetation in riparian zones, along with the preservation of native plant species, stands as an effective measure in mitigating the escalating water temperature levels induced by the urban heat island effect.

**2.6 Effects of Urbanization on Stream Morphology**

The intense changes in land use due to urbanization can alter a range of stream's characteristics. The loss of a natural habitat along stream banks can change the physical appearance of a watershed as changes in the landscape can significantly impact the physical characteristics of a stream. Habitat degradation can reshape the channel size and depth of a stream (Fitzpatrick & Peppler, 2010). Several studies have explored the effects of urban development on the geomorphology of urban streams (Short et al., 2005). Booth and Bledsoe (2009) found that stream width could increase with the construction of roads and other infrastructure. This is also known as "urban-induced channel changes". Channel widths commonly increase throughout urban areas but are not universal to every drainage basin. If a channel width is increased, it will also increase the surface area that is exposed to the atmosphere. This will then increase the overall water temperature of the creek since there is a larger area for solar radiation to reach the creek (Booth & Bledsoe, 2009). This phenomenon also causes the overall depth of flow to decrease which makes for more efficient heating. A wider creek will cause the water flow to be slower compared to a narrower creek. When the water flow is slower, the water residence time is increased, which again increases the overall water temperature (Booth & Bledsoe, 2009).

Numerous studies have documented the differences in stream characteristics in rural and urban streams. Most studies show a higher presence of morphological changes in urban streams (Kang & Marston, 2006). Fitzpatrick and Peppler (2010) compared streams in metropolitan areas of the United States to streams in rural areas to understand the changes in stream characteristics. Findings showed that 90% of urban streams had at least one type of channel alteration whereas 70% of the rural streams had channel alterations. Ramírez et al. (2009) found that urbanization can cause an increased frequency of high-flow events which can cause channels to become wider and deeper. The literature shows that streams may also become shallower because of urbanization. With increased amounts of bank erosion and sedimentation, the accumulation of sediments can lead to stream bed aggradation. This occurs when the bed of the streams rises from the amount of sediment in a stream (Doyle et al., 2000).

Urbanization can also accelerate overland sediment transport. Construction near a stream will reduce the amount of riparian vegetation, creating more exposed soil and increasing bank erosion (Chin, 2006). Erosion increases the amount of sediment that is flowing in a stream. When urban streams have an increase in sediments, this is a major factor affecting channel shape (Whipple and DiLouie, 1981). The increase in sediment can also cause the transport capacity of a stream to exceed its actual sediment supply which in time can continue to erode the beds and banks of a stream further (Whipple and DiLouie, 1981). Another study found that over an 11-

year period, 80% of urban streams that were being measured show an average width change of 60 mm per year due to erosion (Wigmosta & Burges, 2001). Wider review of relevant literature shows that streams can become wider and shallower in urbanized areas. This creates several issues within a watershed including reduced habitat quality, loss of riparian vegetation, impaired water quality, and higher water temperatures.

### 2.7 Urbanization Impacts on McVicar Creek

The natural flow of McVicar Creek has been compromised due to the level of urbanization within the city of Thunder Bay. Stream crossings allow a stream to function as naturally as it can within a city. This is vital for the health of a watershed. The stream crossings along McVicar Creek include pedestrian bridges and culverts. The infrastructure built around McVicar Creek for stream crossings exhibits multiple issues, affecting both the stream's impact and its long-term sustainability (McVicar Creek Protection & Rehabilitation Plan, 2014). The city of Thunder Bay has recognized that there are undersized crossings along the creek which can restrict the natural flow of the creek, create erosion, and create high flow velocities, clogging, and ponding (McVicar Creek Protection & Rehabilitation Plan, 2014). There are also shallow crossings which are caused by culverts being too large for the flow of the creek. Water depths in these crossings could become too low for aquatic species to swim through the culvert. Perched crossings have also been observed which is a crossing that is elevated and can be vertical or have velocity barriers (McVicar Creek Protection & Rehabilitation Plan, 2014). This can cause erosion and ponding. The last issue observed around crossing infrastructure is insufficient culvert length. This causes the road shoulders to become unstable and increases the amount of sediment loading and road maintenance (McVicar Creek Protection & Rehabilitation Plan, 2014).

Urbanization has caused the city of Thunder Bay to alter the stream beds and banks through channel revetment and native vegetation removal. When native vegetation is removed from a creek bank, it increases the rate of erosion and stream widening. The city has also dredged and straightened some sections of McVicar Creek (McVicar Creek Protection & Rehabilitation Plan, 2014). This was done with the intention of helping drainage and flood control of the creek, instead, this impacts the natural flow of the stream. This issue stems from the lack of planning that occurred when the city began to develop residential areas along the floodplain (Lakehead Region Conservation Authority, 2002). The land that surrounds the creek was developed without the consideration of natural ecosystem functions. The primary land use within the floodplain of the McVicar Creek consists of residential lots. The proximity of residential lots to the creek has caused a lot of harm to the natural watershed, with erosion being one of the most common issues. Another issue is these lots maintain ownership to both sides of the creek, including the creek bed. This allows property owners to have full control over their portion of the creek which leads to the clearing of vegetation, cutting down trees, dumping of yard waste, and application of fertilizers, herbicides, and pesticides all alongside the creek (Lakehead Region Conservation Authority, 2002).

Stormwater discharge is classified as another issue within the McVicar Creek watershed. Heavy metals have been found in McVicar Creek including lead, zinc, copper, chromium, cadmium, and nickel (Northshore Remedial Action Plans, 2012). These contaminants are not natural to the creek and are derived from the stormwater discharge. Stormwater discharge flows along impervious surfaces which have high solar absorbance and increases the temperature of the discharge. This discharge then flows into McVicar Creek at an elevated temperature and raises the overall water temperature of the creek. The heavy metals found within the stormwater discharge are contaminants from water pipe and roof erosion, vehicle emissions, wear of vehicle materials, and degradation of impervious surfaces (Northshore Remedial Action Plans, 2012). This puts the creek at an extremely high risk of water quality impairments. The North Shore Remedial Action Plan at Lakehead University's Department of Geography has found that McVicar Creek falls below the Provincial Water Quality Objectives and Canadian Environmental Quality Guidelines (Northshore Remedial Action Plans, 2012). The water quality is impacting the health of the ecosystem as well as the water temperature within this creek.

**2.8 Stream Restoration Projects**

Stream restoration projects are conducted to help urban streams exist within a city in more natural ways. These efforts enhance the local ecology of a stream and help restore flow patterns. They can also help remove invasive species, reconstruct stream channels, and plant more riparian vegetation (Moran, 2007). There have been multiple stream restoration projects conducted on McVicar Creek. The objective of these remedial projects is to restore McVicar Creek to its original state, predating the impacts of urbanization. The majority of these projects have been created by the LRCA. Since the beginning of these projects in the mid-1960s, there has been an increased awareness of the importance of preserving and protecting urban streams in Thunder Bay.

The first stream restoration project was completed between 1966 and 1976. This included erosion protection, regulation and floodplain mapping. In 1991, the McVicar Creek Rehabilitation Project was created. The extent of this project was bank stabilization, replacement of sections along the creek bed, terracing the road embankment, and planting native grasses, trees, and shrubs along the mouth of the creek (Northshore Remedial Action Plans, 2012). The McVicar Creek Tree Planting Project was then brought into effect in 2010. Trees were planted along the creek between Wardrope Avenue and the Thunder Bay Expressway. This multi-year project aims to improve the riparian vegetation zones along McVicar Creek (North Shore Steelhead Association, 2010). Since this last stream restoration project, very few projects have been introduced to McVicar Creek. There has been a great quantity of research conducted on the health of the creek directed separately by the city of Thunder Bay, Lakehead University Department of Geography, and the LRCA. The research shows that the health of this creek is depleting as a result of the stream channel reconstruction and the removal of vegetation (Northshore Remedial Action Plans, 2012). Stream restoration projects are of great importance to McVicar Creek, as urbanization continues to alter the creek's natural formation.

## Chapter Three

## METHODOLOGY

### 3.1 Study Area

McVicar Creek is 16 km in length and typically is 2.5 to 3 m in width. The creek originates north of the city and flows south along Hazelwood Drive. McVicar Creek enters the urban limits of Thunder Bay near Wardrope Avenue. The creek continues to flow south and east, crossing the Thunder Bay Expressway where it enters the urban core. It drains a total area of 50.65 square km into the Thunder Bay Harbour, where it flows into Lake Superior.

The upper reaches of the stream, which account for 84% of the drainage basin, are in an undeveloped area, with most of the land being forested open meadows. The lower reaches that meander through the city represent 16% of the drainage basin and are labelled as intensely urbanized. The headwaters of McVicar Creek are north of Melbourne Road and have an elevation of 490 m above sea level. The downstream flow of the creek is relatively constant until it reaches Lake Superior at an elevation of 183 m above sea level. (McVicar Creek Protection & Rehabilitation Plan, 2014).

McVicar Creek exhibits a geological transition from a substrate dominated by rolling Precambrian shield in its upper reaches to shaley Sibley Group sedimentary rock in the mid and lower reaches. The creek flows over a solid bedrock surface but passes through 3 different soil conditions. The upper reaches are characterized by undifferentiated soil. The soil conditions then transition into shallow sandy soils within the middle reaches and then eventually become stratified sands and gravel in the lower reaches (Lakehead Region Conservation Authority, 1995). McVicar Creek represents an ecologically rich and visually remarkable ecosystem, hosting a diverse array of species. These species include sculpins, ninespine stickleback, and blacknose dace. The largest species that inhabit the creek include brook trout and rainbow trout (Olivier & Egmond, 2016). The ecological significance of McVicar Creek, characterized by its diverse fish fauna and other species, emphasizes the imperative to preserve its environmental integrity.

Additional study sites were selected on a second, non-urban, creek. Savigny Creek was selected to act as a control stream. The inclusion of a control stream, that is located beyond the urban boundaries, will serve as a reference point for establishing baseline conditions of an unaltered, non-urbanized creek in the area of Thunder Bay. Savigny Creek was chosen based on the proximity to Thunder Bay and ease of access. Savigny Creek is also the closest creek with similar characteristics as McVicar Creek. The length of Savigny Creek is around 13 km compared to 18 km of McVicar Creek. The average channel width is 3 m and McVicar Creek's average channel width is 2.5 - 3 m long.

**3.2 Study Sites**

By incorporating study sites within areas that capture both the urban and non-urban geography of McVicar Creek, as well as Savigny Creek, this study aims to provide a comprehensive assessment of the influence urbanization has on water temperature dynamics. The contrasting urban and non-urban locations create study sites with both extremes: an intensely urbanized area and an undeveloped remote area. The study sites are shown in Figures 3.1 and 3.2 below.

All study sites were chosen based on land cover and ease of access (Heck et al. 2018). The authors recommend picking areas of the stream where the stream is straight with no bends, as straight sections provide a more accurate representation of the stream's channel characteristics. They provide a clear, unobstructed view of the stream's flow, making it easier to observe and measure relevant physical and biological characteristics. Bends in a stream may complicate the data by introducing factors such as changes in flow direction and velocity. The study sites should also be at least 17 cm deep and should not contain slow-moving water. This gives the best representation of water temperature (Heck et al., 2018).

During the month of May 2023, a stream assessment was conducted to choose the specific study sites. The stream assessment consisted of recording the characteristics of the environment at each given study site. Several variables were recorded to help provide a comprehensive picture of each study site to ensure that all relevant factors are considered when interpreting the results of the study. The location of each study site was documented with GPS coordinates, topographic maps, and aerial photographs. Physical characteristics such as topography, hydrology, vegetation types, percentage of shading over the creek, human land use, and infrastructure were recorded at each site. Four study sites were chosen within the city of Thunder Bay, four outside the urban area, and another four along the control creek.

As highlighted in Chapter 2, riparian vegetation significantly affects water temperature. The selection of study sites also considered this factor to control for variations in riparian vegetation and its impact on water temperature across different sites. There are an equal number of study sites with high canopy cover and low canopy cover. The study sites are grouped into four categories: undeveloped sites with high canopy cover, undeveloped sites with low canopy cover, developed sites with high canopy cover, and developed sites with low canopy cover. The procedure for defining high and low canopy cover was referenced from the Ontario Stream Assessment Protocol (OSAP) (Stanfield, 2010). OSAP procedure is to calculate the percent of tree canopy that is shading the stream of the study area. This is done through a visual estimate and categorizing the study sites as more than 60% or less than 60% of shade produced by tree canopies. If the study site has 60% shading from trees, it is classified as a high canopy cover study site and if the shading is below 60%, it is classified as a low canopy cover study site (Stanfield, 2010).

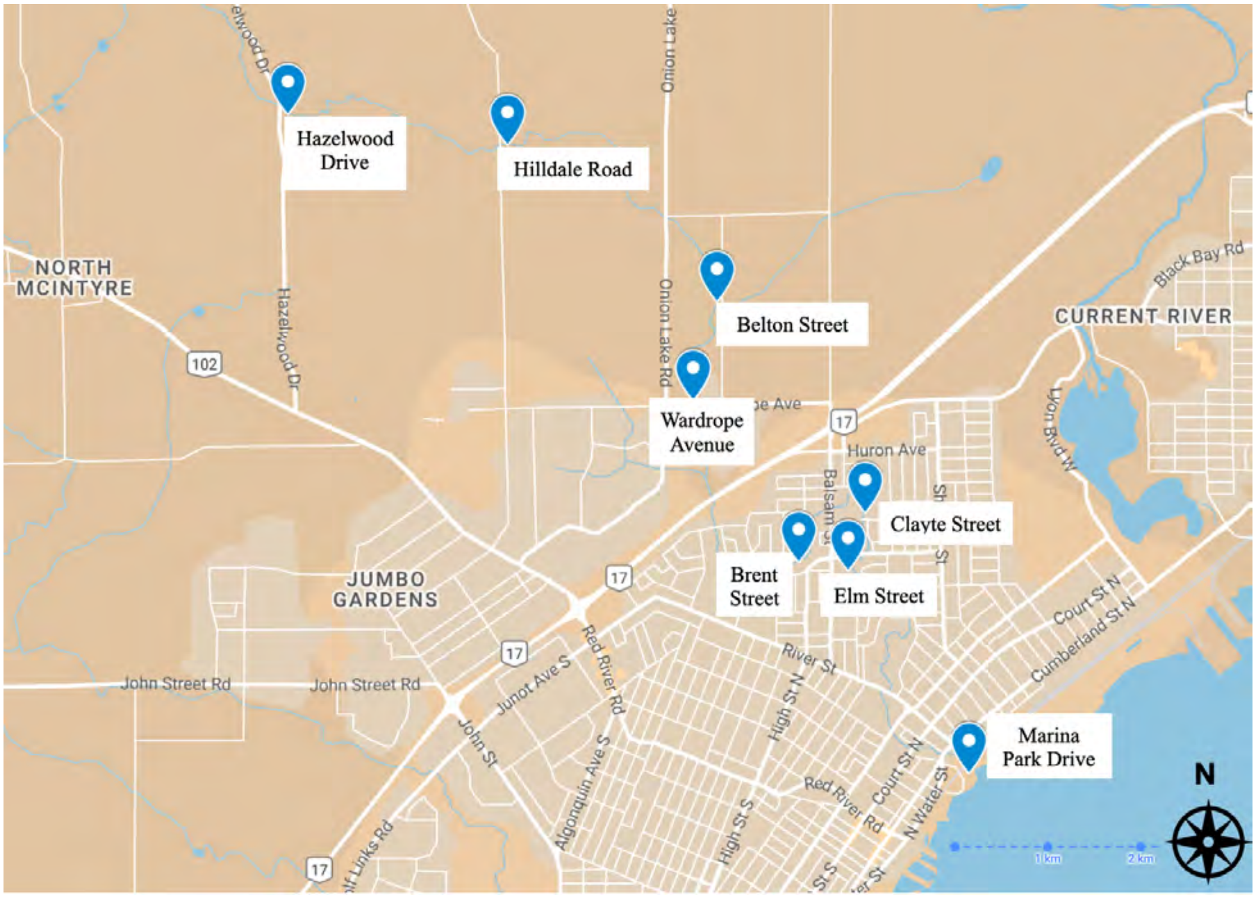


Figure 3.1 Location of Study Sites on McVicar Creek


Figure 3.2 Location of Study Sites on Savigny Creek

**Marina Park**

Marina Park Drive (Figure 3.3) is the first study site. It is located at the end of McVicar Creek where the outlet reaches Lake Superior at the coordinates 48°26'21"N 89°12’42” W. This is an industrial area with the largest amount of impervious surfaces compared to the other study sites. There are multiple bridges that cross the stream in this area, including a railroad track. There are also multiple culverts. The stream width during the summer months is 7.6 m and the stream depth is 7 cm. There is little to no canopy cover and very little riparian vegetation, consisting of small shrubs and grasses. This location represents a developed site with low canopy cover.

Figure 3.3 Marina Park Drive Study Site

**Brent Street**

Brent Street site (Figure 3.4) is in the middle of the city at the coordinates 48°27'10"N 89°13’45” W. This is a residential area with a large area of impervious surface cover. This consists of roads on both sides of the creek and a paved walkway with a bridge to cross the creek. The stream width during the summer months is 6.2 m and the stream depth is 8 cm. There is a high canopy cover at this location as there are larger trees that shade the creek. There is around 14.5 m of riparian vegetation from the stream bed to the start of the roads on both sides. This riparian vegetation consists of mainly grass with some small shrubs. This location represents a developed site with high canopy cover.

Figure 3.4 Brent Street Study Site

**Elm Street**

Elm Street site (Figure 3.5) is located in the middle of the city at the coordinates 48°27'11"N 89°13’20” W. This is a residential area with a large amount of impervious surface cover and a large culvert that the creek runs through. This area of the creek meanders through backyards and therefore has less impervious surfaces close to the creek compared to the other three study sites within the city. The stream width during the summer months is 5.5 m and the stream depth is 7 cm. This location has the highest amount of canopy cover compared to the other city study sites. There is an abundance of large trees and there are 11 m of riparian vegetation between the creek and the road. This location represents a developed site with high canopy cover.

Figure 3.5 Elm Street Study Site

**Clayte Street**

Clayte Street (Figure 3.6) is the last study site located within the city. The coordinates for this site are 48°27'20"N 89°13’22” W. This is a residential area with a large amount of impervious surface cover. This consists of roads on both sides of the creek and a paved walkway with a bridge to cross the creek. There is a rain garden at this study site that was created 2 m from the creek in between the paved pathways. The stream width during the summer months is 5.5 m and the stream depth is 8 cm. There are very few large trees in this area providing very little shade and only 2.5 m of riparian vegetation between the creek and the paved pathways. The vegetation consists mainly of tall grasses. This location represents a developed site with low canopy cover.

Figure 3.6 Clayte Street Study Site

**Belton Street**

Belton Street site (Figure 3.7) is located outside of the city at the coordinates 48°28'15"N 89°14’12" W. This site is largely undeveloped where McVicar Creek flows through a meadow. There is some impervious surface cover as there is a road and a culvert next to the study site. The stream width during the summer months is 3 m and the stream depth is 12 cm. There are no trees at this location. This site does have a lot of riparian vegetation, only consisting of tall grasses. This location represents an undeveloped site with low canopy cover.

Figure 3.7 Belton Street Study Site

**Wardrope Avenue**

Wardrope Avenue site (Figure 3.8) is located outside of the city at the coordinates 48°27'47"N 89°14’22” W. This site is mostly undeveloped but is the non-urban study site that is closest to the city and beside a residential area. There is some impervious surface cover consisting of a road and a large culvert. The stream width during the summer months is 2.5 m and the stream depth is 23 cm. This site has a lot of riparian vegetation and has a few more trees and shrubs compared to Belton Street. This location represents an undeveloped site with high canopy cover.

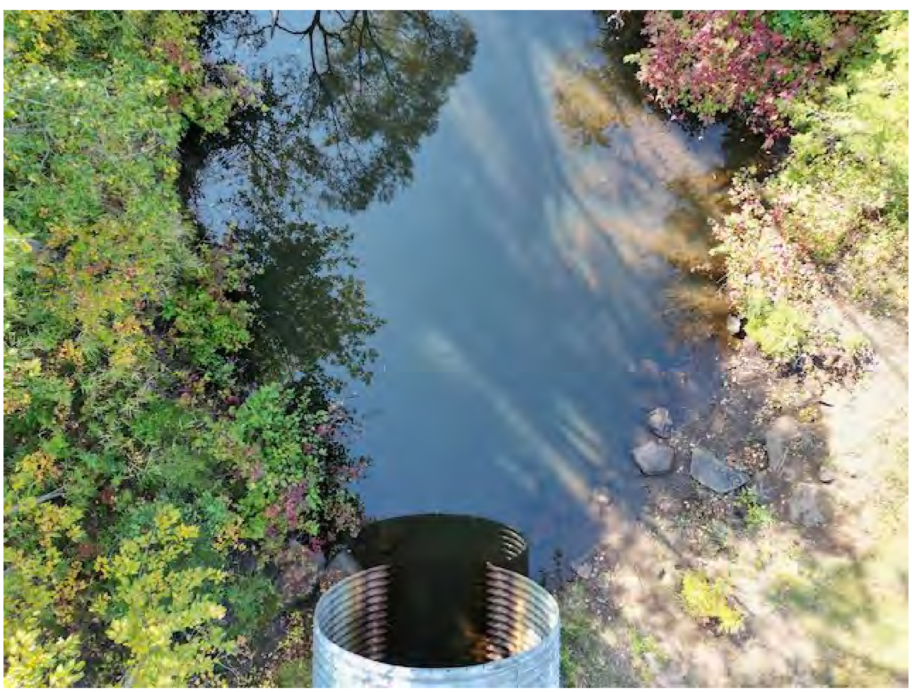

Figure 3.8 Wardrope Avenue Study Site

**Hilldale Road**

Hilldale Road site (Figure 3.9) is located outside of the city at the coordinates 48°28'51"N 89°15’32” W. This site is largely undeveloped except for a culvert where the road crosses the creek. The stream width during the summer months is 3.5 m and the stream depth is 12 cm. This study site is undisturbed and has an abundance of large trees and riparian vegetation. This location represents an undeveloped site with high canopy cover.

Figure 3.9 Hilldale Road Study Site

**Hazelwood Drive**

Hazelwood Drive (Figure 3.10) is the study site for McVicar Creek which is the furthest outside of the city. The coordinates are 48°29'00"N 89°16’51” W. This site is largely undeveloped with the exception of a culvert where the road crosses the creek. The stream width during the summer months is 4.5 m and the stream depth is 32 cm. This study site is undisturbed and has an abundance of large trees and riparian vegetation. This location represents an undeveloped site with low canopy cover.

Figure 3.10 Hazelwood Drive Study Site

**Copenhagen Road**

Copenhagen Road (Figure 3.11) is the first study site along Savigny Creek, the control stream. This creek is located in the municipal township of Shuniah, directly bordering the city of Thunder Bay to the north-east. The creek is 10 minutes east of the city and flows into the Current River. This study site is located at the coordinates 48°29’15"N 89°10’55” W. It is in an undeveloped area with an abundance of large trees and riparian vegetation. The stream width during the summer months is 2.5 m and the stream depth is 13 cm. This location represents an undeveloped site with low canopy cover.

Figure 3.11 Copenhagen Road Study Site

**Trowbridge Road**

Trowbridge Road (Figure 3.12) is located at 48°29'58"N 89°10’04” W. This study site is in an undeveloped area with an abundance of large trees and riparian vegetation. The stream width during the summer months is 2.5 m and the stream depth is 20 cm. This location represents an undeveloped site with high canopy cover.

Figure 3.12 Trowbridge Road Study Site

**Mount Baldy**

Mount Baldy Road (Figure 3.13) is located at 48°31'12"N 89°08’37" W. This study site is in an undeveloped area with an abundance of large trees and riparian vegetation. The stream width during the summer months is 2.5 m and the stream depth is 9 cm. This location represents an undeveloped site with high canopy cover.

Figure 3.13 Mount Baldy Road Study Site

**Road 527**

Road 527 (Figure 3.14) is located at 48°30'19"N 89°09’11" W. This study site is in an undeveloped area with an abundance of large trees and riparian vegetation. The stream width during the summer months is 2 m and the stream depth is 13 cm. This location represents an undeveloped site with low canopy cover.

Figure 3.14 Road 527 Study Site

### 3.3 Data Collection Apparatus and Procedure

A handheld thermometer was chosen to record the water temperature at each of the study sites. Data collection was conducted on McVicar Creek and Savigny Creek from June 14, 2023, until October 29, 2023. Water and air temperature were measured at each study site three times a week. On each data collection day, the fieldwork commenced promptly at 12:00 p.m. at Copenhagen Road. After the completion of each reading, a consistent route was followed to travel to the next study site on each data collection day to ensure uniformity in the time of day when measurements were taken. The route takes three hours and goes as follows: Copenhagen Road, Trowbridge Road, Mount Baldy Road, Road 527, Hazelwood Drive, Hilldale Road, Wardrope Avenue, Belton Street, Clayte Street, Elm Street, Brent Street, Marina Park Drive.

#### 3.3.1 Water Temperature

The data collection procedure adhered to the guidelines outlined in OSAP and was carried out in the same manner at each individual study site. On each data collection day, the following parameters were measured: water temperature and air temperature. The apparatus used to measure both parameters was a handheld thermometer. To ensure accuracy, the thermometer underwent regular calibration and quality control checks were performed before each use at each study site. This was done by placing the thermometer in ice-cold water, waiting 1 minute, then checking to make sure the thermometer read 0 °C. A visual inspection of the thermometer was also taken to ensure there was no damage to the thermometer. To obtain the stream water temperature, the thermometer was placed in the main flow of the stream. Measurements were not taken in deep pools to avoid sources of groundwater upwellings. The thermometer was placed 8 cm below the surface level for 1 minute. Water temperature was recorded to the nearest half-degree. Upon returning from the field each day, data was copied onto an Excel spreadsheet. This follows the guidelines outlined in OSAP (Stanfield, 2010).

### 3.3.2 Air Temperature

Air temperature was taken directly following the water temperature reading with the same calibrated thermometer. To ensure accuracy, the thermometer was dried after each water temperature reading using a towel. The reading was also taken after the thermometer had been in a shaded area for 1 minute. The shaded area minimized any direct exposure to sunlight that could alter the reading of the ambient air temperature. The air temperature was also recorded to the nearest half-degree Celsius. Upon returning from the field each day, data was copied onto an Excel spreadsheet. A comprehensive data validation process was also done after each field day by cross-referencing the data with external sources. A nearby weather station, located at the Thunder Bay Airport, was used for this process. Upon completion of the fieldwork, all the data for both air and water temperature were merged to create continuous data files for analysis. The data sets were checked on multiple occasions for erroneous readings and for any errors that could have occurred during the data collection process.

### 3.3.3 Riparian Vegetation

Stream health parameters were tested during a single session within the data collection period. Riparian vegetation, stream width, and stream depth were measured at each study site to help account for the overall stream health of McVicar Creek. The riparian vegetation was an important variable to measure as the amount of vegetation near a creek can have a major impact on the temperature of the water. The riparian vegetation was measured during the month of

August as this was an ideal time based on the growth cycle of plants. August represents the peak of the growing season for the climate of Thunder Bay, making it an ideal period to capture the full extent of riparian vegetation. Photographs of each study site were taken with a drone to measure the habitat parameters. The drone created aerial photographs and efficiently captured high-resolution images of the entire study site displayed in Figures 3.3 - 3.14. These images were then analyzed using the habitat assessment protocol provided by the *Rapid Bio-assessment Protocols for Use in Wadeable Streams and Rivers*. Habitat quality characteristics from the U.S. Environmental Protection Agency's Rapid Bioassessment Techniques were also a part of the assessment to gain a deeper understanding of the health of each individual study site (Barbour et al., 1999).

A visual based habitat assesment is defined by Barbour et al. (1999) as the evaluation of the physical habitat surrounding a watershed that influences the quality of the water and the aquatic community. Barbour et al. created habitat parameters, such as bank structure and riparian vegetation, to provide a stream classification system that places streams into distinct groups. The stream classification emphasizes specific areas requiring restorative interventions to preserve the overall ecosystem health of the watercourse (Barbour et al., 1999). The riparian vegetation was measured in the riparian zone, which is composed of the floodplain and the channel of the creek. The rating of each study site is based on all material presented on or above the stream bank. This includes the vegetation that offers stream bank protection from solar radiation, erosion, and the vegetation that provides an escape cover or resting security for aquatic species. The riparian vegetation and habitat of the creek were assessed using five qualitative parameters. The habitat parameters that were evaluated were epifaunal substrate/available cover, pool substrate characterization, bank stability, vegetation protection, and riparian vegetation zone width. Each parameter is rated on a scale from 0 to 20 with 20 being the optimal conditions for a creek to thrive in and 0 being poor conditions where the health of a creek is unable to survive. In the case of riparian zone width rating, a study site with 18 m or more of vegetation surrounding the creek would receive the highest scores, falling within the range of 16 to 20. Conversely, a rating of 0 to 5 corresponds to study sites with less than 6 m of vegetation around the creek. Riparian vegetation has one of the largest influences on water temperature within a watershed. If water temperatures are rising within the city, the lack of riparian vegetation could be the contributing factor. The integration of these habitat assessments with the temperature readings will contribute to a holistic analysis of the creek ecosystem.

### 3.3.4 Stream Width and Depth

Stream width and depth were recorded during the month of August. The measurements were taken in August since this is late summer for the city of Thunder Bay. At this time of year, the stream flow is relatively stable, and water levels have fewer fluctuations. August also has lower precipitation levels, reducing the likelihood of sudden changes in streamflow due to rainfall events. These measurements were recorded at each study site and followed the guidelines outlined in OSAP to ensure consistency and reliability of the measurements. Stream width is defined as the horizontal distance from one shoreline to the parallel shoreline along the existing water surface (Stanfield, 2010). A tape measure was stretched across the stream to measure the width to the nearest 0.1 m. Stream depth was recorded at each observation point. The same tape measure was used to record the distance from the surface of the water to the floor of the stream. The tape measure was placed on the stream bottom and the depth was recorded to the nearest 0.1

cm. These stream characteristics, in conjunction with the temperature data, contribute to a comprehensive understanding of the McVicar Creek ecosystem and its responses to urbanization.

### 3.4 Surface Analysis

Surface analysis was conducted using the software program Quantum Geographic Information System (QGIS). Geospatial information was used to map the impervious surfaces and pervious surfaces that are located within the McVicar Creek watershed. Six layers were used in QGIS to create the maps. The riparian vegetation layer was obtained from Google Earth. The buildings and sidewalks layer were obtained from the City of Thunder Bay. The Ontario Roads Network layer was obtained from the Ontario Ministry of Natural Resources and Forestry. The digital elevation model layer and the Ontario Hydrology Network were obtained from the Mapping and Information Resources Branch. The dataset was used to create a map of the impervious surface cover as well as the pervious surface cover and analyzed to identify the land use differences between the urban and the non-urban areas of McVicar Creek. The maps were created for four selected study sites: Marina Park Drive, Clayte Street, Wardrope Avenue, and Hazelwood Drive. These study sites were chosen as they best represent the land use for both the urban area and the non-urban area of the watershed. A map was also created for one study site along Savigny Creek, Mount Baldy Road, to show the impervious and previous surface cover of the control stream. The maps were used to calculate the percentage of the impervious surfaces at each study site. To calculate the percentage, a 500 m buffer zone was created around each study site. There are limited guidelines regarding the size of a buffer zone so 500 m was chosen based on the recommendations from Labib et al. (2020). The 500 m buffer is large enough to capture the immediate land use characteristics influencing stream temperature while remaining specific to the local conditions around each site. Figures 3.15 – 3.19 show the buffer zones for each study site used in this analysis. The total area of impervious surfaces was divided by the total area of the buffer zones to calculate the percentage of impervious surfaces. For the pervious surfaces, Lind et al. (2019) concluded that a minimum of 30 m of riparian vegetation is needed to protect the ecosystem of a stream. Kiffney et al. (2003) also suggest a 30 m riparian zone to ensure sufficient stream temperatures. Based on this literature, a 30 m buffer zone was chosen to measure the riparian vegetation surrounding McVicar Creek. A 50 m buffer zone was also included to show above optimal conditions for the riparian zone of a stream. The areas of the stream that had a 30 m riparian zone and a 50 m riparian zone were measured to calculate the percentage of stream that has sufficient riparian cover within the 500 m buffer zones. These site-specific maps provided detailed insights into the differences in impervious and pervious surfaces between the urban and non-urban areas. The surface analysis provides a visual representation of the spatial variation in land use across the watershed.

Marina Park Drive

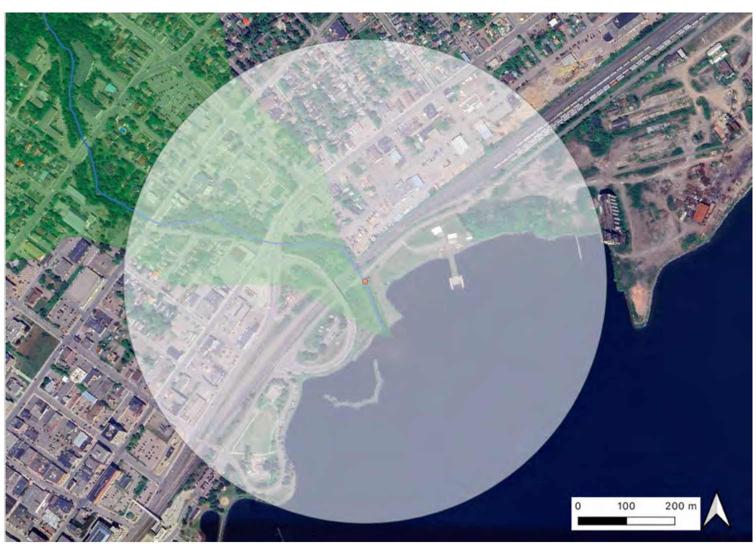


Figure 3.15 Buffer Zone for Marina Park Drive Study Site

Clayte Street

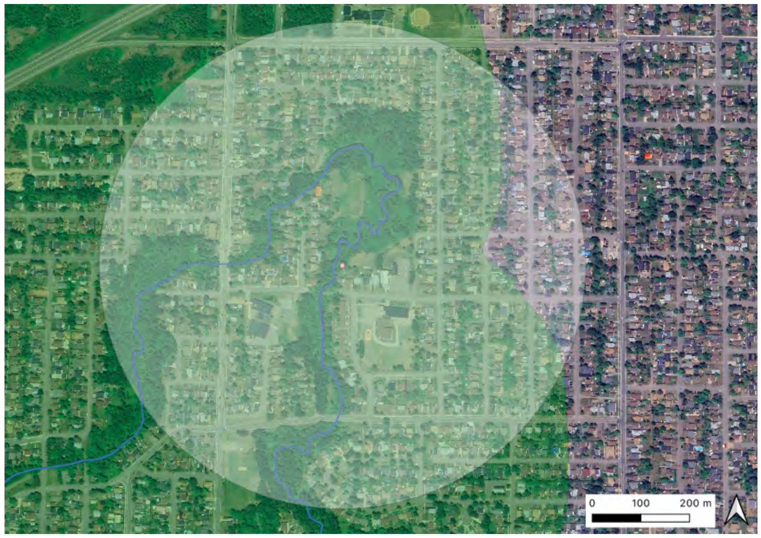


Figure 3.16 Buffer Zone for Clayte Street Study Site

Wardrope Avenue

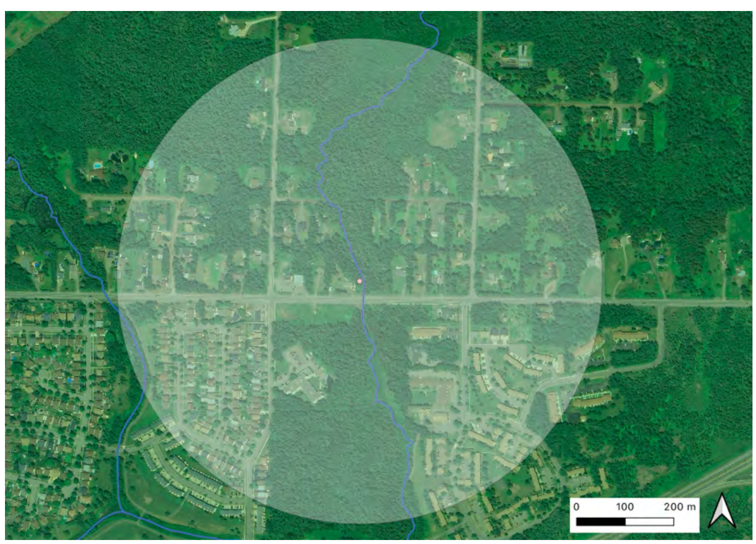


Figure 3.17 Buffer Zone for Wardrope Avenue Study Site

Hazelwood Drive

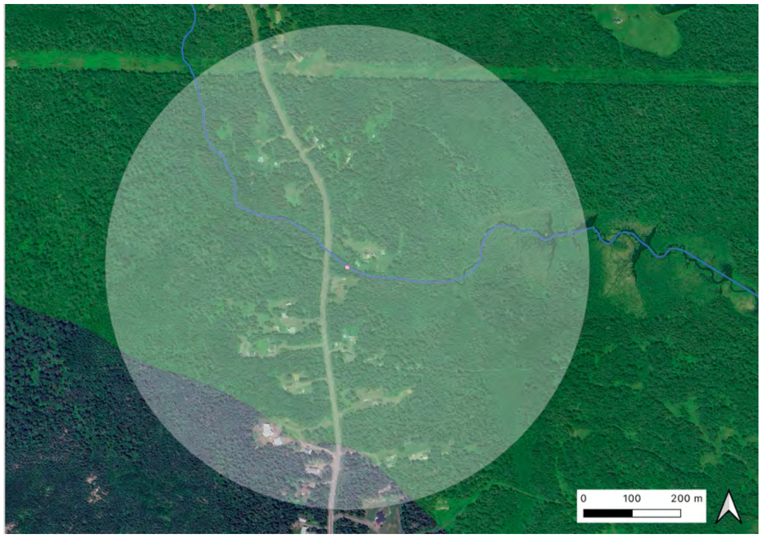


Figure 3.18 Buffer Zone for Hazelwood Drive Study Site

Mount Baldy Road

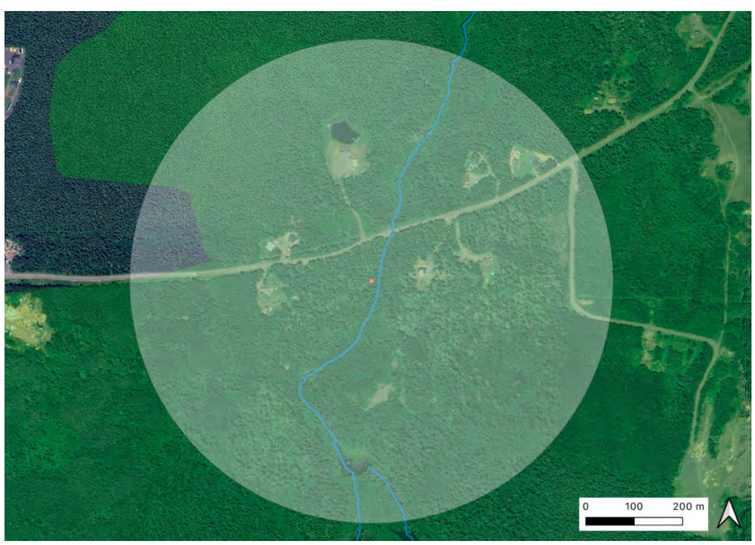


Figure 3.19 Buffer Zone for Mount Baldy Road Study Site

### 3.5 Statistical Analysis

After the data collection period, statistical analysis was performed on the data using the Statistical Package for the Social Sciences (SPSS) software program and Microsoft Excel 2021. Descriptive statistics were applied for each study site and included the maximum, minimum, mean, and standard variation. The descriptive statistics were used to determine the differences between the overall water temperature between study sites. Graphs were used to visually represent this data. A one-sample t-test was conducted to understand the differences in thermal dynamics between the study sites. Given the observed disparities in water temperatures among the study sites, a Tukey's post hoc test was conducted. This test aimed to precisely identify the study sites exhibiting the most significant differences in water temperature. Histograms were used following this test to visually represent the distribution of temperature data across the various sites. Lastly, line graphs were used to illustrate the water temperature data in relation to the distance from the creek outlet. These graphs were also utilized to represent stream width and stream depth measurements.

# Chapter Four

# RESULTS

The purpose of this research was to understand the impacts of urbanization from the city of Thunder Bay on McVicar Creek. The objectives were to demonstrate the differences in water temperatures, as well as other factors, of the urban area of McVicar Creek to the non-urban area of McVicar Creek. This will help to establish a baseline analysis of water temperatures rising in the urban areas of the watershed which can overall diminish the water quality and the ecosystem of McVicar Creek. The data used in this analysis includes air temperature readings, water temperature readings, stream width readings, stream depth readings, riparian vegetation ratings, impervious surface analysis and pervious surface analysis. The fieldwork for collecting this data was done over five months between June 2023 and October 2023.

## 4.1 Air Temperature

Air temperature data was collected to reveal variations in air temperature across distinct study sites. Figure 4.1 below shows the average of all the study sites within the urban area of McVicar Creek, the non-urban area of McVicar Creek, and the control stream. The average was calculated by adding up the daily temperature measurements from the four study sites within each section and then dividing by four, providing a daily average air temperature for the urban area of McVicar, the non-urban area of McVicar, and the control stream. The urban study sites are represented by the blue line on the graph and reveal the highest air temperatures over the five-month period. The control stream, situated in an area unaffected by urbanization, displays lower air temperatures compared to the urban sites. The non-urban study sites exhibit moderate

### 4.6 Impervious Surface Cover

Surface analysis was conducted using QGIS. Figures 4.15 - 4.19 show the impervious surface cover of four study sites along McVicar Creek and one study site along Savigny Creek. Figure 4.15 shows the Marina Park study site, where most of the land cover consists of buildings and parking lots. The figure also highlights the proximity of these impervious surfaces to the creek. The Clayte Street study site (Figure 4.16) shows a large portion of the land cover is a residential area. The study sites located in the non-urban area, Wardrope Avenue (Figure 4.17), Hazelwood Drive (Figure 4.18), and Mount Baldy Road (Figure 4.19), show larger areas of green space and have much less impervious surfaces.

| Legend | |
|---|---|
| **Red dot** | Study site location |
| **Blue line** | Creek |
| **Green shaded area** | Watershed boundaries |
| **Black lines** | Roads |
| **White rectangles** | Buildings |
| **Grey rectangles** | Parking lots |

Marina Park


Figure 4.15 Impervious Surface Cover of Marina Park Urban Study Site

Clayte Street

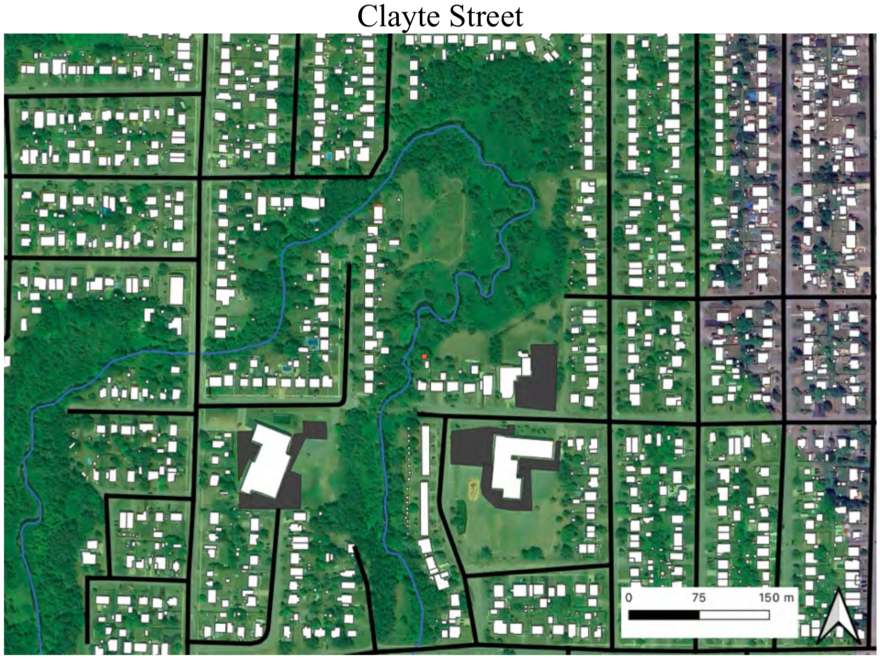


Figure 4.16 Impervious Surface Cover of Clayte Street Urban Study Site

Wardrope Avenue

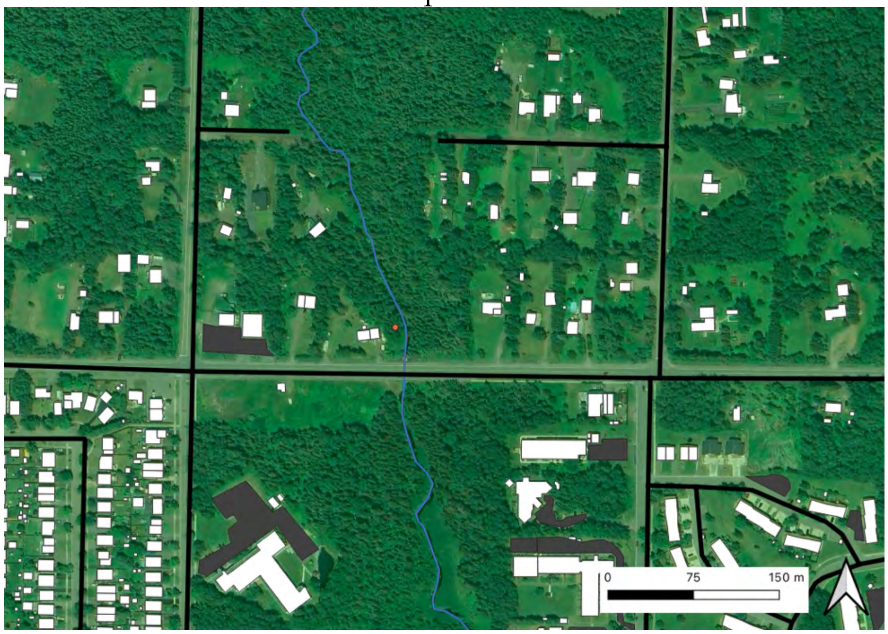


Figure 4.17 Impervious Surface Cover of Wardrope Avenue Non-Urban Study Site

Hazelwood Drive

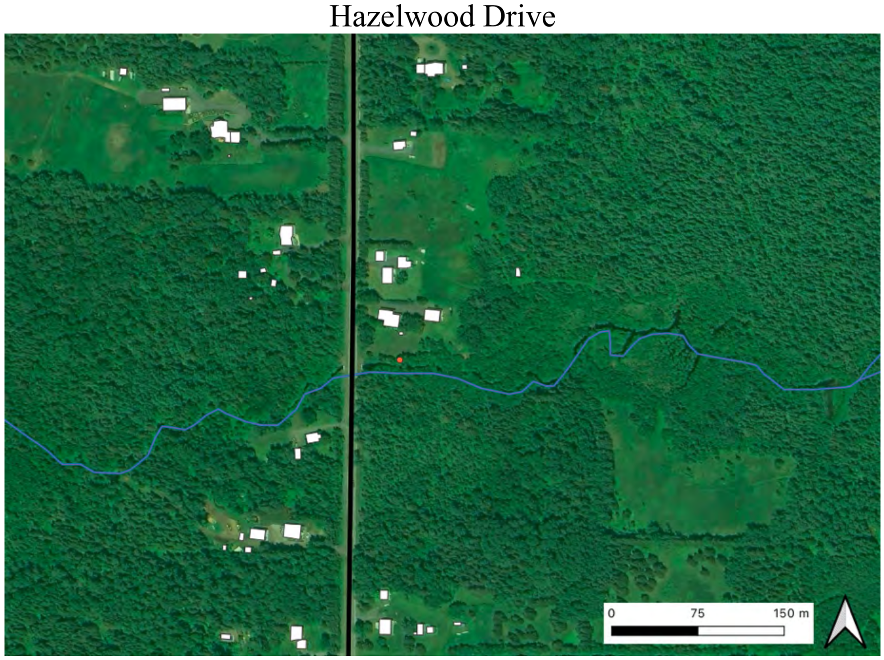


Figure 4.18 Impervious Surface Cover of Hazelwood Drive Non-Urban Study Site

Mount Baldy Road

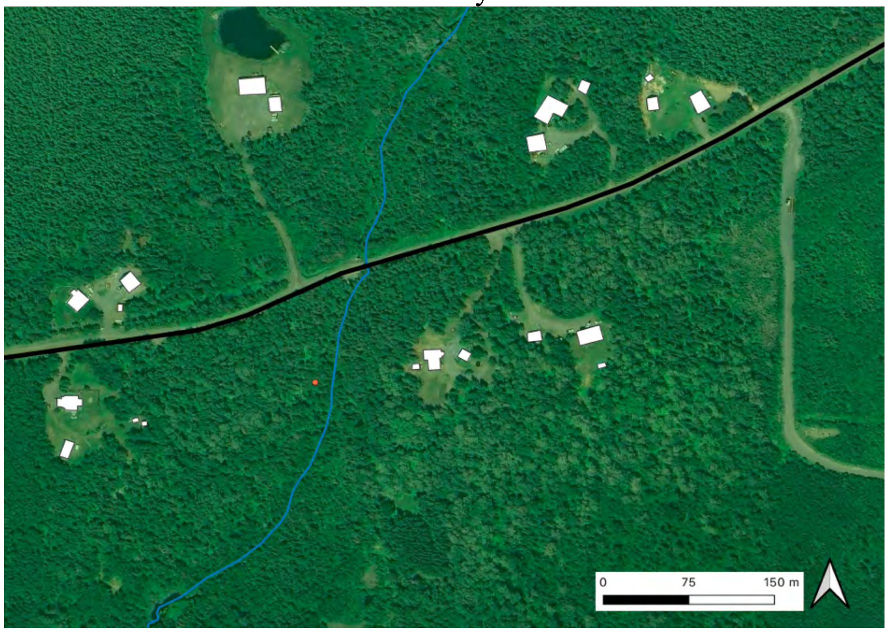


Figure 4.19 Impervious Surface Cover of Savigny Creek Non-Urban Study Site

| Study Site | Total Area ($m^2$) | Impervious Area ($m^2$) | Impervious (%) |
|---|---|---|---|
| **Marina Park (Urban)** | 784702 | 242164 | 31 |
| **Clayte Street (Urban)** | 784698 | 218180 | 28 |
| **Wardrope Avenue (Non-Urban)** | 784690 | 123131 | 16 |
| **Hazelwood Drive (Non-Urban)** | 784671 | 14275 | 2 |
| **Savigny Creek Mount Baldy (Control)** | 785413 | 12914 | 1.5 |

Table 4.6 Impervious Surface Area Percentage

Table 4.6 shows the total area of the buffer zone, how much of the area is covered with impervious surfaces, and the percentage of impervious surfaces in that area. The Marina Park study site (Figure 4.15) has the largest percentage of impervious surfaces with 31% impervious surfaces surrounding the study site. These impervious surfaces comprise commercial and industrial land uses, along with some residential areas. Additionally, a significant portion of the area is dedicated to transportation infrastructure, including roads, recreational trails, and railways. The other urban study site, Clayte Street in Figure 4.16, has 27.8% impervious surfaces. Within the area of this study site, there are two land use types: residential and transportation. The non-urban Wardrope Avenue site in Figure 4.17 also contains a large percentage of impervious surfaces when compared to Hazelwood Drive (Figure 4.18). Wardrope Avenue is similar to Clayte Street as residential and transportation are the primary land uses. With Wardrope Avenue being outside of the city, it has 44% less impervious surfaces compared to Clayte Street.

The Hazelwood Drive study site is the furthest away from the city and has the least amount of impervious surfaces along McVicar Creek. This area includes one road and a few residential lots. With 2% of the area having impervious surfaces, this is 93% less than Marina Park Drive. The Mount Baldy Study Site along Savigny Creek in Figure 4.19 has similar presence of impervious surfaces to Hazelwood. This study site has 1.5% impervious surfaces whereas Hazelwood exhibited 2%. The urban study sites exhibit significantly higher percentages of impervious surfaces when compared to the non-urban study sites.

### 4.7 Pervious Surface Cover

Figures 4.20 - 4.24 show the pervious surface cover of the same four study sites along McVicar Creek and the one study site along Savigny Creek. The orange lines outline the riparian buffer zone. Marina Park (Figure 4.20) shows very little riparian vegetation surrounding the creek. A very small portion of the riparian vegetation is reaching the minimum 30 m buffer zone. Clayte Street (Figure 4.21) and Wardrope Avenue (Figure 4.22) show much more vegetation compared to the Marina Park study site. Hazelwood Drive (Figure 4.23) and Mount Baldy Road (Figure 4.24) have the most extensive riparian buffer zones, with the majority of the creek being enclosed by a 50-meter buffer.

| Legend | |
|---|---|
| **Red dot** | Study site location |
| **Blue line** | Creek |
| **Yellow line beside creek** | 30 m buffer zone |
| **Second yellow line** | 50 m buffer zone |
| **Orange lines** | Riparian vegetation |

Marina Park

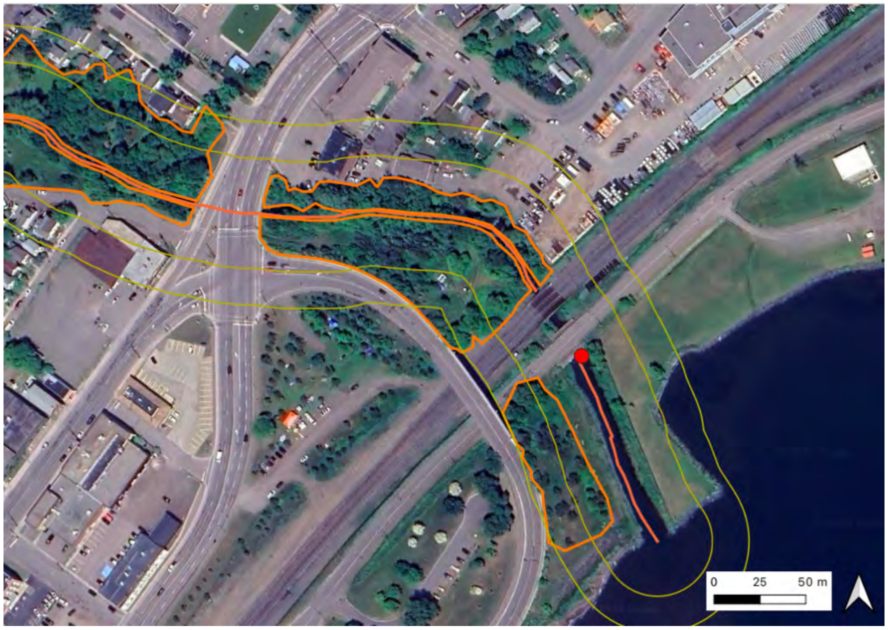


Figure 4.20 Pervious Surface Cover of Marina Park Urban Study Site

Clayte Street

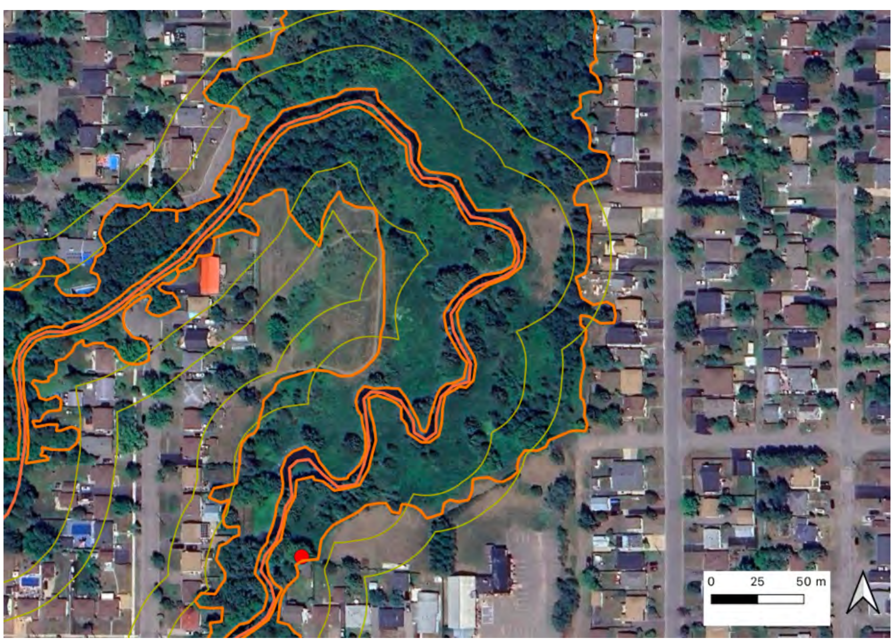


Figure 4.21 Pervious Surface Cover of Clayte Street Urban Study Site

Wardrope Avenue

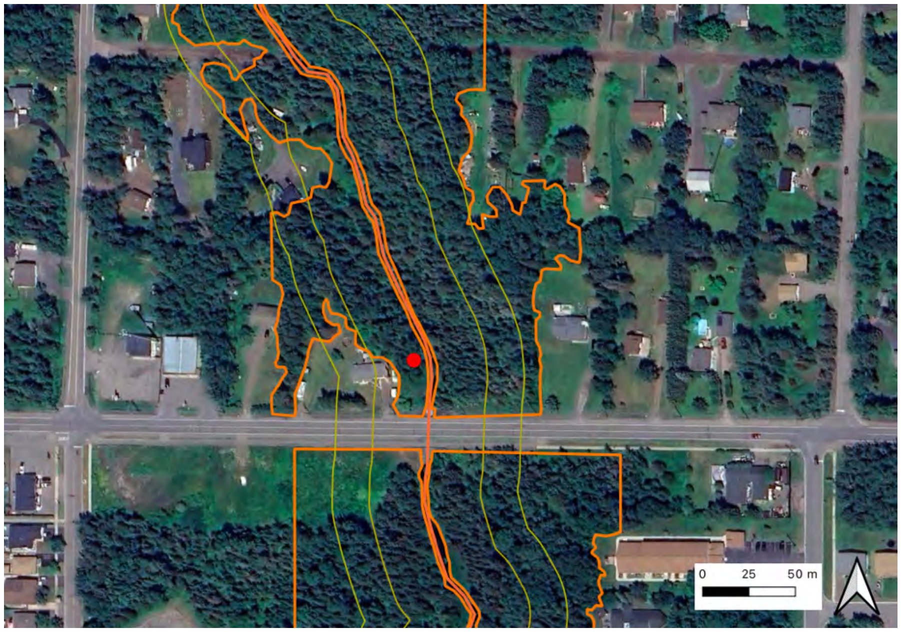


Figure 4.22 Pervious Surface Cover of Wardrope Avenue Non-Urban Study Site

Hazelwood Drive

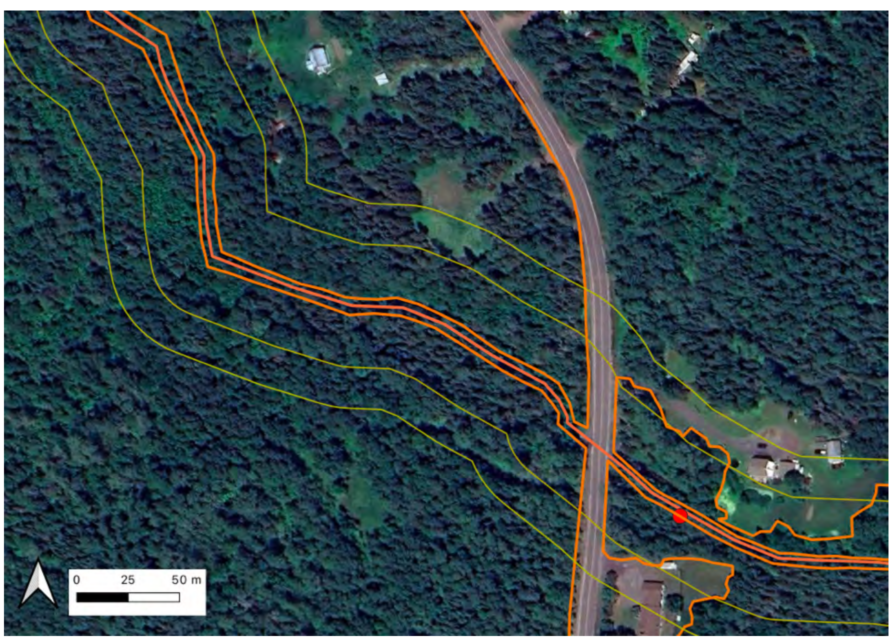


Figure 4.23 Pervious Surface Cover of Hazelwood Drive Non-Urban Study Site

Mount Baldy Road

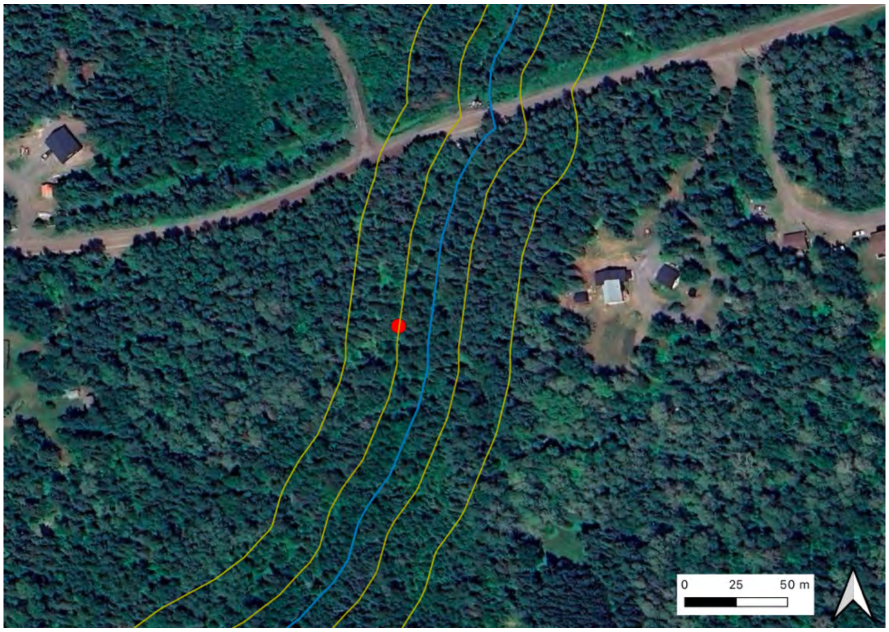

Figure 4.24 Pervious Surface Cover of Savigny Creek Non-Urban Study Site

| Study Site | Total Length of Stream (m) | 50 m Riparian Buffer (m) | 50 m Riparian Buffer (%) | 30 m Riparian Buffer (m) | 30 m Riparian Buffer (%) |
|---|---|---|---|---|---|
| Marina Park (Urban) | 640 | 0 | 0 | 0 | 0 |
| Clayte Street (Urban) | 1967 | 189 | 9 | 626 | 32 |
| Wardrope Avenue (Non-Urban) | 1229 | 478 | 38 | 934 | 76 |
| Hazelwood Drive (Non-Urban) | 1133 | 961 | 84 | 975 | 86 |
| Savigny Creek Mount Baldy (Control) | 1125 | 1115 | 99 | 1115 | 99 |

Table 4.7 Riparian Buffer Area Percentage

Table 4.7 shows the total length of the stream within the study site area, the length of that area that has a riparian buffer zone extending to at least 50 m and 30 m on both sides of the creek, and the percentage of riparian buffers. The study site Marina Park shows 0% of the creek that has a sufficient buffer zone. There are no areas within this section of the creek that reach the minimum standard for a riparian buffer zone. The other urban study site, Clayte Street, exhibits some areas with a 30 m riparian buffer zone but this only contributes to 32% of the total area. The areas of McVicar Creek that are outside of the city show much larger percentages of pervious surfaces. Wardrope Avenue has 76% of the study site area within the 30 m buffer zone and Hazelwood Drive has 86%. Hazelwood Drive exhibits 86% more previous surfaces compared to Marina Park Drive which shows how much more pervious surfaces are within the non-urban study sites. Savigny Creek has the largest riparian buffer with less than 1% of the study area covered with less than a 50 m riparian buffer. The only area within this study site that does exhibit a sufficient riparian buffer is where a road crosses the creek. Overall, Savigny Creek exemplifies the ideal range for a riparian buffer zone, effectively protecting the creek's water temperature.

# Chapter Five

# DISCUSSION

The overarching objective of this research was to gain a better understanding of how the environment of a stream may differ in an urban setting compared to a non-urban setting. The specific focus of this thesis centered on the thermal dynamics within highly urbanized ecosystems in contrast to those areas left undisturbed by human activities. Ultimately, the research conducted in this thesis shows that the urban segment of McVicar Creek exhibits elevated water temperatures compared to its rural equivalent. The results offer valuable insights into the deteriorating health of the creek influenced by prevalent urban practices.

## 5.1 Water Temperature and Brook Trout

Water temperature readings were taken in McVicar Creek and Savigny Creek to analyze any trends within the water temperatures. Water temperature plays a vital role in the health of a stream. If water temperatures are too high, it will start to deteriorate the health of the watershed and affect the species distribution as well as the community composition (Woznicki et al., 2016). The largest animal species found in McVicar Creek are brook trout (McVicar Creek Protection & Rehabilitation Plan, 2014). They are also the most populous species within this creek as they enter the creek from Lake Superior to spawn and reproduce. The stream temperature during the summer months of Thunder Bay is the most important single factor that influences the distribution of brook trout (Picard et al., 2003). McVicar Creek provides a suitable habitat for brook trout reproduction because of its cooler temperatures. The lower stream temperatures in the summer create an optimal thermal environment for these fish species (Picard et al., 2003).

Brook trout are widely distributed around the globe and are experiencing difficulties everywhere due to climate change (Kazyak et al., 2016). There have been widespread declines in the brook trout population due to our warming planet from human activities (Kazyak et al., 2016). Brook trout can only live in the coldest and cleanest waters, which makes them a universal indicator of water quality. The ecological health of McVicar Creek is significantly enhanced by the presence of brook trout. However, the health of the creek could be jeopardized if water temperatures continue in their upward trajectory. If the habitat conditions of McVicar Creek are negatively impacted, including the rise of water temperature, then the brook trout will be the first species to disappear (Stranko et al., 2008).

The statistics in Table 4.5 show the minimum, maximum, and average temperatures of McVicar Creek for all the study sites during the months of August, September, and October. These months are the most important for brook trout as this is when they swim up McVicar Creek to spawn and reproduce. The optimal temperature for brook trout survival and optimal spawning capacities is 9 °C (Behar, 1997). The month of August is the earliest time of year when brook trout will begin their journey to reproduce. The average water temperature within McVicar Creek at this time is 17.2 °C. A temperature difference of 8 degrees between the water temperature in August and the optimal temperature for this species could potentially prolong their spawning process. During the month of September, temperatures moderate to an average of 14.6 °C, moving closer to the optimal range for brook trout survival and reproduction. The month of October has an average of just above 9 °C which aligns with the preferred spawning conditions. The month of October also has the largest temperature variations. The beginning of the month had the warmest temperature recorded for October of 18.5 °C. By the end of the month, the water temperature drastically cooled off to a temperature of 4 °C. McVicar Creek also reached 0 °C by the last day of October and was completely frozen over by November 1. This rapid temperature shift poses challenges for brook trout, as the narrowing window of optimal temperatures coincides with the onset of freezing conditions in late October. The warmer temperatures are creating a limited timeframe for this species to spawn. This raises concerns about the reproductive success and long-term viability of brook trout populations in McVicar Creek.

**5.2 Air and Water Temperature in Relation to the Urban Heat Island Effect**

The results presented in the preceding section illuminate intriguing patterns in water temperatures across distinct study sites within the McVicar Creek watershed. In Figure 4.1, the urban study sites consistently exhibited higher air temperatures over the 5-month period. All study sites located within the city showed warmer air temperatures when compared to both the non-urban area of McVicar Creek and the control stream. These results could be influenced by the effects of urbanization on local climatic conditions. These results also share similar patterns to the body of research focusing on urban ambient temperatures.

Similarly, the water temperature exhibited congruent patterns to those observed in the air temperature. The water temperatures were continuously warmer within the urban study sites compared to the non-urban study sites. The Marina Park study site exhibited the most distinctive characteristics among the selected locations. Marina Park showed significant differences in air and water temperature. Water temperature readings for this study site were between 2 and 3 degrees warmer than any other study site. Figure 4.5 illustrates this outcome, with Marina Park standing out noticeably as an outlier in comparison to all other designated study sites along

McVicar Creek. During the 5-month data collection period, Marina Park continuously displayed a warmer temperature reading.

The remaining 3 study sites within the urban area along McVicar Creek similarly exhibited higher water temperatures when compared to the non-urban study sites, although with a less pronounced deviation than observed at Marina Park. Figure 4.7 shows the water temperature continuously increasing as the readings get closer to the mouth of the creek. This is the typical thermal behaviour for streams. Water temperature has consistently demonstrated an upward trend in various studies as it progresses downstream. While this represents the inherent trend, the existing body of literature indicates that water temperature is influenced by numerous interconnected factors, posing challenges in isolating and examining these variables independently (Poole & Berman, 2001). The literature suggests that even when studies conclude temperature changes downstream, these patterns often show interruptions or reversals because of alterations in the stream's local characteristics (Poole & Berman, 2001).

Typically, in a non-urban stream, water temperature increases along the downstream gradient. Watersheds increase in temperature as water flows downstream from the exposure of solar radiation along the surface water (Ham et al., 2006). Although it is common for streams to experience a temperature increase as they approach the mouth of the watershed, most studies indicate that this warming tends to occur at a gradual pace and is less prominent in smaller streams (Moore & Miner, 1997). McVicar Creek is considered a smaller stream and showed larger temperature variations downstream compared to the control stream used in this research. Figure 4.7 shows the urban study sites along McVicar Creek to have a 4 °C temperature change whereas the non-urban study sites exhibited 0.5 °C temperature change. The control stream exhibited 1.5 °C temperature change. Furthermore, there was a 5.5 °C temperature difference between the study sites closest to the mouth of the creek, Marina Park, and the study site farthest outside of the city, Hazelwood. The temperature patterns in McVicar Creek diverge from the typical gradual warming seen in larger streams. The marked temperature variations downstream, within the city study sites, emphasize the distinct thermal dynamics of this urbanized creek.

Nelson and Palmer (2007) have found air temperature to be the most important factor in changes to stream temperature. When the average air temperature is raised within a city due to human land use it can increase water temperatures within urban streams (Nelson & Palmer, 2007). The larger temperature fluctuations within the urbanized areas of the creek, especially when compared to the non-urban areas of the creek, potentially underscore the influence the urban heat island effect is having on McVicar Creek. In the non-urban study sites and the control stream, the observed temperature variations are relatively minimal, indicating a more stable thermal environment. The pronounced temperature fluctuations observed in the city study sites on the graph may indicate that multiple factors are influencing water temperature.

**5.3 Factors Influencing Water Temperature**

The observed rise in water temperature within the urban study sites prompts a closer examination of the contributing factors that potentially lead to warmer water temperatures in this urban environment. Urbanization alters the natural characteristics of watersheds which can lead to warmer water temperatures. The complications of urbanization, increasing impervious surfaces and reducing soil infiltration, cause more high-flow events and increase the total flow (Cheng et al., 2020). The decreased amount of vegetation in an urban area also affects the annual water yield of a watershed. This all plays a role in altering the natural course of a waterway (Cheng et al., 2020).

In the context of McVicar Creek, the stream bed is composed of the Precambrian shield in the non-urban areas of the creek and Sibley Group sedimentary rock closer to the outlet of the creek (Lakehead Region Conservation Authority, 1995). This makes McVicar Creek a bedrock stream predicting it to follow the typical bedrock erosion rates. The erosion rates for bedrock streams are low and it is very rare to observe erosion within this type of watershed (Turowski & Cook, 2016). Turowski & Cook (2016) suggests that the average erosion rate for bedrock is below 1 mm every year. Since McVicar Creek is a bedrock stream, there should be very little changes in the width of the stream. The control stream demonstrates this in Figure 4.8. McVicar Creek displays a large variation in streambank widths at each study site. The study sites within the city are wider compared to the study sites outside of the city. On average, the urban study sites are 6.2 m and the non-urban study sites are 3.4 m. There is almost a 3 m difference between these study sites. The significant increase in stream width along McVicar Creek is a natural occurrence; however, the excessive widening may be influenced by the impacts of urbanization. Urbanization leads to an increase in impermeable surfaces, causing rainfall to become runoff rather than be absorbed by the soil. Urbanization causes channelization within urban watersheds, which occurs when the stream channel is modified or straightened to accommodate the city. Urbanization also increases the amount of surface drains and sewers which causes water to flow more rapidly into the watershed. All of these factors leave the stream channel unstable and more susceptible to erosion which widens the watercourse (Nabegu, 2014).

The greater the channel width, the greater the surface area for the exchange of heat through evaporation, radiation, and convection (LeBlanc et al., 1997). The literature review explains this trend through the term ‘urban-induced channel changes. ’Krause et al. (2004) showed that channel widening will increase the solar input and elevate the water temperature.

The measured stream exhibited a 0.9 °C increase in mean daily water temperature following the widening of the stream. Pluhowski (1970) also found that the widening of a stream can increase the average stream temperature in the summer by 5 to 8 °C. This could explain why the area of McVicar Creek within the city exhibits warmer water temperatures compared to the non-urban areas.

Warmer water temperatures within urban watersheds can be attributed to changes in the channel morphology. This can also include the depth of a stream. Figure 4.9 shows the depths of each study site on McVicar Creek. McVicar Creek displays a large variation in stream depth, with the city study sites exhibiting much shallower depths. The urban study sites had an average depth of 8 cm and the non-urban study sites had an average depth of 20 cm. The difference in water depths between the non-urban and urban areas averages 12 cm. The 4 study sites located within the city, exhibit drastically shallower depths compared to both the non-urban study sites and the control stream. Similar to the stream width results, this is a common phenomenon to occur when urban development is present.

The urban study sites along McVicar Creek are extremely vulnerable from disturbances to the landscapes that surround it. Urban development has been shown to change the geomorphology of streams, including the depth of a stream. Urbanization has altered the amount of vegetation that surrounds the creek. This creates more exposed soil along the stream banks and increases the amount of channel erosion (Chin, 2006). As shown by Whipple and DiLouie (1981), the increased frequency of eroding banks will increase the amount of sediment that lands in a stream, overall causing the transport capacity of the stream to exceed its actual sediment supply. This phenomenon tends to continue to erode the banks of the stream even further.

As mentioned above, urbanization contributes to various factors that intensify erosion within a watershed. Figure 4.13 shows that the urban study sites along McVicar Creek have much lower vegetative protection along the banks of the stream compared to the non-urban area of McVicar Creek and the control stream. McVicar Creek scored 4/20 on the *Rapid Bio-assessment Protocols for Use in Wadeable Streams and Rivers,* whereas the non-urban study sites scored 16/20 and the control stream scored 20/20. Figure 4.12 shows that the urban study sites along McVicar Creek also scored much lower for bank stability compared to the non-urban study sites and the control stream. The urban study sites scored 6/20 whereas the non-urban study sites scored 16/20 and the control stream scored 20/20. The amount of vegetation along McVicar Creek is directly correlated with the bank stability, which is why this area of the stream scored significantly lower than the non-urban area and the control stream. The vegetation provides large root systems along the stream banks which help hold the soil in place. The vegetation also helps protect the banks from flowing water (Barbour et al., 1999). The lack of vegetation along the banks of the urban study sites could explain the increased amounts of erosion. Stream bank erosion increases the sediment supply, and the sediments can fill urban channels. The increased amount of sediment in a stream can cause stream depths to decrease (Paul & Meyer, 2001). This could explain why the urban study sites along McVicar Creek are shallower than the non-urban study sites.

The impact of urbanization on stream morphology could be evident within the study site Marina Park. This is the most urbanized study site, where the depth is the shallowest and the temperatures are the highest among all study sites. The implications of these shallow depths extend beyond the morphological changes, as they are also closely linked to the thermal dynamics of the stream. A shallow creek will cause the depth of flow to decrease, allowing the water to heat more efficiently. The shallower water also allows for quicker heating through solar radiation (Booth & Bledsoe, 2009). Leblanc et al. (1997) show that streams with larger widths and shallower depths will have larger temperature extremes compared to streams with smaller widths and deeper depths. The author also notes that the larger widths and the shallower depths tend to increase with increasing urbanization. This could explain why the urban study sites along McVicar Creek exhibit both larger widths and shallower depths compared to the non-urban study sites. This change in channel morphology could also be attributed to the warmer temperatures within the city.

Water temperature plays a crucial role in shaping the health of a watershed, significantly impacting stream biota and governing in-stream processes like organic matter decomposition, metabolism, and the solubility of gases (Johnson, 2004). It is important for the water temperature of McVicar Creek to stay cool and consistent in order to protect this ecosystem in its urbanized environment. Urbanization has induced numerous alterations in the creek, disrupting its natural state typical of an untouched stream. The increasing amounts of impervious surfaces in the city of Thunder Bay have replaced the natural vegetation that once protected the creek. The reduced amounts of riparian vegetation have changed the stability of the stream banks, resulting in increased levels of bank erosion. The erosion has changed the channel morphology of McVicar Creek, resulting in a wider and shallower creek bed.

Urbanization results in a proliferation of impervious surfaces, including asphalt roads, parking lots, driveways, concrete sidewalks, and building rooftops. Impervious surfaces can become 50 °C hotter than the air temperature, which contributes to higher water temperatures within streams due to the high levels of runoff during storms (Somers et al., 2013).

Riparian buffer zones act as a protection area between land use activities and watersheds. Vegetated riparian buffers have a major effect on stream temperature as the number of trees surrounding a waterway can affect the amount of solar radiation that is received by the stream. Urbanization leads to a reduction of riparian habitats as trees and green spaces are replaced by buildings and roads. The loss of a riparian buffer zone can increase the water temperature of the stream as well as degrade the water quality and reduce the diversity of aquatic species (Bowler et al., 2012).

The Marina Park study site had 0% of the creek within the minimum standard of 30 m for a riparian buffer zone. This study site also exhibited the largest percentage of impervious surfaces. Within this area of McVicar Creek, there is the least area of pervious surfaces which help cool the water temperature and the most amount of impervious surfaces which contribute to the increase of water temperature in the creek. For these reasons, this could be a factor for the warmer water temperature readings within this study site compared to the other study sites. The non-urban study sites that showed cooler water temperature readings also had higher percentages of pervious surfaces and lower percentages of impervious surfaces. This follows the patterns presented in the literature. The effects of urbanization on the urban study sites, especially Marina Park, are the reduction in riparian buffer zones and the increase in impervious surfaces. Based on the water temperature readings and the literature this could be influencing the warmer water temperatures found within the urban study sites.

### 5.4 Next Steps for McVicar Creek

The protection of McVicar Creek from the effects of urbanization requires a strategic and comprehensive approach that includes different actions to preserve its natural state and minimize the negative consequences of urban growth. The concept of 'natural' in the context of McVicar Creek requires careful definition. Restoration efforts should be guided by clear criteria that identify what a healthy, resilient stream looks like in an urban environment. This involves determining the balance between natural ecological function and the unavoidable impacts of urbanization, ensuring that remediation strategies align with both environmental goals and urban realities. Recent research findings show that even the simplest management strategies can drastically improve the conditions of urban streams. Moore and Palmer (2005) found that introducing more riparian vegetation along stream banks increased the amount of macroinvertebrate taxa in urban streams. Sudduth and Meyer (2006) found that macroinvertebrate richness increased when roots and wood were added to the stream banks, showing that these structures can improve habitat quality. Overall restoration projects have been seen to enhance the resilience and ecological integrity of small urban streams.

Replanting riparian vegetation along stream banks has been one of the most common measures taken for stream restoration. This involves planting vegetation that is native to the area within the riparian zone width of the creek. The presence of any riparian vegetation along urban streams can have a large impact on the health of the watershed. Planting more vegetation along McVicar Creek would improve bank stability, increase the amount of aquatic biodiversity, and decrease the overall water temperature (Bernhardt & Palmer, 2007). Stream-side canopy restoration is another popular method that helps decrease the overall water temperature of a watershed. This includes selective pruning of existing trees along the stream bank, removing invasive species, and planting native trees to increase shade (Solins et al., 2018). Buffer strips can also be used to increase the amount of riparian vegetation in a stream bank. Buffer stripes increase the riparian zone width of a stream and act as a physical barrier to pollutants and contaminants being carried into streams (Hickey & Doran, 2004). Barton et al. (1985) found that narrow riparian buffer stripes were just as sufficient at reducing stream water temperatures as wider riparian buffer stripes. Several other studies also documented the decrease in water temperature with the increase in riparian buffer stripes (Hotlby 1988; Rishel et al. 1982). Enhancing the presence of riparian vegetation along the urban stretch of McVicar Creek holds promising potential to mitigate the rise in water temperature.

Bioretention systems, also known as biofilters and rain gardens, are another widely used restoration strategy. These systems start with a large hole that is in close proximity to an urban stream. The hole is filled with coarse sand as the first layer, followed by a layer of subsoil, and covered with a layer of topsoil. Native plants are then planted throughout the rain garden and mulch is added as the last layer on top. The plants and soils act as a filter for polluted stormwater, removing the contaminants from the water before it enters the stream. This is a popular method as it is relatively affordable and sustainable (Trowsdale & Simcock, 2011). Studies have shown that these bioretention systems have successfully removed sediments, heavy metals, phosphorus, nitrogen, and nitrate (Hatt et al., 2007; Henderson et al., 2007). This restoration strategy also works to cool down the stormwater before it enters the stream (Trowsdale & Simcock, 2011). Bioretention systems could be of benefit to McVicar Creek as they would help increase the water quality and decrease the water temperature.

Streambank stabilization is another practical stream restoration project that aims at reducing streambank erosion. This practice has been implemented within the urban area of McVicar Creek by using large boulders to stabilize the eroding streambanks. This method significantly reduces the amount of erosion, but it limits the growth of riparian vegetation and does not allow for vegetation to grow along the stream banks (Barbour et al., 1999). Streambank stabilization using non-structural methods or bioengineering is a much better method aimed at restoring urban streams. Geotextile fabrics are a common material used to prevent streambank erosion. Geotextile fabrics are made from durable synthetic fibers that are laid on or within the soil. They reinforce the soil, creating a barrier that resists erosion from flowing water. Live cuttings are another popular method that use live plant materials, such as branches, stems, and root cuttings to help stabilize the streambank. Both of these practices mimic the natural structure and function of a fully vegetated streambank. They allow for native plant species to grow along the streambank which prevents erosion, increases the amount of aquatic species, and decreases the overall water temperature (Sudduth & Meyer, 2006). Incorporating non-structural methods for streambank stabilization along McVicar Creek will allow the creek to exist in a more natural state instead of using boulders which inhibits riparian vegetation from growing.

An education and outreach plan would be a great first step for restorative action toward the McVicar Creek. Educating the public plays a crucial role as it encourages public participation in environmental education. This education program would focus on why the community should care about the impacts of urbanization on local ecosystems and small practices they can incorporate to help mitigate the environmental consequences produced by cities. Providing the public with knowledge about their city can keep a community more well-informed and can promote effective conversation. When a community is engaged and informed about local issues, it can be the start of local change. The more education and conversation there is around urban streams, the more people will want to help reduce the impacts of urbanization. The community will begin to understand the value of preserving natural habitats and restoring impaired habitats (McKinney, 2002).

### 5.5 Limitations

This study was successful in obtaining water temperature data on McVicar Creek and could be used in future research assessing the long-term temperature fluctuations of this urban stream. The goal of this research was to obtain an extensive and continuous dataset of the water temperature at each study site along McVicar Creek and Savigny Creek.

The data collection apparatus created limitations to timing of the data collection period. The inability to standardize the recording times across study sites arose due to variations in travel durations between sites. This limited the study to intermittent snapshots of water temperature within the watershed.

Another limitation presented in this study is using Savigny Creek as a control stream. The control stream was chosen based on proximity to the city of Thunder Bay in order to easily travel to and access this creek for fieldwork. Given the limited availability of suitable creeks in proximity to the city, Savigny Creek emerged as the most viable option due to its alignment with the key characteristics exhibited by McVicar Creek. Although the creek exhibited similar characteristics, they differed in length and channel width. The discrepancy in stream length and width may have introduced variability that could impact the study's goal to isolate and attribute observed water temperature differences solely to urbanization. While the control stream aims to represent an undeveloped and natural watershed, it is essential to recognize that local geological, hydrological, and climatic disparities between the 2 creeks may alter the interpretation of results.

The visual habitat assessment provided by the *Rapid Bio-assessment Protocols for Use in Wadeable Streams and Rivers,* was a very feasible way to evaluate the conditions of both creeks. Although it produced a number of useful observations, the qualitative parameters involved subjective ratings. Each parameter was scored using a self-assessment, which may have introduced a degree of subjectivity. The subjective nature of these ratings could lead to potential biases as well as an element of uncertainty since each rating was influenced by my own individual perspective. Future studies would need to enhance the objectivity in order to contribute to a more robust understanding of the relationship between riparian habits and water temperature dynamics in urbanized environments.

The stream width and depth may also pose limitations to this study. The decision to record these characteristics during the month of August, representing late summer conditions, may not fully capture the dynamic nature of stream features throughout the entire year. Streamflow and depth can exhibit considerable variability across seasons, with a large influence from precipitation and snowmelt. The study may have missed important information in regard to the effect of spring runoff on stream characteristics. This limitation may impact the study's ability to analyze the relationship between stream characteristics and water temperature dynamics.

Future research should focus on refining the methodology to address the identified limitations. To address these limitations, it is recommended to incorporate continuous monitoring equipment, extend the data collection across multiple years, and select a better-suited control stream. These will help mitigate the limitations of the current study and also provide a stronger understanding of the interplay between urbanization and water temperature in small streams.

## Chapter Six

## CONCLUSION

This research compares the water and air temperatures, as well as the channel width, channel length, riparian vegetation, impervious surfaces and pervious surfaces of the urban area of McVicar Creek to the non-urban area of McVicar Creek. The results successfully demonstrated that water temperatures in the urban area of McVicar Creek were warmer compared to those in the non-urban area. The results show a presence of an urban heat island in the city of Thunder Bay and offer valuable insights into the deteriorating health of the creek influenced by prevalent urban practices.

The correlation between the elevated air and water temperatures within the city study sites suggests a potential influence of urbanization on local climate conditions. These results aligned with the established urban heat island research, consistently showing warmer temperatures within highly populated urban areas. Urbanization within the city of Thunder Bay has created urban-induced alterations to the natural course of McVicar Creek. Factors such as increased impervious surfaces and reduced soil infiltration have changed the urban area of this creek. The results show increased stream width, shallower depths, and reduced riparian vegetation within the urban section of the creek when comparing it to the non-urban area of the creek. Past research has found similar findings, with all of these factors relating to the effects of urbanization.

The distinct thermal dynamics of McVicar Creek highlight the need for strategic and comprehensive approaches to help mitigate the impacts of urbanization. The results emphasize the importance of riparian vegetation in stabilizing stream banks, reducing erosion, and moderating water temperatures. Stream restoration projects, such as riparian planting, streambank stabilization using bioengineering, and bioretention systems, offer promising ways to enhance the resilience of this urban stream.

The protection of McVicar Creek is dependent upon community engagement through education and outreach programs. Creating a sense of awareness and understanding among the public about the impacts of urbanization on local ecosystems, including McVicar Creek, can help the preservation of urban streams. Community engagement encourages the preservation of these watersheds and shares the importance of why these streams matter.

This research also provides a foundation for future studies on McVicar Creek. Future research would create a deeper investigation into the interactions between urbanization, stream morphology and water temperature dynamics. The research would help to better understand which specific areas of McVicar Creek are most influenced by the effects of urbanization. This would help the city of Thunder Bay develop sustainable strategies for urban watershed management.

Through observation of water temperatures, riparian vegetation, and stream characteristics, this thesis has shown how urbanization has negatively impacted McVicar Creek within the urban areas of the watershed. This research highlights the importance of keeping our streams clean through restoration projects and long-term monitoring. The results and conclusions of this thesis are significant to the implementation of management strategies for stream restoration projects aimed at protecting watersheds from the effects of urbanization.

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## APPENDICES

Appendix 1: Riparian vegetation visual assessment for individual study sites.

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| **1. Epifaunal Substrate/ Available Cover** <br><br> **(high and low gradient)** | Greater than 70% (50% for low gradient streams) of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient). | 40-70% (30-50% for low gradient streams) mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale). | 20-40% (10-30% for low gradient streams) mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed. | Less than 20% (10% for low gradient streams) stable habitat; lack of habitat is obvious; substrate unstable or lacking. |
| **SCORE** | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |

| **Study Site** | **Score** |
|---|---|
| **Marina Park** | 1 |
| **Brent** | 4 |
| **Elm** | 6 |
| **Clayte** | 5 |
| **Belton** | 10 |
| **Wardrope** | 17 |
| **Hilldale** | 13 |
| **Hazelwood** | 16 |
| **Copenhagen** | 18 |
| **Trowbridge** | 19 |
| **Mount Baldy** | 20 |
| **Road 527** | 15 |

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| **2b. Pool Substrate Characterization**<br><br>**(low gradient)** | Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common. | Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present. | All mud or clay or sand bottom; little or no root mat; no submerged vegetation. | Hard-pan clay or bedrock; no root mat or submerged vegetation. |
| **SCORE** | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |

| Study Site | Score |
|---|---|
| **Marina Park** | 1 |
| **Brent** | 3 |
| **Elm** | 5 |
| **Clayte** | 3 |
| **Belton** | 6 |
| **Wardrope** | 10 |
| **Hilldale** | 8 |
| **Hazelwood** | 8 |
| **Copenhagen** | 19 |
| **Trowbridge** | 20 |
| **Mount Baldy** | 20 |
| **Road 527** | 17 |

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| **8. Bank Stability (score each bank)**<br><br>**Note: determine left or right side by facing downstream**<br><br>**(high and low gradient)** | Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected. | Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion. | Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods. | Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars. |
| SCORE ___ (LB) | Left Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |
| SCORE (RB) | Right Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |

| Study Site | Left Bank Score | Right Bank Score |
|---|---|---|
| **Marina Park** | 2 | 2 |
| **Brent** | 1 | 1 |
| **Elm** | 5 | 5 |
| **Clayte** | 4 | 4 |
| **Belton** | 6 | 6 |
| **Wardrope** | 10 | 10 |
| **Hilldale** | 7 | 7 |
| **Hazelwood** | 9 | 9 |
| **Copenhagen** | 10 | 10 |
| **Trowbridge** | 10 | 10 |
| **Mount Baldy** | 10 | 10 |
| **Road 527** | 10 | 10 |

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| **9. Vegetative Protection (score each bank)**<br><br>**Note: determine left or right side by facing downstream.**<br><br>**(high and low gradient)** | More than 90% of the streambank surfaces and immediate riparian zones covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally. | 70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining. | 50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining. | Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height. |
| SCORE ___ (LB) | Left Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |
| SCORE (RB) | Right Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |

| Study Site | Left Bank Score | Right Bank Score |
|---|---|---|
| **Marina Park** | 1 | 1 |
| **Brent** | 4 | 4 |
| **Elm** | 6 | 6 |
| **Clayte** | 5 | 5 |

| | | |
|---|---|---|
| **Belton** | 4 | 4 |
| **Wardrope** | 10 | 10 |
| **Hilldale** | 9 | 9 |
| **Hazelwood** | 9 | 9 |
| **Copenhagen** | 10 | 10 |
| **Trowbridge** | 10 | 10 |
| **Mount Baldy** | 10 | 10 |
| **Road 527** | 10 | 10 |

| **Habitat Parameter** | **Condition Category** | | | |
|---|---|---|---|---|
| | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| **10. Riparian Vegetative Zone Width (score each bank riparian zone)**<br><br>**(high and low gradient)** | Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone. | Width of riparian zone 12-18 meters; human activities have impacted zone only minimally. | Width of riparian zone 6-12 meters; human activities have impacted zone a great deal. | Width of riparian zone <6 meters: little or no riparian vegetation due to human activities. |
| SCORE ___ (LB) | Left Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |
| SCORE ___ (RB) | Right Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |

| Study Site | Left Bank Score | Right Bank Score |
|---|---|---|
| **Marina Park** | 3 | 3 |
| **Brent** | 5 | 2 |
| **Elm** | 7 | 1 |
| **Clayte** | 5 | 2 |
| **Belton** | 8 | 10 |
| **Wardrope** | 10 | 10 |
| **Hilldale** | 10 | 10 |
| **Hazelwood** | 10 | 10 |
| **Copenhagen** | 10 | 10 |
| **Trowbridge** | 10 | 8 |

| | | |
|---|---|---|
| **Mount Baldy** | 10 | 10 |
| **Road 527** | 10 | 10 |

fluctuations in air temperature, with some temperatures being warmer compared to the city. There were 9 data collection days where the non-urban area of McVicar Creek exhibited warmer air temperature compared to the urban area of McVicar Creek. This only occurred at the beginning of the data collection period, from June 21, 2023, to August 1, 2023. The data reveals a trend within the graph suggesting higher temperatures within the urban setting.

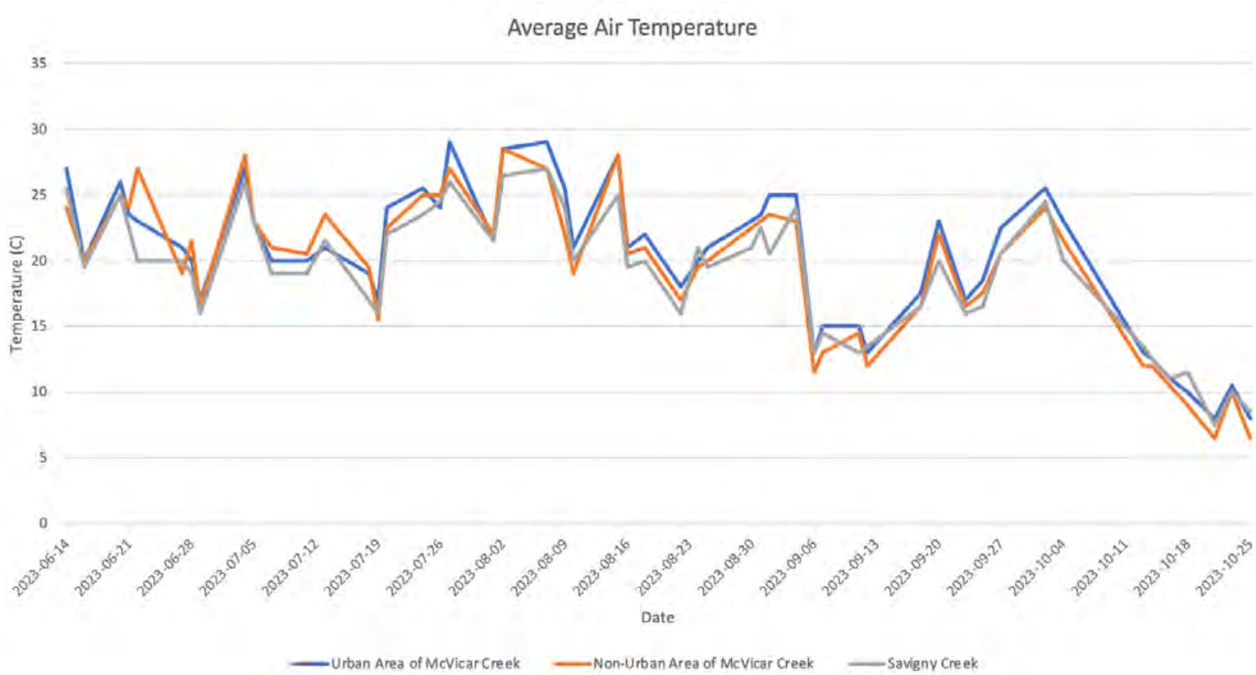


Figure 4.1 Average Air Temperature of all Study Sites

Table 4.1 below shows a paired sample t-test for the air temperature of the urban and non-urban study sites. A paired samples t-test was conducted to compare the means of air temperature between the urban study sites and the non-urban study sites. This test was set up by pairing temperature measurements taken at the same times across both types of sites, allowing a direct comparison of air temperatures in urban versus non-urban environments. By pairing measurements from identical time points, it can be assessed whether the mean air temperature significantly differed between the urban and non-urban areas. The mean air temperature for the urban study sites was 20.28 °C, while the mean for the non-urban study sites was 19.62 °C. The difference in means indicates that the air temperature is higher in the urban area compared to the non-urban area.

Paired Sample T-Test for Air Temperature

| | Mean | Std. Deviation | N | One-Sided p | Two-Sided p |
|---|---|---|---|---|---|
| Urban Air Temperature | 20.28 | 5.5 | 53 | <.001 | <.001 |
| Non-Urban Air Temperature | 19.62 | 5.67 | 53 | <.001 | <.001 |

Table 4.1 Paired Sample T-Test for Difference in Means of Air Temperature

Figures 4.2 to 4.4 below show three scatter plots of water temperature compared to air temperature. Figure 4.2 represents the average water temperature of the urban study sites throughout the data collection period. Figure 4.3 represents the average water temperature of the non-urban study sites throughout the data collection period. Figure 4.4 represents the average water temperature of the control stream study sites throughout the data collection period. Across all three scatter plots, a positive correlation is evident, with rising air temperatures corresponding to higher water temperatures. Water temperature has a high dependance on air temperature. A stronger correlation between air and water temperatures suggests greater stability in water temperatures with reduced fluctuations (Graf, 2019). The strength of the relationship was assessed using the R-squared ($R^2$) value. The urban study sites have an $R^2$ value of 0.747. This indicates that almost 75% of the variation in water temperature can be explained by changes in air temperature. The non-urban study sites have an $R^2$ value of 0.719. Although this is slightly lower than the urban sites, this still reflects a strong relationship between air and water temperature outside of the city. The control stream study sites have an $R^2$ value of 0.7042. While this is the lowest among the three groups, it still represents a strong relationship, with 70% of the variation in water temperature explained by air temperature. The study sites all exhibit a low p-value which shows that the relationship between water and air temperature is statistically significant.

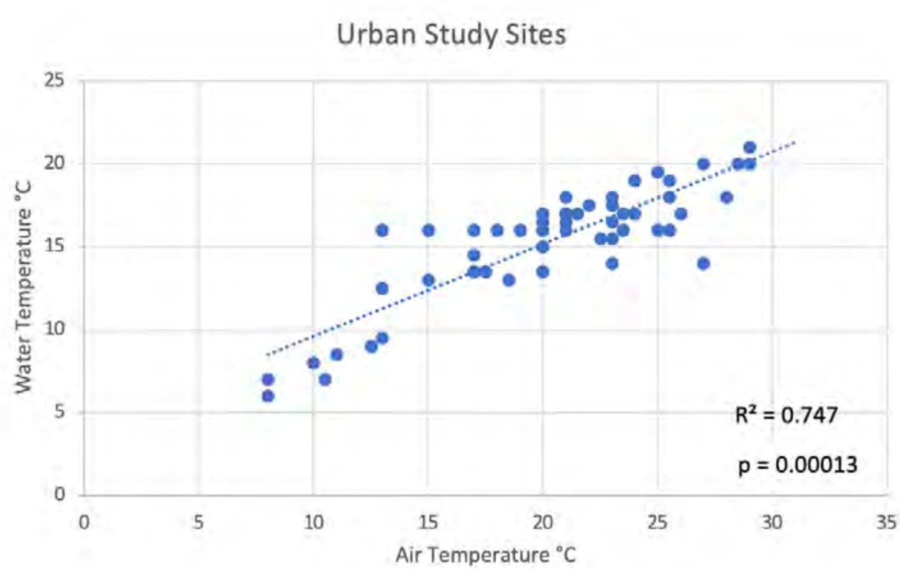


Figure 4.2 Air Temperature compared to Water Temperature of the Urban Study Sites

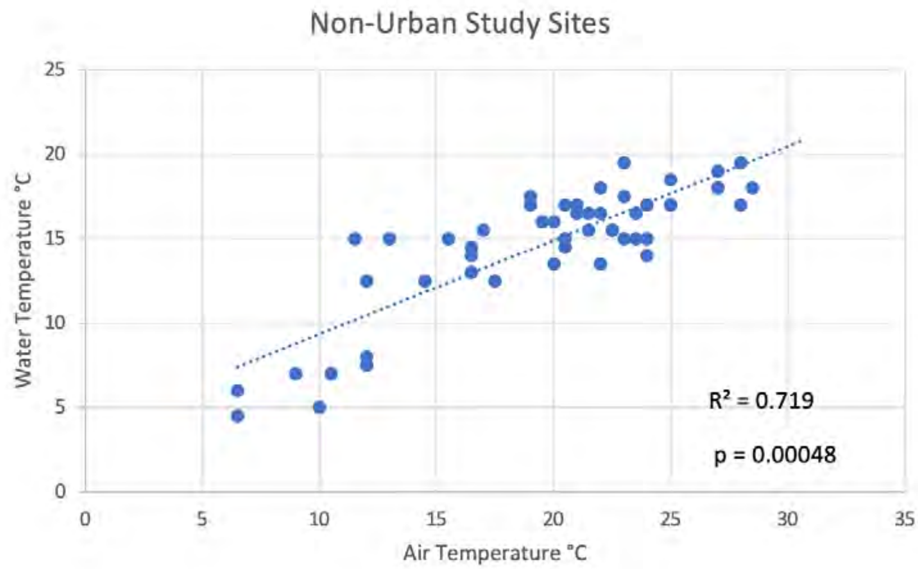


Figure 4.3 Air Temperature compared to Water Temperature of the Non-Urban Study Sites

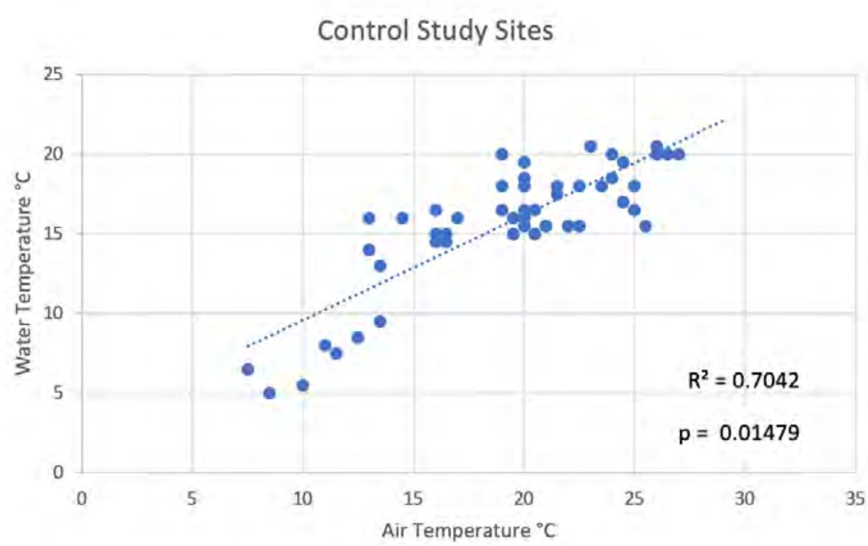


Figure 4.4 Air Temperature compared to Water Temperature of the Control Stream Study Sites

### 4.2 Water Temperature

A Repeated Measures ANOVA (Table 4.2) was conducted to examine the differences in water temperature between the urban and non-urban study sites. This analysis used a time series of water temperature data collected at each study site, with measurements recorded over identical intervals. In the model, sites were categorized as either urban or non-urban but treated individually to capture temperature variation at each specific location. The p-value is <.001, indicating that water temperatures differed significantly across the various study sites along McVicar Creek. This finding suggests that the water temperature is not uniform throughout the creek and varies depending on the specific study site.

Tests of Within-Subjects Effects

| Soure | | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| Site | Sphericity Assumed | 274.481 | 7 | 39.212 | 85.87 | <.001 |
| | Greenhouse-Geisser | 274.481 | 3.353 | 81.857 | 85.87 | <.001 |
| | Huynh-Feldt | 274.481 | 3.618 | 75.875 | 85.87 | <.001 |
| | Lower-bound | 274.481 | 1 | 274.481 | 85.87 | <.001 |
| Error (Site) | Sphericity Assumed | 163.019 | 357 | 0.457 | | |
| | Greenhouse-Geisser | 163.019 | 171.012 | 0.953 | | |
| | Huynh-Feldt | 163.019 | 184.496 | 0.884 | | |
| | Lower-bound | 163.019 | 51 | 3.196 | | |

Table 4.2 Repeated Measures ANOVA of Water Temperature

Table 4.3 below shows a paired sample t-test for the water temperature of the urban and non-urban study sites. Following the Repeated Measures ANOVA, which examined temperature differences across individual study sites along McVicar Creek, a paired samples t-test was conducted to directly compare the mean water temperatures between the upper flow (non-urban study sites) and the lower flow (urban study sites) of the creek. The mean water temperature for the urban study sites was 15.14 °C, while the mean for the non-urban study sites was 14.58 °C.

The difference in means indicates that the water temperature is higher in the urban study sites compared to the non-urban study sites. The results show a statistically significant increase in water temperature from the non-urban to the urban study sites, with a one-sided p-value of <0.001.

Paired Sample T-Test for Water Temperature

| | Mean | Std. Deviation | N | One-Sided p | Two-Sided p |
|---|---|---|---|---|---|
| Urban Water Temperature | 15.14 | 3.98 | 53 | <.001 | <.001 |
| Non-Urban Water Temperature | 14.58 | 4.12 | 53 | <.001 | <.001 |

Table 4.3 Paired Sample T-Test for Difference in Means of Water Temperature

The water temperature readings along McVicar Creek reveal notable variations in thermal conditions. Average summer water temperatures for McVicar Creek, as well as minimum and maximum water temperatures, are shown in Table 4.4 below. The study site Marina Park is located at the mouth of the creek where it enters Lake Superior. This study site is drastically warmer compared to the other sites located on McVicar Creek. Marina Park has an average water temperature of 17 °C whereas the study site located the farthest away from the city is on average 2 degrees cooler.

Water Temperature Statistics for each Study Site

| Study Sites | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| Marina Park (Urban) | 52 | 7.5 | 23.5 | 17 | 3.7 |
| Brent (Urban) | 52 | 6 | 20 | 14.5 | 3.5 |
| Elm (Urban) | 52 | 6 | 19.5 | 14.8 | 3.5 |
| Clayte (Urban) | 52 | 5.5 | 20 | 15 | 3.7 |
| Belton (Non-Urban) | 52 | 5.5 | 21 | 15.5 | 3.6 |
| Wardrope (Non-Urban) | 52 | 4.5 | 19.5 | 14.3 | 3.6 |
| Hilldale (Non-Urban) | 52 | 4.5 | 20 | 14.6 | 3.8 |
| Hazelwood (Non-Urban) | 52 | 5 | 19.5 | 14.8 | 3.8 |

Table 4.4 Descriptive Statistics for McVicar Creek from June to October 2023

Combined Water Temperature Statistics

| Month | N | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|---|
| August | 104 | 14.5 | 23.5 | 17.2 | 1.7 |
| September | 88 | 12 | 21 | 14.6 | 2 |
| October | 72 | 4 | 18.5 | 9.2 | 3.9 |

Table 4.5 Descriptive Statistics for McVicar Creek from August to October 2023

Table 4.5 shows the average water temperature readings of all the study sites. This table focuses on the temperatures during the months of August, September, and October. These specific months were chosen as this is the time of year when brook trout swim upstream to spawn and reproduce. The average water temperature of McVicar Creek during the month of August is 17.2 °C. The average water temperature drops by 2.6 °C in the month of September and drops another 5.4 °C in the month of October.

Figure 4.5 below shows the water temperature of each study site along McVicar Creek. This graph is a visual representation of the data and reveals a trend among the temperatures. All study sites follow the same pattern and are close to one another regarding their water temperature readings. The outlier within this graph is the darker blue line labelled "Marina Park". This study site exhibited consistently higher water temperatures compared to the other locations along the creek. During the peak summer months of July and August, water temperatures reached a maximum of 23.5 °C at the mouth of the creek. This is on average 3.5 degrees warmer than the maximum water temperature at any other study site.

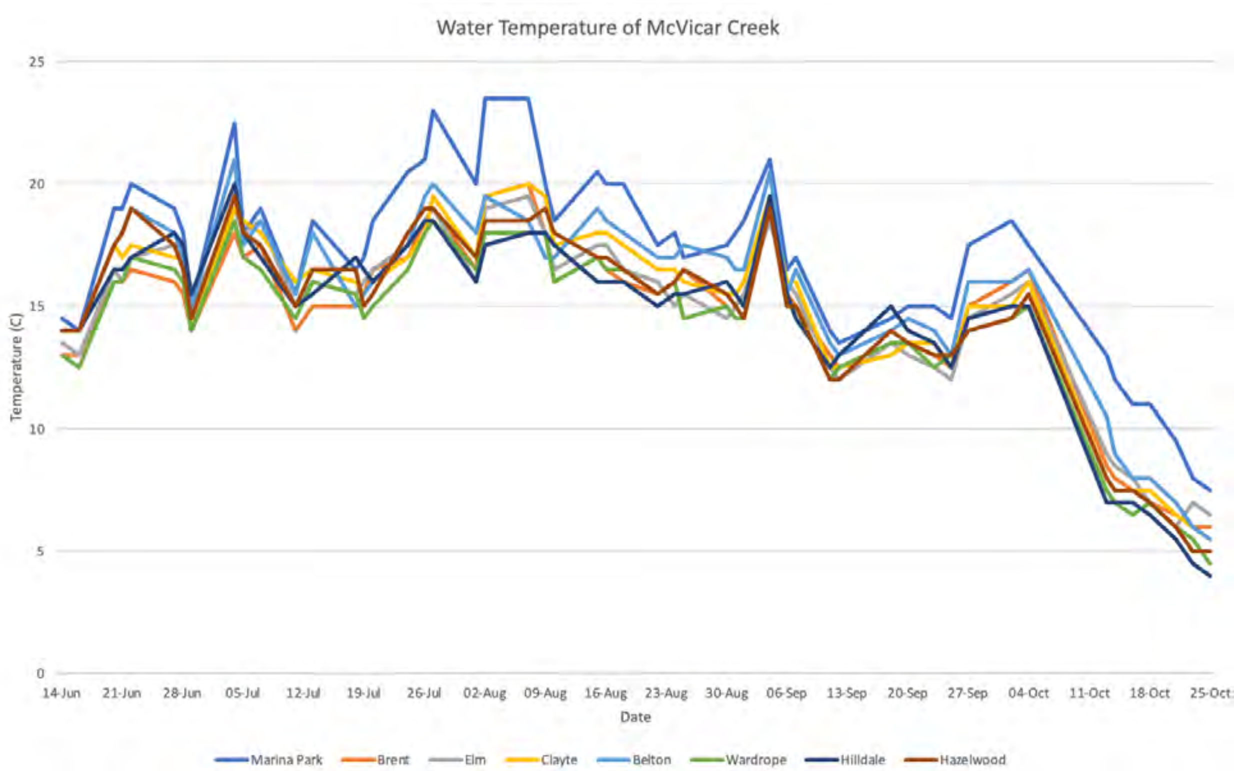


Figure 4.5 Water Temperature of McVicar Creek from June to October 2023

Figure 4.6 below presents a modified version of the graph from Figure 4.5, displaying water temperature readings from only two study sites. As mentioned above, the blue line from Marina Park presents the warmest water temperature readings. The orange line from Wardrope has the coolest water temperatures over this period. The study site Wardrope is located in a more rural area. Although it is not the study site that is located furthest away from the city, this location has an abundance of shading and riparian vegetation. Riparian vegetation is a significant factor influencing water temperature and will be discussed in the next section. These results show how an urban study site differs from a non-urban study site.

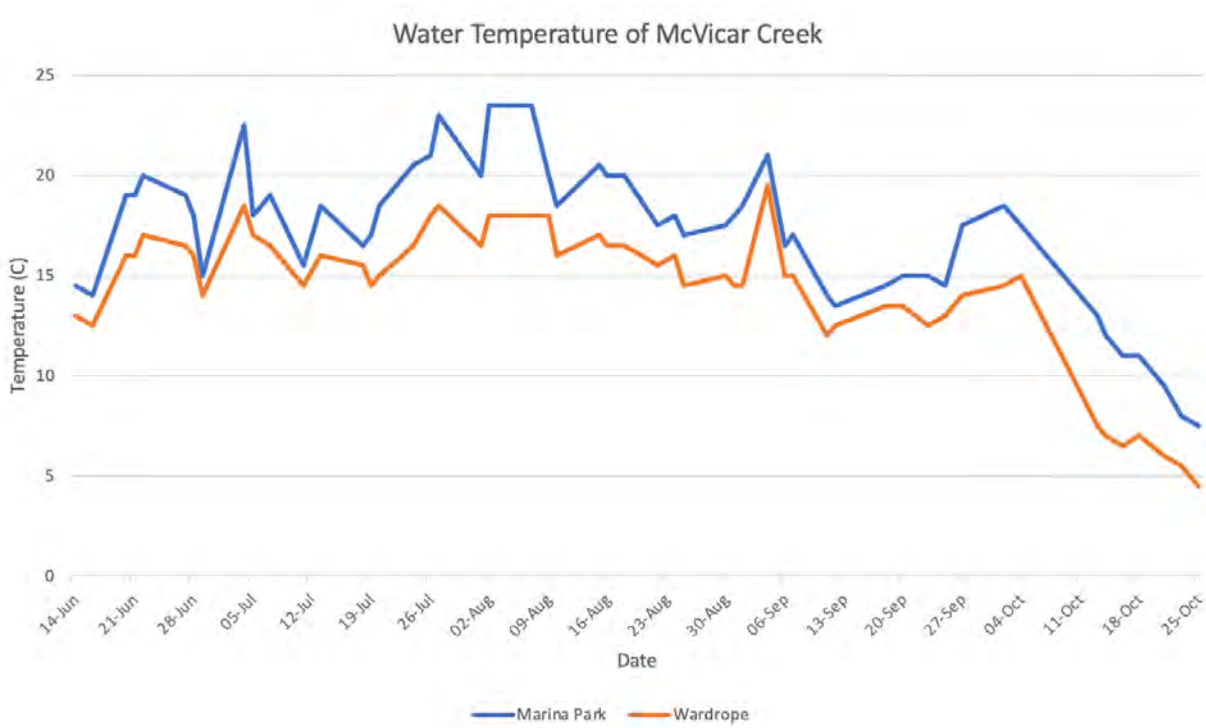


Figure 4.6 Water Temperature of an Urban Study Site and a Non-Urban Study Site Along the McVicar Creek from June to October 2023

Further analysis was done to provide additional evidence for the higher water temperatures observed within the urban study sites. Figure 4.7 illustrates the relationship between water temperature and the distance from the outlet of the creek. This graph focuses on the water temperature of each study site during the warmest air temperature readings from this data collection period, which was on August 7, 2023. The blue line is labelled as McVicar Creek, and each point represents the specific study site in regard to how many kilometres along the course of the creek the location is from the outlet of the creek. The outlet of the creek (at the left end) is the study site Marina Park. The orange line is labelled as Savigny Creek. There are no signs of urbanization along this creek allowing this creek to provide an example of thermal dynamics in an undisturbed area.

The graph reveals a distinct inverse relationship between temperature and the distance from the McVicar Creek's outlet. As study sites move farther away from the outlet and farther away from the city, the water temperature consistently decreases. The first 4 points along McVicar Creek represent the study sites within the city which all have warmer water temperature readings compared to the last 4 points which represent the non-urban study sites.

The control stream, labelled "Savigny Creek", exhibits a faint upward trend. The temperature was 19.5 °C at the mouth of the creek and increases to 21 °C toward the headwaters of the creek, indicating modest temperature changes with distance. Although the study sites along Savigny Creek only account for just over 6 km compared to McVicar Creek spanning across 12 km, the 4 points along Savigny Creek only have a difference of 1.5 °C. The 4 urban study sites along McVicar Creek have a difference of 4 °C, the non-urban study sites have a difference of 0.5 °C, and the difference between the most urbanized study site and the most rural study site is 5.5 °C. The largest difference in water temperature is shown within the urban study sites.

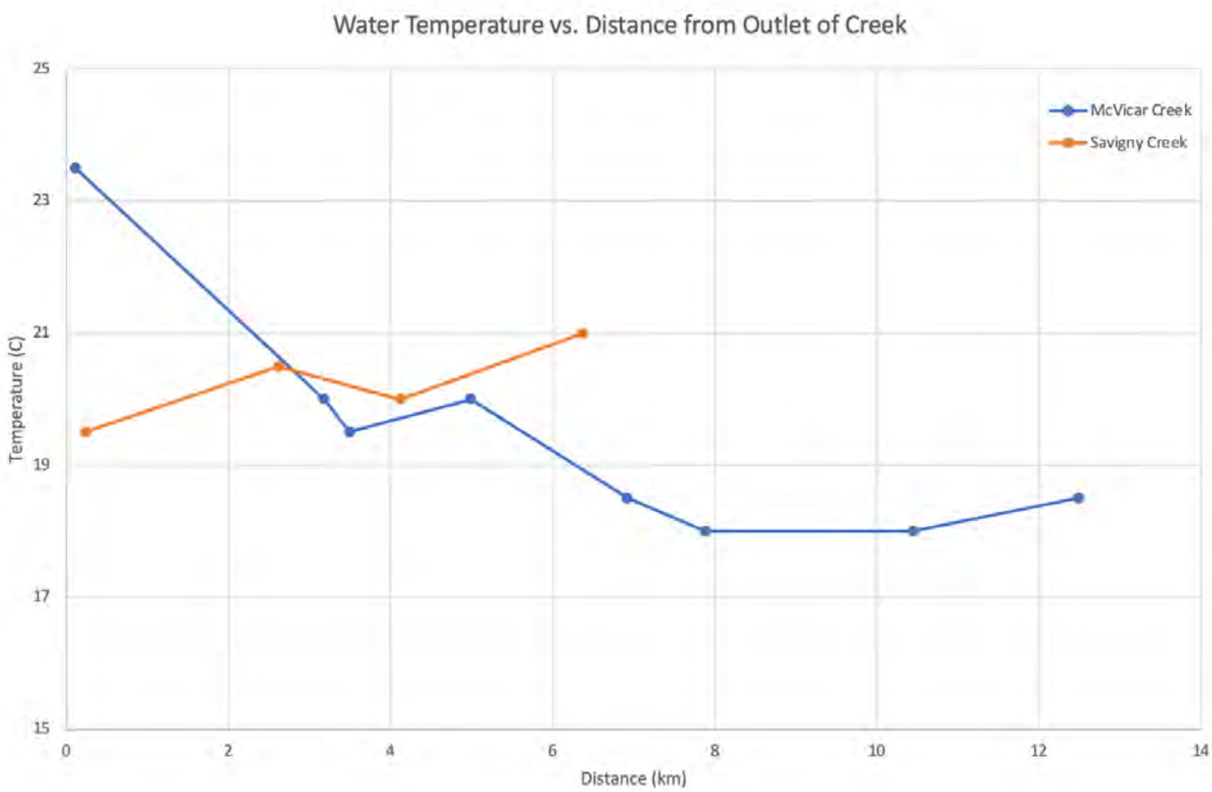


Figure 4.7 Relationship between Water Temperature at Each Study Site and Distance from the Creek Outlet on August 7, 2023

### 4.3 Width of Creek

Figure 4.8 below shows the average width of each study site during the summer months. The blue line represents McVicar Creek and the orange line represents Savigny Creek. Each point represents a study site and its relative distance from the outlet of the creek. The results show that the control stream has little to no changes in the width of the surface water. The subtle variation in stream width suggests that this creek has a more natural and unaltered flow regime. When looking at McVicar Creek, a distinctive pattern emerges. As the creek traverses through the urbanized areas, there is a substantial increase in width compared to the non-urban study sites. The average width for the study sites in the city is 6.2 m. The average width for the study sites in the non-urban areas is 3.3 m. There is almost a 3 m difference between the average width of the urban stream and the average width of the non-urban stream. The most urbanized study site, Marina Park, has a width of 7.6 m which is almost 5 m wider than the narrowest area of the creek.

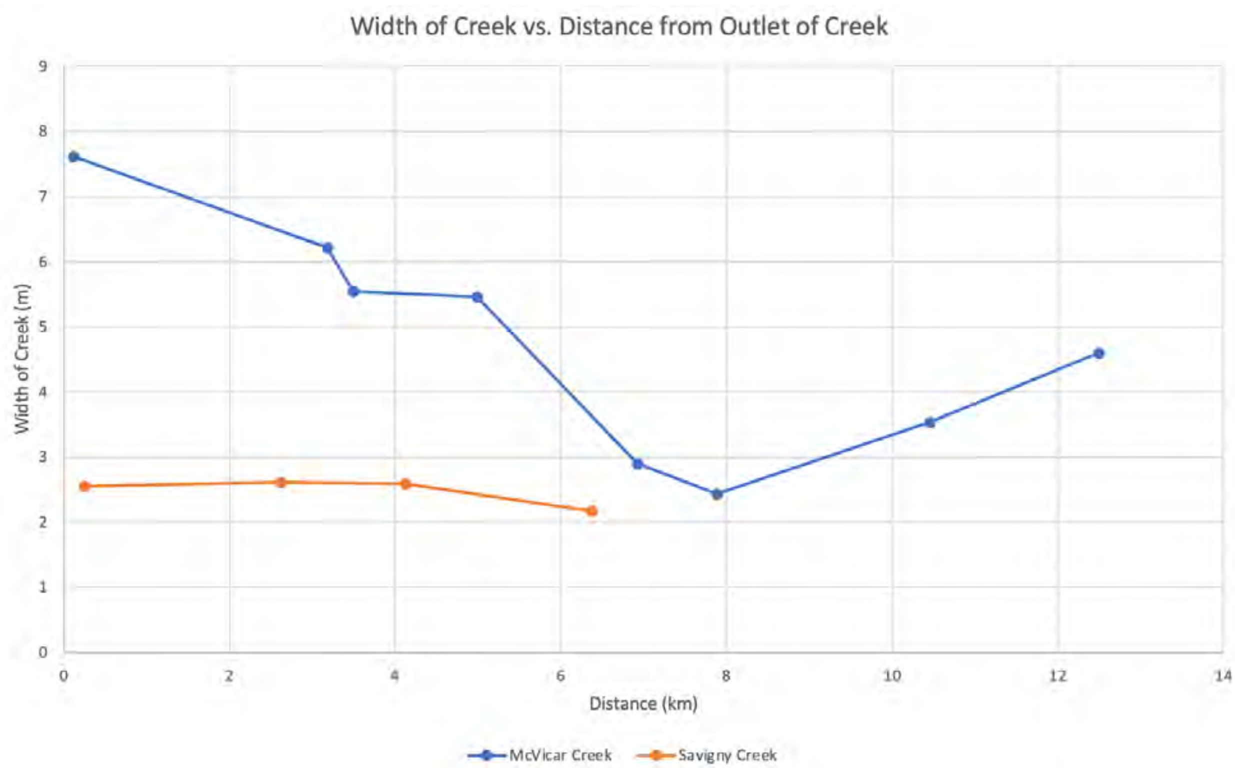


Figure 4.8 Width of McVicar Creek and Savigny Creek

**4.4 Depth of Creek**

Figure 4.9 below shows the average depth of each study site during the summer months. Each point represents a study site and its relative distance from the outlet of the creek (at left). When examining stream depths relative to their distance from the outlet of the creeks, distinct patterns emerged within the control stream and McVicar Creek. Savigny Creek, exhibits relatively consistent depths, ranging from 12 cm to 20 cm. The average depth of Savigny Creek, based on my study sites, was 14 cm. In contrast, McVicar Creek displays a large range in stream depth, particularly between the first 4 points on the graph, which represent the study sites within the city, and the last 4 points on the graph, which represent the study sites outside of the city. The urban study sites have shallower depths, ranging from 7 cm to 8.5 cm, with an average depth of 7.8 cm. The non-urban study sites exhibited a wider range of depths, from 12 cm to 32 cm, and an average depth of 19.8 cm. Marina Park, the first point for McVicar Creek, recorded the shallowest depth. The study site Hazelwood is the last point on McVicar Creek and had the deepest depth.

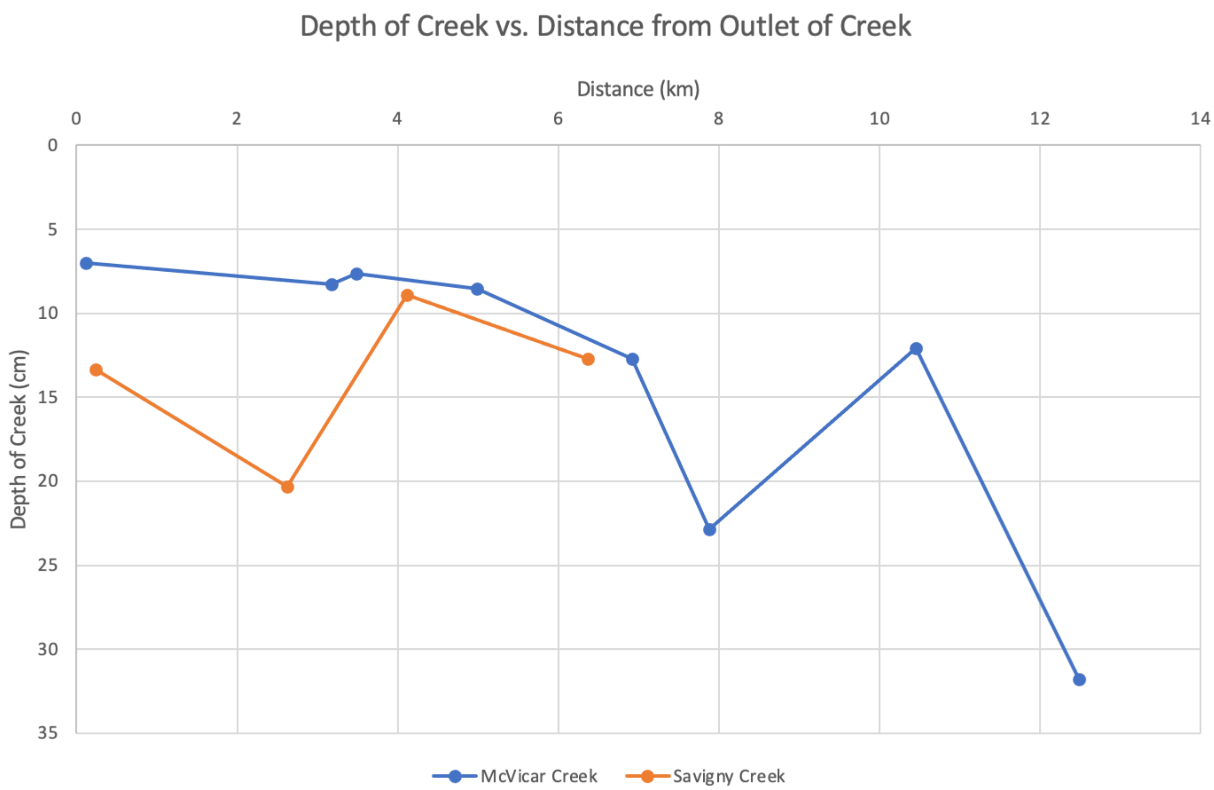


Figure 4.9 Depth of McVicar Creek and Savigny Creek

**4.5 Riparian Vegetation**

The riparian vegetation is measured at each study site using the *Rapid Bio-assessment Protocols for Use in Wadeable Streams and Rivers* (Barbour et al., 1999). The importance of assessing riparian vegetation lies in the direct correlation observed: study sites with sparse tree and plant cover along the creek tend to exhibit higher water temperatures (Timm et al., 2021). The use of the Bio-assessment Protocol will provide a technical reference to conduct a cost-effective biological assessment of each study site. The purpose of this assessment is to identify which study sites have been impaired from lack of vegetation and to characterize the severity of impairment for specific study sites. As well, the purpose serves as a tool to establish baseline conditions for each study site to be later used to reevaluate the effectiveness of restoration activities.

These protocols are measured based on the area surrounding the study site, specifically the in-stream and riparian habitat that influences the aquatic community of the creek. If a study site is ranked lower within the scales, this translates to the site having an altered habitat structure, which is a major stressor on watersheds and can lead to warmer water temperatures. The presence of a degraded habitat is most often related to toxicity and/or pollution, which is usually caused by the presence of humans (Barbour et al., 1999). The study sites located in the city have the biggest disadvantage, being the most influenced by human activity. The assessments below are the averages of each study site and are categorized into the control stream, the urban study sites, and the non-urban study sites. The assessments for each individual study site are in Appendix 1. The classifications allow a representative understanding of each environment to compare the riparian vegetation in the urban watershed to the riparian vegetation that has not been altered by human land use.

McVicar Creek Urban Study Sites

McVicar Creek Non-Urban Study Sites

Savigny Creek Control Stream

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| **1. Epifaunal Substrate/ Available Cover**<br><br>**(high and low gradient)** | Greater than 70% (50% for low gradient streams) of substrate favorable for epifaunal colonization and fish cover; mix of snags, submerged logs, undercut banks, cobble or other stable habitat and at stage to allow full colonization potential (i.e., logs/snags that are not new fall and not transient). | 40-70% (30-50% for low gradient streams) mix of stable habitat; well-suited for full colonization potential; adequate habitat for maintenance of populations; presence of additional substrate in the form of newfall, but not yet prepared for colonization (may rate at high end of scale). | 20-40% (10-30% for low gradient streams) mix of stable habitat; habitat availability less than desirable; substrate frequently disturbed or removed. | Less than 20% (10% for low gradient streams) stable habitat; lack of habitat is obvious; substrate unstable or lacking. |
| **SCORE** | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |

Figure 4.10 Epifaunal Substrate/Available Cover Habitat Parameter

The first habit parameter measured is epifaunal substrate/available cover. This parameter includes the quantity and variety of natural structures found in the creek. This can be riffles, large rocks, logs and branches, undercut banks, and fallen trees, all of which are used by aquatic species for safety, feeding, spawning, and nursery. More submerged structures in an area of a stream provides more habitats for macroinvertebrates and fish. If an area of the stream has little to no available cover, the habitat diversity will decrease as well as the amount of aquatic species. Riffles are also of great importance for fish as riffles maintain the abundance of insects in streams for feeding and spawning. Snags and submerged logs are the most productive habitat structure for aquatic species as they provide the most amount of shelter (Barbour et al., 1999).

The control stream received the highest rating for epifaunal substrate/available cover. Each study site along the control stream provides lots of available shelter for aquatic species. Snags, large rocks, and logs were present at each study site. There were undercut banks within Savigny Creek in two out of the four study sites. There were also riffles at three out of the four study sites. Based on this information, Savigny Creek was rated an 18/20 in Figure 4.10. Savigny Creek is far from any human land use. This allows the creek to flourish in its natural state, which provides a large variety of habitats for the aquatic species that live in Savigny Creek.

The non-urban study sites were rated 14/20. On average, the non-urban study sites have lots of available cover and submerged structures but not an abundance compared to the control stream. Three out of the four study sites have lots of large rocks, but only a few branches. There are riffles at two out of the four study sites. There were only submerged structures present at one study site, Wardrope Avenue, in the non-urban area of McVicar Creek. The study site Belton Street had less than 10% of stable habitat. The non-urban study sites, with the exception of Belton Street, still provide lots of available cover for fish and other aquatic species.

The study sites located within the city scored the lowest with a rating of 4/20. There was a lack of habitat at each study site. Each study site had rocks and only one out of the four study sites had any sign of branches or snags. There were riffles present at two study sites but for the majority of the area, the substrate was unstable. The urban study sites can be described as open and empty compared to the non-urban area of McVicar Creek, as well as the control stream. The study sites within the city provide very few habitats for the aquatic species to survive in. This makes the survival rates very low, with very few places to feed, hide, and reproduce, for the species that inhabit this aquatic environment.

McVicar Creek Urban Study Sites
McVicar Creek Non-Urban Study Sites
Savigny Creek Control Stream

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| **2b. Pool Substrate Characterization**<br><br>**(low gradient)** | Mixture of substrate materials, with gravel and firm sand prevalent; root mats and submerged vegetation common. | Mixture of soft sand, mud, or clay; mud may be dominant; some root mats and submerged vegetation present. | All mud or clay or sand bottom; little or no root mat; no submerged vegetation. | Hard-pan clay or bedrock; no root mat or submerged vegetation. |
| **SCORE** | 20 19 18 17 16 | 15 14 13 12 11 | 10 9 8 7 6 | 5 4 3 2 1 0 |

Figure 4.11 Pool Substrate Characterization Habitat Parameter

The second habitat parameter measured is the pool substrate characterization. This parameter evaluates the type and the condition of the bottom surface within pool habitats. It measures the amount of firmer sediment types, such as gravel and sand, and rooted aquatic plants. The more plants and sediment found within a stream, the healthier the ecosystem as the sediment and plants support a large variety of aquatic species. The firmer sediment prevents erosion by providing a more stable stream bed and maintaining the integrity of the stream channel (Barbour et al., 1999).

Within the control stream, all four study sites provided optimal pool substrate characterization. Three out of the four study sites had multiple species of aquatic plants. The fourth study site had some aquatic plants along the stream banks but had no submerged plants within the area of the study site. For most of the study sites along Savigny Creek, a large amount of submerged vegetation existed for the aquatic species to enjoy. All four study sites also exhibited a mixture of substrate materials. Each area of the control stream had a mix of gravel and sand.

The non-urban study sites along McVicar Creek scored 8/20. There was a large difference between the control stream and the rural area of McVicar Creek, specifically for aquatic vegetation. All four study sites at this location exhibited diverse sediment compositions. One site exclusively featured substantial rock formations, while the subsequent three sites displayed a heterogeneous combination of rocks of varying sizes interspersed with sands. Only one site had aquatic vegetation present. Although only one out of the four study sites showed plants within the watershed, this area had a large variety of plant species, and the submerged vegetation covered the entire area of the study site.

The study sites located within the city had poor conditions for pool substrates and scored a 3/20. Firmer sediment types were not found within the four study sites. Each study site had only large and medium-sized rocks along the stream bed. There was no indication of any submerged vegetation present within the city location of McVicar Creek. The only study site that had some aquatic plants present was Elm Street. There were a few plants within this area of the watershed. Overall, McVicar Creek suffers from the lack of substrate materials and submerged vegetation when compared to Savigny Creek. Without the mixture of gravel and sands and aquatic plants, McVicar Creek has very few habitats for any aquatic species trying to survive. The lack of firmer sediment types is also a contributing factor to the continuing erosion that is occurring within the urban study sites. Both the non-urban and the urban study sites displayed suboptimal conditions in the pool substrate characterization assessment, indicating a precarious state for the creek and its vulnerability to ecosystem degradation.

McVicar Creek Urban Study Sites

McVicar Creek Non-Urban Study Sites

Savigny Creek Control Stream

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | Optimal | Suboptimal | Marginal | Poor |
| **8. Bank Stability (score each bank)**<br><br>**Note: determine left or right side by facing downstream**<br><br>**(high and low gradient)** | Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected. | Moderately stable; infrequent, small areas of erosion mostly healed over. 5-30% of bank in reach has areas of erosion. | Moderately unstable; 30-60% of bank in reach has areas of erosion; high erosion potential during floods. | Unstable; many eroded areas; "raw" areas frequent along straight sections and bends; obvious bank sloughing; 60-100% of bank has erosional scars. |
| SCORE ___ (LB) | Left Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |
| SCORE ___ (RB) | Right Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |

Figure 4.12 Bank Stability Habitat Parameter

The third habit parameter measured is bank stability. This habitat parameter measures the erosion or the potential for erosion along the stream banks. Steep banks are dangerous for streams as they are more likely to collapse or be prone to erosion. Gently sloping banks are a lot more stable and keep the stream banks from collapsing. When assessing the stream banks of each study site, signs of erosion were considered. This includes crumbling banks, exposed tree roots, banks without any vegetation, and exposed soil (Barbour et al., 1999). Each stream bank was evaluated separately, and the average of all study sites in the group was used to determine the right and left banks. The right and left bank scores are cumulative and used for the overall score of this parameter out of 20.

The control stream had no signs of erosion present along its banks, receiving a total score of 20/20. Along Savigny Creek the banks are very stable, providing very little risk for erosion to occur. The banks are covered in an abundance of vegetation, creating a covered and unexposed stream bank. The banks at each study site show no signs of any exposed tree roots or soil and no signs of any bank failure.

The non-urban study sites along McVicar Creek also exhibited minimal signs of erosion, generating a score comparable to the control stream. Two out of the four study sites shared identical characteristics to the control stream, featuring stable banks with minimal risk of erosion. These study sites have abundant vegetation which prevents any exposure of the stream bank. The other two sites had less vegetation along one side of their stream bank. This caused the stream bank to become moderately unstable and at moderate risk for erosion. The lack of vegetation at these study sites reduces the bank cohesion. Without the roots of plants to stabilize the soil, the soil has no protection, becoming more susceptible to being washed away by flowing water. There are obvious signs of the soil along the stream banks being exposed to the impact of rainfall, leading to increased erosion.

The urban study sites along McVicar Creek exhibit a higher prevalence of erosion indicators when compared to both the non-urban locations and the control stream, resulting in a score of only 6 out of 20. Large boulders have been placed along the entire stream bank of McVicar Creek within the city, to help prevent further erosion from occurring. These rocks now act as the stream bank instead of the natural vegetation that used to be present. This indicates that this area had a high potential for erosion. The placement of the boulders acts as a bank stabilizer, helping to prevent further collapse or erosion. These physical barriers help to mitigate soil erosion but do cause harm to the natural environment of the stream. The large rocks may change the substrate composition which limits the variety of habitats for the aquatic species. It also limits the growth of riparian vegetation and does not allow for vegetation to grow along the stream banks. The reduction of vegetation reduces the bank stability even further (Barbour et al., 1999).

McVicar Creek Urban Study Sites

McVicar Creek Non-Urban Study Sites

Savigny Creek Control Stream

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | **Optimal** | **Suboptimal** | **Marginal** | **Poor** |
| **9. Vegetative Protection (score each bank)**<br><br>**Note: determine left or right side by facing downstream.**<br><br>**(high and low gradient)** | More than 90% of the streambank surfaces and immediate riparian zones covered by native vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally. | 70-90% of the streambank surfaces covered by native vegetation, but one class of plants is not well-represented; disruption evident but not affecting full plant growth potential to any great extent; more than one-half of the potential plant stubble height remaining. | 50-70% of the streambank surfaces covered by vegetation; disruption obvious; patches of bare soil or closely cropped vegetation common; less than one-half of the potential plant stubble height remaining. | Less than 50% of the streambank surfaces covered by vegetation; disruption of streambank vegetation is very high; vegetation has been removed to 5 centimeters or less in average stubble height. |
| SCORE ___ (LB) | Left Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |
| SCORE ___ (RB) | Right Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |

Figure 4.13 Vegetative Protection Habitat Parameter

The fourth habitat parameter measured is vegetative protection. This parameter measures the amount of vegetation that is protecting the stream bank. This parameter is correlated with the bank stability habitat parameter as the amount of vegetation reduces the likelihood of erosion occurring along the stream bank. The vegetation provides large root systems that can hold soil in place, protecting the stream banks from flowing water. The assessment of this parameter includes the risk of erosion for each bank, and the variety of plant species along the bank (Barbour et al., 1999). Each stream bank was evaluated separately, and the average of all study sites was used to determine the right and left banks. The right and left bank scores are cumulative and used for the overall score of this parameter out of 20.

The control stream was evaluated similarly to the habitat parameter bank stability above. All four study sites displayed a large percentage of stream bank surfaces covered in vegetation. Since the control stream has no anthropogenic alterations caused by humans, all vegetation is left untouched. This means that the plants are all native, including a variety of trees, shrubs, and small plants, and the plants are free to grow naturally. The amount of natural vegetation along the stream banks is correlated with the bank stability of these study sites. The vegetation keeps the banks from eroding, keeping the ecosystem of Savigny Creek healthy.

The non-urban study sites of McVicar Creek had similar stream banks compared to the control stream. Three out of the four study sites exhibit optimal levels of vegetative protection. These three study sites have a large variety of native trees, shrubs, and plants which all cover more than 90 % of the stream bank surfaces. The non-urban stretches of McVicar Creek largely remain undisturbed by humans, fostering the natural and abundant growth of vegetation. Only one of the four study sites is classified as suboptimal for its growing conditions, as the Belton Street site flows through a large meadow. This meadow consists of only tall grasses.

The urban study sites have very poor vegetative cover compared to the non-urban study sites and the control stream. This section of McVicar Creek has very little vegetation along its stream banks, for a score of only 4/20. The city constructed bank stabilizers along the creek and the large rocks do not allow for any natural vegetation to grow along the stream banks. The study site Marina Park does have a section of vegetation along its stream bank surfaces, consisting only of tall grasses. The boulders limit the growth of riparian vegetation which impacts the ecological functions that plants provide.

McVicar Creek Urban Study Sites
McVicar Creek Non-Urban Study Sites
Savigny Creek Control Stream

| Habitat Parameter | Condition Category | | | |
|---|---|---|---|---|
| | Optimal | Suboptimal | Marginal | Poor |
| **10. Riparian Vegetative Zone Width (score each bank riparian zone)**<br><br>**(high and low gradient)** | Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone. | Width of riparian zone 12-18 meters; human activities have impacted zone only minimally. | Width of riparian zone 6-12 meters; human activities have impacted zone a great deal. | Width of riparian zone <6 meters: little or no riparian vegetation due to human activities. |
| SCORE ___ (LB) | Left Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |
| SCORE ___ (RB) | Right Bank 10 9 | 8 7 6 | 5 4 3 | 2 1 0 |

Figure 4.14 Riparian Vegetative Zone Width Habitat Parameter

The last habitat parameter measured is the riparian vegetative zone width. This parameter measures the width of the natural vegetation from the start of the stream bank out through the riparian zone. The riparian zone is essential for the health of a creek. It provides shade for the creek and can help regulate the thermal dynamics of a stream. The absence of riparian vegetation can leave creeks vulnerable to a range of issues, including erosion, loss of habitat for aquatic species, and loss of nutrients within the stream.

Savigny Creek and the non-urban study sites of McVicar Creek have optimal levels for the riparian vegetation zone width. All eight study sites for these two groups have over 18 m of riparian vegetation. Savigny Creek and the non-urban section of McVicar Creek benefit from a full riparian zone and have no stress caused on their ecosystems due to human activities.

The urban study sites along McVicar Creek have been impacted by the roads that have been built around the creek. The urbanization around this creek has destroyed the natural environment of the creek. Rather than a spacious riparian zone enveloping this stretch of the creek, the area has been developed with paved roads tailored to meet urban requirements. The Marina Park study site has 4 m of riparian vegetation near the mouth of the creek. Much of this study site is disturbed by bridges and railway crossings. The Brent Street study site has the largest riparian zone within the city. There are 14.5 m of grass between the stream bank and a road. This however is classified as a suboptimal level of a riparian zone width as it consists of regularly mowed grass. The Elm Street study site has 3.1 m of vegetation between the left bank and residential lots and 11.2 m of vegetation between the right bank and a road. The last city study site, Clayte Street, has only 2.6 m of vegetation between both banks and a paved pathway. On average, the city study sites display poor and marginal levels of riparian zone width. The construction of roads in this area leaves little space for vegetation to grow, compromising the overall health and resilience of McVicar Creek's ecosystem.