AN EVALUATION OF STORMWATER REMEDIATION OPTIONS ON MCVICAR CREEK, THUNDER BAY, ONTARIO

By

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Abstract

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Keywords: integrated stormwater management, McVicar Creek, Thunder Bay, remediation, Low Impact Development, stakeholders, education, soil, infiltration, water quality.

Stormwater discharge has been shown to impair aquatic ecosystems through the transportation of nitrogen, nitrate, ammonium, phosphorus, orthophosphate, organic carbon, fecal coli form bacteria, biochemical oxygen, metals and grease and oil from urban environments (Mallin *et al.*, 2009). Stormwater is generally considered a non-point source of pollution which can cause difficulty in managing habitat and ecosystem degradation. Current municipal stormwater management is often focused on the deployment of end of pipe solutions in the form of detention or retention basins (Roy *et al.,* 2008). There is however a growing recognition that the public needs to be involved and aware of urban drainage planning if we are to move away from strictly engineered solutions and shift to integrated stormwater management (Rauch *et al.*, 2005).

In 2002, the Lakehead Region Conservation Authority (LRCA) recognized that McVicar Creek, one of Thunder Bay's major tributaries to Lake Superior, was potentially contributing significant sources of stormwater related pollutants to the Thunder Bay Area of Concern. The lower reaches of the creek are highly developed putting the water system at high risk of excessive urban runoff causing ecosystem impairments.

This thesis is aimed at providing stormwater remediation recommendations along McVicar Creek through quantitative and qualitative research techniques. McVicar Creek was the selected location due to the urbanized environment surrounding the creek and the initial recognition from the LRCA. Three representative sites were selected that best characterized stormwater impacts along the creek. The sites were chosen based on previous research completed on the creek by Lakehead University and the Northshore Remedial Action Plans (RAP). Of the three sites selected, one site was further studied as a case study site in order to complete a multi-decision making workshop with stakeholders. All three sites had in-depth subwatershed catchment assessments and water quality data. In addition, soil texture and composition, soil nutrients, soil organic matter, infiltration rates and upstream and downstream water quality were examined. These parameters were evaluated to determine the efficacy of Low Impact Development (LID) best management practices on the site.

In relation to the literature, the quantitative data show the case study site is a suitable option for LID remediation. The areas within the case study site that have less than ideal LID soil conditions could be altered through engineering practices and designs to achieve successful implementation. The water quality results show excess amounts of ammonia, nitrate, nitrite phosphate and chloride exceeding specified guidelines outlined by the provincial and federal governments. The stakeholder group concludes that a watershed-wide education and outreach campaign is a more valued stormwater remediation option in Thunder Bay.

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1.0 Introduction

Stormwater discharge can impair aquatic ecosystems because it often contains elevated levels of nitrogen, nitrate, ammonium, phosphorus, orthophosphate, organic carbon, fecal coli form bacteria, biochemical oxygen, metals, grease and oil (Mallin *et al.*, 2009). Stormwater is generally considered a non-point source of pollution which can degrade habitat and ecosystem services of urban streams. In addition, urban runoff alters temperature and dissolved oxygen levels and strongly influences the flow characteristics of receiving streams (Heaney *et al.*, 1999). Typical stormwater impacts include stream channel modification, erosion, sedimentation, modified hydrology and changes in riparian vegetation (Heaney *et al.*, 1999).

Stormwater collects pollutants as it flows over urban surfaces. The most common pollutant source is from roofs of houses and buildings and impervious surfaces with heavy motorized traffic (Boller, 2004). The highest water quality degradation due to stormwater discharge has been shown to occur when the impervious cover of the watershed is more than 10% (Mallin *et al.*, 2009). The current stormwater infrastructure system is designed to work independently of other environmental variables and based on historical weather events (Rauch *et al.*, 2005). Municipal stormwater management is focused on end of pipe solutions such as wet and dry detention basins (Roy *et al.,* 2008). There is however a growing recognition that the public needs to be involved in decision making and aware of urban drainage planning if we are to move away from strictly engineered solutions and shift to integrated stormwater management (Rauch *et al.*, 2005). In 2002, the Lakehead Region Conservation Authority (LRCA) recognized that McVicar Creek, one of Thunder Bay's major tributaries to Lake Superior, was potentially contributing significant amounts of stormwater related pollutants to the Thunder Bay Area of Concern (AOC). The lower reaches of the creek are highly developed placing the aquatic ecosystem at high risk of excessive urban runoff causing impairments to the goods and services of the aquatic system.

This thesis is aimed at providing stormwater remediation recommendations along McVicar Creek through quantitative and qualitative research techniques to meet the specified objectives. McVicar Creek was selected for study in this research because the urbanized environment surrounding the creek has been recognized by the LRCA as having a negative impact on the creek. Three representative sites were elected that best characterize stormwater impacts along the creek. The sites were chosen based on previous research completed by Lakehead University and the Northshore Remedial Action Plans (RAP). Of the three sites selected, one site was further studied as a case study site in order to complete a multi-decision making workshop with stakeholders. Stakeholders for the purposes of this thesis are explained in the methods section. All three sites had in-depth subwatershed catchment assessments and water quality testing at the outfall completed on them. The case study site was further studied for soil texture and composition, soil nutrients, soil organic matter, infiltration rates and upstream and downstream water quality. These parameters were tested to help determine the suitability of deploying a range of Low Impact Development (LID) best management practices on the site. A Multi-Stakeholder Decision Making (MSDM) framework was followed to complete the involvement (Sinclair *et al.*, 1998). This framework included an introduction session, a site visit and a decision-making workshop. The recommendations are based on the site specific data presented to the group throughout the involvement process.

1.1 Background

Although there is no set Stormwater master plans at the Municipal level, there have been huge accomplishments around the city in stormwater awareness, remediation and naturalization.

Between 1966 and 1976, the LRCA completed an Ersion Protection, Regultation and Flood Plain Mapping of McVicar Creek (Lakehead Region Conservation Authority, 2002). The project was aimed at erosion and flood control which are a direct link to stormwater discharge impacts. The addition of rip-rap at the mouth of the creek has provided a reduction in erosion and in turn helped imrove water quality from runoff (Alberti, 2005). In 1996 a Pollution Prevention and Control Plan was adopted in the City of Thunder Bay (City of Thunder Bay, 2010). The plan adressed the need for long-term pollution prevention plan based on combined sewer overflow, basement flooding, stormwater management and the establishment of the Thunder Bay Pollution Control Plant. In 2007 the LRCA completed a Stewardship program along McVicar Creek (Lakehead Region Conservation Authority, 2007). The program provided residents living along the creek with information on how to properly care for their property backing onto the creek.

In 2008 the City adopted the Earthwise® Community Environmental Acton Plan (Earthwise, 2008). From the Earthwise® Community Environmental Action Plan, a Water Working Group was formed. This group is comprised of representatives from government agencies, not-for-profit organizations and Lakehead University. The Water Working Group focused on discussing issues surrounding water, specifically Stormwater in the Thunder Bay area. The issues that arise and potntial solutions are presented to the City of Thunder Bay. In 2010, the City proposed a Sewer Use Bylaw restricting certain materials from entering the stormwater sewer system (City of Thunder Bay, 2010). In 2010 consultants were also hired by the City to complete a scpoing study of the feasibility of a stormwater management plan for the city of Thunder Bay (STANTEC, 2011). The goal of the feasibility study was to further invesitgate the possibility of a Master Stormwater Management Plan.

Thunder Bay Stormwater management is currently progressing at the municipal level with a focus on McVicar Creek itself. The sites studied in this thesis were selected to represent McVicar Creek as a whole and build-up base line data on the area. The three specific subwatershed site descriptions have been determined through the Stormwater Impacts Assessment research to-date. The descriptions are based on; existing literature, site assessments, GIS analysis of pipe length and input, previous research results, water quality and the feasibility study completed by STANTEC (Northshore Remedial Action Plans, 2010; STANTEC, 2011). Water quality results were based on the Provincial Water Quality Objectives (PWQO's) if available or the Canadian Water Quality Guidelines (CWQG's).

In 2010, the Northshore RAP in partnership with Lakehead University started a Stormwater Impacts Assessment research project. The project began with an initial Unified Stream Assessment (USA) on the entire creek. The project plan was based on the method proposed by Centre for Watershed Protection's *Urban Subwatershed Restoration Manual Series*. The project included first the USA and then the completion of a Unified Subwatershed and Site Reconnaissance (USSR) study. The results of the USA provide clear evidence of negative impacts of stormwater on the aquatic system (Remedial Action Plans, 2010). The results of the USA allowed for the further completion of the project and provided proof of the need for remediation along the creek.

1.2 Purpose

The purpose of this thesis is to develop suitable remediation options for the three identified hotspot sites through quantitative and qualitative data collection to meet the following objectives. This is done through monitoring of the sites, stakeholder engagement, BMP's and a case study.

1.3 Objectives

Specific objectives of this thesis are to

- Develop feasibility criteria of site-specific stormwater remediation options for critical reaches of McVicar Creek.
- Implement a decision-support criterion to identify effective stormwater remedial options based on Low Impact Development (LID), community education, policy/regulation and maintenance.
- Produce a remediation option plan for identified subwatershed hotspots using expert information and local feedback and relevant field data.

2.0 Literature Review

This literature review is an overview of current literature that supports the research and data collection in this thesis. It explores research to date on feasibility criteria for Best Management Practices (BMPs) in stormwater management, decision support criteria and implementation, as well as the use of field data and decision-support for the development of Low Impact Development (LID) and stormwater education. The last section of this literature review examines specific criterion outlined by multiple sources for stormwater remediation implementation with a focus on; LID and retrofits, maintenance and policy, education and a leave alone naturalization approach.

2.1 History of Stormwater Management

Urban runoff was originally thought of as an undesired substance that needed to be diverted from developed areas as quickly and efficiently as possible (Boller, 2004). Around the beginning of the 20th century, urban areas experienced a shift to clean and dry downtown cores (Debo *et al.*, 2003). All liquid waste created from toilets and sinks was being transported out of the urban areas into streams and rivers through pipes. Soon after, stormwater runoff was diverted into the same pipes as the liquid sewer wastes that also lead directly into streams and rivers. Once people started contracting various diseases, it was apparent that dumping sewage into the potable water supply was the cause. The easiest solution to the stormwater problem presented itself as combined sewers (Boller, 2004). These systems were combined until recently, due to heavy rain events overwhelming the system causing untreated sewage to enter potable waterways (Roy *et al.*, 2008).

Communities generally perceived stormwater as a nuisance problem with no social or ecological value (Brown, 2005). The extent of most stormwater infrastructure was not even known by most local governments up until the late 1990`s, early 2000's (Brown, 2005). This is due to the fact that stormwater infrastructure was generally created with the development of residential areas and roads. Stormwater infrastructure was just built into design construction, and not recorded in municipal documents as a significant part of urban design (Brown, 2005).

The stormwater infrastructure that was created as an alternative to combined sewers posed a threat to downstream flooding during heavy rain events (Roy *et al.*, 2008). This threat sparked the paradigm of on-site retention of stormwater (Debo *et al.*, 2003). During the 1990's the idea of watershed level stormwater planning emerged (Ontario Ministry of the Environment, 2003). This theory has been adopted by nearly all current stormwater planners in Ontario. This theory emerged with the growing concern of sustainability, ecosystem restoration and natural hydrologic regimes. There is a general green revolution emerging within stormwater management as people come to the common acceptance that urban sprawl and increased impervious surfaces are contributing to the contamination of water systems (Debo *et al.*, 2003).

Into the 1990`s and beyond there has been more of a shift towards integrated urban stormwater management (IUSM) and it is continuing to evolve (Brown, 2005). In the beginning of stormwater infrastructure and flood control, stormwater was considered to be environmentally benign, so focus was based on economical convenience. Through social attitude studies done during the 1990`s it was determined that waterway health and water pollution was ranked at the highest environmental value of the public (Brown, 2005). There are some specific factors that can mark the transition period to sustainable stormwater management throughout the 1990's: increased social values of watercourses, evolving international research in integrated stormwater management and local policy development. IUSM poses a challenge to administration because it requires a new form of governance involving participatory, interdisciplinary and interorganization adaptive management. This new approach needs to consider a holistic ideology with the inclusion of community participation and other stakeholders (Brown, 2005).

Sundberg *et al.* (2004) suggest that stormwater systems should provide water for domestic use, rather than being treated as wastewater. The theory of stormwater reuse is a common theme among stormwater literature. Sundberg *et al.* (2004) suggest a re-assessment of the system as an indicator framework based on the idea that sustainable water resources can't be quantified. The systems theory approach needs to be based on organized learning rather than traditional systems engineering. Stormwater management needs to represent the surrounding environment, the local society and the contributing urban water systems. Stomwater management has the oppotunity to not only enhance the quality of the ecosystem, but also the urban aesthetics of the area.

2.2 Human Health Risks Associated with Stormwater Discharge

According to Gaffield *et al* (2003), over 50% of waterborne illness outbreaks since 1948 have been linked to stormwater runoff primarily during extreme rainfall events. In Long Island Sound, U.S.A, 47% of pathogen contamination is caused by stormwater runoff (Gaffield *et al.*, 2003). Excess sediment to water bodies causes the natural bacteria in the system to die and creates habitat for terrestrial bacteria entering the aquatic environment from stormwater discharge. Fecal coliform is another common bacterium found in stormwater runoff that can lead to human health problems. Nitrate, another common element found in stormwater runoff can cause shortness of breath, blueness of the skin and increase the chances of a miscarriage in pregnant women. Significant levels of copper, zinc and lead are also commonly found in stormwater runoff which has toxic effects on human health.

The chlorine used in drinking water treatment plants cannot remove many of the terrestrial bacteria that are introduced to the water system through stormwater runoff (Gaffield *et al.*, 2003). Some treatment facilities have converted from using chlorine to ozone to treat drinking water to solve the stormwater contamination issue. This seems to be an issue in itself because the disinfectants used create carcinogenic by-products. These by-products have been estimated to cause up to 9,300 cases of bladder cancer in the U.S each year. They have also been linked to neural tube defects and spontaneous abortions in pregnant women.

Gaffield *et al.* (2003) conducted a cost analysis, comparing the cost of complex water treatment facilities; the cost to treat waterborne illnesses caused by stormwater runoff and simple stormwater management practices. They reported that stormwater management practices, such as regional site design planning, best management practices, enhanced infiltration and watershed planning cost about one third the amount of improved drinking water treatment and three quarters the amount of treating waterborne illness.

2.3 Overview of Stormwater Remediation options

The evidence of ecosystem degradation caused by stormwater discharge arose in the early 1960's in Australia. This awareness created holistic stormwater management approaches in recreational green-spaces around the country to increase public awareness of the issue (Roy *et al.*, 2008). The value of stormwater runoff in Australia has shifted from being a liability to being a precious water resource concerning droughts. The most frequent stormwater management techniques used in Australia are city-wide stormwater management plans with both structural and non-structural guidelines (Taylor *et al.*, 2007). These guidelines often adopt LID and BMP techniques.

The City of Salisbury in South Australia has designed a stormwater retention system called the Parafield system (Howlett *et al.*, 2009). The system is designed to catch stormwater runoff into a capture dam and then pump the water from the original dam into a subsequent holding dam. During the second phase of the process many of the discharged pollutants are removed through infiltration. Once the stormwater is released from the holding dam it runs through a small wetland for further infiltration and bioretention treatment. From the wetland the water is supplied either directly to the consumer, usually for industry and non potable purposes, or it is further held in an underground aquifer for future use. There is no guarantee of a consistent water supply to consumers as the system is based on rainfall events, however; the water from the Parafield system is significantly less expensive than treated water from the main municipal supply (Howlett *et al.*, 2009).

The United States are required to comply with the Total Daily Maximum Load discharge limits from all point sources (Rauch *et al.*, 2005). This system is based on the Hydrologic Simulation Program Fortran that accounts for rainfall, infiltration, point and nonpoint sources of waste and stream flows. Tulsa Oklahoma enforced an illicit discharge elimination program in 1994 to deal with the excessive expected illicit discharge into the stormwater system (Taylor *et al.*, 2007). The program was heavily enforced by government agencies. There was stormwater quality testing done prior to the implementation of the program and at four intervals after the program implementation. The program was proven successful in reducing 13% of total suspended solids, 17% of total phosphorus, 18% of total nitrogen and more than 55% of total metals. The success of this program spiralled into a nation-wide acceptance of the program and led to implementation in many municipalities across the country. Education of Master Gardeners in the USA has also proven to be a successful and cost effective stormwater management technique. The adoption of the program in Virginia and Florida increased public awareness of stormwater issues by 41%, increased 75% of the public undertaking personal stormwater mitigation activities and pesticide loads applied to lawns decreased by 25% (Taylor *et al.*, 2007).

The most effective way of controlling stormwater pollution, according to Boller (2004) is through source controls. Source controls involve education of the public and local level guidelines on contaminated substance use reduction. Source control research to date has been focused on the restructuring of urban stormwater systems. These include rainwater harvesting techniques, physical retention and infiltration and wetland bioretention systems. The implementation of source control measures according to Rauch *et al.* (2005) is not sufficient on its own because it does not address the contamination issues coming from the catchment basin itself. Rauch *et al.* (2005) defines the inclusion of social dimensions within the catchment area as non-structural source controls. These controls identify stakeholder collaboration and public participation. There appears to be a lack of support for non-structural source control research such as integrated stormwater planning and community education. There is also little support for reducing the level of dangerous household waste products that enter the stormwater drainage system.

The clearing of dust and dirt from roads and scheduled road cleaning significantly decreases the level of heavy metals and PAH's present in stormwater runoff (Boller, 2004). Pollution barrier systems can also help reduce the contaminants entering the aquatic system from roads and limit the amount of required road cleaning. There are two types of pollution barrier systems used in Switzerland; natural soil passages and passage through adsorber [sic] systems (Boller, 2004). The natural soil passage is a system designed to allow infiltration into the soil generally through a trench system. Natural soil passages are most effective on road shoulders as they efficiently retain heavy metals and PAH's.

Awareness of environmental issues around stormwater has pushed Ontario municipalities to widely adopt wet stormwater detention ponds over the last 10-15 years (Drake *et al.*, 2008). Wet stormwater ponds can be very effective in decreasing excessive stormwater discharge into natural water bodies. However, municipalities in Ontario have not been maintaining municipal ponds properly. Stormwater ponds need to be dredged and cleaned in order to continue providing effective stormwater treatment. Contaminated sediment accumulates at the bottom of these ponds threatening wildlife and human health (Drake *et al*, 2008). Stormwater ponds also tend to leach into groundwater potentially contaminating the potable aquifer water supply. An effective urban stormwater management system has to maintain natural ecological function and structure including flow, geomorphology, temperature, water quality, ecosystem diversity and nutrient cycling (Roy *et al.*, 2008). Urban stormwater management needs to be planned and implemented at the watershed scale rather than through detention ponds only.

Low Impact Development (LID) consists of small scale stormwater management on the local level such as; rainwater harvesting, green roofs, roof downspout disconnection, infiltration trenches, bioretention, permeable pavement, etc (Toronto and Region Conservation Authority, 2010). The purpose of LID is to convert developed land into a predevelopment hydrological setting to minimize urban impacts on water bodies (Muthanna, 2007). Technologies currently exist within LID that mimic natural water cycles and reduce the transport of stormwater contaminants downstream (Roy *et al.*, 2008). The use of LID can temporarily retain stormwater through rain barrels, infiltration and evapotranspiration. Some issues arise with LID techniques when there is limited space for storage and infiltration systems. Contaminants can also overwhelm infiltration systems or the area may be passed the point of recovery. Bioretention is an infiltration technique that can be used as an LID in stormwater management. In a natural environment, 50% of rainfall infiltrates into the ground and 10% is runoff into water bodies (Muthanna, 2007). In an urban environment only about 10-15% of rainfall is infiltrated while about 55% becomes urban runoff. There have been studies showing that heavy metal concentrations can be decreased by over 90% if the proper technique is used (Muthanna, 2007).

2.4 Site Selection Methods

Boller (2004) suggests that effective stormwater remediation options can only be determined when site hydrology and pollution fluxes are estimated for design storms. The selected site and option needs to control the pollution either by source control or through pollution barriers. There needs to also be proper disposal of accumulated waste. The materials present in the urban catchment basin must be identified as pollution contributors in order to assess the stormwater discharge impacts (Boller, 2004). Zhang (2009) suggests a site selection approach similar to that of Boller (2004) based on a watershed level stormwater optimization process. The process identifies the most suitable and cost effective LID technique. The approach assesses the peak flow relative to the total runoff control as well as total cost and pollution prevention. The United States Environmental Protection Agency (USEPA) developed a Stormwater Management Model (SWMM) that predicts water quantity and quality of stormwater runoff. The SWMM can be run in conjunction with a genetic algorithm (GA) to determine optimal LID techniques post-development. The optimization process is very much in its infancy at this point. In order to perform the process effectively the land cover, local geology and soils and daily climate needs to be known. Flood control and previous modelling on the area should also be known before conducting the optimization process (Zhang, 2009).

Echols (2002) created a stormwater management system with the intention of decreasing downstream flow rates, reducing non-point source contamination increasing infiltration and the protecting f groundwater from contamination. The system is based on a two stage process; infiltration and bioretention through mulch, soil and plant material and excess runoff is diverted into a flow splitter. The flow splitter mimics predevelopment infiltration and runoff. The flow splitter allows predevelopment flow rates to enter water systems and the remaining runoff is diverted to an infiltration system. The size of the infiltration area and the flow splitter is based on predevelopment hydrology. Predevelopment infiltration rates or initial abstraction can be determined by calculating current impervious surface areas created by urban development. Bioretention volume can be calculated by dividing the initial abstraction rate by 12 and multiplying by the area of impervious surface. This calculation provides the area needed to retain runoff in a specific area such as a small parking lot. Sites should be divided into as many drainage areas as possible requiring many small infiltration areas. If there are too few infiltration areas the recharge capacity of the ground will be exceeded and infiltration will be ineffective. Flow splitters are generally composed of plastic inlets with a diversion weir, a bypass weir and a filter. The filter screen prevents mosquitoes from reproducing and reduces the amount of sediment, organic debris and trash that enter the infiltration area (Zhang, 2009).

Although many LID, BMP and source control techniques have been studied, there is a large amount of scepticism from professionals of variable soil and climatic conditions. Most practitioners need to see successful demonstrations of projects before implementation can be considered in regulation (Roy *et al.*, 2008). Regulations often prevent developers from implementing source control measures such as the requirements to build curbs and gutters rather than bioswales. Watershed scale stormwater management generally requires the support of multiple municipal divisions which creates confusion. Funding, human resources and guidelines in many institutions are lacking. There is a risk associated with adopting stormwater development engineering standards that both the public and professionals are resistant to accept (Roy *et al.*, 2008). There is little certainty in the performance, efficiency and long-term costs of most stormwater management techniques (Taylor *et al.*, 2007). Many stormwater management practices are employed with very little understanding of the effectiveness such as storm drain stencilling programs. There are many hesitations from the general public, designers and decision makers of LID implementation, particularly when funds are limited.

The complexity of performance based LID manuals often lead designers to implement the minimum requirement for detention ponds rather than explore alternative BMP's or LID's (Fassman, 2012). Most prescriptive BMP designs also require little to no monitoring, making cost/benefit analysis difficult to determine. Current LID/BMP design should not be based on percent removal metrics because that leaves the potential of mass loads of other pollutants. Design of BMPs should be focused on the adverse effects of the discharge because the duration of contamination can be as significant to ecosystem health as the discharge quality itself. The effectiveness of a BMP needs to be based on design, watershed characteristics and storm characteristics which are not considered in a percent removal metric model. Permeable pavement monitoring data is only internationally available from a single source in Colorado and another in New Hampshire. Grass swale LID's are mostly represented from sites in Florida. There is very little information on the efficiency of wetland basins on copper and zinc contaminants. According to Fassman (2012), bioretention and grassed swales are more effective than constructed wetlands, detention basins or media filters in reducing Total Suspended Solids. Bioretention basins show the highest reduction in zinc levels. Bioretention studies have been generally formed in laboratories or using synthetic runoff (Dietz, 2007). Few studies have been published on the effectiveness of in-the-ground bioretention areas with real precipitation and runoff. Fassman (2012), suggests that permeable pavement is should be considered with "cautious optimism", however there is very little information known about the pollutant removal efficiency and it only treats the precipitation falling directly onto it. There are ongoing studies being done in Ontario to test winter performance of permeable pavement, results however, are not yet published (Dietz, 2007).

Distributed Low Impact Development within the catchment are necessary to facilitate infiltration, evaporation, transpiration and storage (Walsh *et al.*, 2005). Walsh *et al.* suggests that most in-stream habitat restoration projects create a very small positive ecological impact. Imperviousness of the catchment area is a strong predictor of urban impacts and environmental degradation of urban streams. An ideal LID would disconnect the entire impervious surface from the existing storm system. Decreasing impervious surface runoff to urban streams is the most effective method in controlling small to moderate rain event contamination. Near natural infiltration and runoff rates needs to be the primary objective of stormwater LID. Bioinfiltration trenches are the most suggested LID in an urban environment (Walsh *et al.*, 2005). In order to properly assess the potential success of an LID or BMP design, the soil structure, infiltration and discharge of pollutants needs to be known (Toronto and Region Conservation Authority, 2010).

2.4.1 Soil Composition and Texture

The optimal composition for the top soil layer of a natural soil passage or LID is 30cm with over 4% humus content and 10-35% clay content, with a pH of 6.5 (Boller, 2004). The optimal subsoil composition is 50cm with less than 1% humus content and 10-35% clay content, with a pH of 5.5. The downside of using natural soil passages is that eventually the soil becomes hazardous waste and needs to be disposed of and refilled. The adsorber system has been proven to effectively remove heavy metals and dissolved organic materials. Granulated calcite often needs to be added to the media to achieve the optimum pH conditions. The technique is most efficient in a column structure to capture mainly roof and road runoff. If the runoff is not partially filtered before reaching the adsorber system, the media will generally become obstructed and need to be replaced. According to Tsihrintzis *et al.* (1997) Some of the most effective and efficient BMP's are infiltration trenches, dry wells, infiltration basins, grass swales, pervious pavement, wet and dry detention basins, constructed wetlands, sand filters and separators.

2.4.2 Infiltration

Hydraulic conductivity is a measurement of the ability of water to move through unsaturated, porous surfaces (Reynolds, 1986). Soil sorptivity is a measurement of the capacity of soil to absorb water as it passes through unsaturated surfaces. Both hydraulic conductivity and soil sorptivity need to be known in order to create a successful biofiltration or retrofit system (Jonasson *et al.*, 2010). Research has shown that a high hydraulic conductivity generally results in a more efficient and effective bioinfiltration project, however, the base media must also be considered for proper plant and vegetation growth.

The Guelph Permeameter is a device created at University of Guelph in 1986 to determine field saturated hydraulic conductivity, soil sorptivity and matrix flux potential (Reynolds, 1986). The Guelph Permeameter uses a constant head well method while remaining statistically equivalent to the air entry permeameter method resulting in an increased efficiency and range of use when compared to; the tube method, the ring infiltrometer method, the profile method, the column method, the cavity method and the open hole infiltration method (Reynolds, 1986).

2.4.3 Water Quality Associated with Stormwater

One of the most common contaminants of stormwater discharge is increased sediment. Sediment is generally found in the form of Total Suspended Solids and Turbidity which causes a reduction in channel capacity and light penetration (Chiew *et al.*, 1997). Sedimentation in stormwater discharge has also been shown to decrease primary production and food quality, coat the gills and respiratory surfaces of fish and reduce stream depth, altering aquatic habitats (Allan, 2004). Stormwater pollutants, mainly heavy metals have been shown to get trapped in sediment (Williamson *et al.*, 2000).

The most common nutrients found in stormwater discharge are nitrogen and phosphorus (Allan, 2004). These nutrients can be found in many different forms such as PO_4, NH_3 and NH_4, NO_2 and NO_3 and TNK. Excess amounts of these nutrients can cause eutrophiciation of aquatic systems, lower oxygen levels and create algal blooms that are toxic to living organisms (Chiew *et al.*, 1997; Allan, 2004). Urban nutrient sources include fertilizers and pesticides, lawn clippings and organic matter in runoff (Center for Watershed Protection, 2005). Ammonia is another nutrient commonly found in stormwater discharge. Ammonia is highly soluble in water and is naturally converted to nitrate in surface waters (Rideau Valley Conservation Authority, 2011). This conversion removes oxygen from water sources which can adversly affect aquatic species and habitats. Sources of ammonia generally include sewage, steel mills, fertilizers, laundry detergents, petrolium and farming.

Heavy metals such as lead, zinc, copper, chromium, cadmium and nickel are contaminants of stormwater discharge due to vehicle emissions, wear of vehicle materials, water pipe and roof erosion and degradation of impervious surfaces (Burton *et al.*, 2002). Elevated heavy metals can be toxic to living organisms. Toxic organic wastes are common in stormwater discharge due to garden and lawn chemicals such as herbicides and pesticides as well as household cleaners. These materials also often contain high levels of nutrients. Hydrocarbons are also a common contaminant found in urban stormwater discharge. Hydrocarbons are contributed by oil and grease, lubrication, protective coatings and surfactants in detergent. The most common cause of hydrocarbons in stormwater is oil spills from automobiles (Chiew *et al.*, 1997).

According to Health Canada (2007), chloride levels in stormwater tend to be lower during precipitation events. This is fairly common across Canadian watersheds. Heightened chloride levels during the dry season can be attributed to the highly water soluble nature of chloride. When evaporation occurs, the concentration of chloride and respective cations are elevated (Health Canada, 2007). Almost all elevated chloride levels in stormwater discharge are due to road salt applications (Chiew *et al.*, 1997). In 2001, the Canadian Environmental Protection Act deemed road salts a toxic substance.

Stormwater pollution contributions have been shown to be fairly erratic over time, making general seasonal variation trends difficult to define and conclude (Goonetilleke *et al.*, 2005). The first flush theory is also highly over emphasized and stormwater contamination is very difficult to pin point at any specific time. The physical impacts of stormwater are important in the decision making process of implementing an LID or BMP measure, it is however, not the only factor. In residential areas, lawns and driveways contribute large phosphorus loads to urban stormwater runoff making public awareness also crucial to successful stormwater management (Mallin *et al*, 2009).

Although effective community capacity and public participation research in stormwater management is in its infancy, if communities are not directly involved in stormwater planning, problems will continue to increase (Rauch *et al.*, 2005). The stormwater system is extremely complex and unpredictable and the cause and effect relationships are very difficult to determine. Rauch *et al* (2005) suggests that the solution to the complex issues in stormwater management is implementing the precautionary principal in all planning; plan for all the potential issues that may arise in the stormwater management process. Public participation ensures a bottom-up decision making process rather than the typical top-down approach (Rauch *et al.*, 2005, Roy *et al.*, 2008). Some issues involving public participation approaches to stormwater management is that the capacity of communities is often overestimated when dealing with time, resources and political knowledge of stormwater management. Community members often identify urban drainage engineers to be the most qualified for stormwater planning, however the profession has historically lacked public participation and input. The structural organization and divisions within municipalities is an obstacle for stormwater planning knowledge transfer and planning responsibility (Rauch *et al.*, 2005).

Roy *et al.* (2008) suggests that before any stormwater management implementation can occur there needs to be workshops developed to educate professionals dealing with design such as engineers, planners and policy makers. There needs to be Education and engagement of the community through demonstrations and small scale projects that lead to wide spread support. Small scale local environmental projects have been shown to engage community members in urban environments (Byrne *et al.*, 2008). These projects enable people to consider their landscaping choices, recreational activities and lifestyle choices that impact their local environment. Small scale environmental projects on parcels of land lead to large scale urban patterns and design (Byrne *et al.*, 2008). Uncertainties in performance and cost are at the forefront of stormwater conflicts (Roy *et al.*, 2008). These issues must be addressed when attempting to educate professionals and the public in stormwater management.

2.5 Best Management Practices Decision Support Criteria

In order for public participation to be successfully applied to stormwater management decision-making, there must be decision-making tools provided as a basis (Centre for Watershed Protection, 2005). A BMP decision support criteria is outlined in the literature as Low Impact Development and retrofits, municipal maintenance and policy, education and outreach and finally a leave-alone naturalization or a do nothing approach. The following section will describe the decision support criteria used in this thesis.

2.7.1 Low Impact Development and Retrofit criteria

The Toronto and Region Conservation Authority (2010) define LID as;

> "A stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff and distributed, small scale structural practices that mimic natural or predevelopment hydrology through the process of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows."

According to social science research done on LID implementation by Olorunkiya *et al.* (2012) there is still a high amount of reluctance of LID implementation in both the public and construction professionals. LID implementation is still considered very risky with uncertain outcomes and results due to lack of conviction and knowledge (Olorunkiya *et al.*, 2012). In order to properly assess a potential LID site, an evaluation is typically done through field investigation and monitoring focusing on topography and soil conditions (Ahiablame *et al.*, 2012). Most existing retrofits and LIDs are currently used as prototypes, pilot projects or education projects; however, many have the potential to be bundled with municipal construction projects such as streetscaping, transportation projects, school construction, park improvements, drainage improvements and neighbourhood revitalization (Toronto and Region Conservation Authority, 2010).

LID is generally aimed at solving chronic flooding problems, stormwater demonstration and education, trapping trash and floatables, reducing runoff and reducing pollutants of concern. There are two main types of retrofits outlined by the Toronto and Region Conservation Authority and the Centre for Watershed Protection; Storage retrofits and on-site retrofits. Storage retrofits generally treat a drainage area of 5 to 200 ha. There may be a need for dozens within a single watershed, if done properly it can me*et al*l the stormwater LID and retrofit objectives and it consists of extended detention, wet ponds and constructed wetlands. On-site retrofits tend to treat a drainage area of <1-5 ha in size. There may be a need for hundreds within a single watershed, generally only meets recharge and water quality stormwater targets, few permits are needed for implementation and can serve as a neighbourhood education tool. On-site retrofits generally consist of: rainbarrels, rain gardens, landscaping, bioretention, filtering, infiltration and permeable pavers.

2.7.2 Municipal Maintenance and Policy Criteria

According to the Centre for Watershed Protection (CWP) (2005) Thunder Bay is considered a Phase I community which is defined as a community with a separated storm drain system with a population of over 100,000 people. Under this definition, according to the CWP, the municipality should be responsible for the monitoring of stormwater quality, up-to-date mapping of the storm drain network, outfall screening, removal of illicit discharge, pollution source identification, structural and source control measures to reduce pollutants, erosion and sediment control programs and fiscal analysis of stormwater. General conflicts that tend to occur within Phase I communities is uneven administration by permitting agencies and municipality and fragmented jurisdictional responsibilities related to integrated stormwater issues. There is very little published literature on the role of municipalities in stormwater management. Municipal policy criteria should be implemented when there are current municipal by-laws that are not being followed and causing impacts on stormwater systems and if there are activities occurring within the subwatershed that need a new by-law in place to mitigate negative stormwater impacts (Centre for Watershed Protection, 2005). According to the Toronto and Region Conservation Authority (2010), municipalities across Ontario generally rely on the expertise within the local Conservation Authority for water management and the restoration and enhancement of the natural environment. The *Conservation Authorities Act* (1990) states that the Conservation Authority (CA) is to study and investigate the watershed and to determine a program whereby the natural resources of the watershed may be conserved, restored, developed and managed; and, to cause research to be done (Section 21); and to make regulations applicable in the area under its jurisdiction (Section 28). Some municipal maintenance activities that could incorporate stormwater impacts mitigation outlined by the Centre for Watershed Protection (2005) include: hotspot facility management, construction project management, street repair and maintenance, street sweeping, storm drain maintenance and park and landscape maintenance.

2.7.3 Education and Outreach Criteria

According to Barten *et al* (2004) in a survey done across the United States, water quality is the most consistetly important value for the public in association with land protection. Water issues, including stormwater issues tend to have a successful public support because the general public can generally make the connection between water quality and human health risks (Barten *et al.*, 2004). There are no definitively set criteria to determine whether one area is more suited to education and outreach over another as community education can occur in residential, commercial or industrial areas (Centre for Watershed Protection , 2005). There are however five specific major sources of stormwater pollution that can be examined and considered in any given area. These sources consist of: yards and lawns, driveways, sidewalks and curbs, garages and sheds, rooftops and common areas. It is suggested that if there is a large amount of any of these pollution sources in an area, negative stormwater impacts are associated.

The Centre for Watershed Protection (2005) suggests a theory called Residential Stewardship. This theory considers that residents of an area engage in many behaviours and activities that can influence water quality. Behaviours such as over-fertilizing, oil dumping, littering and excessive pesitcide use can negatively impact water quality. However, other behaviours such as tree planting, disconnecting rooftops and picking up pet waste can help improve water quality. In order to reduce the amount of pollution contributed to streams and other local aquatic resources through negative residential behaviours, communities can develop stewardship programs that discourage the negative behaviours and encourage positive ones. These programs are often supplimented with education and outreach events, financial incentives and in-kind services. Studies have shown that neighbourhoods and communities that are engaged in social activities are more likely to adapt an education and outreach campaign.

2.8 Future Research Needs

The literature shows that there is still obvious hesitation and reluctance of communities to adopt alternative stormwater BMP's. The literature is showing a lack of long-term cost-benefit studies, effectiveness, base line data studies and easy to use technical stormwater manuals. Most of the available literature in progressive stormwater BMP's is based in the United States or Australia. This makes adapting the baseline data and technical manuals to a northern climate difficult at times. There is a lack of literature published on the effectiveness of stormwater management in Ontario, specifically. The most recent Ontario-wide stormwater manual was developed by the Ontario Ministry of the Environment in 2003; *Stormwater Management Planning and Design Manual.* The manual has been criticized by Bradford *et al* (2004) as not encorporating enough LID measures and focusing too much on end of pipe solutions. The manual does, however, place Ontario as a leading province in stormwater management in Canada (Bradford *et al.*, 2004). In 2010 the Toronto and Region Conservation Authority (TRCA) released a Low Impact Development manual; *Low Impact Development Stormwater Management Planning and Design Guide.* The guide focuses on the implementation of LID measures mainly in the southern portion of the province based on very heavy engineering techniques.

In 2010 the province of Ontario proposed the Water Opportunities Act. This Act states that all municipalities within the province will have to prepare a Municipal Water Sustainability Plan (Government of Ontario, 2010). The plan must include details on physical infrastructure, finances, a conservation plan and long term strategies of the municipality. The Act was passed in November of 2011 stating that all municipalities within the province will have to develop a plan that includes the effects of stormwater discharge. The implimentation of the Act will create a new paradigm in stormwater management across the province. Currently stormwater BMP's in Ontario are concentrated in the southern portion of the province. In 2010 the Ontario Ministry of the Environment (MOE) completed a review process of existing policies, acts and regulations surrounding stormwater management in Ontario (Ministry of the Environment, 2010). The ministry concluded that there is a need for Ontario to develop municipal stormwater management plans across the province.

There is currently very little published literature on stormwater management in Thunder Bay. One paper was found written by Harun Rasid (1988) called *Urban Floodplain Management in Thunder Bay: Protecting or Preventing Floodplain Occupancy?* The outcome of researching stormwater management in Thunder Bay has suggested that there needs to be more literature produced for the area. Taylor *et al.* (2007) states that future stormwater research has to evaluate the effectiveness of management systems to improve the quality of stormwater discharge. Literature needs to be produced on how to develop effective education programs involving participants from commercial businesses, industry and the general public. According to Roy *et al.* (2008) Research on the cost and benefits of stormwater projects consisting of on the ground data comparing effectiveness needs to be done. There needs to be proof that watershed wide stormwater management is not only a plausible concept but actually improves downstream ecosystem quality. There also needs to be integrated management across all levels of government and municipal divisions when managing stormwater. More information on effectiveness and efficiency is needed before wide spread stormwater implementation will be accepted.

More studies are required to evaluate the long-term effectiveness of LID's and BMP's. Monitoring of long-term effectiveness was a future research need in 1997, and current literature is still saying the same thing (Tsihrintzis *et al.*, 1997). A question that arises from most developers is the site suitability and winter performance of LID practices (Dietz, 2007). There has been development of large scale LID practices in North America, however, as of 2007, there has only been one study published on long-term monitoring of stormwater quantity and quality.

Although there is not extensive research published on LID implementation, the literature to-date shows great promise in the effectiveness of watershed restoration. There needs to be more research done on long-term effectiveness of LID implementation, along with cost-benefit analysis (Dietz, 2007).

Climate change is expected to have significant impacts on water resources in Canada, particularly in the north causing threats to the existing socio-ecological system (Loe *et al.*, 2010). The current design of stormwater drainage systems are based on historical weather events. An increase of rainfall and precipitation into these systems threatens the structural integrity of the system and increases the chance of urban flooding (Mailhot *et al.*, 2010). The increased precipitation events also increase the levels of non-aquatic contaminants to the aquatic system through stormwater discharge (Mailhot *et al.*, 2010). Climate change is forcing water managers to not only consider existing environmental impacts but also the implications of emerging issues due to climate change never seen before (Loe *et al.*, 2010). As these issues become more prevelant in stormwater management, there needs to be a focus placed on strengthening the capacity of all actors involved (Loe *et al.*, 2010). Mailhot *et al.* (2010) believes there should be a global stormwater drainage adaptation strategy to maintain resillience of the stormwater socio-ecological system over the long-term.

3.0 Study Site Description

In order to assess remediation options along McVicar Creek, three sites were chosen. The sites were chosen based on recommendations of previous studies completed by the Northshore RAP and Lakehead University (Northshore Remedial Action Plans, 2010 and 2011). Since the City of Thunder Bay does not currently have stormwater management policies in place at the municipal level, the completion of this thesis could aid the City of Thunder Bay in implementing stormwater management strategies along McVicar Creek. The City could adopt the idea of small scale stormwater development projects leading to a larger municipal wide stormwater management plan.

The following site description maps are showing the subwatersheds that were mapped for this study. The pictures are showing the visual condition of the stormwater outfalls, as the outfalls themselves are described and had an influence on site selection.

3.1 McVicar Creek

McVicar Creek is one of five major tributaries within the City of Thunder Bay that enter the north shore of Lake Superior. The McVicar Creek watershed drains an area of almost 52 km^2 and spans across approximately 16 kilometers of the city. The creek receives significant loads of stormwater pollution due to the highly urbanized lower reaches of the creek (Lakehead Region Conservation Authority, 2002). The hydraulic geometrics of the lower reaches of the creek is approximately 3m in width with a peak flow ranging from 4.8 to 39.5m^3/s at the mouth of Lake Superior. The three subwatersheds studied in this thesis are all located in the lower, more urbanized portion of the McVicar Creek watershed (Figure 1).

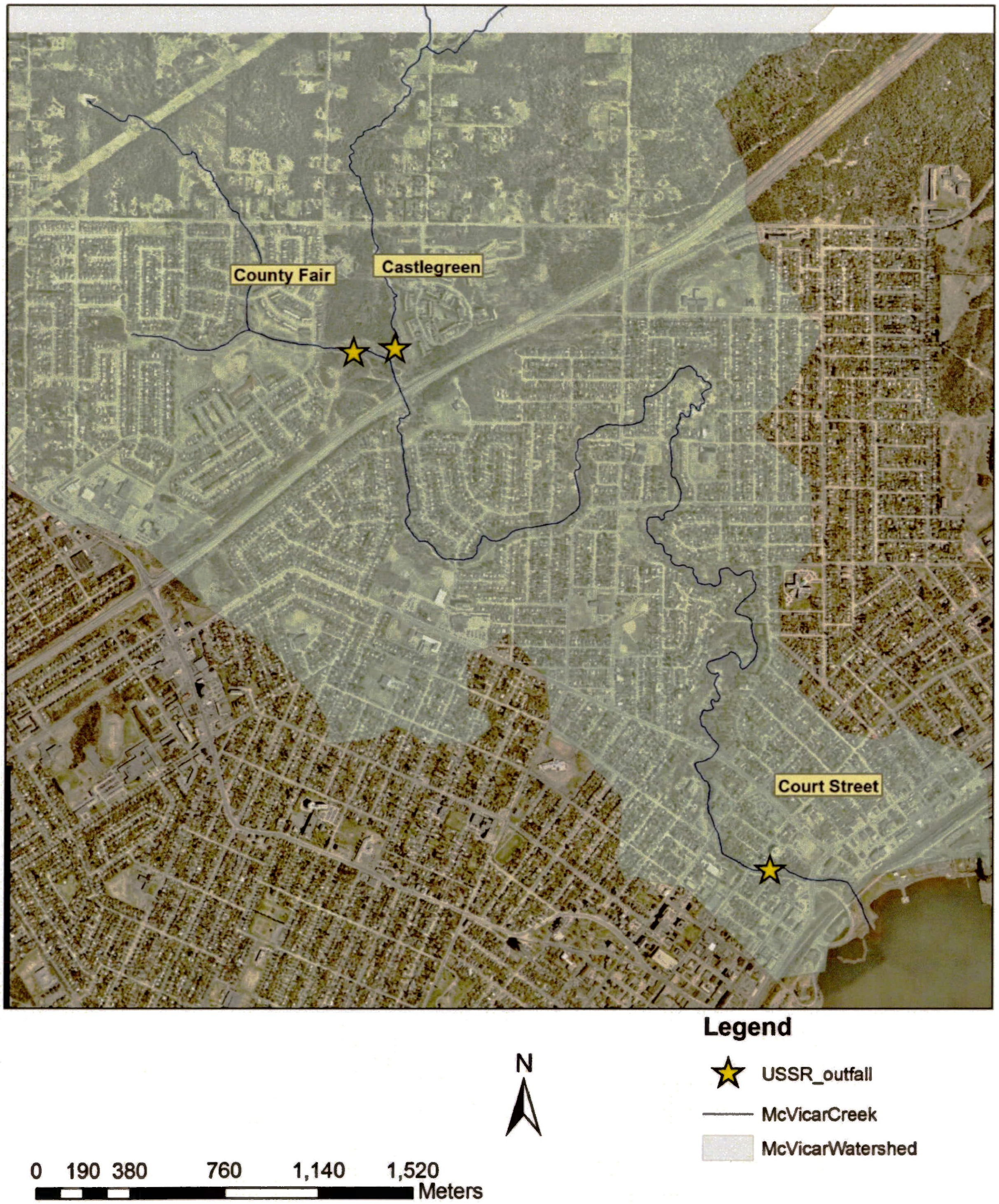

Figure 1. Map showing McVicar Creek watershed and locations of three study sites along the creek.

3.2 Court Street

The Court Street subwatershed can be characterized as mainly residential with scattered commercial areas. Most residences within the catchment basin are single family detached homes. The Court Street catchment is located on the north side of Thunder Bay, having initially developed as part of the then-city of Port Arthur in the late 1800's (City of Thunder Bay, 2011). Court Street is the oldest subwatershed development studied in this thesis as well as the largest. According to GIS analysis, the catchment area is 22 hectares in size. Impervious area makes up 39% of the catchment basin which is the lowest percentage of the three areas studied. The remaining 61% consists of open green space, private lawns and large urban tree cover.

The outfall discharging stormwater from the Court Street subwatershed has a constant dry weather flow, as well as a pipe diameter of over 90 cm. The outfall was ranked number one in severity out of eight, one being the most severe, based on water quality sample results exceeding water quality levels outlined in the PWQO's and CWQG's in 2010 (Northshore Remedial Action Plans, 2010). The 2010 and 2011 water quality results show that the Court Street outfall has exceeding levels of ammonia, aluminum, copper, iron and zinc (Northshore Remedial Action Plans, 2010; 2011). The outfall has light erosion of the concrete due to the constant flow of water. The dry weather flow is at the rate of a trickle. See Figure 2 for Court Street subwatershed.

Figure 2. Map showing Court Street Subwatershed and associated stormwater pipes and outfall.

3.3 Castlegreen

The Castlegreen subwatershed can be characterized as completely residential. Most residences within the catchment basin are single family attached homes. The Castlegreen catchment is a more recent residential development created in 1976 (Castlegreen co-operative, 2010). The development is a community co-operative consisting of affordable housing. There are many residential gardens in the catchement along with a community garden located on the edge of the community. The co-operative has a no herbicide spraying policy on communal lands within the community. According to GIS analysis, the catchment area is 7 hectares in size, being the smallest area studied in this thesis. Impervious area makes up 45% of the catchment basin. The remaining 55% consists of manicured open space, private lawns and parks.

The outfall discharging stormwater from the Castlegreen subwatershed has constant dry weather flow and a pipe diameter of less than 90cm. The outfall was ranked number seven in severity out of eight, one being the most severe, based on water quality sample results exceeding water quality levels outlined in the PWQO's and the CWQG's in 2010 (Northshore Remedial Action Plans, 2010). The 2010 and 2011 water quality results show that the Castlegreen outfall has exceeding levels of ammonia, phosphate, iron and zinc (Northshore Remedial Action Plans, 2010; 2011). This outfall has oil-stained concrete with a constant trickle flow of cloudy water, as well as thick green algae growth, brown foam floating in the pool and excessive benthic growth. The concrete base on the outfall is corroded to the point of rebar exposure. See Figure 3 for Castlegreen subwatershed.

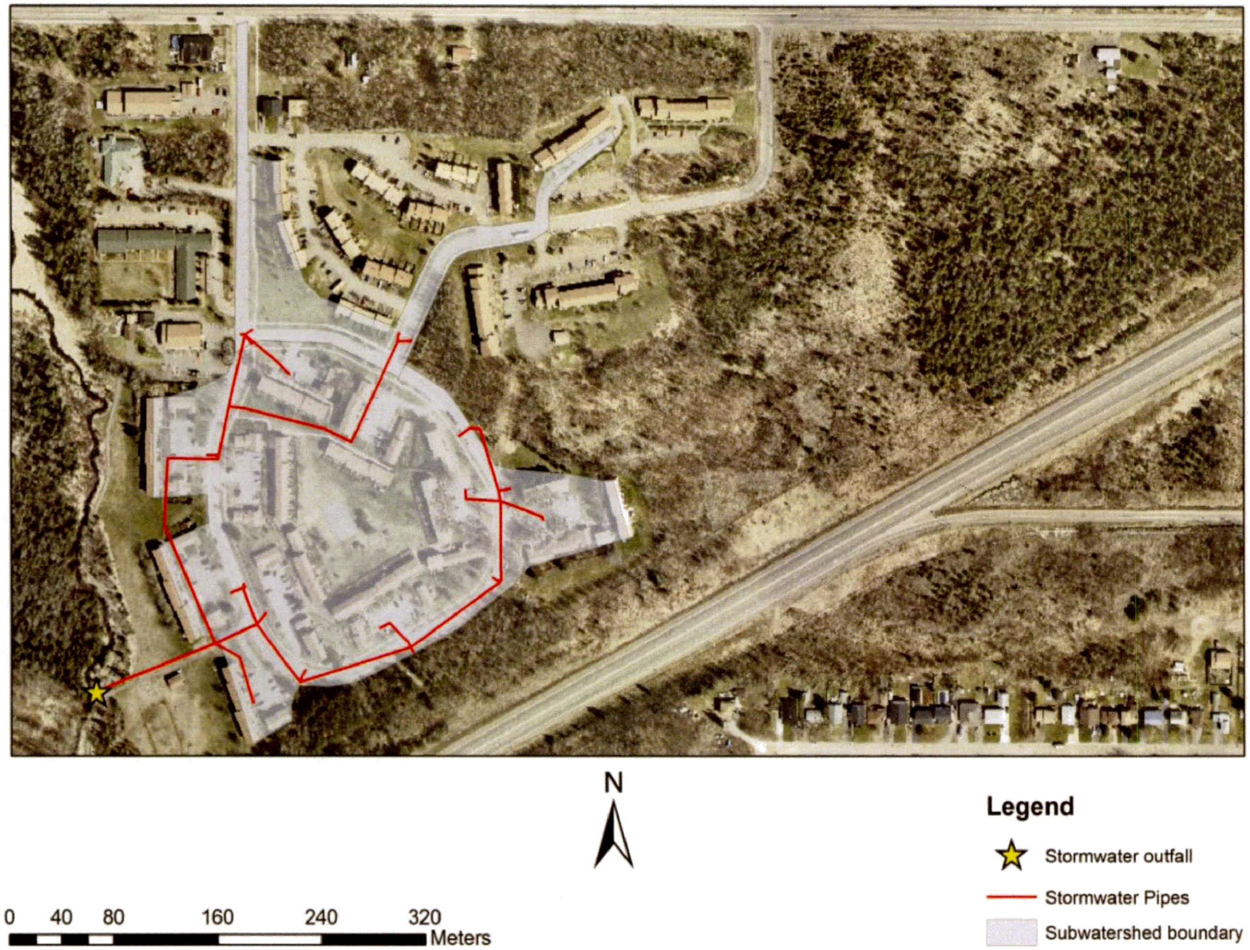

Figure 3. Map showing Castlegreen subwatershed and associated stormwater pipes and outfall.

3.4 County Fair

The County Fair catchment basin can be characterized as a mix of commercial and institutional land uses, with only a small component of residential land. Most residences within the catchment basin are single family detached homes. The commercial structures are a mix of single and multi business complexes. The institutions within the catchment basin are churches and schools. The County Fair catchment is a relatively recent development. According to GIS analysis, the catchment area is 20 hectares in size. Impervious area makes up 62% of the catchment basin which is the largest percentage of the areas being studied in this thesis. The remaining 28% consists of private lawns and open stormwater ditches.

The outfall discharging stormwater from the County Fair subwatershed has constant dry weather flow and a pipe diameter of over 90 cm. The outfall was ranked five in severity out of eight, one being the most severe, based on water quality sample results exceeding water quality levels outlined in the PWQO's and the CWQG's in 2010 (Northshore Remedial Action Plans, 2010). The 2010 and 2011 water quality results show that the County Fair outfall has exceeding levels of ammonia, chloride, aluminum, copper, iron and zinc (Northshore Remedial Action Plans, 2010; 2011). This outfall has a constant high flow rate with trash clogging the grate, as well as sediment accumulation of over 50% of the pipe at times. Based on GIS analysis of the pipe line inputs, the majority of the stormwater flowing into this outfall is coming from County Fair Mall. The County Fair outfall is located on a portion of the creek that was excavated in the early 1980's to serve as a municipal wastewater channel. According to the 1994 Lakehead Region Conservation Authority floodplain mapping data, that portion of the creek is now considered part of the creek itself and is incorporated in the McVicar Creek floodplain. See Figure 4 for County Fair subwatershed.

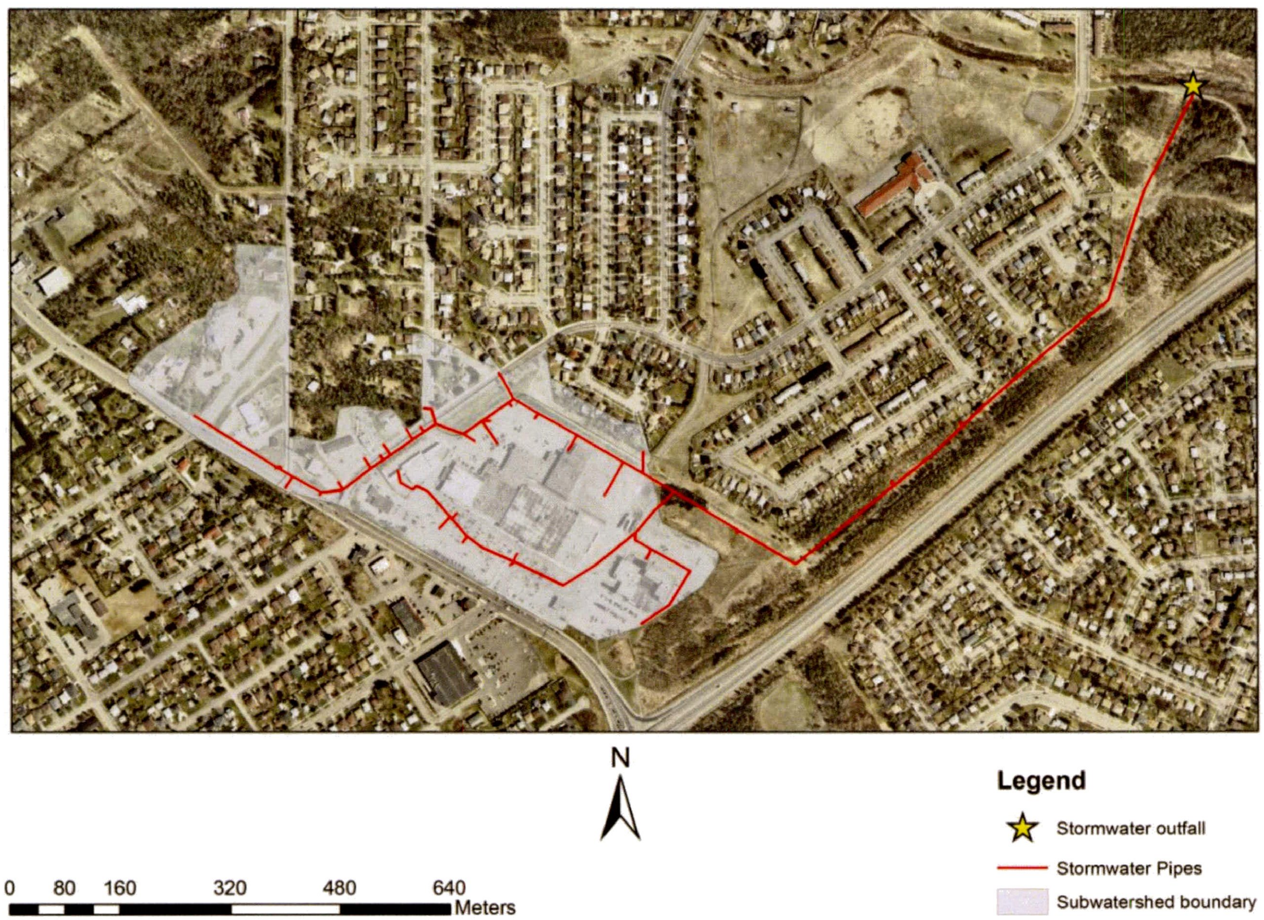

Figure 4. Map showing County Fair Subwatershed with associated stormwater pipes and outfall.

3.5 Case Study Site Selection

In order to properly assess a site for a Low Impact Development (LID), the local hydrology and soil properties need to be known (Toronto and Region Conservation Authority, 2010). Low Impact Development pilot projects are developing fairly rapidly around the Province of Ontario (Stewardship Network of Ontario, 2012). There are provincial-wide along with federal-wide funding opportunities to develop stormwater remediation pilot projects. The majority of LID and stormwater projects currently being pursued are concentrated in the southern portions of the province of Ontario (Ministy of the Environment, 2010). The purpose of this case study is to build-up base line data for the area to evaluate LID opportunity, as well as develop decision-support criteria for assessing potential LID sites around the city.

All three sites were assessed for a potential LID case study. A portion of the selection method involved comparing aerial photos of the sites with existing literature and pilot studies. A group was formed involving members from Lakehead University's stormwater research team and an engineer from the Bear Point Pollution Treatment Plant in Thunder Bay. Possible LID scenario's were discussed and drawn out by the group for each site. Each possible LID idea that came from the group was further researched for feasibility and cost. A site selection criterion was determined to suit a Thunder Bay local environment. These criteria ultimately included:

- Ownership of land (public or private)
- Overall cost
- Feasibility based on Thunder Bay's current stormwater management practises
- Location for optimal community education and outreach, and;
- Localized stormwater inputs

Ownership of land is an important factor in a watershed project time frame (Centre for Watershed Protection, 2005). The time frame is generally much shorter for implementation of a pilot project on public lands if the municipality and permitting agencies, in this case the Lakehead Region Conservation Authority, are supportive. At the time of criteria selection for a case study, the only known and secured source of funding was through the Northshore Remedial Action Plans (RAP). This made cost analysis a high priority. At the time of selection there were little to no stormwater remediation pilot projects done in the City of Thunder Bay. Due to the lack of pilot projects and stormwater awareness in the city, it was determined that the case study should reflect an end-of-pipe LID solution. It was determined that the case study should also be located in an area of heavy non-automobile traffic for optimal community environmental education and outreach. The localized stormwater inputs for each site were determined through previous research done by the Northshore RAP and Lakehead University.

Once the County Fair site was agreed on for the case study, further research was done to create a field based case study project to determine a suitable stormwater remediation option on this site. The County Fair site was also chosen because of the fact that it was already a human influenced channel due to excavation.

4.0 Methodology

The methods used in this thesis were selected to effectively achieve the objectives of; developing a feasibility criterion of site-specific stormwater remediation options for each identified site along McVicar Creek; to implement a decision-support criterion to identify the most effective stormwater remedial options based on Low Impact Development (LID), community education, policy/regulation and maintenance. The stormwater remediation recommendations produced in the study have been developed through a mixed methodology that uses quantitative (i.e. land-use, soil and water quality data) as well as qualitative research methods (i.e. decision-makers workshop). In addition to journal articles, the methods for this thesis were adapted to local conditions from applicable technical manuals including; The Toronto and Region Conservation Authority and Credit Valley Conservation Authority's *Low Impact Development Stormwater Management Planning and Design Guide*, The Centre for Watershed Protection's *Urban Subwatershed Restoration Manual Series* and The Ontario Ministry of the Environment's *Stormwater Management Planning and Design Manual.* All quantitative method procedures used in this thesis, where applicable and available, meet the American Society for Testing and Materials (ASTM) international standards. The methodology used in this thesis is consistent with the methods used in previous Lakehead University and Northshore Remedial Action Plans stormwater remediation research (Northshore Remedial Action Plans 2010 and 2011).

A large portion of the qualitative methods used in this thesis consisted of stakeholder participation. The stakeholders were presented in a workshop with two scales of decision making criteria after several expert stakeholder sessions involving an introduction and a site visit. The first was on a larger watershed scale, looking at broad water quality and site information categorizing McVicar Creek as a whole. The other was on an individual case study scale looking at very specific topographic, soil, infiltration and water quality up-stream and downstream data. Both scales of data and information were presented to the group for multiple-scale decision making criteria. The initial data collection for this thesis was the completion of a Unified Subwatershed and Site Reconnaissance (USSR) on each site. The USSR examines potential pollution sources upland of stormwater outfalls within an urban watershed (Center for Watershed Protection, 2005). Once the USSR was completed; soil, infiltration and further water quality testing was completed on the County Fair case study site in order to present all relevant information to Stakeholders. This methods section first describes the methods of the USSR assessment, then provides methods of water quality sampling across the three sites, then details the collection of physical quantitative data on the case study site, this methods section concludes with described methods of expert stakeholder involvement.

4.1 USSR Assessment

The USSR assessment is an extended phase of the previous stormwater remediation research completed by the Northshore RAP and Lakehead University. The USSR results were presented in detail to the stakeholder group to properly develop a feasibility criterion of site-specific stormwater remediation options for each identified site. The USSR results also heavily influenced the implementation of a decision-support criterion to identify the most effective stormwater remedial options. This was done by the group having a full understanding of the subwatersheds contributing stormwater inputs. By characterizing the subwatersheds, a better understanding of where a suitable community education program, policy/regulation implementation or maintenance option could be further pursued based on behaviours and activities observed in the terrestrial environment (Centre for Watershed Protection, 2005). The subwatershed characterization also aides in determining what negative stormwater behaviours in the terrestrial environment need to be addressed.

The USSR assessments consisted of a standardized qualitative analysis of urban subwatersheds. Land-use surveys were completed on the three sites using the adapted field forms from the Centre for Watershed Protection which can be found in Appendix 1. Characteristics of each urban area were recorded into an iPad that contained all adapted field forms. The assessment started with the Court Street site and continued with Castlegreen and into County Fair. Each site was separated into multiple sub-areas based on drainage features and land-use. The sub-areas were delineated into separate polygons on the iPad, and a Catchment Source area was completed on each. Three different assessment components were completed on each site based on potential pollution sources. These components included the Catchment Source Assessment (CSA), the Hotspot Source Assessment (HSI) and the Streets and Storm Drains assessment (SSD). The assessments were completed by walking the entirety of each subwatershed and observing and recording behaviours and activities.

The CSA assesses the overall pollution contributing behaviours in a given site to gain an idea of contamination severity (Center for Watershed Protection, 2005). The CSA produced a detailed analysis and inventory of the health of yards and lawns within an area, driveways, sidewalks and curbs, rooftops and common areas. The assessment also collects basic information about an urban area in order to characterize runoff being contributed from that specific area.

The HSI assesses individual "hotspots" that could potentially be contributing significant sources of pollution to the water system. The HSI identifies specific points of pollution located within the generalized catchment source area. An area would be considered a "hotspot" if it was a commercial, industrial, institutional or transport-related operation that is contributing excessive levels of pollutants to the stormwater system, or if there is a high risk of spills, leaks or discharge from the operation (Center for Watershed Protection, 2005). The HSI produced a detailed analysis of the vehicle operations on the premises, hazardous materials being stored outside, the management of waste, the physical building itself and the stormwater infrastructure.

The SSD assesses the quality and cleanliness of individual streets, sidewalks, parking lots and storm drains. An SSD is performed if any of the above urban features is visually impaired in some way. Examples of these impairments are excessive oil stains, excessive sediment accumulation, excessive cracking and breaking of pavement, or accumulation of organic material or litter. The SSD produced a detailed analysis of the location of the impaired feature, the condition and the storm drain infrastructure. There are two separate assessments within the SSD, one is used for the assessment of a street or parking lot and the other is used for individual storm drains. The difference is a polygon or point, respectively, in the iPad.

All three assessment forms were adopted from the Urban Subwatershed Restoration Manual 11 created by the Center for Watershed Protection in 2005. The forms were adapted to suit a northern environment, and to be applicable in a smaller urban setting such as Thunder Bay. The USSR site assessments are used and interpreted to make broad preliminary remediation recommendations on each site. These recommendations are based on observed stormwater impacts and behaviour within a given subwatershed. The recommendations that are produced from the completion of the USSR are, however, recommendations for further investigation and to be possibly pursued further by an organization or group. The USSR does not encompass the values and views of the general public or stakeholders.

4.2 Water Quality Testing

The water quality parameters tested in this thesis were ammonia, nitrate, nitrite, phosphate and chloride. Water quality results were compared to applicable criteria published in the Provincial Water Quality Objectives (PWQO) protocol (Ministry of the Environment, 1994), the Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life (Canadian Council of Ministers of the Environment, 2007). If there are no standards in either the PWQO's or the CWQG's, the United States Environmental Protection Agency guidelines were used (US Environmental Protection Agency, 2011). The Canadian water quality guidelines are intended to provide protection of freshwater and marine life from anthropogenic stressors such as chemical inputs or changes to physical components (Canadian Council of Ministers of the Environment, 1999). The PQWOs have a similar goal of ensuring "that the surface waters of the province are of quality which is satisfactory for aquatic life and recreation" (Ministry of the Environment and Energy, 1994). The PWQO's general procedures states that their objectives are most commonly used for municipal or industrial point sources but can also be applied to stormwater or other polluting sources. The information collected through water quality testing provides stakeholders and the public with a direct link of stormwater to water quality impairments. This information also provides real aquatic impairment data in a visual form to stakeholders. The water quality parameters that were found to exceed the specified guidelines were presented to stakeholders to aide in the development of site-specific feasibility criteria, as this information provides individual pollution levels contributed directly from stormwater outfall inputs. The water quality data is also used in the implantation of a decision-support criterion to identify the most effective stormwater remedial options based on the aquatic effects of the individual contaminants. The water quality information can also provide insight on possible point-sources with the data collected through the USSR process, which provides a context for site-specific feasibility criteria.

Water quality testing in this thesis was consistent with the testing done in the previous stormwater research through the RAP and Lakehead University (Northshore Remedial Action Plans, 2010 and 2011). The original water quality testing protocol was based on the U.S Geological Survey National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 2006). A 9500 series YSI photometer was used to determine levels of ammonia, nitrate, nitrite, phosphate and chloride. The YSI 9500 series photometer has been used for researching water quality internationally for a variety of research studies including but not limited to; research published by the Journal of the World Aquaculture Society in 2012, using all parameters of the 9500 series water quality testing and research published by Aquatic Toxicology in 2011 using nitrite sampling. This thesis looks at the levels of ammonia, nitrate, nitrite phosphate and chloride discharging from all three outfalls. Sample days were determined in advance to account for randomness in weather patterns and urban contributions. During this water quality sample procedure, both dry (no precipitation) and wet (during a rain event) samples were collected and accounted for. Water sampling was divided into two seasons; spring and summer to determine potential seasonal variability. Samples were taken once a week, every Tuesday for six weeks in the spring season, which was defined as May 22, 2012 – June 26, 2012, and five weeks in the summer season, which was defined as July 17, 2012 – August 14, 2012.

Grab samples were taken from each outfall on collection days, as well as directly upstream and 100 meters downstream from the County Fair outfall. Water quality samples were taken upstream and downstream from the County Fair outfall to further characterize the case study site. The grab samples were taken directly at the mouth of the outfalls, being careful to only collect liquid being expelled from those outfalls. The samples were collected in sterilized 1 litre plastic bottles. Once the samples were processed, the containers were thoroughly cleaned and sterilized with distilled water. The containers were always triple rinsed in stream before any sample was taken. The containers were clearly marked by site, so there was no confusion in the lab. The county Fair site was always done first using chest waders and gloves. The Castlegreen site was always done second as it was in walking distance and the Court Street was always done third. Once the samples were taken, they were brought back to the lab right away and processed.

The YSI 9500 series photometer used similar reagents to that of the LaMotte soil testing kit. For each test, there is a reagent pill and a specified waiting time for each parameter. The photometer was quality assurance tested several times prior to field sampling. The tests were conducted on water of relatively known parameter levels. The quality assurance tests were done at least 5 times per parameter prior to data collection. While using the photometer it was ensured that the test chamber was clean, the test tubes were cleaned and sterilized before any test was completed, that blanking tubes were clear of fingerprints, that stated instructions were followed exactly from the manual, that proper timing was always followed, that the sample was not disturbed in any way during settling time, that the dilution factor was properly selected and procedure followed, that the light cap was used when needed and that the equipment was stored in the case at all times when not in use.

One site was done at a time with all parameters. The testing started with Ammonia, then nitrite, nitrate, phosphate and then chloride. The duration of settling time was ten minutes for most tests. Time was kept using a stop watch. The sample water was poured into a test tube using a funnel up to the specified line. Once the water was in the tube, the reagent(s) were added, crushed up if necessary and shaken if necessary. Ammonia, nitrite, phosphate and chloride all had two reagents added to the solution. Once the solution settled for the specified amount of time, it changed to a pre-determined colour. Once the samples had settled, the photometer was set to the specified testing number and a test tube of the clear water sample, or blanking tube, was inserted to be compared to the reagent sample. Once the blanking tube was finished calibrating, the settled sample was inserted. The photometer read the sample and displayed the level of contaminant in mg/L. Ammonia was tested for N, NH_3 and NH_4, nitrate and nitrite were tested only for that specific parameter, phosphate was tested for PO_4 and P and chloride was tested for Cl, $CaCO_3$ and NaCl. For the purposes of this thesis, the results from NH_3 will be used for ammonia, P will be used for phosphate and Cl will be used for chloride. These parameters are consistent with the previous nutrient water quality sampling. Metal parameters were tested for 4 weeks; however the photometer showed inaccurate levels, or no levels at all in the water samples, so the metal parameters were not pursued further. This thesis does not detail the target of reducing automobile traffic in the city, so metal parameters were abandoned. If the sample was read as too high to process, the sample was then diluted in the dilution tube to either 2x, 3x, 4x, 5x or 10x the original level. All water used in any aspect of water quality testing outside of the sample, for either dilution or rinsing, was distilled. All results were recorded in a spread sheet in real time.

4.2 Case Study Field Sampling

The methods used in the case study field sampling were only done on the County Fair end-of-pipe site. They were the first data collection to occur for this thesis as the information is needed to present to expert stakeholders. Upstream and downstream samples, along with outfall discharge water quality samples were taken on the County Fair site as well to further characterize the case study. The case study was further studied quantitatively to provide stakeholders with multi-scale decision making ability. According to the Toronto and Region Conservation Authority (2010), soil characteristics and infiltration rates need to be known prior to the decision to implement an LID. The data collected on the case study site was strongly correlated to the possible decision of an LID remediation option recommendation. This research method was used partially to observe if this information would push the stakeholders towards this obvious remediation recommendation option, as well as to provide site specific data for the stakeholders to make a fully informed decision. Soil characteristics along with infiltration rates and water quality data provide an in-depth characterization of a specific site, specifically how it relates to stormwater inputs (Toronto and Region Conservation Authority, 2010).

4.2.1 Soil Sampling

The soil sampling was completed at the beginning of the field season in order to properly conduct the soil testing procedures outlined in the following sections. The amounts of soil needed for testing was determined prior to collection to ensure enough dried sample was available to complete the nutrient, organic and composition testing. The results of these tests were then presented and explained to the stakeholder group at the decision-making workshop. This section outlines the procedure of just collecting the soil needed for further testing. There are two common soil sampling techniques; test pits and soil boring. The use of soil pits are the preferred method due to the limited sample and visual observations of the boring method (Toronto and Region Conservation Authority, 2010). The soil pit method was used for the purposes of this thesis.

A total of 6 soil pits were dug with a common shovel. One pit with a repetition located 20 meters due east was dug near the mouth of the outfall. One pit with a repetition located 10 meters north-east adjacent to the creek was dug 100 meters downstream of the outfall. One pit with no repetition was dug 65 meters north-east of the outfall on a higher elevation, treed area outside of the creeks floodplain. This area is known to be the excess sediment excavated from the creek during construction of the channel. The last soil pit with no repetition was dug 30 meters south of the outfall. This soil pit was located on the south side of the recreation trail following the creek, and is expected to correspond to the soil structure that would have existed in the current floodplain prior to excavation. All soil pits were dug at a 1 meter width, 1 meter length and 1 meter depth unless bedrock, water table or parent material was encountered. The soil pit locations were chosen to fully and effectively evaluate the case study area. See figure 8 for soil pit locations.

All soil pit locations and information were recorded on an iPad through the GIS Roam application. The information collected included; date, depth of pit, horizons present and whether bedrock or water table was encountered. Five bags of 4 oz sample were taken, using a trowel, of each horizon of each pit totalling 20 oz of sample per horizon. There were fifteen horizons in total across the six soil pits. Once the samples were completed, they were brought back to the Department of Geography soils lab and placed on ceramic plates in a drying oven set to 40°C. Intermittent weights were taken throughout 2 weeks to determine the complete loss of moisture from the sample. Once the recorded sample weight was consistent over 3 consecutive periods, the sample was completely dry. No tests could be completed on the soil sample until it was proven dry. The samples were kept in the drying oven at any point in which they were not being used over the duration of soil testing. Each sample was then tested for nutrients, organic content and texture and composition.

4.2.2 Soil Testing

Once the soil was collected and processed to the necessary point of testing, the testing could begin. The tests completed on the soil samples used a range of chemical and mechanical techniques. Details are described below. One of the most important pieces of information needed for an LID consideration is the soil particle size, structure, drainage, nutrients, depth and pH, due to the relationship between soil structure and vegetation (Toronto and Region Conservation Authority, 2010). Most LID measures require a certain amount of vegetation to be planted. It is common for a planting plan to include the removal of current soil and replace it with a more effective soil media for optimal growing conditions. The soil test results were provided to the stakeholder group as a tool to make an informed decision about a possible LID remediation option. Without this detailed information, according to the TRCA (2010), the group could not have made a properly informed site-specific feasibility criteria or decision-support criterion with the possibility of an LID. All of the soil test results were provided and considered in the decision-support criteria determined by the stakeholders when considering an LID as a remediation option.

4.2.2.1 Soil Nutrient Testing

Soil nutrients such as nitrogen and phosphorus, along with pH play a key role in plant development and growth (Toronto and Region Conservation Authority, 2010). It is important to be aware of the available nutrients in the soil when planning any type of vegetated LID in order to determine a suitable and effective planting plan. Stormwater discharge has been shown to increase the level of these nutrients in localized sediment, particularly at the source of stormwater drainage (Davis *et al.*, 2001). There is no Canadian or American sediment guideline pertaining to any nutrients tested in this thesis. The nutrients are being looked at more so for vegetation quality and suitability, rather than contaminants. Most plants thrive well in a neutral soil pH falling between 6 and 7.5 (Toronto and Region Conservation Authority, 2010).

The most shallow soil horizon of each soil pit was tested for levels of ammonia, chloride, nitrate, nitrite, phosphorus and pH. All macro-nutrient testing of soil was done using the LaMotte STH-4 5029 series soil testing kit. ALS Environmental Labs, as well as the Forest soils lab located within the Faculty of Natural Resources Management at Lakehead University, are the other two locations in Thunder Bay that could have completed the same nutrient testing as the LaMotte soil test kit. The LaMotte kit was used in this thesis due to the known accuracy and regular use through the Department of Geography at Lakehead University. I performed the testing with the guidance of professionals within the department. The testing was done first on soils with known nutrient levels such as fertilized gardening soil for quality assurance purposes. The quality assurance was done on each test at least 5 times with several different, known soil types. The nutrients tested were chosen due to the correlation of tested nutrients in water quality sampling. Each test was done using a pre-defined amount of soil and reagent. For any tests that needed H_2O dilution, mineralized or distilled water was used. The specified soil, reagents and H_2O were placed together in either a test tube or spot plate, shaken or stirred respectively, and left for a specified duration. The remaining substance was then visually compared to a colour chart under light. The colour charts had either a range or an exact number associated with the colour of the remaining substance. Ammonia was recorded as very low, low, moderate, high or very high, chloride was recorded in parts per million (ppm), nitrate was recorded as pounds per acre (lbs/acre), nitrite was recorded as ppm, and phosphorus was recorded as lbs/acre. The imperial pound per acre was then converted into the metric kilograms per hectare (kg/ha) by multiplying the lbs/acre by 1.12085116. After each set of tests, the equipment was thoroughly cleaned, sanitized with distilled water and left to air dry before the next tests were completed.

4.2.2.2 Soil Organic Content Testing

Soil texture is determined through the known ratio of particle size and organic content. The most suitable soil type for growing the broadest plant species is a loamy soil with 3-5% organic matter shown as dry weight (Toronto and Region Conservation Authority, 2010). Organic content of soil also tends to limit extreme pH levels in soil. Organic matter is often added to the soil during an LID to meet the desired level.

Once the all the soil samples were dry and nutrient testing was completed, the organic testing was done. Organic testing was done on all horizons collected from all soil pits. The samples were taken out of the drying oven two at a time. The soil was placed into ceramic crucibles using a metal scoop and weighed. The weight was recorded to the nearest 0.01 gram (g), using an electronic balance with a precision of 0.001g. The original weight was made as close to 5 grams as possible. Four samples at a time were placed in a muffle furnace set to a temperature of 850°C for thirty minutes. The samples were removed from the muffle furnace after thirty minutes with leather gloves and metal crucible tongs. The samples were then placed on a ceramic fireproof surface and left to cool for no longer than four minutes. If the samples are exposed to moisture in the air for an extended period of time, they would need to be re-placed in the muffle furnace for another thirty minutes to result in an accurate reading. Each crucible was then weighed again to the nearest 0.01g and recorded. The difference in weight was then determined and the ignition loss was multiplied by 1.75. The calculated loss on ignition burned represents the volatilization of organic carbon, rather than the actual weight of organic matter. It is generally accepted that organic matter is estimated to be 1.75 x the amount of the burned off organic carbon. To correct for this, the original difference of loss on ignition was multiplied by 1.75. The resulting number was the subtracted from the original weight to determine the corrected resulting weight. The percentage was then determined by dividing corrected final weight by the original weight and subtracting one.

4.2.2.3 Soil Composition and Texture Testing

Soil composition and texture is plays a key role in determining infiltration and retention potential, as well as the planting ability of the current soil conditions (Toronto and Region Conservation Authority, 2010). The texture of the soil can influence the effectiveness of a proposed LID as well as the aesthetics of the project. Soil texture is directly related to the organic content present and the retention abilities of a soil type.

Two soil texture methods were used for the purpose of this thesis; the hydrometer method and the sieving method. Many studies show that sieving is an acceptable method for determining soil texture in stormwater management and LID planning including; ASTM standards, Hsieh *et al* (2003) and Toronto and Region Conservation Authority (2010). However, for assurance reasons, both methods were used in this thesis. The hydrometer method was only used on the deepest horizons found in each soil pit, with exception of the repetition pits. The hydrometer method was completed before the sieving method. The hydrometer method involved first sieving the soil into < 2mm soil particles. This is done to remove all potential organic particles from the soil. The amount of soil used in the hydrometer test is determined by the initial sieving results; sandy soil uses 75g, loamy soil uses 50g and clayey soil uses 25g of sample. There was only sample through this test that was classified as anything but sandy soil after the initial sieving results and that was out of soil pit B2, which was classified as clayey. The proper amount of soil was weighed out and recorded to the nearest 0.01g, using an electronic balance with a precision of 0.001g. The soil samples were then placed in separate beakers and 100 ml of H_2O_2 was added to the beaker to remove any remaining organics. The samples with the H_2O_2 were left for 24 hours to ensure complete removal of organic materials. After 24 hours, the solution was diluted with distilled water to the 200 ml mark on the beaker and 50 ml of sodium hexametaphosphate was added to the solution. The solution was then transferred to a baffle plated metal cup and mechanically stirred at full capacity for 15 minutes. The solution was then transferred into a 1 litre cylinder and diluted with distilled water to the mark. Amyl alcohol was added to minimize any froth at the top of the cylinder. The solution was stirred and the temperature was taken and recorded to determine settling duration. The hydrometer was placed in the solution for one minute after the determined amount of time based on temperature, which in all cases was 4 minutes and 34 seconds. After that time the first reading was taken from the top of the meniscus to determine the suspended silt and clay content. The second reading was then taken with the hydrometer to determine silt suspension after the specified amount of time based on temperature, which in all cases was 7 hours and 37 minutes. Both readings were recorded. To determine the actual clay and silt content a specific formula was used; first, the density of water was determined based on temperature in grams per litre. The density of water was then multiplied by 950ml, as that is the amount of water used in the process. The density of the sodium hexametaphosphate was then determined by multiplying 50ml by 0.97 g/ml. The density of the initial 100ml of H_2O_2 is also considered in the calculation. Densities of both the sodium hexametaphosphate and hydrogen peroxide were determined in the lab. The following formula is used for the calculations of density in all hydrometer results in this thesis;

850 (ml of H_20) x 0.997 (g/ml) = 847.45 g

100 (ml of H_2O_2) x 0.96 (g/ml) = 96 g

50 (ml of $(NaPO_3)_6$) x 0.97 (g/ml) = 48.5 g

847.15 (g of H_20) + 96 (g of H_2O_2) + 48.5 (g of $(NaPO_3)_6$) = 991.65 g/L (Density of liquid)

The first hydrometer reading was subtracted by the density of liquid to determine the amount of both suspended clay and silt. The second hydrometer reading was then subtracted by the density of liquid to determine the amount of clay particles. With these results the percentage of clay and silt in relation to sand was determined based on the original weight of the sample. In all instances, the density of liquid was 991.65 (g/L) as the temperature was consistently 22°C.

The sieving method was done on every soil horizon from each pit. For the purposes of this thesis, a 5 sieve stack was used to determine texture. The sieve stack comprised of sieves; Ø (representing gravel), Ø 2 (representing coarse sand), Ø 4 (representing fine sand), Ø 8 (representing silt), and the pan (representing clay). Approximately 200g of each sample was weighed out for sieving. The weight was recorded to the nearest 0.01g using an electronic balance with a precision of 0.001g. The sample was placed on the top of the stack, the lid was placed on, and the stack was put in the mechanical shaker for three minutes for each sample. The sieves were cleaned using appropriate brushes between each test. After the three minutes, the sieve stack was removed from the shaker and each sieve was individually removed very carefully from the stack starting with the top, or Ø. The contents of the stack was placed onto a sheet of large white paper and transferred back into the weighing boat. The boat was then weighed again for the final weight of the separated soil particles. Individual sieve and end weights were recorded and texture percentages determined. Soil texture and composition was determined using a soil texture triangle once all percentages were known.

4.2.3 Infiltration Testing

The Infiltration rate of soil is directly correlated to the texture, organic matter and planting abilities, which are all important parts of an LID project plan (Toronto and Region Conservation Authority, 2010). Infiltration rates of the soil are directly related to the soil testing that was done in this case study. The infiltration rates of the soil determine whether external soil media needs to replace the existing soil and what vegetation can properly grow on that site. This influences cost and duration of a possible LID site. Infiltration rates of the case study site were presented to the stakeholder group to aide in determining an informed decision-support criterion. According to the Toronto and Region Conservation Authority (2010), the infiltration rate is as crucial in determining a suitable LID as the soil structure. The infiltration results were provided and considered in the decision-support criteria determined by the stakeholders when considering an LID as a remediation option.

It is highly recommended that infiltration rates for LID projects be determined through the collection of field saturated hydraulic conductivity (K_{fs}). Hydraulic conductivity is a measurement of the ability of water to move through unsaturated, porous surfaces (Reynolds, 1986). Soil sorptivity is a measurement of the capacity of soil to absorb water as it passes through unsaturated surfaces. Both hydraulic conductivity and soil sorptivity need to be known in order to create a successful biofiltration or LID system (Jonasson *et al.*, 2010). Research has shown that a high hydraulic conductivity generally results in a more efficient and effective bioinfiltration project, however, the base media must also be considered for proper plant and vegetation growth. The Guelph Permeameter is a device created at University of Guelph in 1986 to determine field saturated hydraulic conductivity, soil sorptivity and matrix flux potential (Reynolds, 1986). The Guelph Permeameter uses a constant head well method while remaining statistically equivalent to the air entry permeameter method resulting in an increased efficiency and range of use when compared to; the tube method, the ring infiltrometer method, the profile method, the column method, the cavity method and the open-hole infiltration method (Reynolds, 1986).

The Guelph Permeameter was used for the collection of infiltration rates in this thesis. The permeameter needed to be set up and tested before any field collection could occur. With assistance from a professional at Lakehead University, the permeameter was set up correctly and tested for quality assurance. As per the infiltration testing protocol, no tests were completed within twenty-four hours of rain and all were completed before the second week in June for the most accurate results. The first test was done using a bucket of soil from outside and tested in the lab. This proved to be unsuccessful. The remaining tests were done outside in a courtyard at Lakehead University. The permeameter was tested on at least four occasions for accuracy. The locations for the infiltration tests were planned prior to going into the field. The test locations were based on soil pit locations. For soil pits A1, A2, B1 and B2 one infiltration test was performed on the soil above the observed water table, where available, with a repetition on each, totalling eight tests done on the first four soil pits. The initial test was performed 2m east of the pit and the repetition 2m to the west of the pit. For soil pits C1 and D1 there were two infiltration tests done on each pit, in the upper horizon and the lower horizon, with a repetition on each. The first test was done on the upper horizon 2m south-east of the pit with the repetition located 2m north-east of the pit. The lower horizon tests were located 2m west of the pit with the repetition locate 2m south of the pit. The distance of 2m was determined in order to ensure the soil tested was not disturbed by the previous excavation of soil pits. Lower horizons were defined as any soil below 24 cm from the surface. Lower horizon tests could not be done on the first four pits, as the water table was too close to the surface. See Figure 8 for infiltration test locations.

Once the quality assurance was finished, the permeameter was brought to the field for data collection. All in-field infiltration tests were conducted using a one-head method and combination reservoir procedure. A hole was made in the ground with the auger supplied with the Guelph Permeameter. The depth of the hole was dependent on the previous soil pit observations of water table depth, in most cases for upper horizons; the hole was augured 12-15 cm below the surface. The tripod was set up above the augured hole and the support tube on the permeameter was lowered in until it was sitting on the tripod base. It is important to note that for each test, the well head indicator base was sitting in the proper position and the air inlet tip was fully sealed with the tip seating washer. Once the permeameter was in place, the reservoir valve was turned to the 12 o'clock position and water from the creek was poured into the top of the permeameter until the reservoir was full. Once full, the #0 stopper was placed in the fill hole to seal off the reservoir. Once the reservoir was sealed the upper air tube was raised very slowly to establish the head well height. The head well height was based on the permeability of the soil previously observed during soil collection, which in all cases of this thesis; fell between 5 and 10 cm. The first reading was taken once the water in the reservoir was at a fairly steady state. Readings were taken every 2 minutes until the readings showed a steady-state rate of fall over 3 consecutive readings with a minimum of eight readings. In cases where 2 minutes was too long and the water level in the reservoir was dropping too fast, reading intervals were altered to suit the rate of fall. To determine the final rate in cm/sec, the following calculation is used:

Where,

R = Rate of fall

x_1 = First interval reading

x_2 = Second interval reading

T = Time interval in minutes

$$R = \frac{(x_1 - x_2)}{T} / 60$$

Infiltration rate (mm/hr) is then determined using the approximate relationship chart outlined in the *Site Evaluation and Soil Testing Protocol for Stormwater infiltration* (Toronto and Region Conservation Authority, 2010). Once the infiltration rate is determined, it then needs to consider the safety correction factor which is based on the infiltration rate. The safety correction factor table can also be found in the *Site Evaluation and Soil Testing Protocol for Stormwater infiltration* (Toronto and Region Conservation Authority, 2010). In all cases pertaining to this thesis, the safety correction factor was 8.5. The ideal infiltration rate for any structural LID is >15 mm/hr. Anything less that 15 mm/hr would need to be replaced or altered for ideal infiltration conditions.

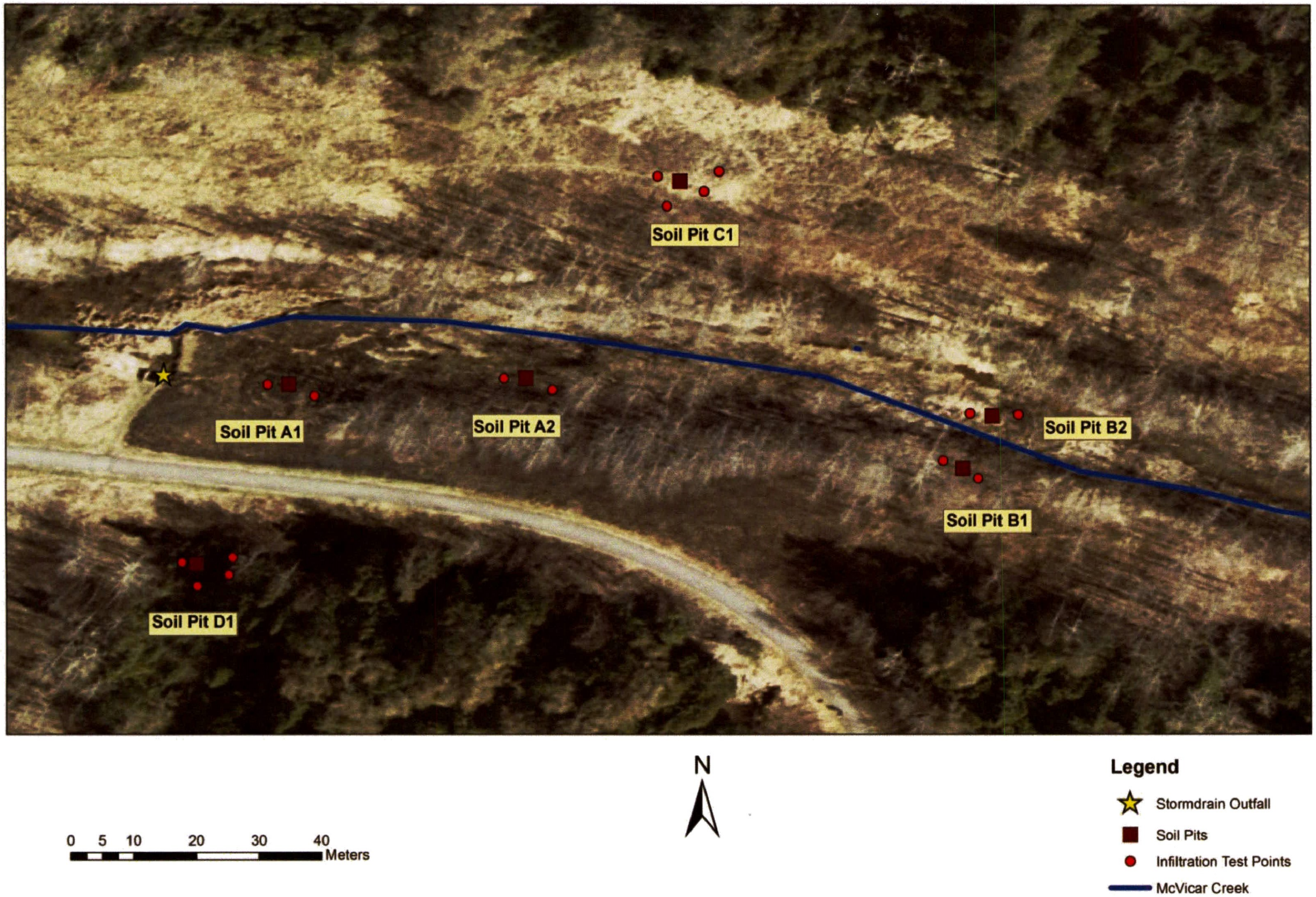

Figure 5. Case Study Infiltration Test and Soil Pit Sampling Locations

4.3 **Stakeholder** ***Involvement in Decision-Making***

Multi-Stakeholder Decision Making (MSDM) has been a growing trend in Canadian environmental decision making since the 1990's (Sinclair *et al.*, 1998). The stakeholder involvement portion of this thesis follows the Framework of MSDM. The Framework for MSDM can be defined as the following (extracted from Sinclair *et al.*, 1998; developed by Canadian Round Tables, 1994):

1) Preconditions for the use of the MSDM process: There must be an unresolved conflict; in the case of this thesis the conflict is defined as a need for stormwater remediation options along McVicar Creek, all key stakeholders must have an incentive to seek a decision by consensus, all stakeholders must be involved and support the MSDM process, there must be a political will to see the process through; in the case of Thunder Bay, the city is making strides in stormwater management with a proposed Stormwater Master Plan and the intent of stormwater remediation in this thesis' area of concern, there must be an entity supporting the consensus process that can provide initial credibility and an excuse for adversaries to work together; in the case of this thesis, this entity is Lakehead University and the Northshore RAP.
2) Designing the process: Identify the Stakeholders and the representatives for the stakeholders, and participants determine the rules of the process; in the case of this thesis, the Stakeholders were able to decide what the next steps in the participation process were and how they would like to see them structured.
3) Using the process: Participants adopt a positive attitude towards the process; In the case of this thesis, all participating Stakeholders were enthusiastic and positive about the involvement process.

4) Implementing and monitoring agreements: There must be monitoring on the progress of any agreements; throughout the duration of Stakeholder participation for this thesis, participants were kept up-to-date on all results from sessions and asked for input. The creation of this thesis itself is another way of monitoring all involvement of participants.

The MSDM process must include the following steps or phases;

1) Define the problem: In the case of this thesis, the initial introduction and discussion of the project was used to meet these criteria. With the help of the Stakeholder group in the initial introduction, the problem of stormwater impacts along McVicar creek was further defined.
2) Access information and understanding for participants that falls outside of the scientific realm: In the case of this thesis, these criteria were met through the site visit process. Although some scientific data was provided to the group, they were able to see the sites and visualize the concerns. The collection of the USSR data also helps meet this criterion by providing observed site characterizations rather than only quantitative site data. The USSR information was provided at the site visit.
3) Identify alternative solutions that will be socially acceptable: In the case of this thesis, this criterion was met through the multi-stakeholder decision making workshop. The alternatives are presented as remediation option recommendations.

The stakeholder phased process used in this thesis is also very similar to the European Water Framework Directive which also follows the MSDM process (Jonsson, 2005). The European Water Framework Directive in 2005 used a phased process of several meetings with five different stakeholder groups lasting about two hours per meeting and assessed for perceptions for participation at different scales. The participants were asked to list water related values, interests and developments of proposals. The information recorded and collected was used to assess what stakeholders' water related values and perceptions are in Europe.

For the purposes of this thesis the stakeholders are the individuals and organizations that sit on the Earthwise® Water Working Group. These organizations include; The City of Thunder Bay, EcoSuperior, The Northshore RAP, Lakehead University, The Ontario Ministry of Natural Resources, The Ontario Ministry of the Environment, The Northshore Steelhead Association and The Lakehead Region Conservation Authority.

4.3.1 Initial Stakeholder Introduction

The initial stakeholder introduction helped to define the problem of stormwater impacts along McVicar Creek, as well as provide a context to the participants. The initial information provided to the participants gave them the ability to start considering a feasibility criteria of site-specific stormwater remediation options along McVicar creek, a decision-support criterion and the beginning of expert feedback to ultimately produce a remediation option plan. This initial introduction also introduced them for the first time to the objectives of this thesis and where their participation helps achieve them. This step provided the building blocks to develop remediation recommendations based on the feasibility and decision-support criteria. This step also provided the ability for the participants to offer initial feedback and aide in the planning process for remaining participation.

This initial stakeholder introduction was done through a presentation made to the group at the beginning of the testing season. All the known information about the research to-date on the area was shared with the group. This included all the information collected from the USA and

USSR research to-date. A brief introduction of broad stormwater impacts was given at the beginning of the presentation to get the participants thinking about stormwater. Most of the stakeholder participants have some background in stormwater issues and management due to the affiliation of most groups to the City of Thunder Bay. Each of the three study sites were introduced to the group and decision-making process on site selection was explained. There were several variables resulting from the USA that determined the most suitable possible remediation sites along McVicar Creek. These variables are explained in the background section.

All the USSR site assessment results were shown and explained to the group, mostly in table format. These results included site characterization and classification, along with any known concerns within the subwatersheds such as defined hotspots or possible point-sources of pollution. Water quality results to-date was also shown in the presentation for each site. The water quality results focused on the parameters that were seen to exceed guidelines. The USSR study resulted in initial remediation recommendations for each site based on the site assessments and the water quality results. These recommendations were also presented and were as follows; Court Street was recommended for policy and maintenance due to the home vehicle repair shops and the high levels of chloride observed, Castlegreen was recommended for further investigation of the high ammonia levels and community education due to the private gardens and excessive pet waste, and County Fair was recommended for an LID due to the identification of subwatershed hotspots and being a commercial area.

The group was introduced through this presentation to the idea of further quantitative research done on the County Fair site as a case study for a possible LID. The procedures were covered; soil sampling and testing, infiltration testing and further water quality. The benefits to a possible LID were outlined; The end-of-pipe is publicly owned land, the channel is a man-made feature to begin with, the subwatershed has the highest impervious surface area, the channel receives a high number of stormwater inputs, the city is aware of the project and that funds are available through the Northshore RAP to further pursue a remediation option. The next steps of Stakeholder participation and of the project in general were then covered and the group was asked if they would like to pursue participation. A unanimous decision was made to pursue participation and a date was set for a site visit that suited the group.

4.3.2 Stakeholder Site Visit

Participants were provided with an information package outlining important information about each site. The information in the booklet provided included all information covered in the previous introduction presentation along with aerial photos of the three subwatersheds. The information covered was all information collected to-date which included USSR results and water quality results to-date. The booklet explained general information about each site such as subwatershed characteristics, including, the area in hectares, and impervious surface cover as a percentage and land-use classification. The booklet included outfall characteristics such as pipe diameter, pipe condition, and largest input observed and the end-of-pipe condition.

The USSR results outlined the major concerns that were observed in each subwatershed during the site assessments. These concerns included excess sediment, hotspot identification, and high levels of certain water quality parameters, excess waste, street and sidewalk conditions, spilling and leaking of gas and oil and residential use of current stormwater tools such as rain barrels. The booklet also outlined the water quality parameters that have been seen to exceed water quality guidelines on each site. The water quality parameters were shown just as the name of any given parameter that was seen to exceed guidelines rather than a graph or table. This was done to provide information that falls outside of the scientific realm and allows for easy interpretation of the data. An aerial map of each subwatershed was given with the booklet to allow for participants to see the area in question. Due to time constraints of the participants, the site visit was only done to each of the stormwater outfalls rather than the entire subwatersheds. The photos allowed the participants to visually interpret the subwatershed in relation to where they were standing at the outfall.

As mentioned in the USSR methods section, the completion of the USSR site assessments provides broad preliminary recommendations for further investigation of remediation options. These recommendations were also included in the site visit booklet. The initial recommendations for County Fair were; maintenance, policy enforcement, landscaping and end-of-pipe LID. The initial recommendations for Castlegreen were; community education, landscaping, maintenance and further investigation. The initial recommendations for Court Street were; community education, alternative snow removal and policy enforcement.

All the information provided in the booklet was to allow the Stakeholder group to develop informed and proper feasibility criteria and implement a decision-support criterion in the future decision-making workshop. The participants all agreed prior to and after the site visit that being able to physically see the sites in question would aide in making informed decisions later. Many of the participants had not seen the physical areas being discussed before the site visit. This visit got the group thinking about the options available in those areas based on the location and environment observed. Observing the sites allowed for further discussion from the group of the visual stormwater outfall aquatic impairments such as built-up garbage and sediment, discolouration of water and bank erosion. See the full site visit booklet in Appendix 2.

The quantitative data collection for the case study site had not yet been completed at the time of the site visit, however, the group was shown where the collection would take place and unanimously agreed on the locations. The results of the case study data collection would be provided to the group at the decision-making workshop later in the season. The vegetation that was currently thriving at the County Fair end-of-pipe was noted by the group as being a naturalizing wetland. The Lakehead Region Conservation Authority (LRCA) noted that the County Fair channel, which has at one point been created for municipal wastewater was incorporated into the floodplain mapping of 1994. This began the discussion of whether it would even be possible to gain the proper permits needed to develop the area as an LID project. The incorporation of the area into the LRCA's floodplain mapping made the area an area of interest for the Department of Fisheries and Oceans (DFO) as well. The discussion ultimately concluded with the statement that permits would need to be approved and obtained from both the LRCA and the DFO if any development was going to be proposed at this site.

The participants were asked to write down their comments and questions in the comments section provided in the booklet. These questions and comments were based on the discussions surrounding each site. The topic of discussion that was brought up most often involved potential partnerships with residents or organizations within the subwatersheds. At the County Fair site, the possibility of a partnership with Walmart was a main topic of discussion, at the Castlegreen site a partnership with the Co-op was a main topic and at Court Street a partnership with the residents was a main topic. For each site the idea of an end-of-pipe LID was explored based on the condition of the outfall and creek. The initial recommendations that were produced from the USSR results were also all discussed for possible remediation options on each site. All if the discussions and ideas were recorded into the booklets for further investigation.

The recommendations that came from the site visit were considered a second recommendation stage, with the USSR recommendation results as the first. These second recommendations, many stemming from the first, would be used as a base to finalize the development of feasibility criteria of site-specific stormwater remediation options for each identified site along McVicar in the decision-making workshop and to ultimately implement a decision-support criterion to identify the most effective stormwater remedial options. The decision-support criterion would have to incorporate a set of decision-making criteria outlined in the workshop from the proven literature as well; however, the experience from the discussions and the initial recommendations would aide in the final decision. All the recommendations submitted in the booklets were recorded into tables by site and presented to the group again at the decision-making workshop as preliminary recommendations.

4.3.3 Stakeholder *Decision-Making Workshop*

A decision-making workshop was held at Lakehead University with stakeholders to complete the last two objectives of this thesis; to implement a decision-support criterion to identify the most effective stormwater remedial options based on Low Impact Development, community education, policy and regulation and maintenance; and use expert and local feedback, along with field data collection to produce a remediation option plan for identified subwatershed hotspots. The stakeholder decision-making workshop was the last step in completing these objectives; however, it was not the only factor. To finalize these last two objectives, the quantitative data such as the USSR assessments and the case study data would also have to be considered, in conjunction with the workshop. Due to the decision-making workshop being only a part of the finalization of these objectives, the workshop was given its own objectives in order to meet the needs of the objectives of this thesis and keep the workshop structured. The specific objectives of the workshop were:

1. To determine suitable and feasible remediation options for the three sites based on education, policy, maintenance, development or leave alone with two scopes of provided decision making;
2. To determine stakeholder preferences for stormwater remediation along McVicar Creek
3. To collect and use ascribed and non-ascribed knowledge to determine a ranking of importance and feasibility for each site;
4. To expand on and provide detail and insight on preliminary site visit recommendations.

The results of this workshop provide stakeholder recommendations on stormwater remedial options based on two scales of decision making (watershed and subwatershed catchment unit). The structure of the workshop was modified and adapted from the United States Fish and Wildlife Service (USFWS) "Structured Decision Making Fact Sheet (2008)." The USFWS suggests a structured decision making criteria in six steps; identifying the problem, determining objectives, identifying the alternatives, determining the consequences, tradeoffs and action. The Stormwater Remediation workshop held on October 2nd, 2012 was separated into four main parts; presentation and questions on background information, identification of successes and obstacles in Thunder Bay stormwater management, definition of local stormwater objectives and determination of feasible stormwater remedial options. Roy *et al.* (2008) suggests that before any stormwater management implementation can occur, there needs to be workshops developed to educate professionals dealing with design such as engineers, planners and policy makers.

The introduction and background presentation given to the group consisted of all the final USSR results previously presented to the group, water quality data to-date, and initial recommendations made from the previous site visit and case study data collected such as soil, infiltration and water quality data. The case study data was provided to the group as very basic results rather than charts and tables of the physical numbers collected. The information was given generally, as whether it was suitable for an LID as it is, or if there would need to be alterations to the current site. The information was presented in this way because the group was not intended to focus too much on physical numbers of the case study as that was not the objective of the workshop. The case study information was given as a tool to make informed decisions rather than to focus too in-depth on any given variable. The decision making criterion was introduced and a condensed and easy to read criteria booklet was provided to participants summarizing the LID and retrofit, education, policy and maintenance and leave-alone decision making criteria.

The group was asked to brainstorm potential successes and obstacles in Thunder Bay stormwater management. The main themes presented and brainstormed tended to be associated with political and social factors. There were more obstacles brainstormed than successes for this particular session. Once the obstacles and successes were determined and somewhat condensed, the group was asked to brainstorm a host of objectives for Thunder Bay stormwater management. This session was separated into two parts; first the participants were asked to come up with as many general stormwater objectives as they could think of, and then asked to condense the objectives to consider a Thunder Bay context as well as sort them into four categories. The four objective categories were environmental, social and cultural, economic and political. The group was able to condense the lengthy list of original objectives into two-three localized overarching objectives for each category. Once the objectives were determined and lunch was served, the group was presented with three aerial photo maps of the subwatersheds, pipelines and outfalls. Using the criteria provided and the basic intent of meeting the outlined objectives, the group was asked to determine feasible and valued stormwater remediation on each site. See Appendix 3 for criteria provided.

The information provided for the case study site was physically descriptive including topography, soil classification, infiltration rates and upstream and downstream water quality. The information for the case study site was also given along with a recommendation and suggestion of an end-of-pipe LID. The information given for the other two sites was much broader with a focus on McVicar creek as a whole rather than an individual case study. This was done to assess the multi-scale decision making process and assess the extent of detailed information needed for a similar group to make stormwater remediation recommendations. The information collected through the multi-scale decision making aides in the objective of determining a decision-support criterion to identify the most effective stormwater remedial option. When given all the information, along with the aerial photos, the group came up with several remedial options for each site. The remedial options were based mainly around LID and retrofits and education and outreach. The group determined that in order to complete a successful remediation option, the option should be feasible across all three subwatersheds, as well as McVicar creek as a whole. The group determined that rather than site specific remedial options, the research should first be focused on a broader overarching option such as a watershed-wide education campaign.

5.0 Results

This results section is structured to first highlight the results of the USSR site assessments for each subwatershed and to then show the water quality results for all three subwatersheds including the upstream and downstream results from the County Fair case study site. After the case study water quality results, this section then shows the results of the other quantitative data of the case study and finishes with the results from the stakeholder involvement sessions. This section is structured this way to first showcase the quantitative data collection results and then the qualitative to see how one influenced the other. The results of the quantitative data collection were also completed and showcased during the qualitative data collection process. The results that are described in the case study that were not completed on the other two sites are as follows; soil pit sample results, Infiltration testing results, soil nutrient testing results, soil organic testing results, soil composition and texture results and upstream/downstream water quality results.

5.1 USSR Site Assessment Results

Historically, land use studies relating to stormwater contamination have been highly inconclusive due to the inability to derive statistically significant relationships (Goonetilleke *et al.*, 2005). We can however conclusively determine that urban activities such as removal of vegetation, replacement of pervious surface with impervious surface and channel modifications are among the most impacting characteristics of changes in surface runoff. The initial recommendations that were drawn from the USSR study were used and referred to throughout the duration of the other qualitative and quantitative data collection completed in this thesis. The USSR study was done prior to other data collection to determine these preliminary results and use them for a base in this thesis to determine the most suitable stormwater remediation options.

The results of the USSR site assessments are broken down for each site. The maps show the subwatershed and the numbers on the map correspond to the CSA numbers in the table.

5.1.1 Court Street USSR Results

The most significant site assessment result for the Court Street subwatershed was the presence of home vehicle repair operations, some of which were leaking oil and gas. There were no hotspots identified in the subwatershed or storm drain points. Site assessment results suggest that the largest urban impact on stormwater discharge in the Court Street subwatershed is vehicle related activities. Another interesting result from the site assessment was that 4 rainbarrels observed within the residential neighbourhoods were not connected to downspouts. See Figure 9 and Table 1 for detailed site assessment results.

Table 1. Court Street Site Assessment results

Significan Court Street site assessment results	
CSA 1	Home vehicle repair operations Leaking oil and gas onto impervious surface High sediment accumulation
CSA 3	Home vehicle repair operations High sediment accumulation
CSA 4	Storage of junk vehicles in private yards High sediment accumulation
CSA 5	Pesticide tank backpack observed Well kept chicken coop High sediment accumulation
SSD Poly	Excessive sediment accumulation Stained
# Downspouts connected to impervious surface	13
# Rainbarrels observed	9 (only 5 connected)
# Raingardens observed	5

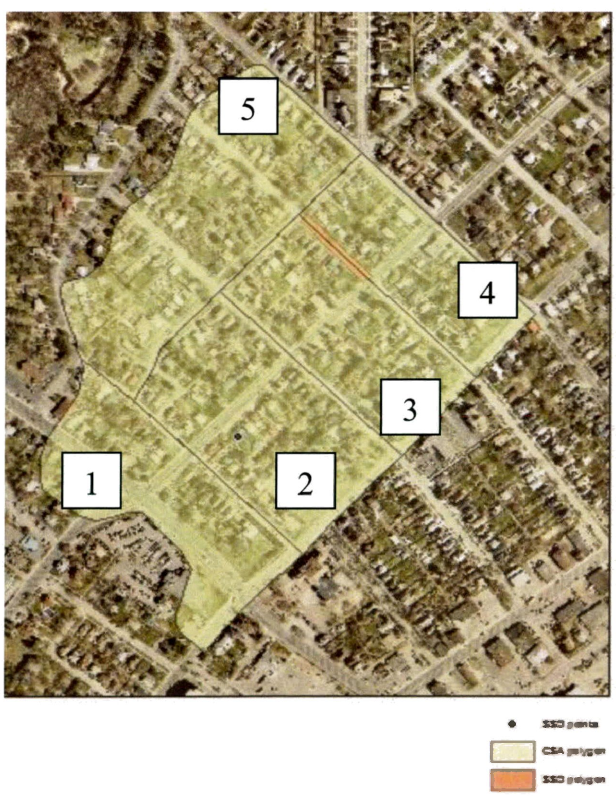

Figure 6. Court Street USSR results with associated CSA assessment points.

The table above shows the results of the USSR site assessments completed in the field. All the CSA polygons seem to show high sediment accumulation within the area. There were also 13 downspouts connected to impervious surfaces, which lead directly to a stormwater catchment.

5.1.2 Castlegreen USSR Results

The most significant site assessment results for Castlegreen were the amount of private gardens, the excessive pet waste and the heavily heaving and buckling street. The street that was heaving was observed to have water flow lines leading directly into the storm drain. There were two street SSDs identified, one storm sewer SSD point and no hotspots identified within the subwatershed. See Figure 10 and Table 2 for detailed site assessment results.

Table 2. Castlgreen Site Assessment results

Significan Castlegreen site assessment results	
CSA 1	Road surfaces warped All parking lots and driveways are paved High sediment accumulation
CSA 2	High number of private gardens Excessive pet waste on property High sediment accumulation
SSD poly 1	High sediment accumulation Many ashalt patches
SSD poly 2	High sediment accumulation Street level dropping and ashphalt is heavily heaving and buckling
SSD point	High sediment accumulation downspout connected to grate
# Downspouts connected to impervious surface	20
# Rainbarrels observed	25
# Raingardens observed	9

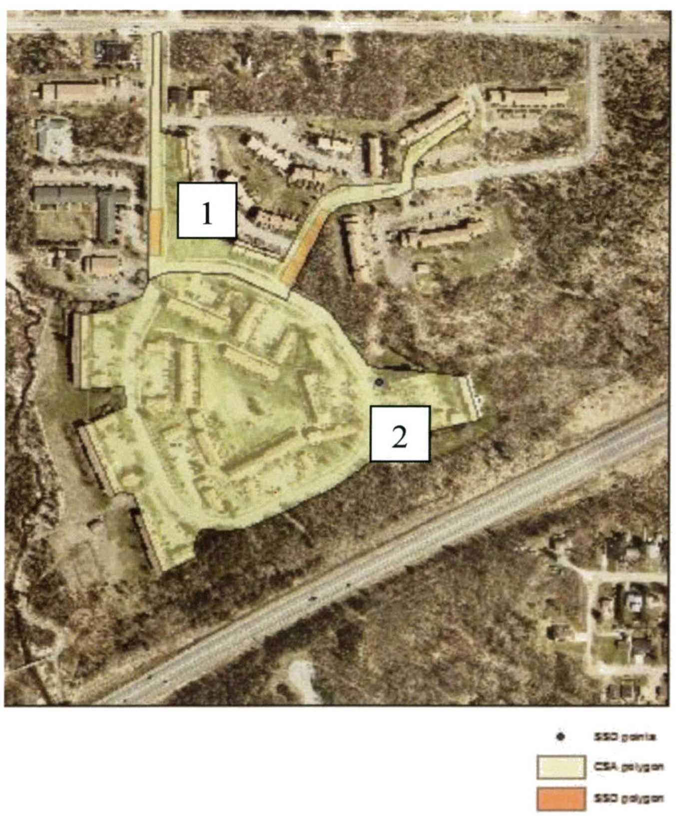

Figure 7. Castlegreen USSR results with associated CSA assessment points.

Both CSA polygons in the Castlegreen subwatershed also have high sediment accumulation. All rain barrels that were observed were connected to the downspout, however, there were 20 observed downspouts connected to impervious surfaces.

5.1.3 County Fair USSR Results

The most significant site assessment results for County Fair were the number of identified hotspots, the percent of impervious surface area, the high level of illegal dumping and long term parking and the excessive sediment accumulation across the entire subwatershed. County Fair had the most severe site assessment ranking. County Fair was the only subwatershed studied that had identified hotspots within it. It was also however the only commercial area that was studied. The gas station was identified as a hotspot because gas stations tend to have significant fluid leaks that are directed into the stormwater system, high traffic volumes and uncovered hazardous materials (Center for Watershed Protection, 2005). There was no evidence of direct leakage or spillage of auto fluids on-site of this particular gas station. The outdoor garden centre was identified as a hotspot because outdoor garden centers tend to use high amounts of fertilizers, water vegetation outside and keep hazardous materials uncovered (Center for Watershed Protection, 2005). This particular garden center had evidence of all characteristics listed above. The commercial drive through was identified as a hotspot because a drive through tends to have heavy traffic flow, loading and unloading operations and dumpsters located near storm drains (Center for Watershed Protection, 2005). This particular drive through showed evidence of all characteristics listed above. See Figure 11 and Table 3 for detailed site assessment results.

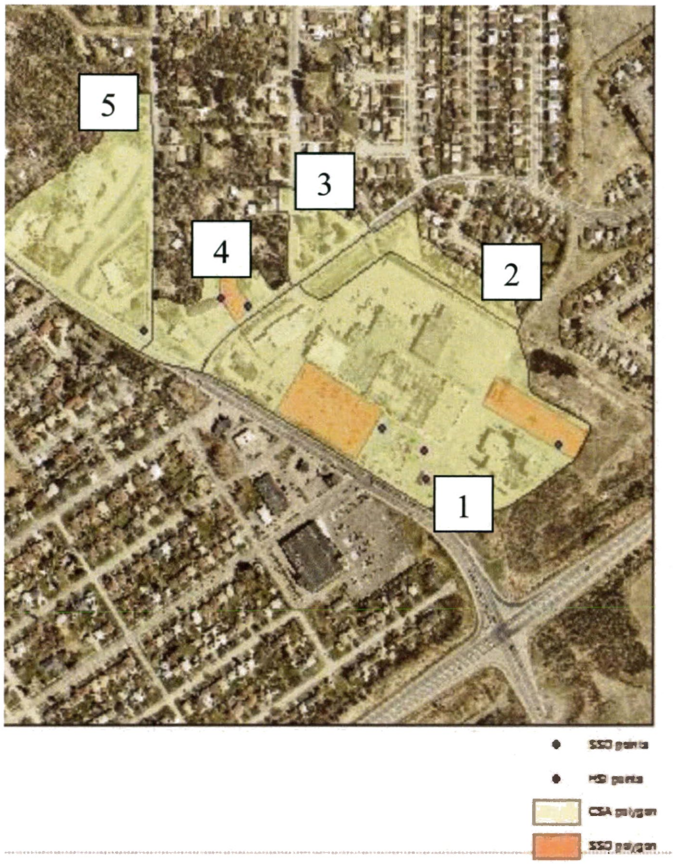

Figure 8. County Fair USSR results with associated CSA assessment points.

Table 3. County Fair Site Assessment results

Significan County Fair site assessment results	
CSA 1	Illegal long term parking and storage Construction material dumpage Evidence of long term loitering and dumping Petrol stains evident Excessive sediment accumulation
CSA 2	High number of private gardens Construction material storage Stormwater ditch observed
CSA 4	Excessive level of traffic flow Construction material dumpage Car wash present High sediment accumulation
CSA 5	A Creek has been ditched out and manicured High sediment accumulation
SSD poly 1	Drive through parking lot Constant traffic and temporary parking Oil and fuel stains running into grates
SSD poly 2	Large commetcial parking lot

	> 40 temporarily parked vehicles Heavy traffic flow
SSD poly 3	Partially abandoned parking lot Excessive litter and dumping of waste lot used for long term parking and storage of transport trucks High numbers of nesting seagulls
HSI 1	Gas station Heavy traffic flow Evidence of vehicle washing outside Operation owned dumpsters located near stormdrains No evidence of spills/leaks
HSI 2	Seasonal outdoor garden centre Auto fluid and chemical spills evident Loading and unloading operations evident Solid materials stored outside uncovered litter and organic materials on-site
HSI 3	Commercial drive-through Operation and auto fluid spills evident Heavy traffic flow Loading and unloading operations evident On-site runoff and operation owned dumpsters directly connected to stormdrain
# Downspouts connected to impervious surface	10
# Rainbarrels observed	0
# Raingardens observed	7

The County fair site had the most notable possible stormwater impacts observed across all three sites. The County Fair stormwater outfall shows excessive sediment accumulation within the stormwater pipes. The pipe is constantly at least 20% full of sediment and the grate itself is full of trash. There are also various ditches and open spaces within the subwatershed that could be increasing infiltration before the stormwater reaches the system. The lack of rain barrels observed in the subwatershed is expected because the majority of the subwatershed studied is a commercial area.

5.2 Water Quality Results

Water quality samples were taken from the discharge of each of the three stormwater outfalls and at upstream and downstream sites on the County Fair site. The County Fair water parameters are displayed in charts as a comparison of upstream, downstream and outfall quality. The Castlegreen and Court Street sites are displayed as only one factor in the charts, rather than a comparison, as only one site in those study areas was tested. An asterisk symbol (*) is displayed on the charts' horizontal axis, or date of sample taken, to illustrate precipitation days. Precipitation days are as follows; May 22, 2012 received 1.2mm, May 29, 2012 received 2.1mm, June 19, 2012 received 28.6mm and July 31, 2012 received 0.3mm. It is important to note that May 27th -May 28th of 2012, the City of Thunder Bay received over 100mm of precipitation within 24 hours that caused a city-wide state of emergency. Water quality samples were taken on May 29th after the extreme rain event. Water quality levels are based on the Provincial Water Quality Objectives (PWQO's) where applicable, or the Canadian Water Quality Guidelines (CWQG's) where applicable, or the U.S. Environmental Protection Agency (EPA) guidelines. The black strike through the charts represents the associated guideline or objective. Water quality guideline levels are as follows:

Ammonia – PWQO: 20 μg/L (expressed as 0.02 mg/L)

Nitrate – CWQG: 13 μg/L (expressed as 0.01 mg/L)

Nitrite – CWQG: 60 μg/L (expressed as 0.06 mg/L)

Phosphate – PWQO: 30 μg/L (expressed as 0.03 mg/L)

Chloride – EPA: 210 mg/L

5.2.3 Court Street Water Quality Results

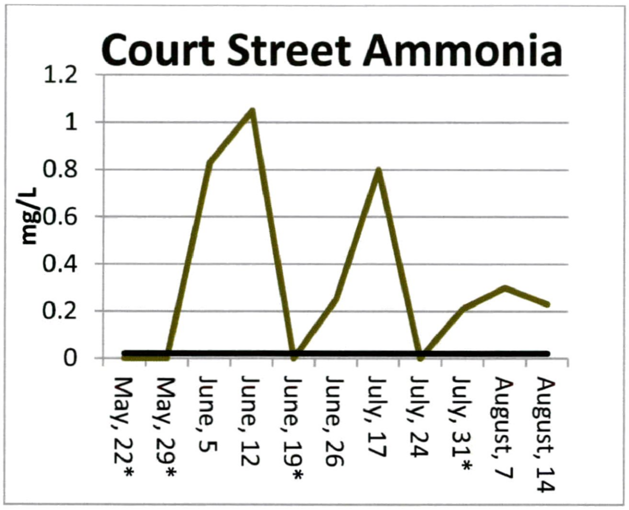

Figure 9. CS Ammonia, 2012

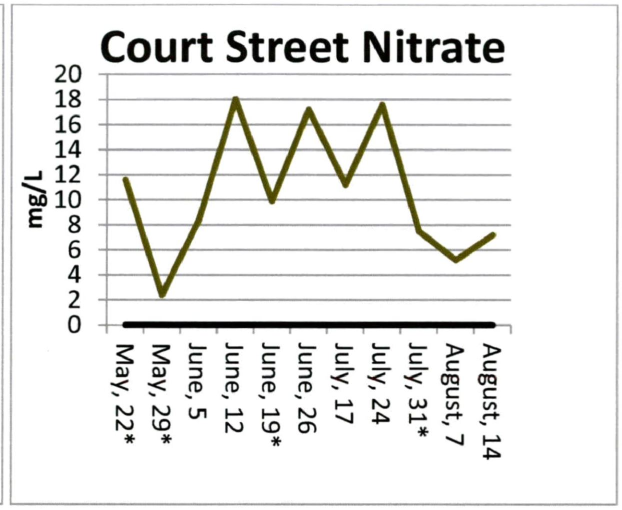

Figure 10. CS Nitrate, 2012

Ammonia levels seem to be fairly erratic over time at the Court Street outfall. However, the collection days that show the lowest levels of ammonia are precipitation days with the exception of July 24th. The highest levels of ammonia seem to peak during mid-June collection. This trend is fairly consistent with past water quality sampling.

Nitrate levels are shown to be consistently high. The lowest levels of nitrate were recorded on May 29th, which was the day after the severe precipitation event. The levels of nitrate seem to drop on precipitaiton day collections in comparison to the dry collection days with the exception of August 7th. Nitrate levels were recorded above the water quality guideline on all collection days.

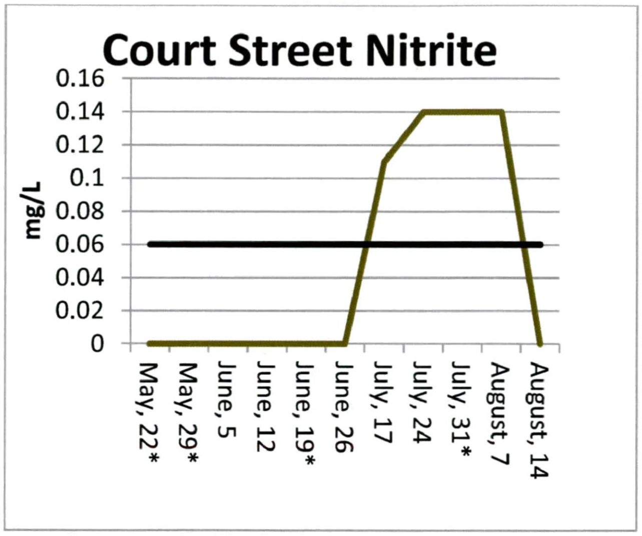

Figure 11. CS Nitrite, 2012

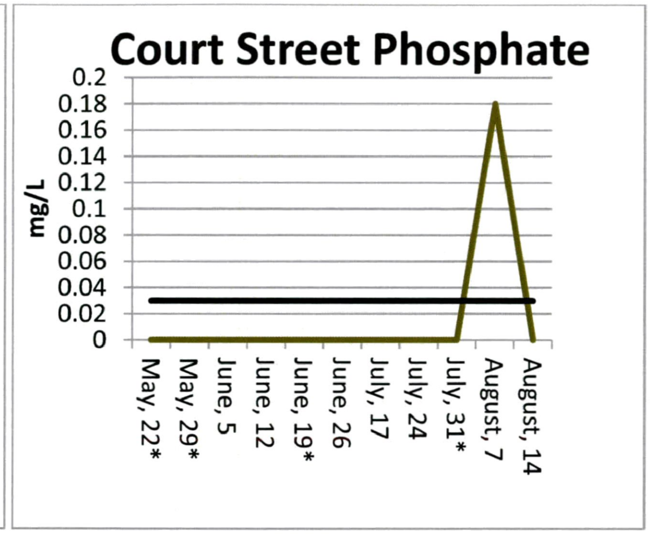

Figure 12. CS Phosphate, 2012

Nitrite levels seem to peak during July collection and are virtually non existent during any other collection period. The levels of nitrite are consistent during the rain event of July 31st and the pre and post collection days.

Phosphate levels seem to be non-existent with the exception of the significant spike on August 7th.

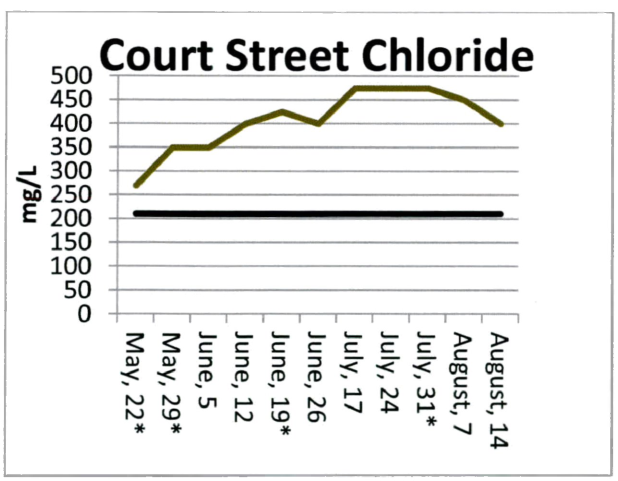

Figure 13. CS Chloride, 2012

Chloride levels tend to be consistently high. Levels are above the guideline on all collection days. This trend is fairly consistent with past water quality sampling.

5.2.4 Castlegreen Water Quality Results

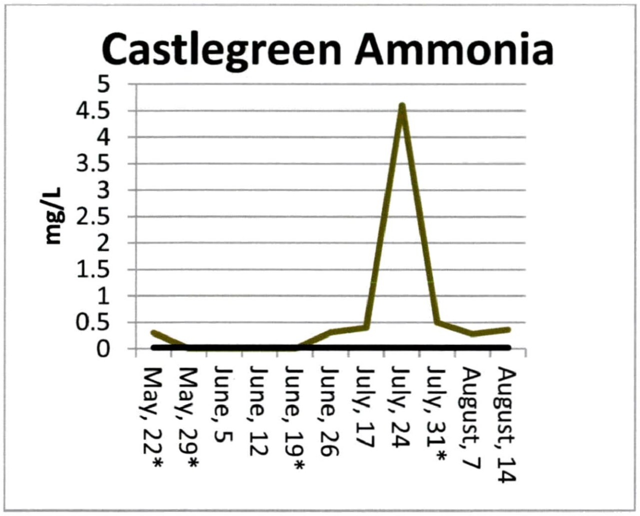

Figure 14. CG Ammonia, 2012

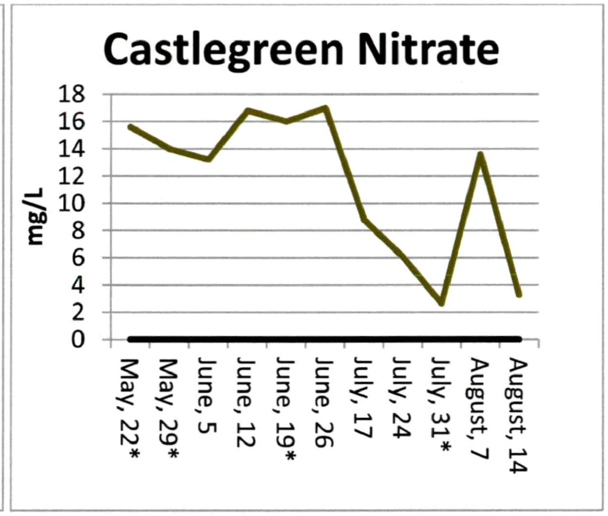

Figure 15. CG Nitrate, 2012

Ammonia levels seem to peak during July collection and seem to be non-existent during June collection. The highest levels are seen on July 24th collection which was a dry collection day. These results are not consistent with past water quality sampling.

Nitrate levels seem to be consistently high throughout collection. The most significant decrease in nitrate levels seems to be on the precipitation day collection on July 31st. Nitrate levels are consistently above water quality guidelines throughout the duration of collection.

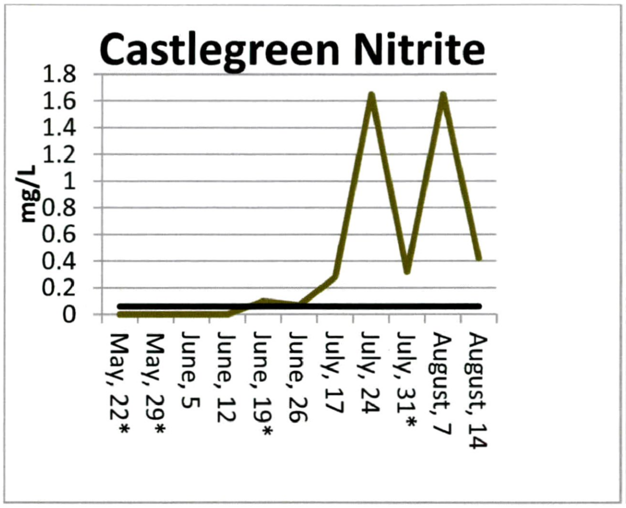

Figure 16. CG Nitrite, 2012

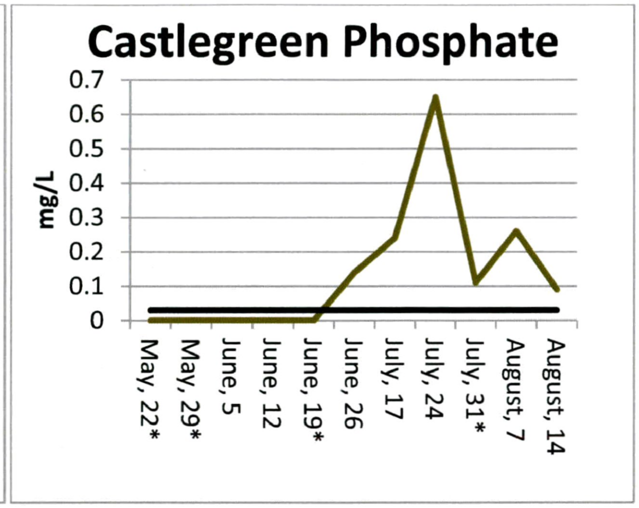

Figure 17. CG Phosphate, 2012

Nitrite levels seem to peak during summer collection. The nitritr level drops during the precipitation collection on July 31st. This trend is realtively similar to previous water sampling, as nitrite levels have been elevated further into the season.

Phosphate levels also seem to peak further into the collection period. The levels also drop during the precipitation collection on July 31st and are significantly elevated on July 24th during the dry season.

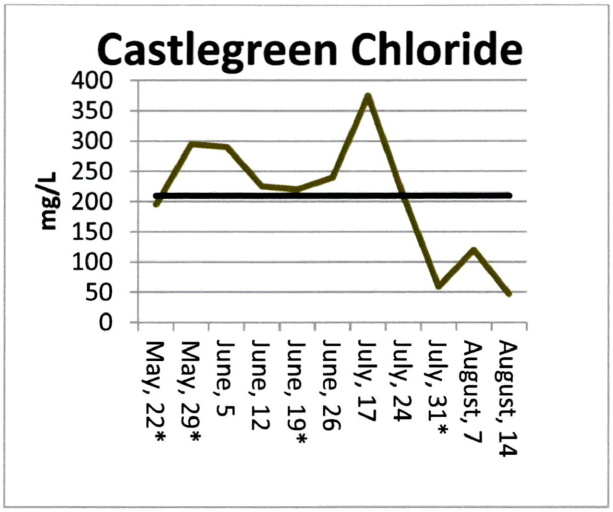

Figure 18. CG Chloride, 2012

Chloride levels seem to peak during the dry spell in July collection and drop off significantly later in the season. This is consistent with the water quality sampling completed in the past.

5.2.5 County Fair Water Quality results

The following results show the comparison on charts of the upstream, downstream and at the stormwater outfall for the County Fair site for case study purposes.

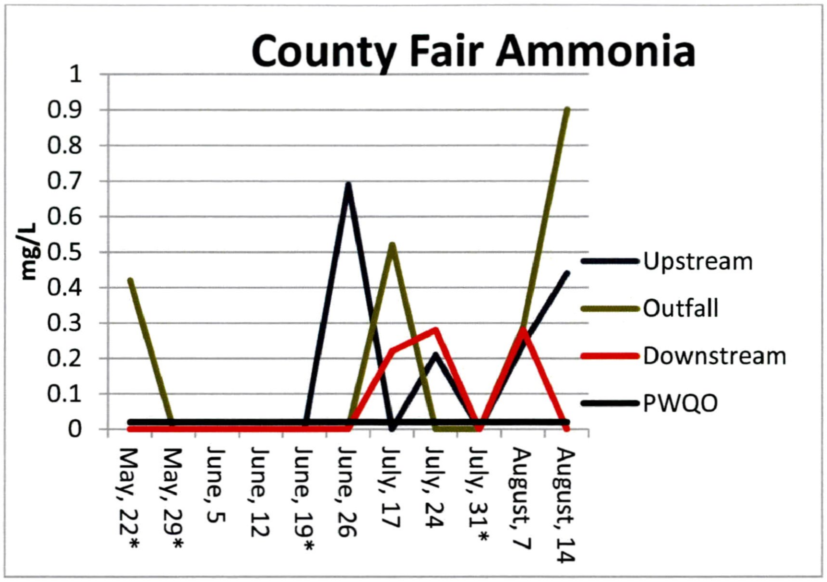

Figure 19. CF Ammonia, 2012

Ammonia levels seem to be fairly erratic over the County Fair site towards the end of the spring season and into the summer season. The outfall levels seem to be elevated during dry periods and collections with the exception of the first collection on May 22nd. There does not seem to be a strong correlation between outfall, downstream and upstream ammonia levels.

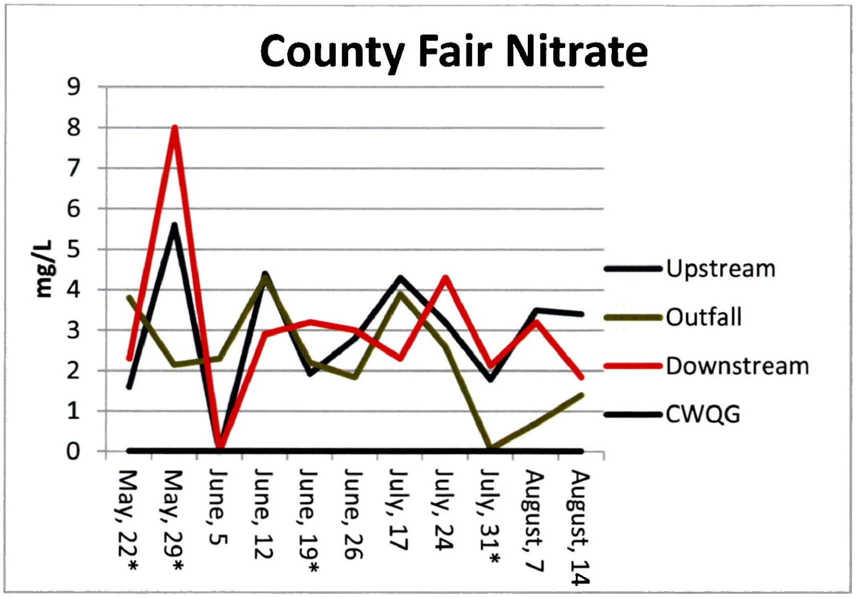

Figure 20. CF Nitrate, 2012

Nitrate levels are consistently above the water quality guideline on all locations. However, June 5th shows the outfall location elevated from the downstream and upstream locations. There does not appear to be a strong correlation between upstream, outfall and downstream locations.

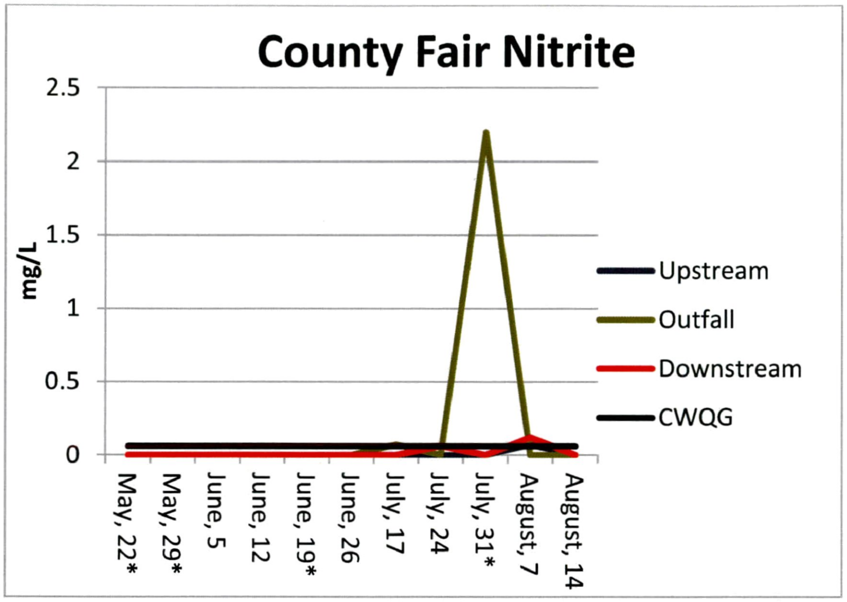

Figure 21. CF Nitrite, 2012

Nitrite levels are consistently low across the collection season with the exception to a peak at the outfall during the precipitation collection on July 31st.

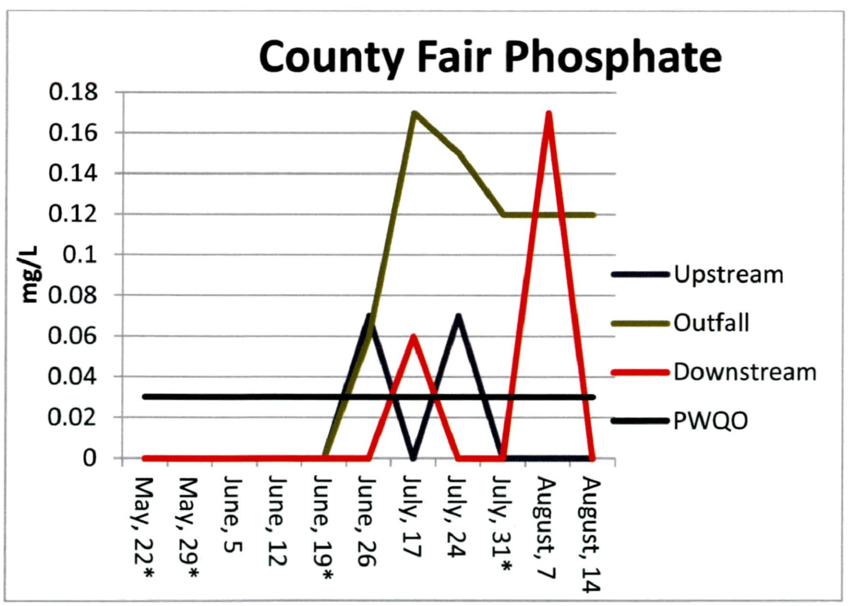

Figure 22. CF Phosphate, 2012

Phosphate levels seem to be non-existent up until later in the spring season and into the summer collection season. Outfall levels are consistently higher than downstream levels with the exception of August 7th. There does not appear to be a strong correlation between upstream downstream and outfall locations.

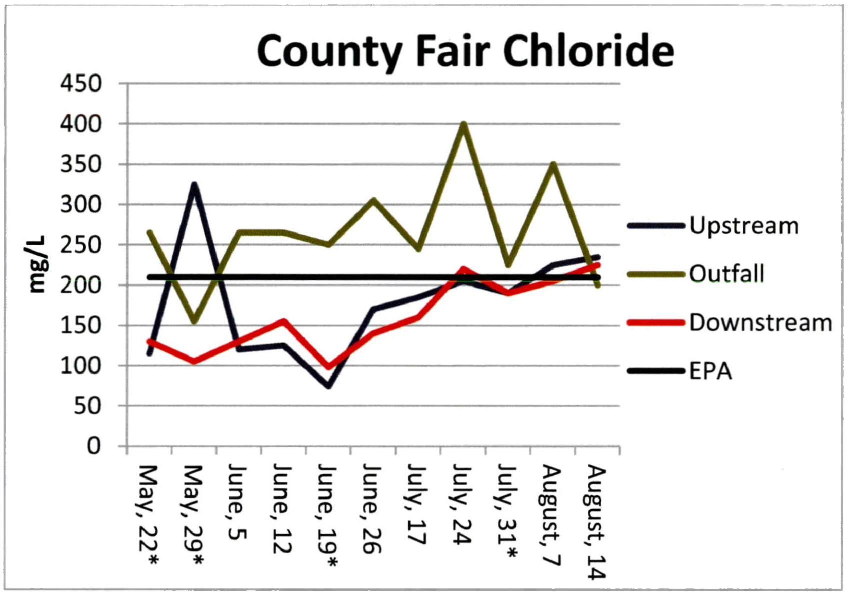

Figure 23. CF Chloride, 2012

Chloride levels downstream of the outfall are consistently lower than levels at the outfall with the exception of the last August 14th collection. Upstream and downstream levels are generally lower than levels at the outfall.

5.3 Case Study Results

This results section shows the results from the data collected from the case study site only. These results were presented to the Stakeholder group at the decision-making workshop in a simplified form. Most of these results are shown here as tables and further explained. The C1 soil sample pit was recorded as shallow and deep, rather than as horizons because the soil pit did not have defined horizons. The soil that the pit was dug into was piled from the previous excavation of the channel, therefore did not have defined horizons.

5.3.1 Soil Nutrient Testing Results

Table 4 shows the results of the nutrient testing done in the soils lab on all the upper horizons of the soil pits. The results do not vary much between sites. The first letter and number in the ID represent the soil pit and the two letters after represent the soil horizon.

Table 4. Soil nutrient testing results of upper horizons

ID	Ammonia	Chloride (ppm)	Nitrate (kg/ha)	Nitrite (ppm)	Phosphorus (kg/ha)	pH
A1 - HA	Very low	25-50	16.81	<1	112-168	6.9
A2 – HA	Very low	25-50	11.21	<1	28-56	7.1
B1 – HA	Very low	25-50	11.21	<1	56-84	6.9
B2 - HA	Very low	25-50	11.21	1.12	11.2-28	6.7
C1 - Shallow	Very low	100-500	11.21	1.12	11.2-28	7
D1 - HA	Very low	25	11.21-21.21	28.02	<11.2	5

Table 4 shows relatively similar nutrient levels across the pits. Pit C1 seems to have the highest chloride levels, pit A1 seems to have the highest nitrate levels, pit D1 seem to have the highest nitrite levels, pit A1 seems to have the highest phosphorus levels and D1 has the lowest pH. Nitrate and Phosphate levels are relatively high coming from the outfall water quality sampling and pit A1 is located closest to the outfall itself. Soil pit D1, in theory, should show the natural nutrient levels in the area because it has not been disturbed by excavation or excess wastewater. The optimal pH of topsoil for an LID is 6.5 (Boller, 2004).

5.3.2 Soil Organic Testing Results

Table 5 shows the results of the organic testing done in the lab on each soil horizon. The results were recorded in the lab once each test was completed. The % total organic was calculated once the loss on ignition was determined.

Table 5. Soil organic test results of all horizons

ID	**Initial Weight (g)**	**Final Weight (g)**	**Loss on Ignition (%)**	**% of Total Organic (correction of x1.75)**
A1 - HA	5.23	5.03	**3.8**	**6.69**
A1 – HB	6.53	6.28	**3.8**	**6.7**
A1 – HC	5.15	4.96	**3.7**	**6.46**
A2 – HA	5.19	4.62	**11**	**19.22**
A2 – HB	5.43	5.19	**4.4**	**7.73**
A2 – HC	5.24	4.86	**7.3**	**12.69**
B1 – HA	5.16	4.48	**13.2**	**23.06**
B1 – HB	5.34	5.14	**3.7**	**6.55**
B2 - HA	5.32	4.78	**10.2**	**17.76**
B2 – HB	5.73	5.3	**7.5**	**13.13**
C1 - Shallow	5.69	5.13	**9.8**	**17.22**
C1 – Deep	5.17	4.81	**7**	**12.19**
D1 – HA	5.4	3.76	**30.37**	**53.15**
D1 – HB	5.28	4.99	**5.5**	**9.61**
D1 - P	5.6	5.34	**4.6**	**8.13**

According to Boller (2004), the ideal topsoil for an LID implementation should have an organic content of over 4% and the subsoil with less than 1%. According to table 5, the topsoil of all samples is over 4%, however, the subsoil of all sample pits is over 1%. Conversely, The Toronto and Region Conservation Authority (2010) suggest that the optimal soil conditions for a vegetated LID require 3-5% dry weight of organic matter, which in this case would be the loss on ignition. The topsoil of pit D1 is the highest level of organic content of all the sample pits, showing the natural progression of less organic matter in further horizons.

5.3.3 Soil Texture and Composition Results

Table 6 shows the hydrometer method composition and texture results. Table 7 shows the soil sieving composition and texture results. The results were recorded once each test was completed in the lab. The soil type column was determined by percent shown on a soil triangle. All measurements are recorded in grams (g), unless stated otherwise as a percentage.

Table 6. Soil texture and composition hydrometer results of lower horizons

ID	Start Weight (g)	Temp (°C)	First Reading	Clay and Silt (g)	Second Reading	Final clay (g)	Final Clay (%)	Final Silt (%)	Final Sand (%)
A1-HC	74.9	22	1004	12.35	1003.5	11.85	15.8	0.6	83.6
B2-HB	38.9	22	1008	16.35	1002.5	10.85	27.8	14.1	58.1
C1- Deep	69.2	22	1011.5	19.85	1004	12.35	17.8	10.8	71.4
D1- P	77.6	22	1006	14.35	1004	12.35	15.9	2.5	81.6

Table 6 shows that most soil has relatively high sand content when compared to silt and clay. Sample B2 shows the highest silt and clay content. Boller (2005) suggests that the ideal soil composition of both the topsoil and subsoil for an LID should have 10-35% clay content. Although all the subsoil samples tested are within this suggested range, they are all at the lower end, with a high content of sand, with the exception of pit B2. The TRCA (2010) suggests that permeable soils with a high composition of sand should not be compacted or removed for the purposes of an LID, as they provide an important function of groundwater recharge (Toronto and Region Conservation Authority, 2010).

Table 7. Soil texture and composition sieving results of all horizons

ID	Start Weight	Ø	Percent	Ø 2	Percent	Ø 4	Percent	Ø 8	Percent	Pan	Percent	Soil Type
A1 - HA	200.2	10.8	5.39	89.5	44.71	84.9	42.41	5.2	2.6	9	4.5	**Sand**
A1 – HB	199.7	27	13.52	109	54.58	58.7	29.39	2	1	2.9	1.45	**Loamy Sand**
A1 – HC	199.8	39.2	19.62	103.6	51.85	50.5	25.28	2.3	1.15	3.9	1.95	**Loamy Sand**
A2 – HA	192.2	3.2	1.66	34.5	17.95	109.7	57.08	13.9	7.23	30.5	15.87	**Sandy Loam**
A2 – HB	199.8	2.6	1.30	76.5	38.29	110.1	55.11	3.7	1.85	6.9	3.45	**Sand**
A2 – HC	203.3	3.6	1.77	36.3	17.86	126.2	62.08	11.3	5.56	25.3	12.44	**Sandy Loam**
B1 – HA	174.7	12.7	7.27	23.2	13.28	65.7	37.61	17.9	10.25	54.6	31.25	**Clay Loam**
B1 – HB	200.5	28.3	14.11	95.3	47.53	60.4	30.12	5	2.49	11.2	5.59	**Loamy Sand**
B2 - HA	190	6.7	3.53	19.6	10.32	77.2	40.63	19.5	10.26	66.2	34.84	**Clay Loam**
B2 – HB	199.9	4.6	2.3	14.5	7.25	91.2	45.62	21.5	10.76	67.4	33.72	**Clay Loam**
C1 - Shallow	199.9	80.9	40.47	62.5	31.27	37.5	18.76	4.7	2.35	14.2	7.1	**Sandy Loam**
C1 – Deep	200.5	88.1	43.94	47.4	23.64	39.7	19.8	5.1	2.54	19.8	9.88	**Silt Loam**
D1 – HA	132.8	17.9	13.48	41	30.87	33.6	25.3	7.6	5.72	31.9	24.02	**Loam**
D1 – HB	200.6	38.7	19.29	99	49.35	48.6	24.23	4.4	2.19	9.2	4.59	**Sandy Loam**
D1 - P	199.5	30.4	15.24	104.3	52.28	50.2	25.16	4.7	2.36	9.5	4.76	**Loamy Sand**

Most of the texture and composition results in Table 7 show a high level of sand content with the exception of soil sample pit B2. Soil sample pit B2 is the only sample pit that does not have a high concentration of loam or sand. The TRCA (2010) suggest that a presents of loamy soil is the most suitable for a vegetated infiltration LID. The hydrometer results compared to the sieving results show a variation in silt and clay content, which can be expected. Although the hydrometer results show a higher concentration of silts and clays, all samples in both tests still confirm high sand content, with the exception of sample B2 shown in both tests.

5.3.4 Infiltration test results

Table 8 shows the results of the infiltration testing done using the Guelph Permeameter. The results were recorded on-site with GIS Roam and transferred into this table. The suitability column was determined using the *Site Evaluation and Soil Testing Protocol for Stormwater infiltration* (Toronto and Region Conservation Authority, 2010). The suitability was determined once the proper calculations were completed.

Table 8. Infiltration test results with possible LID suitability

ID	Depth (m)	Waterwell head height	Horizon	Final K_{fs}	Approximate Final Infiltration Rate (mm/hr)	Suitable soil for structural LID
A1.1	.15	7	upper	0.17	35.3	Yes
A1.1 rep	.13	7	upper	0.027	17.6	Yes
A2.1	.15	8	upper	0.013	17.6	Yes
A2.1 rep	.16	7.5	upper	0.023	17.6	Yes
B1.1	0	N/A*	N/A	N/A	0*	No
B1.1 rep	0	N/A	N/A	N/A	0	No
B2.1	.14	7.5	upper	0.005	8.8	No
B2.1 rep	.13	9	upper	0.0025	8.8	No
C1.1	.15	7	upper	0.013	17.6	Yes
C1.1 rep	.13	7	upper	0.283	35.3	Yes
C1.2	.25	7.5	lower	0.0042	8.8	No
C1.2 rep	.25	7	lower	0.0075	8.8	No
D1.1	.11	7	upper	0.083	17.6	Yes
D1.1 rep	.13	6	upper	0.24	35.3	Yes
D1.2	.33	6	lower	0.02	17.6	Yes
D1.2 rep	.33	7	lower	0.013	17.6	Yes

- N/A – The water table was directly at the surface of the test area. The infiltration test cannot be done in fully saturated conditions. This means the infiltration rate in that area is 0.

According to the TRCA (2010), if the final infiltration rate is above 15mm/hr the site soils can be used as they exist for infiltration LID purposes. As shown in Table 8, soil sample pits B1, B2 and C1 would not be suitable soil infiltration rates as they currently exist for a vegetated or infiltration LID. The site is structured in a way that the areas that pits B1 and B2 are located in could not be excavated and replaced with external media without disturbing the A1 and A2 pits. The results of Table 8 suggest that the B1 and B2 pits are fully saturated as they exist currently.

5.4 **Stakeholder** ***Involvement Results***

The following results are the initial recommendations and comments that were produced from the site visit. They are broken down into each site and summarized. The results then go into describe the outcome of the Stakeholder workshop. The workshop results are broken down into a summary of the potential successes and obstacles determined for Stormwater Remediation in Thunder Bay, the first brainstorm of the overall stormwater management objectives for Thunder Bay, the finalized and focused stormwater objectives for Thunder Bay and the site specific results based on meeting objectives. The site specific results are broken down into each site.

5.4.1 Site Visit Initial Comments and Recommendations

5.4.1.1 County Fair

At the county fair site, the discussion began with general comments made about the condition of the water at the base of the outfall, which looked turbid and had colourful algal growth, and the garbage in the outfall bars. There was a general group acceptance that the site looked like it was naturalizing already without human development, and that the existing wetland should be further characterized. The discussion at the County Fair site was mostly surrounding the potential LID. The main political issue that the group agreed would need to be explored before any development could occur was considering potential flooding impacts. It was suggested that the flood plain mapping located at the Lakehead Region Conservation Authority should be evaluated before any development could occur. The main social issue that was discussed was possible residential complaints of development. The site is located on a well travelled bike/walking path that many people feel strongly connected to. There are also surrounding residential neighbourhoods adjacent to the site that may not want to see any sort of development. There were some suggestions for alternative remediation options to an end-of-pipe LID on this site as well.

These alternatives included; a pre-treatment at source, a removal of the existing sediment, public education and improvements to the County Fair mall parking lot. There was a unanimous agreement that if an LID was to be developed in this area, a partnership with the Walmart in the mall should be pursued. The group did not think there was currently enough information of the site to move forward with an LID proposal, however, once the physical case study data collection and analysis was done, the idea would be reconsidered.

5.4.1.2 Castlegreen

At the Castlegreen site, the discussion began with the outfall condition. The rebar is showing and there is excessive algal growth at the base of the outfall. This led the discussion into the excessive amount of nutrient levels that have been observed at this outfall. The group unanimously agreed that the first next step for Castlegreen should be an inspection of the sewer lines and testing for e.coli. Thunder Bay still has approximately 14 kilometers of combined sewers left around the city. Most of the sewers are concentrated in the East end of the city; however, the group believes there may be one at this site. If this site is not a combined sewer, the group agreed that there should be an investigative study done on where the excess nutrients are coming from, this could be done through a case study education strategy. The group agreed that the co-op environment of the Castlegreen community would be an ideal area to facilitate a public outreach plan. There were a few LID suggestions made such as an opportunity to develop an offline wetland on the east side of the path and adding an LID into road construction projects. Most of the group still determined that an education plan in the community would be a more successful remediation option on this site than an LID project.

5.4.1.3 Court Street

Court Street was the last site visit of the session. The outfall was observed from the opposite side of the creek as private property must be crossed to reach the outfall itself. The main discussion surrounding the Court Street subwatershed was the highly urbanized nature of the residential area. The group unanimously agreed that the most successful remediation option strategy for this area would be an education and outreach campaign as opposed to an end-of-pipe or at source LID. An LID in this area would be difficult as the water current at the end-of-pipe is fairly fast moving with very little existing vegetation and the subwatershed is significantly privately owned. The group did decide however that there should also be more by law enforcement on privately owned car repair and maintenance activities on personal property. The group agreed that this subwatershed could be a case study for a city management strategy using education and by law enforcement.

5.4.2 Stakeholder *Workshop Results*

The Stakeholder multi-scale decision making workshop achieved the ultimate goals of this thesis. The workshop achieved the requirement of the MSDM by ultimately identifying alternative solutions and also achieved the last two objectives of this thesis; completion of the implementation of a decision-support criterion to identify the most effective stormwater remedial option based on Low Impact Development, community education, policy and regulation and maintenance; and the completion of using expert and local feedback, along with field data collection to produce a remediation option plan for the identified subwatershed hotspots. The stakeholder workshop was the last step in data collection for this thesis and will aide in ultimately producing the remediation recommendations for this thesis.

After the initial presentation on background information, the group was asked to brainstorm the potential successes and obstacles in Thunder Bay stormwater Management. There were no restrictions put on the group to categorize or limit the context. This exercise built a base that the remainder of the workshop would be based on. The group was asked to say whatever they thought was appropriate for these categories. The group was continually asked throughout the duration of the workshop to refer back to this list as a feasibility criterion. The results of this task are outlined in Table 9.

Table 9. Successes and obstacles in Thunder Bay stormwater management defined by stakeholders

Successes	Obstacles
The Thunder Bay footprint is light due to low population	Aging infrastructure
The city of Thunder Bay is moving forward with SWM* (funding and process for adaptation plan for climate change)	General confusion about stormwater priorities (ex. Water quality vs. infrastructure)
There are organizations set up with education capacity (ex. Earthwise and Ecosuperior)	No erosion/sediment or progressive SWM policy
Thunder Bay is still fairly naturalized within city limits	Thunder Bay has not had stormwater education in about 10 years (general public is uneducated on SWM)
Several assessments completed; WPCD flood, drainage study, outfall survey, review of master plan and Urban design guidelines	Public perception on natural lands (We have so much of it so why do we need to protect it)
There is a heightened awareness of stormwater outfalls	Perfect stormwater management areas are designated for other purposes
Higher interest in SWM in upper management	Lack of coordination, responsibility, enforcement and implementation, local expertise and priorities
	MONEY $$
	Outdated development plans
	No defined valued system for water quality
	Thunder Bay is very automobile focused
	Snow removal not considering SWM
	Capacity and time within the City

*SWM – Stormwater Management

Table 9 shows that there are more obstacles than successes in Thunder Bay stormwater management in Thunder Bay according to stakeholders. It also shows that responses were based highly on political and social aspects.

Once the successes and obstacles were determined, the group was asked to brainstorm overall stormwater management objectives while considering the successes and obstacles. The group was asked to think of the objectives in terms of social, economic, environmental and political terms. This would make the categorization and condensed table easier to manage later. The results of this brainstorm are shown in Table 10.

Table 10. Broad overall stormwater management objectives in general stormwater management defined by stakeholders

Social	Economic	Environmental	Political
Education of stormwater issues	Determine responsibility of maintenance	Maximize surface infiltration	Monitoring of stormwater
Ensure awareness of flooding impacts	Reduce costs and have money aside for maintenance	Sediment (nutrients, excess, etc)	Monitoring baseline conditions
Increase awareness of stormwater aesthetics	Develop (20,30,50) year models	Bioretention	Commitment from council
Education on proper use of stormsystems (ie. Rainbarrels)	Determine long term cost and benefit	Biodiversity/habitat	Re-evaluation of stormwater bylaws
Community safety	Sustained finances	Reducing peak flows	SWMP*
Education on the value of water	Determine value of stormwater and stormwater systems	Build up science surrounding stormwater impacts	Cost and benefit analysis
Finding the easiest way to overcome barriers	Seize finding opportunities	Groundwater	Stormwater ideals re-evaluated through changes
	Use of an integrated framework (asset management plan)	Water quality (clearly defined targets)	Education of council
	PARTNERSHIPS	PARTNERSHIPS	

*SWMP – Stormwater Management Plan

As shown in Table 10, the most valued overall stormwater management objective is partnerships.

Once the overall stormwater management objectives were determined, the group was asked to condense the list into two-three focused stormwater objectives for Thunder Bay. There were some initial disputes over wording and which objectives were the most valued of the group, but in the end Table 11 shows the groups unanimous focused stormwater objectives for Thunder Bay.

Table 11. Final focused Thunder Bay specific stormwater management objectives defined by stakeholders

Social	Economic	Environmental	Political
*Context specific plans	To internalize cost of new stormwater management	Reduce surface volume runoff	Creation and adoption of the stormwater management plan
Ensure community safety	Integration of stormwater into asset management plan	Improve quality of runoff	Ensure balance between short and long term planning
		Increase and enhance integrity	
	PARTNERSHIPS	PARTNERSHIPS	

*Context – Local environments including community perceptions of environment and stormwater impacts

Table 11 shows the focused stormwater management objectives from the stakeholders in a Thunder Bay context. The political column of the objectives is directly related to the creation of a Master Stormwater Management Plan for the city. The group was hopeful that the Master plan will be created in the near future, and these objectives will be incorporated into that plan. Again, the group determined that partnerships were a highly valued objective of Thunder Bay stormwater management across all categories. These partnerships can include internal partnerships within the city, or external and distant partnerships outside of the City of Thunder Bay. The group determined that these specified objectives could be met by both embracing the successes of Thunder Bay stormwater management and overcoming the obstacles defined in Thunder Bay stormwater management.

Once the group had agreed and finalized the focused objectives, they were provided with the aerial photo maps and feasibility and decision making criteria and asked to determine what the most valued stakeholder recommendations were for these areas. The two multi-scale scenarios were provided along with the initial recommendations from the site visit. The County Fair case study site was presented with all physical quantitative data and an initial recommendation of an end-of-pipe LID. The other two sites were presented with the broader information, more so representing McVicar creek as a whole. This step in the stakeholder participation finalizes the completion of the objectives of this thesis. The remediation recommendations that resulted from this step are the recommendations used in the conclusion section of this thesis. The participants were asked to come up with several recommendations for each site and then establish the most valued recommendation based on meeting the determined objectives of Thunder Bay stormwater management. Most of the group discussion surrounded the County Fair case study site and potential remediation options. Below are the final results for each site unanimously made by the group.

5.4.2.1 County Fair remediation recommendations:

1. Remove section of the pipe and create LID, or create LID at end-of pipe
2. Educate and partner with land owner to remediate parking lot and commercial area; engage with the landowner to do a pilot project, use project as a transformation paradigm
3. Leave alone

Most valued stakeholder recommendation for meeting objectives:

Educate and partner with land owner

- Produce an information booklet on the impacts of the condition and potential opportunities of the property. Highlight personal incentives and determine if there are any economic incentives.

5.4.2.2 Castlegreen remediation recommendations:

1. Further investigation on pipe system

2. Work with the co-op to educate the community
3. Maintenance on the heaving and buckling road

Most valued stakeholder recommendation for meeting objectives:

First and foremost, send Jim a summary of outfall and pipe condition

Partnership with the co-op

- Develop a small scale homeowner education campaign in partnership with the co-op to educate residents on stormwater impacts in their community

5.4.2.3 Court Street remediation recommendations:

1. Increased by law enforcement
2. Community stewardship initiative
3. Adopt the LRCA's previous education strategy

Most valued stakeholder recommendation for meeting objectives:

Community education campaign

- An adaptation to the LRCA's previous education campaign with a focus on a context specific plan

As shown above, the group determined that the most valued remediation recommendation across each site was an education and outreach campaign. Although there are several other remediation recommendations for each site, the group decided that the first step in each case should be education. The discussion finished with the stakeholder group agreeing that eventually the other recommendations and values should be addressed and further pursued, however, at this point in Thunder Bay stormwater remediation, education is the most important factor.

6.0 Discussion

The USSR appears to have successfully characterized urban catchment basins associated with the selected outfalls. The study was based on an adopted criteria and assessment from the Center for Watershed Protection (CWP), (2005); therefore the conclusions drawn from this study reflect the suggested outcomes of the CWP. Potential remediation options are focused on community participation, outreach and education, landscaping, retrofits, maintenance and policy enforcement. The initial recommendations from the USSR study are as follows;

The Court Street site needs a focus on community education and alternative snow removal. The majority of the court street subwatershed is privately owned land with densely populated residential areas which makes retrofits difficult to employ. The community should be educated in properly connecting rainbarrels to downspouts, the effects of auto fluids from home repair shops on aquatic ecosystems and downspouts to impervious surfaces. The Court Street subwatershed was the largest residential area studied with the lowest number of raingardens observed. This can be altered through education on diverting downspouts to private gardens. The Court Street stormwater outfall had the highest chloride levels recorded suggesting alternative snow and ice removal is necessary.

The Castlegreen site needs a focus also on community education as well as landscaping and retrofits. The community needs to be educated on the effects of garden chemicals and pet waste on aquatic ecosystems. The Castlegreen subwatershed had the highest number of raingardens and rainbarrels observed across all three sites and all rainbarrels were connected to downspouts. However, 100% of parking lots, driveways and roads are impervious paved surfaces within the subwatershed. These parking lots need bioretention islands and runoff splitters in the form of depressions leading stormwater into open space for infiltration as an alternative to stormwater drains. There is a large open common space within the community that needs simple planting of native tree species and shrubs for increased bioretention. There is also a large forested area within the community that should be protected from development. The road that is lifting and heaving in the subwaterhed needs to be repaired. There is an excessive amount of sediment accumulation from the road degradation leading directly into the storm system. The road should be repaired with permeable pavement to increase infiltration. There are also opportunities for bioswales and stormwater infiltration ditches throughout the entire subwatershed. There needs to be further investigation into the excessive ammonia levels being discharged from the Castlegreen outfall. This can consist of investigation into a combined sewer or sewer pipe leak.

The County Fair site needs a focus on maintenance, policy enforcement, landscaping and retrofits. The main focus of the County Fair subwatershed needs to be on the back parking lot of County Fair mall. The parking lot is full of mounds of sediment that need to be removed, illegal long and short term parking and storage of transport trucks and large machinery. There is an excessive amount of illegal dumping and loitering. The parking lot either needs to be cleaned up and maintained or pulled up and landscaped with native vegetation. There is a saturated forested area adjacent to the parking lot that could be expanded into the lot. The stormwater pipes within the entire subwaterhed need to be vacuumed and consistently maintained to avoid sediment clogging and input into the creek. There are many ditches within the subwatershed that are currently being mowed completely. These ditches could be converted into bioswales with native semi-aquatic vegetation. The gas station within the subwatershed seemed fairly well maintained, however there needs to be a diversion of liquids from the storm system from washing vehicles outside and the dumpsters. The outdoor garden center needs to keep the garden chemicals in a storage area, or at the least, sheltered from precipitation events. There were fertilizers observed spilling onto the ground and running directly into the storm system. The front parking lot of County Fair mall needs bioretention islands and runoff splitters. There is an opportunity in the County Fair site to further investigate a possible end-of-pipe LID due to the current condition of the end-of-pipe environment. The area is also publicly owned and was once excavated by humans suggesting a non-natural area as it is currently.

The initial recommendations that were produced through the USSR study are fairly consistent with the recommendations that were produced by the Stakeholder group, even after the other quantitative water quality and case study data was presented. Water quality data was used more as a visual tool in this thesis due to the fact that stormwater pollution contributions are fairly erratic over time and very difficult to point-source (Goonetilleke *et al.*, 2005). The goal of the water quality sampling was to show that there are stormwater related contaminants entering McVicar Creek through stormwater outfalls.

Ammonia, nitrate and phosphate levels according to the results of the water quality sampling are the only parameters that showed a possible correlation to stormwater itself. All three of those parameters seemed to record lower levels during precipitation collection days and elevated levels during the dry spell of July 17th-July 24th. This is probably due to the flush or dilution theory. During a single precipitation event, most common stormwater contaminants are flushed out into the aquatic system within the first hour of the event (Hall *et al.*, 1987). This theory suggests that if water quality testing is completed after the flush of contaminants, the bulk of contamination will have already entered into the aquatic system. This would also explain why in the constant weather flow from the outfalls, during the dry spell, the parameters were heightened. The water quality sampling regiment and duration used in this thesis can not conclusively state that stormwater contamination on any of the sites is causing acute impairments to McVicar Creek.

The results can state, however, that parameters tested that are strongly correlated to stormwater contributions are being discharged into McVicar Creek through existing stormwater outfalls. The results vary too drastically from the water quality sampling done on these sites in the past to make a strong conclusion for comparison. This does show however, that stormwater contamination and discharge is variable, difficult to source, but does exist. Ammonia, nitrate, nitrite, phosphate and chloride have all presented themselves as contaminants being discharged through stormwater inputs into these sites in the past as well.

The water quality samples were taken upstream, downstream and at the outfall for the Court Street case study to try and determine a relationship between the water already in that part of the creek, water being discharged through the outfall and water quality downstream of the existing naturalizing wetland. Based on the samples collected and analyzed in this thesis, no strong relationship was identified between any of those sites for any parameters tested. The projected outcome of the water quality sampling was that the water quality downstream of the naturalizing wetland would be significantly improved from the water being discharged from the outfall. Unfortunately, this conclusion cannot be made based on the results produced from the water quality testing on the County fair site. This conclusion does not necessarily mean that the existing wetland is not contributing to water quality improvement as it is; it just means that more rigorous water quality research will need to be done to make a conclusive statement. Water quality results aside, observations made on the County Fair site would suggest the site is naturalizing well and becoming important wildlife habitat. During weekly water quality sample visits to the site, there was an active beaver dam observed, a muskrat sighting, a blue heron nesting site, several deer grazing encounters and many duck, bird and insect activities observed.

The quantitative studies that were done on the County Fair case study generally show that the site could be used for an LID with some alterations to the natural soil environment. The soil testing results actually achieve two purposes; the first is to show whether the area is currently suitable for an LID and the other is to show what the soil conditions of the site were prior to the excavation of the channel. Soil pit D1 was located in a relatively undisturbed area just south of the site in question. Before the excavation of the channel, the whole area, in theory, should have been similar to the results from D1.

The results from the nutrient testing show that the A1 soil test pit might be receiving the highest contributions of phosphorus and nitrate from the stormwater outfall. A1 is located closest to the outfall and nitrate was observed to be at consistently elevated levels during water quality sampling and phosphate was elevated at specific times. Nutrient levels tested on the other soil pits that were located within the saturated area of the channel did not vary much from one another outside of A1. These results suggest that the area around the A1 sample pit would be the most suited for a wide array of vegetated LID measures due to the excess availability of nitrate and phosphorus which both contribute to plant growth and development (Toronto and Region Conservation Authority, 2010). The pH levels recorded from all sample soil pits would be suited for an LID implementation without alteration, except for D1 which only had a pH of 5.

The only sample soil pit that showed the natural decrease in organic content from higher to lower horizons was D1. This is most likely due to the fact that D1 was the only soil pit dug on undisturbed soil from excavation. According to Boller (2005) none of the soil in the area tested for organics is suitable as it exists for an LID, as the content is too high. According to the TRCA (2010) however, soil pits A1, A2 and B1 would not need alterations to organic content for a successful vegetated LID. The conflicts in specific site details of LID suitability seems to vary within the literature depending on sources of research data and location.

According to the TRCA (2010), every sample soil pit composition and texture is suitable for LID implementation as it exists with the exception of soil pit B2. The suitability of the site is based on the relatively high occurrence of loam and sand within the area which is ideal for proper infiltration of an LID and vegetation growth. However, the TRCA also suggests that permeable soils with a high concentration of sand content should be left to perform the vital function of groundwater recharge rather than being developed for an LID. The reason for this is because the development of an LID often involves the compaction or complete removal of existing soil and alterations of the entire local hydrological regime. Groundwater recharge, especially when urban areas are increasing impervious surfaces over aquifers is extremely important to the health of the ecosystem as well as the long term availability of fresh water to humans (Muthanna, 2007). This suggests that an ecological benefit analysis should be considered before further development on the site. The hydrometer tests compared to the sieving results did show a higher concentration of clay in all soil sampled. However, sand content within all the samples, with the exception of B2, is still dominant suggesting relatively permeable soils resulting from both tests. The variation in results between the sieving and hydrometer method were expected as the hydrometer method is more accurate at determining specific silt and clay content. For the purposes of LID in this thesis, the comparison between the two tests still concluded similar results in that all soils, with exception of B2, are high in sand content and fairly permeable.

The infiltration test results show that the soil is suitable for a structural infiltration LID implementation on all sites except B1, B2 and C1. It would however be very difficult to remove and replace the soil in the area surrounding B1 and leave the area surrounding A1 and A2. The pits were dug within the floodplain of the channel, so some areas were more saturated than others. This is the case with the pits located in B1 and especially B2. The infiltration holes augured for B1 were so highly saturated that the test was inconclusive. Results were similar for B2. Infiltration rates do not necessarily determine the suitability for any LID, only LID's that require certain infiltration rates. The infiltration rates of the soil could be overlooked if an LID was going to be developed based strictly on planting vegetation and focused on water and contaminant uptake of plants (Toronto and Region Conservation Authority, 2010). In this case though, soil sample pit B2 does not appear to be suitable for any LID development.

In general, a successful LID could possibly be implemented into the County Fair case study site with few alterations to the existing soil conditions. The soil and infiltration test results suggest however, that the development would need to be contained to the existing naturalizing wetland unless significant engineered alterations were made. Soil pit B2 seemed to have the most consistently unsuitable conditions for an LID with pit B1 in a similar condition. Both these pits were located downstream of the existing wetland which suggests that conditions are more saturated and soil structure is altered from upstream. If an LID was to be considered in this area, the loss of current groundwater recharge function would have to be considered as a negative impact along with the alteration of current wildlife habitat. With some engineered alterations however, an LID is a viable option for the County Fair Case study site.

Based on all the above information, the Stakeholder group was able to provide informed and educated recommendations. One of the most useful and productive results that came from Stakeholder involvement throughout this thesis was the definition of focused stormwater objectives for Thunder Bay. Up until now, these objectives have not been defined locally to suit the needs of Thunder Bay stormwater management. These objectives are as follows;

Social Objectives: Context specific plans and ensure a safe community

Economic Objectives: To internalize the cost of new stormwater management and to integrate stormwater into an asset management plan

Environmental Objectives: To reduce surface volume runoff, to improve quality of runoff and to increase and enhance integrity

Political Objectives: The creation and adoption of the stormwater management plan and to ensure balance between short and long term planning

Overall Objective: To create partnerships

By defining these objectives, Thunder Bay can move forward in Stormwater management with context and goals in mind. The stakeholder group was also able to develop recommendations for each site based on all the information provided. Using the feasibility criteria, the decision support criterion while following the requirements of MSDM, the following recommendations were made by the Stakeholder group;

An education and outreach plan should be the next steps in Thunder Bay stormwater management with a focus on McVicar Creek subwatershed hotspots. The focused education and outreach plans should include; In the County Fair subwateshed, to produce an information booklet on the impacts of the condition and potential opportunities of the property, to highlight personal incentives and determine if there are economic incentives, to ultimately educate and partner with the land owner. In the Castlegreen subwatershed, to first send the City a summary of the outfall and pipe condition, and then develop a small scale homeowner education campaign in partnership with the co-op to educate residents on stormwater impacts in their community, to ultimately form a partnership with the co-op. In the Court Street subwatershed, to adapt a plan similar to the LRCA's previous education campaign with a focus on a context specific plan, ultimately create a community education campaign. There were other recommendations on each of these subwatersheds as well; however, these were the most valued stakeholder recommendations meeting the outlined stormwater management objectives. In conclusion, Thunder Bay stakeholders are not yet ready for a large-scale stormwater development project on McVicar Creek however, this may change in the near future and will definitely change following a watershed-wide education and outreach campaign.

Australia is known to be at the forefront of LID and BMP stormwater management, most likely due to the awareness of impacts arising in the 1960's (Roy *et al.*, 2008). Most stormwater remediation in Australia started with the education and involvement of the public and has evolved over time as an accepted form of management. Thunder Bay is at the beginning stages of public awareness of stormwater impacts on the aquatic system. If Thunder Bay follows a similar stormwater progression as Australia started in the 1960's; stormwater remediation measures will be widely accepted by the public and implemented City-wide. Initial public participation and acceptance is also crucial in the successful implementation of stormwater remediation (Rauch *et al.*, 2005). Residential behaviours have significant impacts on water quality being discharged through stormwater systems, so public education and awareness can often act as a source control technique for contamination.

7.0 Conclusion

Ultimately the research done in this thesis has shown that, although there are suitable sites within the City, Thunder Bay is not currently ready for an LID implementation plan according to Stakeholders. The process used in this thesis however, has developed a suitable methodology for future stormwater remediation research or investigation. The methodology built through this thesis could be used not only in Thunder Bay remediation plans, but across Northern Ontario communities. The objectives of this thesis were met through both quantitative and qualitative data collection. The qualitative data collection was used as a base to provide a multi-scale decision making process and aide in the feasibility criteria of a case study site. The first objective of this thesis; to develop feasibility criteria of site-specific stormwater remediation options for each identified site along McVicar Creek, was achieved through an extensive literature review of both academic and technical literature. The feasibility criteria created through this literature was provided and used by the stakeholder group to determine the ultimate remediation recommendations. The second objective of this thesis; to implement a decision-support criterion to identify the most effective stormwater remedial options based on Low Impact Development, community education, policy and regulation and maintenance was achieved through each step of this thesis process.

The literature review created a base of knowledge for the researcher to pass along to the stakeholders throughout the process. The review of literature also aided in the development of a quantitative data collection plan that was crucial to the success of a multi-scale decision making process. This was the first step in implementing the decision-support criterion. The second step of the decision-support criterion was the physical quantitative field data collection. This gave the decision makers a wide array of information to make educated and informed remediation decisions. Without this data, there would be no evidence of a potential successful LID on the case study. The data collection process can be used now as a baseline data collection for any potential LID site within Thunder Bay. This is a large part of the decision-support criterion produced by this thesis. The data collected throughout this process can also be used by other researchers when looking at the local physical environment on McVicar Creek. This is data that has not ever been collected previously on any other sites in Thunder Bay. An LID development could not proceed without this crucial quantitative information.

The stakeholder involvement was the final step in completing the decision-support criterion. The introduction session created a base of knowledge within the participating stakeholder group to effectively evaluate the project and make informed decisions. This step met the first requirement of the Multi Stakeholder Decision Making process; to define the problem. This step laid the groundwork for all other participation sessions. The second stakeholder participation step, the site visit, was the next step in the decision-support criterion. This step allowed the participants to individually relate to the study sites. It also gave them a chance to observe both the physical and ecological aspects of each site. Giving the participants an opportunity to make initial remediation recommendations on-site for each site proved to be very successful in engaging interest in the project. It gave the stakeholders' time between the site visit and the workshop to reflect on the initial recommendations and the physical sites themselves, which ultimately aided in the success of the workshop later. The site visit step also achieved the second requirement of the Multi Stakeholder Decision Making Process: to access information that falls outside of the scientific realm. The last step in the stakeholder involvement process, the multi-scale decision making workshop, was the final stage of completing the decision-support criterion.

The workshop also achieved the last objective in this thesis: using expert and local feedback, along with field data collection to produce a remediation option plan for identified subwatershed hotspots. The results of the workshop are the concluding recommendation remediation options for this thesis. The decision-support criterion that was developed and used for this thesis has proved successful in identifying potential remediation options as well as local valued stormwater remediation options. The workshop also achieved the last requirement of the Multi Stakeholder Decision Making process; to identify alternative solutions.

The results of the quantitative data according to the literature show that the County Fair case study site is a suitable option for an LID/retrofit. The soil is generally suitable for an LID based on the infiltration results, soil texture, soil nutrients and organic matter results. The areas within the case study site that have less than ideal LID soil conditions, could be altered through engineering practises and designs to achieve a successful LID implementation. These sites are also located downstream of the existing wetland, so could easily be avoided in development. The water quality results show excess amounts of water quality parameters exceeding guidelines. Ammonia, nitrate and phosphate seem to show erratic tendencies regardless of samples taken upstream, downstream or at the outfall itself. This suggests that the existing wetland is not functioning as a stormwater remediation technique as efficiently as it could through engineered alterations, whether these alterations are soil composition and depth or vegetation replacement.

Regardless of these results, the stakeholder group has determined that at this time in Thunder Bay stormwater management, a watershed-wide education and outreach campaign is a more valued remediation option. This could be due to Thunder Bay stormwater management currently being in its infancy. Mallin *et al* (2009), Rauch *et al* (2005) and Roy *et al* (2008) suggest that stormwater management begins with community education on stormwater issues and residential behaviour impacts on aquatic ecosystem, and only once this is successfully communicated and known in a community, can stormwater management at any other level begin. Thunder Bay is still in a phase of learning and knowledge dissemination when it comes to stormwater management. The stakeholders and public are clearly not ready for any large-scale stormwater development measures until there is at least more local knowledge and baseline information. There are also high levels of uncertainty, unknown results and reluctance in stormwater development due to the lack of information on monitoring and successes of LID and retrofit projects (Fassman, 2012; Taylor *et al*, 2007; Roy *et al*, 2008; Olorunkiya *et al*, 2012). This could very well contribute to the reluctance of Thunder Bay stormwater stakeholders to currently pursue an LID project within the city.

Current stormwater literature is saying that although stormwater is an emerging social and environmental concern, there is a significant reluctance to adopt stormwater development projects due to little known long-term benefits. This reluctance comes from not only the public, but from construction professionals as well as political standings. Although there are pilot projects and research projects out there monitoring the successes of stormwater remedial development, they are in their infancy and when funding is a factor, it is shown that people are hesitant to take that risk. The literature is also showing that there is a significant impact on the environment caused by untreated stormwater such as habitat degradation, soil erosion, water quality impairments and flooding impacts. There are also proven human health risks related to untreated stormwater and cost-benefit analysis on the treatment of potable water at the source or at the treatment plant. Regardless of these known impacts on environment and social behaviours, people on all scales are still reluctant to accept alternative stormwater management. However, the trend in the literature is showing a current paradigm shift in the values and ideals of stormwater. If this shift follows a similar trend to other historical environmental movements, there should be an acceptance of alternative stormwater in the future, we just might not quite be there yet especially in the case of Thunder Bay.

The decision of Thunder Bay stakeholders to focus on an education and outreach program before delving into an LID project is a trend shown throughout stormwater literature. There are many researchers that believe that to produce a successful stormwater management plan with alternative and ecological stormwater options, there needs to be a general education of the public. Much of the general public is unaware of stormwater impacts and even where it goes. Public acceptance is near impossible without a general knowledge of the problem.

Although Thunder Bay stakeholders decided against an LID implementation for the time being, this researcher believes the feasibility criteria and the decision-support criterion produced and used in this process was successful in determining remediation option plans for the identified subwatershed hotspots, as well as the larger McVicar Creek watershed. The multi-scale decision making process was also successful and a useful tool in guiding the stakeholder participation sessions. The feasibility criteria of site-specific stormwater remediation options for each identified site along McVicar Creek was produced and adopted from the academic and technical literature reviewed in this thesis. The implementation of a decision-support criterion to identify the most effective stormwater remedial options based on Low Impact Development, community education, policy and regulation and maintenance was produced through data collection. The decision-support criterion involves the introduction of the stakeholder group to the project itself, the physical qualitative data collection of the case study site, the site visits with the group and the multi-scale stakeholder decision making workshop. The production of a remediation option plan for identified subwatershed hotspots using Stakeholder feedback, along with field data collection was done through the final multi-scale decision making workshop and the tools provided within that workshop to the participants.

8.0 Final Recommendations

1. The first recommendation is that first and foremost, the defined objectives for Thunder Bay Stormwater management be considered and used in all further stormwater management in the City. These objectives are:

a) Social Objectives: Context specific plans and ensure a safe community
b) Economic Objectives: To internalize the cost of new stormwater management and to integrate stormwater into an asset management plan
c) Environmental Objectives: To reduce surface volume runoff, to improve quality of runoff and to increase and enhance integrity
d) Political Objectives: The creation and adoption of the stormwater management plan and to ensure balance between short and long term planning
e) Overall Objective: To create partnerships

2. The second recommendation is that before further stormwater remediation plans are pursued on McVicar Creek, that the final recommendations proposed by the Stakeholder group are considered and completed. These recommendations are;

An education and outreach plan on McVicar Creek subwatershed hotspots. The focused education and outreach plans should include; In the County Fair subwateshed, to produce an information booklet on the impacts of the condition and potential opportunities of the property, to highlight personal incentives and determine if there are economic incentives, to ultimately educate and partner with the land owner. In the Castlegreen subwatershed, to first send the City a summary of the outfall and pipe condition, and then develop a small scale homeowner education campaign in partnership with the co-op to educate residents on stormwater impacts in their community, to ultimately form a partnership with the co-op. In the Court Street subwatershed, to adapt a plan similar to the LRCA's previous education campaign with a focus on a context specific plan, ultimately create a community education campaign.

3. The third recommendation is that decision-support criterion and feasibility criteria process used in this thesis should be used to determine further stormwater remediation options along any Thunder Bay water body.
4. The fourth recommendation is that the base line data collected in this thesis be used for any future LID proposal on the County Fair case study site.

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Appendices

Appendix 1: Adapted USSR Field Forms

TALLY SHEET (TICK TALLY): **SITE ID:**

Paved Lots/driveways-

Pervious Lots/driveways (gravel, dirt, stone)-

Oil Stains on Driveways-

Downspouts Connected to Impervious Surfaces-

Downspouts Discharged into Rain-barrel, Cistern, etc-

Downspouts Discharged into Rain Garden-

Garages/carports/sheds-

Bare/exposed ground (un-vegetated and vulnerable to erosion) and size-

Subwatershed:	Outfall ID:	Site ID:	
Date: ___/___/_____ (yr/mo/day)	Assessed By: Time:	Camera ID:	Pic#:

A. Development Characterization

Total Development Area (meters) _______

Land Use:

Residential ___% Commercial ___% Industrial ___% Institutional ___% Municipal ___% Transport-Related ___%

If Residential: ______________________________

☐ Single Family Attached (Duplexes, Row Homes) ☐ Multifamily (Apts, Townhomes, Condos)

☐ Single Family Detached ☐ Mobile Home Park

			INDEX*
Percent of Homes with Garages/Carport/Shed: _____%			
Index of Infill, Redevelopment, and Remodeling ☐ No Evidence ☐ <5% of units ☐ 5-10% ☐ >10% Construction ☐ Hydro ☐ Residential Development ☐			○
Record percent observed for each of the following indicators, depending on applicability and/or site complexity	Percentage	Comments/Notes	
B. Yard and Lawn Conditions			
B1. % of lot with impervious cover			
B2. % of lot with grass cover			○
B3. % of lot with landscaping (e.g., mulched bed areas)			◇
B4. % of lot with bare soil			○
**Note: B1 through B4 must total 100%*			
B5. % of lot with forest canopy			◇

B6. Outdoor swimming pools? ☐Y ☐N ☐ Can't Tell Estimated # ____			○
B7. Junk or trash on property? ☐ Y ☐ N ☐ Can't Tell			○
Notes:			
C. Driveways, Sidewalks, Curbs and Parking Lots			
C1. % of driveways and parking lots that are impervious ☐ N/A			
C2. Driveway/Parking Lot Condition ☐ Clean ☐ Stained ☐ Dirty ☐ Breaking up ☐ Sediment build-up			○
C3. Are sidewalks present? ☐ Y ☐ N Sometimes ☐ If yes, are they on one side of street ☐ or along both sides ☐			
☐ Spotless ☐ Covered with lawn clippings/leaves ☐ Breaking-up ☐ Sediment build-up ☐ Other ________			○
What is the distance between the sidewalk and street? _____ m.			◇
Is pet waste present in this area? ☐ Y ☐ N ☐ N/A			○
C4. Is curb and gutter present? ☐ Y ☐ N If yes, check all that apply:			
☐ Clean and Dry ☐ Flowing or standing water ☐ Long-term car parking ☐ Sediment			○
☐ Organic matter, leaves, lawn clippings ☐ Trash, litter, or debris ☐ Overhead tree canopy			◇

* INDEX: ○ denotes potential pollution source; ◇ denotes a neighborhood restoration opportunity

D. Rooftops			
D2. Number of Downspouts directed to impervious surface (tally sheet)			
D3. Number of downspouts discharged to a cistern, rain barrel, etc. (tally)			
D4. Number of downspouts discharging into rain garden (tally)			◇
E. Common Areas and open space			
E1. Storm drain grates? ☐ Y ☐ N If yes, are they stenciled? ☐ Y ☐ N Condition: ☐ Clean ☐ Dirty Is it obstructed/full? ☐ Y ☐ N *if yes*, ☐ Clogged w/ sediment ☐ Filled with water ☐ Garbage ☐Other___________			◇
E3. Open Space: ☐ N/A *(Skip to part F)* Type: Turf__% Weedy/Overgrown__% Shrubs__% Trees__% is pet waste present? ☐ Y ☐ N dumping? ☐ Y ☐ N (details in notes) Area ___m			○
Buffers present? ☐ Y ☐ Floodplain present: ☐ Y ☐ N, If yes, is encroachment evident? ☐Y ☐ N Nearby water source? ☐Y☐ N Are aquatic plants present? ☐ Y ☐ N			
F. Vehicle Operations			
F2. Type of vehicle operations: ☐ Car traffic ☐ Fleet vehicles ☐ buses ☐ Freight ☐ other ________ F3. Is there evidence of spills/leakage from vehicle operations? ☐ Y ☐ N ☐ Can't Tell F4. Is there a drive through present? ☐ Y ☐ N			○
G. Waste Management			
G1. Type of waste *(check all that apply)*: ☐ Garbage ☐ Litter ☐ Construction materials ☐ Hazardous materials ☐Recycling ☐ Organic material ☐ Other _______________			
G2. Dumpster condition (*check all that apply)*: ☐ No cover/Lid is open ☐ Damaged/poor condition ☐Leaking or evidence of leakage (stains on ground) ☐ Overflowing			
G3. . Is the dumpster located near a storm drain grate? ☐ Y ☐ N ☐ Can't Tell If yes, are runoff diversion methods (berms, curbs) present? ☐ Y ☐ N ☐ Can't Tell			

G4. Are there abandoned buildings present? ☐ Y ☐ N	
Describe Recommended Actions:	

Subwatershed:	Outfall ID:		Site ID:
Date: ___/___/_____ (yr/mo/day)	Assessed By:	Camera ID:	Pic#:

Northing____________________ Easting____________________
Time:

A. Site Data and Basic Classification

Name and Address: ____________________ ______________________________ _____ ______________________________ _____

Category: ☐ Commercial ☐ Industrial ☐ Other_______
☐ Institutional ☐ Municipal
☐ Transport-Related

Basic Description of Operation:____ __________

INDEX *

B. Vehicle Operations ☐ N/A *(Skip to part C)*	Observed Pollution Source? ☐
B1. Types of vehicles: ☐ Fleet vehicles ☐ School buses ☐ Other: ____________	
B2. Approximate number of vehicles: ________	
B3. Vehicle through traffic: ☐ Low ☐ Medium ☐ High ☐ Can't tell	
B4. Ownership of vehicles: ☐ Internal ☐ External	
B3. Vehicle activities *(circle all that apply)*: Maintained Repaired Recycled Fueled Washed Stored	○
B4. Are vehicles stored and/or repaired outside? ☐ Y ☐ N ☐ Can't Tell Are these vehicles lacking runoff diversion methods? ☐ Y ☐ N ☐ Can't Tell	○
B5. Is there evidence of spills/leakage from vehicles? ☐ Y ☐ N ☐ Can't Tell	○
B6. Are uncovered outdoor fueling areas present? ☐ Y ☐ N ☐ Can't Tell	○
B7. Are fueling areas directly connected to storm drains? ☐ Y ☐ N ☐ Can't Tell	○

B8. Are vehicles washed outdoors? ☐ Y ☐ N ☐ Can't Tell Does the area where vehicles are washed discharge to the storm drain? ☐ Y ☐ N ☐ Can't Tell	○
C. Outdoor Materials ☐ N/A *(Skip to part D)*	Observed Pollution Source? ☐
C1. Are loading/unloading operations present? ☐ Y ☐ N ☐ Can't Tell If yes, are they uncovered *and* draining towards a storm drain inlet? ☐ Y ☐ N ☐ Can't Tell	○
C2. Are materials stored outside? ☐ Y ☐ N ☐ Can't Tell If yes, are they ☐ Liquid ☐ Solid Description: _______ Where are they stored? ☐ grass/dirt area ☐ concrete/asphalt ☐ bermed area	○
C3. Is the storage area directly or indirectly connected to storm drain (circle one)? ☐ Y ☐ N ☐ Can't Tell	○
C4. Is staining or discoloration around the area visible? ☐ Y ☐ N ☐ Can't Tell	○
C5. Does outdoor storage area lack a cover? ☐ Y ☐ N ☐ Can't Tell	○
C6. Are liquid materials stored *without* secondary containment? ☐ Y ☐ N ☐ Can't Tell	○
C7. Are storage containers missing labels or in poor condition (rusting)? ☐ Y ☐ N ☐ Can't Tell	○
D. Waste Management ☐ N/A *(Skip to part E)*	Observed Pollution Source? ☐
D1. Type of waste *(check all that apply)*: ☐ Garbage ☐ Litter ☐ Construction materials ☐ Hazardous materials ☐ Recycling ☐ Organic material ☐ Other _______________	○
D2. Dumpster condition (*check all that apply)*: ☐ No cover/Lid is open ☐ Damaged/poor condition ☐Leaking or evidence of leakage (stains on ground) ☐ Overflowing	○
D3. Is the dumpster located near a storm drain grate? ☐ Y ☐ N ☐ Can't Tell If yes, are runoff diversion methods (berms, curbs) present? ☐ Y ☐ N ☐ Can't Tell	○
E. Physical Building ☐ N/A *(Skip to part F)*	Observed Pollution Source? ☐

E1. Building Condition of surfaces: ☐ Clean ☐ Stained ☐ Dirty ☐ Damaged Evidence that maintenance results in discharge to storm drains (staining/discoloration)? ☐ Y ☐ N ☐ Don't know	○ ○

*Index: ○ denotes potential pollution source; ☐ denotes confirmed polluter (evidence was seen)

E2. Parking Lot Condition: ☐ Clean ☐ Stained ☐ Breaking up ☐ Sediment build-up ☐ Other ____________ Surface material: ☐ Paved/Concrete ☐ Gravel ☐ Permeable ☐ Dirt ☐ Other _________	○
E3. Do downspouts discharge to impervious surface? ☐ Y ☐ N ☐ Don't know Are downspouts directly connected into the ground? ☐ Y ☐ N ☐ Don't know Are downspouts visibly connected to water body? ☐ Y ☐ N ☐ Don't know	○
E4. Evidence of poor cleaning practices for construction activities (stains leading to storm drain)? ☐ Y ☐ N ☐ Can't Tell	○
F. TURF/LANDSCAPING AREAS ☐ N/A *(skip to part G)*	Observed Pollution Source? ☐
F1. Is there signs of pesticide use? ☐ Y ☐ N ☐ Can't Tell, if yes what signs? ______________________	○
F2. Do landscaped areas drain to the storm drain system? ☐ Y ☐ N ☐ Can't Tell	○
F3. Do landscape plants accumulate organic matter (leaves, grass clippings) on adjacent impervious surface? ☐ Y ☐ N ☐ Can't Tell	○
G. STORMWATER INFRASTRUCTURE ☐ N/A *(skip to part H)*	Observed Pollution Source? ☐
G1. Are stormwater treatment practices present? ☐ Y ☐ N ☐ Unknown If yes, please describe: ____________________	○
G2. Are private storm drains located at the facility? ☐ Y ☐ N ☐ Unknown Is trash present in gutters leading to storm drains? If so, complete the index below.	○

Index Rating for Accumulation in Gutters

	Clean	choked

Sediment	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Organic material	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Litter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

H. Initial Hotspot Status - Index Results

☐ Not a hotspot (fewer than 5 circles and no boxes checked) ☐ Potential hotspot (5 to 10 circles but no boxes checked)

☐ Confirmed hotspot (10 to 15 circles and/or 1 box checked) ☐ Severe hotspot (>15 circles and/or 2 or more boxes checked)

Follow-up Action:

☐ Refer for immediate enforcement

☐ Suggest follow-up on-site inspection

☐ Test for illicit discharge

☐ Include in future education effort

☐ Check to see if hotspot is an NPDES non-filer

☐ Onsite non-residential retrofit

☐ Pervious area restoration; complete PAA sheet and record Unique Site ID here: ______________________

☐ Schedule a review of storm water pollution prevention plan

Notes:

Subwatershed:	Outfall ID:	Site ID:
Date: ___/___/_____ (yr/mo/day)	Assessed By:	Camera ID:
Rain in Last 24 Hours ☐ Y ☐ N	Pic #	Time:

A. Location
A1. Extent of streets surveyed (area):

B. Street Conditions ☐ N/A *(skip to part C)*
B1. Road Type: ☐ Arterial ☐ Local ☐ Alley ☐ Other: __________
B2. Condition of Pavement: ☐ Clean ☐ Stained ☐ Sediment build-up ☐ Breaking-up
B3. Is on-street parking permitted ☐ Y ☐ N If yes, approximate number of cars: _________

B5. Is trash present in curb and gutter? If so, use the index to the right to record amount.	Average Accumulation in Gutters				
	Clean				Choked
Sediment	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Organic Material	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
Litter	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

C. Storm Drain grates and Catch Basins		
C1. Type of storm drain conveyance: ☐ Open ☐ Closed		
Sample 1-2 storm drians per CSA/HSI	C3. Storm Drain #1	C4. Storm Drain #2
Easting		
Northerning		
Picture #		
Current Condition	☐ Wet ☐ Dry	☐ Wet ☐ Dry
Condition of drain	☐Clear ☐Obstructed	☐Clear ☐Obstructed
Litter Accumulation	☐Y ☐N	☐Y ☐N

Organics Accumulation	☐Y ☐N	☐Y ☐N
Sediment Accumulation	☐Y ☐N	☐Y ☐N
Evidence of oil and grease	☐Y ☐N	☐Y ☐N
Smell, specify ______________	☐Y ☐N	☐Y ☐N
Accessible to vacuum truck	☐Y ☐N	☐Y ☐N
Notes:		

D. Non-Residential Parking Lot (>2 acres) ☐ N/A *(skip to part E)*
D1. Size: _________ m
D2. Lot Utilization: _____%
D3. Lot material: ☐ Paved/Concrete ☐ Gravel ☐ Permeable ☐ Dirt ☐ Other ________
D3. Type of vehicles: ☐ Personal ☐ Fleet vehicles ☐ buses ☐ Freight ☐ other _______
D3. Overall condition: ☐ Clean ☐ Stained ☐ Breaking up ☐ Sediment build-up ☐ Other __________
D4. Does Water go directly or indirectly into the stormwater system? ☐ Y ☐ N If yes, describe: ____________________

Appendix 2: Site Visit Booklet

Information Overview Booklet of Three Selected Stormwater Remediation Sites Along McVicar Creek

2012

Prepared for:

Earthwise® Water Working Group Experts

Prepared By:

Kestrel Wraggett (Lakehead University Graduate Student)

Dr. Robert Stewart (Lakehead University Department of Geography)

Aaron Nicholson (Northshore Remedial Action Plan)

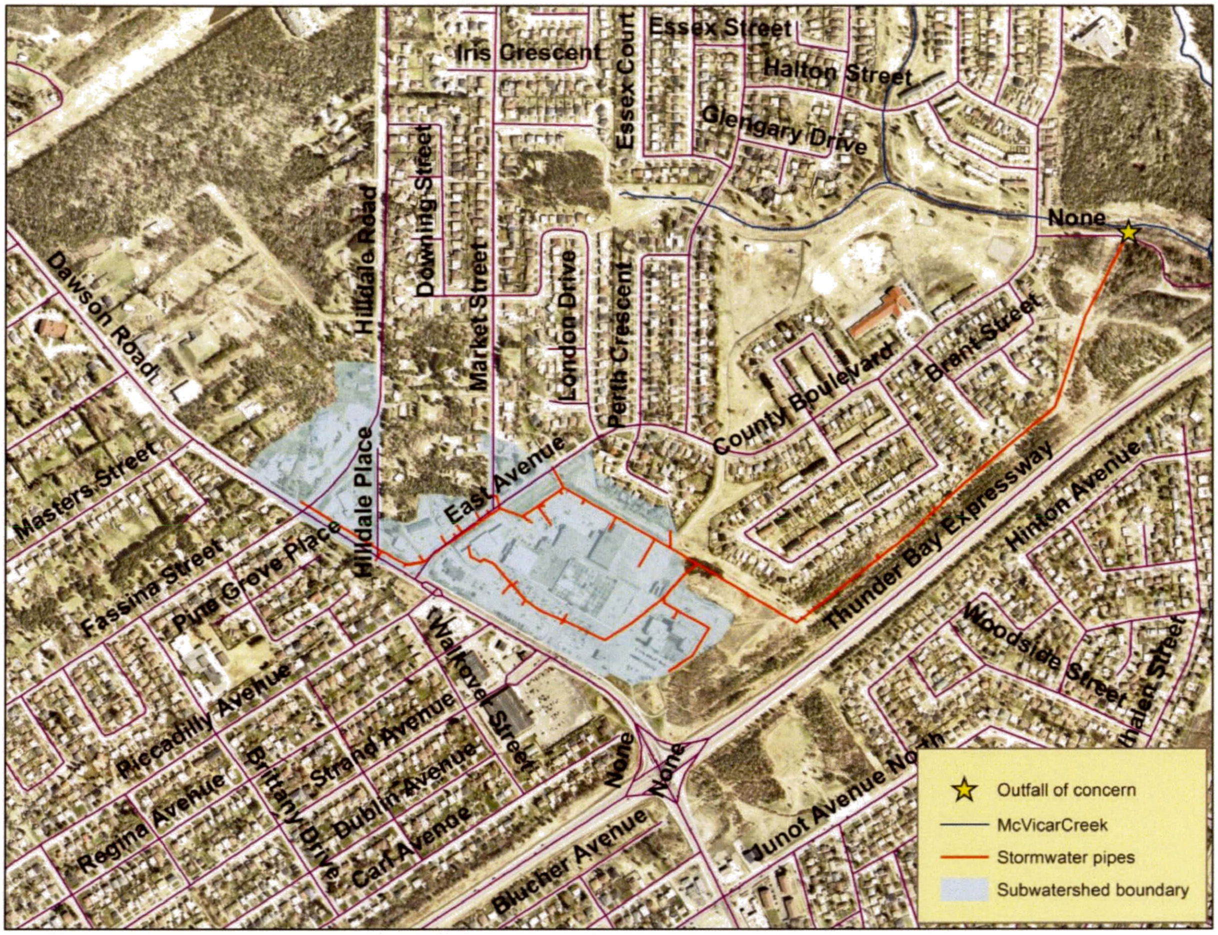
Purpose of the study:

- Develop feasibility criteria of site-specific stormwater remediation options for each identified site along McVicar Creek.
- Implement a decision-support criterion to identify the most effective stormwater remedial options based on Low Impact Development (LID), community education, policy/regulation and maintenance.
- Use expert and local feedback, along with field data collection (infiltration rates, soil analysis and water quality sampling) to produce a remediation design and plan for identified subwatersheds.

Next Steps:

Lakehead University Department of Geography and Northshore Remedial Action Plan would like to host a one day workshop with local experts to discuss and identify the most feasible stormwater remediation options for each subwatershed based on the information provided. The workshop will be held in September of 2012 and preliminary data collection results from the summer of 2012 will be distributed along with existing results and information from each site. There is a possibility of having a non-local expert attend the workshop to aid in identification of remediation options and provide alternative information. The results of the workshop along with data collection results will be presented and distributed to the City of Thunder Bay and Earthwise® Water Working Group Experts by May 2013.

County Fair:



Subwatershed characteristics:

Area (hectares) → 20 ha

Impervious surface cover → 62%

Land-use → Mainly commercial with scatters of residential and institutional

Comments:

Outfall Characteristics:

Pipe diameter → > 90 cm

Pipe condition: Clogged with garbage

Largest input → Sediment

End of pipe condition → Excess sediment, channel is naturalizing with vegetation

Comments:

Concerns:

- Use of County Fair mall back parking lot
- Hotspot Identification (Gas station, Drive through and outdoor garden center)

Comments:

Water quality exceeding guidelines:

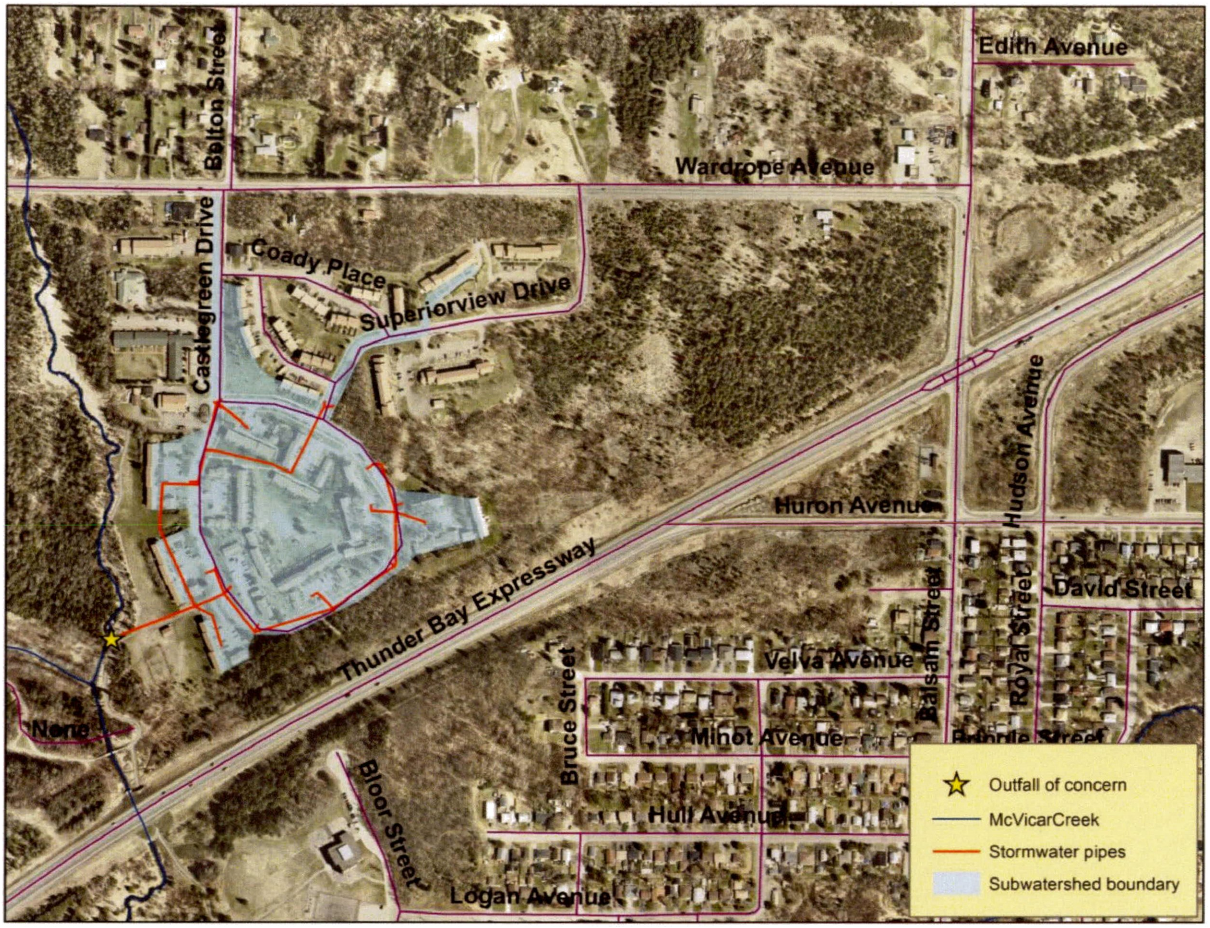
- Ammonia, Nitrite, Chloride, Copper, Iron and Zinc

Preliminary Remediation Recommendations:

- Maintenence
- Policy enforcement
- Landscaping
- End of pipe Low Impact Development

Comments:

Castlegreen:



Subwatershed characteristics:

Area (hectares) → 7 ha

Impervious surface cover → 45%

Land-use → Residential

Comments:

Outfall Characteristics:

Pipe diameter → < 90 cm

Pipe condition: Corroded with rebar exposure, strong sewage odour

Largest input → Ammonia and Nitrate

End of pipe condition → Strong current flow, natural vegetation on either side of creek

Comments:

Concerns:

- High ammonia levels
- Private gardens
- Excessive pet waste
- Street heaving and buckling

Comments:

Water quality exceeding guidelines:

- Ammonia, Nitrite, Nitrate, Chloride, Aluminum, Copper, Iron, Lead and Zinc

Preliminary Remediation Recommendations:

- Community education
- Landscaping
- Maintenance
- Further investigation

Comments:

Court Street:

Subwatershed characteristics:

Area (hectares) → 22 ha

Impervious surface cover → 39%

Land-use → Mainly residential with scattered commercial

Comments:

Outfall Characteristics:

Pipe diameter → < 90 cm

Pipe condition: Clean, corroded flow line on concrete

Largest input → Chloride

End of pipe condition → Strong current flow, some natural vegetation on either side of creek with road approximately 100 meters from creek

Comments:

Concerns:

- Home vehicle repair shops
- Disconnected rainbarrels
- High chloride levels
- Excess sediment

Comments:

Water quality exceeding guidelines:

- Ammonia, Nitrate, Chloride, Cadmium, Aluminum, Copper, Iron, Lead, Vanadium and Zinc

Preliminary Remediation Recommendations:

- Community education
- Alternative snow removal
- Policy enforcement

Comments:

Appendix 3: Decision- Making **criteria** *provided at the Workshop*

Stormwater Remediation Option Criteria; for the purposes of October 2, 2012 Workshop

These criteria for determining LID/Retrofit, municipal maintenance and policy, education, and natural leave-alone have been adopted by this researcher from the Centre for Watershed Protection, the Toronto and Region Conservation Authority and the Ontario Ministry of the Environment where applicable and available.

1.0 RETROFIT AND LOW IMPACT DEVELOPMENT (LID)

1.1 Retrofit and LID General Information:

- Retrofits generally cost 1.5-4 times more than the cost to construct stormwater practices on new development sites.
- Most retrofits currently are used as prototypes, pilot projects and education projects.
- Many retrofits can be bundled with municipal construction projects such as streetscaping, transportation projects, school construction, park improvements, drainage improvements and neighbourhood revitalization.
- For the purposes of this project, retrofits by this definition are interchangeable with Low Impact Development.

LID definition (TRCA 2010):

"Low Impact Development is a stormwater management strategy that seeks to mitigate the impacts of increased runoff and stormwater pollution by managing runoff as close to its source as possible. LID comprises a set of site design strategies that minimize runoff and distributed , small scale structural practices that mimic natural or predevelopment hydrology through the process of infiltration, evapotranspiration, harvesting, filtration and detention of stormwater. These practices can effectively remove nutrients, pathogens and metals from runoff, and they reduce the volume and intensity of stormwater flows."

1.2 Retrofit/LID Criteria:

Generally aimed at:

- Solving chronic flooding problems
- Stormwater demonstration and education
- Trapping trash and floatables
- Reducing runoff
- Reducing pollutants of concern

Generally to treat stormwater coming from:

- Parking lots
- Individual streets
- Rooftops
- Other open space

1.2.1 Storage retrofits – Treats drainage areas from 5 - 200 ha

- May need dozens in a subwatershed
- Moderate cost per impervious hectare treated
- Can provide all stormwater targets
- Comprised mainly of ponds and wetlands

Extended Detention – Relies on 12-24 hour detention after each rain event, with portions of the pond drying out between rain events. Allows pollutants to settle out.

Wet Ponds –A permanent area of standing water. Successful in removing (> 50% average) significant levels of suspended solids, phosphorus, zinc, copper, bacteria, hydrocarbons and trash

Constructed Wetlands – runoff from each new storm displaces runoff from previous storms, several days to weeks allows for multiple pollutant removal. Successful in reducing (>50% average) levels of TSS, phosphorus, copper, bacteria, hydrocarbons and trash

1.2.2 On-site retrofits - Treats drainage areas from >1 ha – 5 ha

- May need hundreds in a subwatershed
- High cost per impervious hectare treated
- Few permits are needed
- Only provides recharge and water quality targets
- Comprised of mainly bioretention, filtering, infiltration and swales and neighbourhood rooftops
- Can serve as a neighbourhood education tool (ie. Rainbarrels and raingardens)

Rooftops (Rainbarrels , Rain gardens, Little retrofits, Landscaping) – Best used when there is a strong neighbourhood association with environmental concern, medium density residential areas.

Bioretention – Uses native forest ecosystems and landscape processes to enhance stormwater quality. Catches flow from impervious areas and teats the stormwater through microbial soil processes, infiltration, evapotranspiration and plants. Generally serves areas of one acre or less. Successful in reducing (>50% average) levels of TSS, zinc, copper, bacteria, hydrocarbons and trash.

Filtering Practices – Filtering runoff through an engineered media and collecting treated runoff through an underdrain. Successful in reducing (>50% average) levels of TSS, phosphorus, Carbon, Zinc, hydrocarbons and trash.

Infiltration practices – Infiltration trenches such as rock filled chambers allows stormwater to pass through pre-treatment before reaching the waterbody. This includes swales (A series of vegetated open channels in order to treat quality volume of runoff) and sediment basins where water is infiltrated through the soil and roots of vegetation. Successful in reducing (>50% average) levels of TSS, phosphorus, carbon, zinc, copper, bacteria, hydrocarbons and trash. Infiltration practices also aid in groundwater recharge.

Little retrofits – Suitable for areas comprising of less that 5% of total impervious surface. Best suited for publicly owned land, can serve as an educational function, and should be close to large impervious area. Ideal in soils with high infiltration and can be linked with reforestation projects.

Landscaping – ideal for park settings, public and open spaces.

Permeable Pavers – Ideal in areas where roads are being reconstructed on public lands or in new developments.

** See Retrofit Practice cost chart in Appendix

** See Retrofit Options and Stormwater Treatment table in Appendix

2.0 MUNICIPAL MAINTENANCE AND POLICY

2.1 Municipal maintenance and policy general information:

Thunder Bay is considered a phase I community which is defined as "a community that has a separated storm drain system with a population of more than 100,000." Under this definition the municipality is responsible for:

- Stormwater quality monitoring
- Mapping of stormdrain network
- Outfall screening
- Removal of illicit discharges
- Source identification
- Structural and source control measures to reduce pollutants
- Erosion and sediment control programs
- Fiscal analysis

General conflicts:

- Uneven administration by permitting agencies and municipality
- Fragmented jurisdictional responsibilities

2.2 Municipal maintenance criteria:

Municipal maintenance would generally occur on publicly owned land or land owned by the city or other government agency.

2.2.3 Common maintenance activities:

Hotspot Facility Management- Publicly owned or operated facilities that produce higher levels of stormwater pollutants or present a higher risk for spills, leaks or illicit discharge. These could include; fleet storage and school bus depots, waste facilities, local streets and storm drains, pesticide use on public lands, public golf courses, public schools, public yard works, etc.

Construction Project Management – There are a number of construction projects that can generate a wide range of stormwater pollutants including sediment, nutrients, hydrocarbons, pesticides, trash and debris. Common projects include; Public buildings, public golf courses, public works facilities, road construction and widening and utility construction and repair.

Street Repair and Maintenance- Street repair and maintenance activities generally contribute higher levels of metals, chlorides, hydrocarbons, sediment and trash into the stormwater system.

Street Sweeping – Between rain events, pollutants build up on streets and parking lots. If the streets are not being swept regularly, these pollutants are drained directly into the storm system during a rain event.

Storm drain maintenance – Regular storm drain maintenance can significantly reduce the amount of pollutants entering the water system during a rain event. Common storm drain maintenance activities include; catch basin, inlets, and storm drain and outfall cleanouts.

Stormwater Hotline Response – Generally, municipal staff cannot prevent spills, leaks and illicit discharges from occurring within the community. Having a centralized number to call with fast municipal response time could reduce the amount and impact of a spill into the water system.

Park and Landscape Maintenance- public lands that are covered with turf can generate excess amounts of sediment, nutrients, hydrocarbons, pesticides, herbicides and organic debris from activities including; mowing, fertilization, pesticide application and irrigation. These spaces commonly include; parks, schools, golf courses and other open spaces.

** See Stormwater Pollutants Associated with Municipal Operations table in Appendix

2.3 Municipal Policy Criteria:

- If there are current municipal by-laws that are not being followed and causing impacts on stormwater systems, there needs to be stronger enforcement.
- If there are activities occurring within the subwatershed that need a new by-law in place, there needs to be discussion, investigation and actions taken.

- Municipalities across Ontario generally rely on the expertise within the Conservation Authority for water management and the restoration and enhancement of the natural environment. The *Conservation Authorities Act* states that the CA is to;
    - Study and investigate the watershed and to determine a program whereby the natural resources of the watershed may be conserved, restored, developed and managed; and, to cause research to be done (Section 21); and
    - To make regulations applicable in the area under its jurisdiction (Section 28).

3.0 EDUCATION

3.1 Education and outreach general information

Most neighbourhoods by definition range from 20-80 hectares in size. Factors that affect the success of residential education or outreach campaigns is generally based on; the age of the neighbourhood, the lot size, turf cover, tree canopy, drainage, street condition and degree of resident awareness.

3.2 Education and outreach criteria

There are no definitively set criteria to determine if one area is more suited for education and outreach over another. Community education and outreach can occur in residential, commercial or industrial areas. There are however, five major sources of stormwater pollution that can be examined and considered in an area.

3.2.1 Five main education considerations

Yards and Lawns – Fertilizers, pesticides, over-watering, extensive turf cover, tree clearing, improper yard waste disposal, soil compaction, soil erosion, failing septic systems, pool discharges.

Driveways, sidewalks and curbs – Washing of vehicles, hosing/leaf blowing and application of salt and de-icers.

Garages – Dumping of household hazardous wastes, dumping of oil/antifreeze and vehicle maintenance

Rooftops – Downspout connections (Not generally an issue in Thunder Bay) and added impervious cover/exposed soil.

Common Areas—Pet waste, Buffer encroachment, dumping and storm drain dumping.

** See Residential Polluting Behaviour table in Appendix

3.2.2 Residential Stewardship

- Residents engage in many behaviours and activities that can influence water quality. Behaviours such as over-fertilizing, oil dumping, and littering and excessive pesticide use can negatively impact water quality.
- Behaviours such as tree planning, disconnecting rooftops and picking up pet waste can help improve water quality.
- To help reduce the amount of pollution that is conveyed into streams and other local aquatic resources, communities can develop residential stewardship programs that discourage negative behaviours and encourage positive ones. These stewardship programs are often supplemented with education and outreach events, financial incentives and in-kind services.
- Neighbourhoods and communities that are engaged in social activities are more likely to adopt an education and outreach campaign.

4.0 LEAVE-ALONE NATURALIZATION (DO NOTHING)

This option is suitable when the negative impacts on habitat, environment or community outweigh the benefits of the remediation action. This option would generally apply to areas with potential retrofit/LID options, but can apply to all remediation options. This could also be a potential option if communities are unwilling to engage in education and outreach programs. This would usually be the case after all other remediation options have been considered and declined due to negative impacts.

Residential Polluting Behavior	Storm Water Pollutants						
	TSS	Nutrients	Metals	Bacteria	Trash	Oil	Toxins
Improper Fertilization	×	●	×	×	×	×	○
Excess Pesticide Use	×	×	×	×	×	×	●
Over-Watering	○	⦿	○	×	○	×	⦿
Extensive Turf Cover	○	⦿	×	×	×	×	⦿
Tree Clearing	⦿	⦿	×	×	×	×	×
Yard Waste Dumping	⦿	●	×	○	○	×	×
Soil Compaction	⦿	⦿	○	○	×	×	×
Soil Erosion	●	⦿	○	○	×	×	×
Failing Septic Systems	○	●	×	●	×	×	○
Pool Discharges	×	×	×	×	×	×	●
Car Washwater Flows	⦿	●	⦿	×	×	⦿	⦿
Hosing/Leaf-blowing	●	⦿	⦿	×	⦿	⦿	○
Use of De-icers	⦿	○	○	×	×	×	⦿
HHW Dumping	×	○	●	×	×	●	●
Car Fluid Spills/Dumping	×	×	⦿	×	×	●	●
Connected Downspouts	⦿	●	●	⦿	×	○	○
Added IC and Bare Soil	●	○	⦿	×	⦿	○	○
Pet Waste Washoff	×	●	×	●	×	×	×
Poor STP Maintenance	●	●	●	⦿	●	○	○
Buffer Encroachment	○	○	○	○	○	×	×
Storm Drain Dumping	⦿	○	⦿	⦿	●	●	●

Key × = not a pollutant source ⦿ = moderate pollutant contribution
○ = minor pollutant contribution ● = major pollutant contribution

Table 2: Stormwater Pollutants Associated with the 10 Major Municipal Operations

Municipal Operation	Sediment	Nutrients	Metals	Hydro-carbons	Toxins	Others
Hotspot Facility Management	●	●	●	●	●	Trash, Organic Matter, Pesticides, Chlorine
Construction Project Management	●	⦿	○	⦿	⦿	Trash
Street Repair and Maintenance	●	⦿	⦿	●	⦿	Trash
Street Sweeping	●	○	⦿	⦿	○	Trash, Organic Matter
Storm Drain Maintenance	⦿	○	○	○	○	Trash, Organic Matter
Stormwater Hotline Response	●	○	○	●	●	Bacteria
Park and Landscape Maintenance	⦿	●	○	○	⦿	Pesticides
Residential Stewardship	○	●	○	⦿	⦿	Pesticides
Stormwater Management Practice Maintenance	⦿	⦿	⦿	○	○	Bacteria
Employee Training	●	●	●	●	●	Chloride, Trash

Key
● = frequently associated with operation
⦿ = infrequently associated with operation
○ = rarely associated with operation

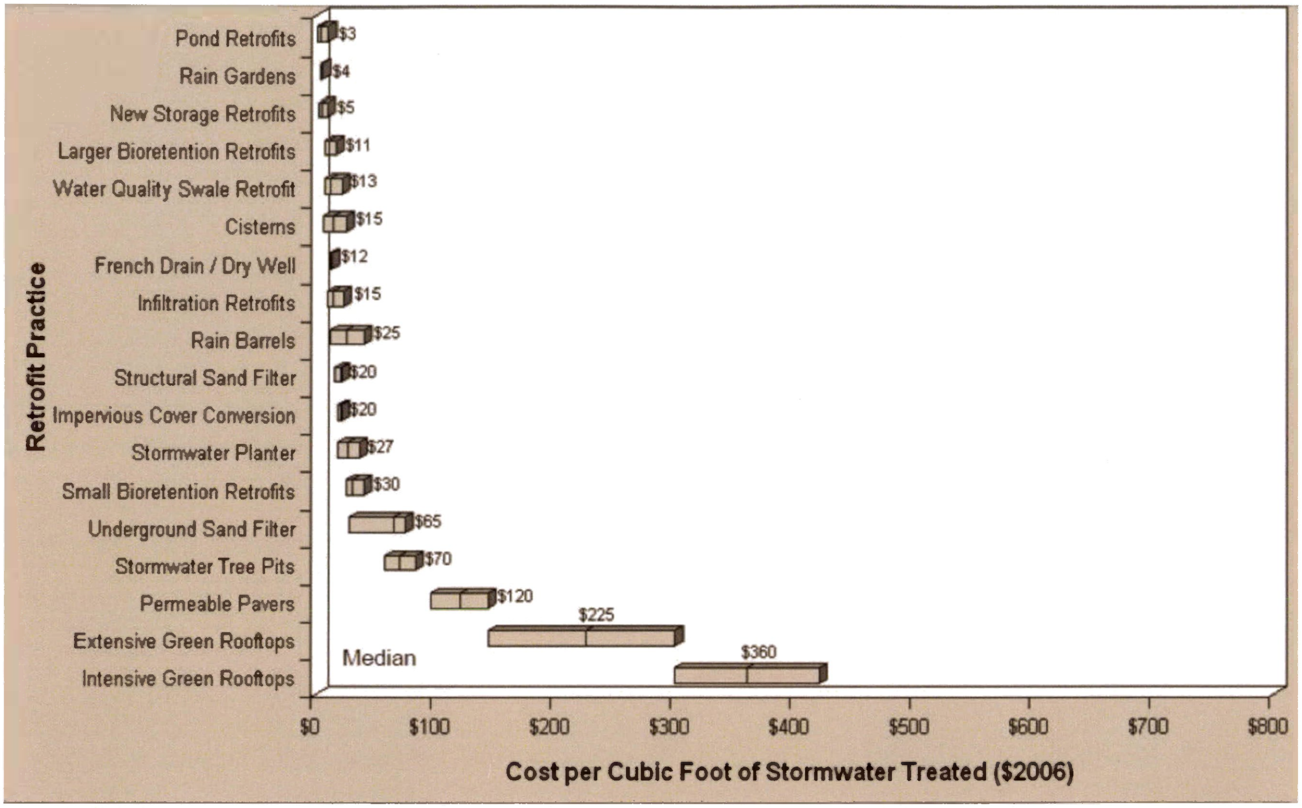


Table 2.2: Retrofit Options and Stormwater Treatment Provided

Subwatershed Location	Stormwater Treatment Provided			
	Water Quality	Runoff Reduction	Channel Protection	Flood Control
SR-1 Add Storage to Existing Ponds	●	○	●	○
SR-2 Storage Above Roadway Culverts	●	○	●	⦿
SR-3 New Storage Below Outfalls	●	⦿	⦿	⦿
SR-4 Storage In the Conveyance System	●	⦿	⦿	⦿
SR-5 Storage in Transport Rights-of-ways	●	⦿	●	⦿
SR-6 Storage Near Large Parking Lots	●	⦿	●	⦿
OS-7 Hotspot Operations	●	○	○	○
OS-8 Small Parking Lots	●	●	⦿	○
OS-9 Individual Streets	●	●	⦿	○
OS-10 Individual Rooftops	⦿	●	○	○
OS-11 Small Impervious Areas	●	●	○	○
OS-12 Landscapes/Hardscapes	●	⦿	○	○
OS-13 Underground	●	⦿	○	○

Key: ●Full ⦿ Partial ○ Rarely