Identifying the potential sources of contaminants to the Welland Canal, the major source of drinking water in the Niagara Region

by

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Bachelor of Science, Shahid Chamran University, 2006

A thesis

presented to Ryerson University

in partial fulfillment of the

requirement for the degree of

Masters of Applied Science

in the Program of

Environmental Applied Science and Management

Toronto, Ontario, Canada, 2010

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Master of Applied Science

Environmental Applied Science and Management

October 2010

Ryerson University

Abstract

Identifying the potential sources of contaminants to the Welland Canal, the major source of drinking water in the Niagara Region

The Welland Canal is the only source of raw water to the largest drinking water treatment plant in the Niagara Region in southern Ontario. The water of the Welland Canal has historically been contaminated from different sources, including discharges from industrial activities, sewage effluent, and agricultural runoff, and identifying these potential pollutants to drinking water relies on direct chemical analysis. This is time-consuming, costly and often very inefficient to identifying the critical contaminants of concern. However, a comprehensive assessment of the sources of contaminants that could help drinking water treatment plants has never been conducted and thus, the aim of this research is to assess and prioritize the chemicals of concern and the possible sources of contamination impacting the Welland Canal water. Metals and organic contaminants originating from industrial effluent, agricultural runoff, Port Colborne STP effluent, Lake Erie sediments and antifouling paints on ship vessels are identified as major contributors of pollutant loads into the Welland Canal. Specifically, atrazine, glyphosate, metolachlor, TBT, mercury, lead and zinc are identified as major contaminants that could pose a health risk to over 300,000 residents in the Niagara Region.

Acknowledgment

First and foremost, I would like to extend my thanks and appreciation to Dr. Lynda McCarthy for allowing me the opportunity to be part of this unique and important project. Her support and guidance is always encouraging and has greatly contributed to the completion of this project. Her enthusiasm and patience has been integral in successful completion of this challenging work.

Special thanks to Dr. Vadim Bostan for proving support as my co-supervisor, and Dr. Andrew Laursen for providing guidance over the past two years in the overall project development. My gratitude is also extended to Karen Terry, who was always there to help with laboratory logistics and conscientiously answering any questions.

I would also like to extend my thanks to all scientists and engineers from different industry and government levels in Niagara Region for their help in data analysis and gracious collaboration with my thesis and their responses to my endless questions.

Thank you also to my fellow graduate students, especially Alisa Tchebotareva for her endless support and friendship since we met on our first day at school. Also, to my friends Isabelle Netto and Vivian Fleet, who where always there to provide input and expertise.

I would like to extend my gratitude to my parents Jaleh Bahasadri and Amin Labbaf, for providing me the opportunity to pursue my studies miles away from home. Their inspiration and unending encouragement have allowed me to overcome challenges, for which there are no words to thank express my feeling. Finally, to my husband, Sam Samsami for being there listening and not giving up. This acknowledgment would not be complete without his drive, determination and unconditional support over the past two years.

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1.0 INTRODUCTION

1.1 Project Background and Objectives

The Region of Niagara operates a total of six Water Treatment Plants (WTPs), together with their attendant monitoring facilities and pumping stations. Located in Thorold, the DeCew WTP is the largest one in the Region (Figure 1). It supplies 227.3 million litres of water per day and serves a population of approximately 300,000 in Niagara-on-the-Lake, St Catharines, Thorold and some parts of Lincoln (RMN, 2010a). Water is drawn from the Welland Canal at the Feeder Canal and flows approximately five kilometres under highways and through agricultural land to the DeCew Plant's reservoirs.

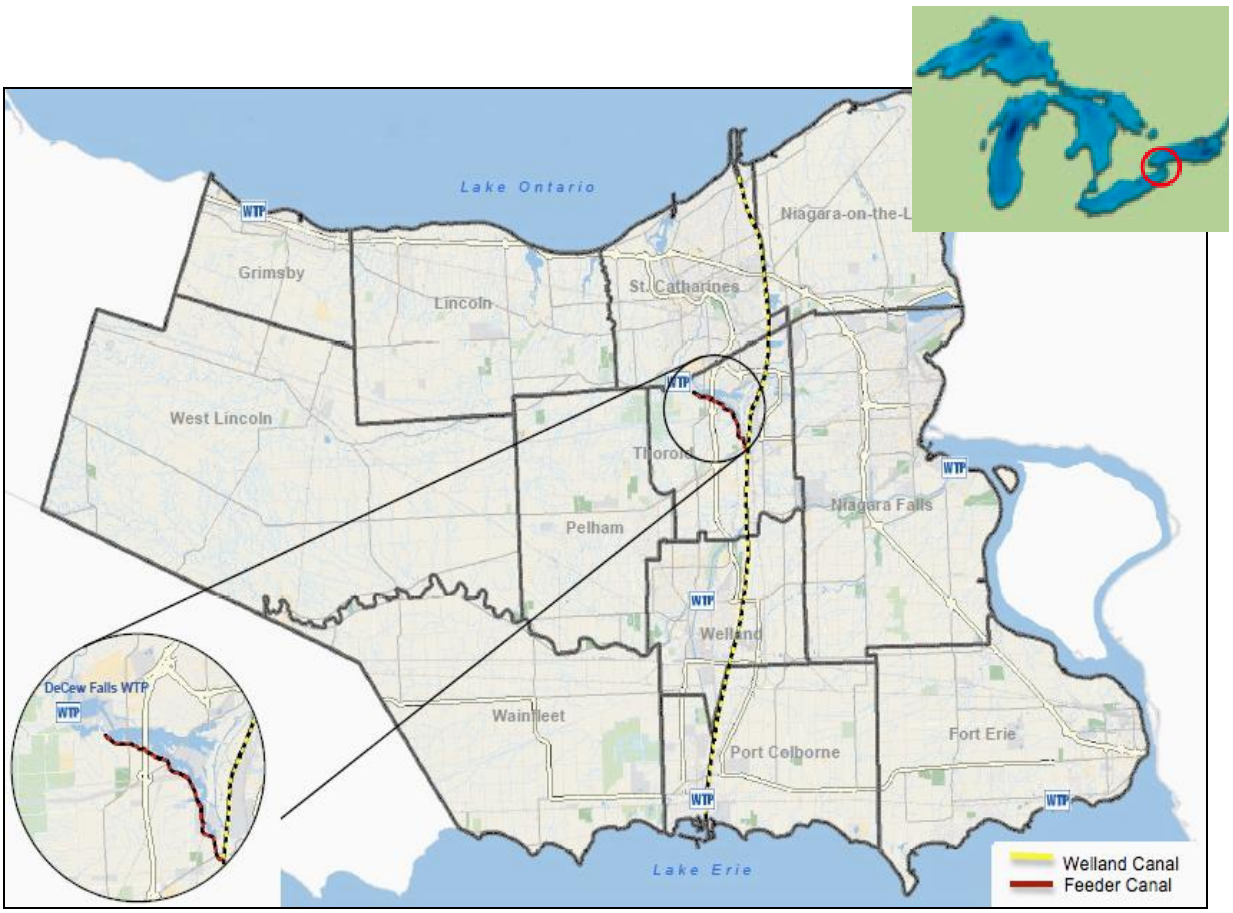


Figure 1. Location of the Welland Canal and the DeCew WTP.

The DeCew WTP was constructed in 1925 and has been expanded several times over the years. Since 1970, it has been operated by the Regional Municipality of Niagara (RMN, 2010a). While the Regional Municipality of Niagara follows the Drinking Water System O.Reg.170/03 to achieve the best quality of water for customers, higher standards of quality control are required as there are potential risks of contamination associated with the Welland Canal. To this end, the current thesis is part of a large NSERC project, in conjunction with the Region of Niagara, that aims to develop an early-warning technology to monitor potential threats to drinking water treatment facilities in Canada. Equivalent to the "miner's canary" used to test air quality of mines, the Early-Warning Biomonitoring System (EWBS) employs living organisms to initiate an immediate response when exposed to contaminants in upstream drinking water sources. EWBS is a multi organism-based strategy where in ecotoxicity models are developed based on the characteristic responses of organisms from different trophic levels to specific classes of contaminants.

A major challenge in designing a EWBS lies in deciding what contaminant parameters should be monitored, based on necessity, system capabilities and costs. Therefore, to add to the success of the "miners canary", this thesis attempts to identify and prioritize all potential sources of contaminants posing a risk to public health in drinking water to develop the best EWBS risk assessment approach. This technology will provide a more reliable and effective way for Canadian water treatment plants to detect potentially dangerous aquatic contaminants before they enter the drinking water supply. It is also beneficial for overcoming the current limitations of available expertise and expensive technologies dealing with water quality analysis, which are primarily based on chemical analysis. The Niagara Region would like to be able to implement the EWBS at the Region of Niagara's DeCew WTP within the next five years. The following objectives were thus examined in the current study to characterize the sources of pollutants.

1. To determine the watershed's physiography, specifically surface and groundwater movement to identify the hydrological connection between the Welland the surrounding waterways and the Welland Canal.
2. To determine the location of the industrial facilities along the Welland Canal and their potential inputs to municipal sewage treatment plant's effluent.
3. To determine an inventory of current agricultural land use within the municipalities along the Welland Canal area including the cities of Thorold, Welland and Port Colborne.
4. To investigate the most current pesticide application on farm lands based on the Region's major crop production.
5. To examine potential atmospheric sources of pollutants and their deposition into the Canal water.

6. To investigate the sediment and water quality of Lake Erie, as it is the main source of water to the Welland Canal.
7. To outline the potential pollutants from ships and ocean vessels passing through the Canal.

It should be emphasized that without a comprehensive detailed analysis of loading pollutant sources entering the Canal, operators and other managers of WTPs have had to analyze for contaminants on a scattershot basis. Thus, this thesis was necessary to assess the most likely sources of contaminants and to suggest what some of the key contaminants may be to the drinking water system. Previous work outlining a land-use inventory of the Welland Canal area was conducted in 1961(Lloyd, 1961). This was a Master's thesis titled " A Land Use Plan for The Welland Canal Area" that assembled the soil and slope characterises in effort to outline the agricultural area in the Welland Canal area (within the four townships of St. Catharines, Thorold, Welland, and Port Colborne). Furthermore, various government agencies have conducted additional research in the Region, adding to this body of knowledge. The Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), the only government agency that has researched agricultural practices in the area, has, since 1973, carried out surveys of agricultural pesticide use in Ontario (every five years). Also, The Regional Municipality of Niagara (RMN), in partnership with the Niagara Peninsula Conservation Authority (NPCA) reported a watershed study for the entire region in the NPCA's jurisdiction in 2009 (NPCA, 2009). This project contains a detailed description of the watershed characterization. While specific information from this NPCA report will be used in this thesis, it does not provide information necessary to understand the hydrological connection of the surrounding waterways to the Canal, information that is critical to understanding potential pollution loads to the shipping waterways.

Lastly, due to the paucity of information from literature resources, it was critical to connect personally with different industry, academia, and government authorities whose expertise in the Niagara Region informed the objectives of this thesis. Thus, it was felt necessary, at this juncture, to highlight the more than thirty people who contributed major and essential information to this thesis and the nature of their involvement. Their information will be detailed more thoroughly in succeeding sections.

Department of Geography at Ryerson

At the beginning of my work, Dr. Douglas Banting shared an extensive explanation of the overland flow modeling and Digital Elevation Models with me. Given his familiarity with the topography of the Region, he suggested that the chance of storm runoff draining to the Canal is likely, although he believed the bank of the canal is designed to be unaffected by overland flow.

Department of Geography at Brock University

Dr. Alun Hughes and Dr. Daryl Dagesse both have done extensive research on the historical development of the Power Glen area below the Niagara Escarpment, in St. Catharines. This area covers the DeCew Falls Generating Station, DeCew WTP reservoir, Lake Moodie and Lake Gibson. They have provided me a detailed account of maps to show the hydrological connection between these lakes following the direction of water from the Canal to its final outlet, Lake Ontario.

Canada Centre for Inland Waters (CCIW), Burlington, ON

Dr. Chris Marvin, Environmental Analytical Chemist, shared with me his thoughts about his latest research on fate and transport of sediment in Lake Erie and provided me his most recent findings in this regards. Dr. John Struger, Aquatic Environmental Scientist, clarified the distribution of pesticide concentrations in Lake Erie itself and in agricultural and urban watersheds in southern Ontario.

Regional Municipality of Niagara

Jason Oatley, Water and Wastewater Division Manager in the Region, informed me of the day-to-day activities of the environmental officers in enforcing the Regional Sewage Bylaws. He also, assisted in clarifying the segregation of responsibilities between provincial and municipal authorities in controlling inflow and outflow of STPs. Information regarding industrial facilities along the Welland Canal and their associated activities was gathered through extensive communications with Darlene Suddard, and Landry Blake.

Niagara Peninsula Conservation Authority

Paul Bond, Senior Watershed Planner; Steve Miller, Coordinator, Watershed Regulations; Jayme D. Campbell, Source Protection Hydrogeologist and Jeff Lee, GIS Technician, all dedicated gracious time to providing me the geospatial data set for the Regional watershed. They assisted me in dealing with GIS related issues.

St. Lawrence Seaway Management Corporation, Niagara Region

Paul Kosince and Fraser Johnston are engineers at St. Lawrence Seaway Management Corporation, Niagara Region. They provided me with unpublished reports for monthly flow and supporting images about the structure and base of the Welland Canal.

Industrial Companies

Colin Dennis from H & S Heat Treating, Shane Smith from Welland Forge Division, Angelo Armenti from Lakeside Steel Corporation, George Maxwell from North American Tool & Die, Mike Detenbeck from Allied Marine & Industrial, Pat Redmond from Kiwi and Kevin Langerak

from Oskam Steel Fabricators Ltd, all provided me various information about their companies and operation systems.

Also, Dr. Songnian Li from Department of Civil Engineering at Ryerson University, reviewed the thesis outline and provided their feedback.

1.2 Development of the Welland Canal and Attendant Pollution Problems

It is important to understand the history of the Welland Canal and its information as we assess the myriad of pollution sources impacting it. As a section of the Great Lakes St. Lawrence Seaway System (GLSS), the Welland Canal links Lake Erie to Lake Ontario, bypassing the 52 metre drop of the Niagara River (Figure 2). The main source of water flows from Lake Erie into the Canal at a rate of $180\,m^3/\text{sec}$ and exits at Port Weller in Lake Ontario (Welland Canal Monthly Report, June, 2010).

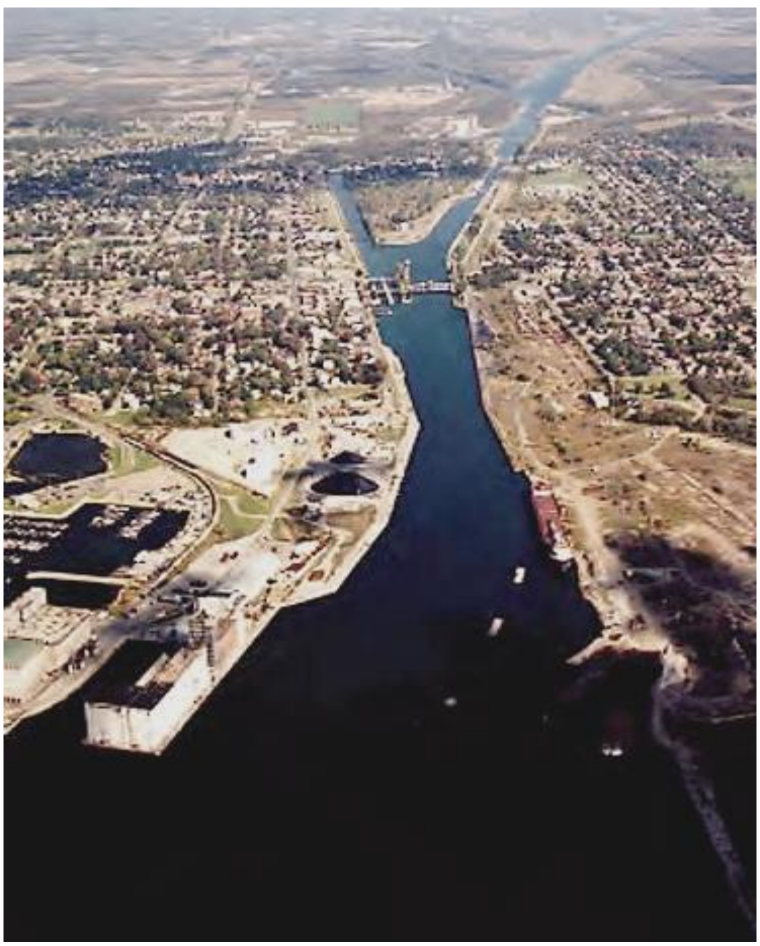


Figure 2. Aerial view of the Lake Erie entrance to the Welland Canal at Port Colborne (Source: GLSS, 2003).

Before 1829, the only route between the two lakes included a lengthy and hazardous portage from Queenston to Chippawa Creek (Jackson, 1997). To circumvent the difference in elevation caused by the Niagara Escarpment and the drop in elevation between Lake Erie and Lake Ontario a constructed feature was required. There have been four Welland Canals constructed throughout the history, with the Fist Canal being opened in 1829. From this point, it has been gone through various changes. The Fourth Canal, which is now referred to as the Welland Ship Canal, was completed in 1932 (Jackson, 1997).

The current Welland Ship Canal is 43.4 kilometres long with minimum depth of 8 meters and eight locks with a total lift of 99.5 meters (GLSS, 2003). The lock structures are similar to those in use at the Panama Canal, in which a fabrication of steel and concrete forms the walls to ensure durability (Jackson, 1997). The side walls consist of reinforced concrete, the greatest thickness of which is 14 meters at the base, stepped in toward the top to a width of 5 meters (Figure 3). Due to the geographic location of the system, the infrastructure is subject to an additional set of stressors associated with sub-freezing temperatures. There are a number of environmental stressors acting on hydraulic structures, the most critical of which is an alkaline-aggregate reaction that is present within the concrete structure in the Welland Canal. The alkaline-aggregate reaction is a chemical reaction between certain types of mineral in aggregate with the alkali hydroxides in concrete. The reaction is responsible in causing the concrete degradation, resulting in separation of the aggregate from the concrete mortar over the long time (GLSS, 2007b).

With respect to the Welland Canal's hydraulic connection to the underlying bedrock aquifer, the Welland Canal's channel bed sits directly on bedrock over two spans, thereby, the Canal acts as a source of recharge to the groundwater system Two spans are located in St. Catharines and Thorold where the Canal bottom is cut into bedrock (Fraser Johnston, personal communication, 2009).

Figure 3. Cross sectional views of a lock in the Welland Canal (Source: USEPA, 2009b).

Urban development in the Niagara Region has been associated with the evolution of the shipping route via the Welland Canal, providing the means of attracting large-scale manufacturing industries to the area (Figure 4).When the shipping Canal was completed in the early 1930's, environmental impacts were poorly appreciated. Over time, however, the significant ecological impacts of the Canal construction became obvious (GLSS, 2007b). Many of these environmental impacts were caused by waste disposal originating from Lake Erie or from industrial, commercial, and residential development around the Canal. Additionally, specific impacts relating to the ongoing discharges of contaminants from the Canal construction activities, ship engines, corrosion-resistant paint on vessels, and cargo sweeping activities were noted and will be discussed in the following chapters.

Figure 4. Closer view of the ship traffic in the Welland Canal upstream of DeCew WTP (Source: GLSS, 2007b).

One of the most significant direct sources of water pollution, dredging, occurs during normal operation and maintenance of the Canal. Dredging is performed in various points within the Canal where it is necessary to ensure continuous safe navigation. However, to the south (upstream) of the Feeder Canal connecting to the DeCew Reservoir, from Lock Seven to Lock Eight, water runs throughout the year supplying surrounding industries and the DeCew water treatment plant reservoir, and dredging is never performed within this section (Paul Kosinec and Fraser Johnston, personal communication, 2009). The material at the bottom of this section is a mixture of clay and fine-grained sediment with an approximate depth of 50 centimetres (GLSS, 2007b). These sediments that are not drained provide the medium for benthic organisms and bacteria and acts as a sink and link for pre-existing and ongoing sources of pollutants. As a result, as ships pass through the Canal, they produce turbulence and dispersion, both of which contribute to increased resuspension of sediments and trapped contaminants to the water column.

All these factors makes the waterway particularly susceptible to toxic contamination.

However, utilizing a relevant and rigorous EWBS program at the intake of the WTP could reduce the health risk of any presents of pollutants by providing timely warning system when concentrations are elevated.

2.0 WATERSHED CHARACTERISTICS

Since the main objective of this thesis was to delineate sources of pollution that may impact the DeCew WTP, characterization in the Niagara Region following an assessment of the hydrological connection to the Welland Canal was essential. Different approaches can be applied to study the catchment basin. In this study, ArcGIS program is used to represent data on land surface and to analyze the water movement based on map data resources mainly obtained from Niagara Region Conservation Authority and the Ryerson University Geospatial Map and Data Centre**.** In 2009, the NPCA staff, from three departments of Geographic Information System (GIS), Engineering and Source Water Protection have prepared inclusive map data sets, using Digital Elevation Model (DEM), to delineate watershed boundaries and calculate slopes, and stream networks. Jeff Lee, GIS Technician, and Jayme D. Campbell, Source Protection Hydrogeologist at NPCA, provided the Niagara Region watershed shapefile data set, which is a geospatial data format for GIS software. Also I used Southern Ontario Land Resource Information System (SOLRIS) geospatial data to produce overlay maps of land use on watersheds. The SOLRIS is a geospatial data set containing information on land form, drainage, soil texture and surface water based on satellite images taken between 2000 to 2002. This data was downloaded from the Ryerson Library data and map centre. Having the watershed and land use data, I used ArcGIS Spatial Analyst tool to derive new information from those existing data to calculate the overland flow to the Welland Canal and percentage of land use.

A watershed is an area of land where all of the surface water drains to a common depression such as river, creek, lake, or wetland (USEPA, 2009c). Watersheds can have different topographies. They may contain mountains and hills or could be relatively flat (USEPA, 2009c). Nevertheless, a boundary, which is also called drainage basin in terminology of watershed study, is the common characteristic of all watersheds. When water falls on watersheds as rain, snow, hail or grapple etc., some is stored in ponds or lakes, some evaporates back to the atmosphere or infiltrate to deep groundwater aquifers (NRCAN, 2009). The water that does not evaporate or becomes infiltrated to deep aquifers ultimately drains to a certain body of surface water (i.e. stream or lake). The flowing water can carry many different materials including pollutants to rivers and other water systems draining the watershed. Accordingly, the quantities and types of non-point pollutants are tied to the characteristics of the activities taking place on lands over which the water passes (RMN, 2004). Since water quality in both surface and subsurface water drainage is affected by activities occurring throughout the entire watershed, land use information needs to be gathered in order to provide a compelling pollution load assessment.

The entire Niagara Region, as shown in figure 5, covers approximately 2,424 square kilometers of watershed, encompassing twelve municipalities, along with a portion of the city of Hamilton, and Haldimand County (RMN, 2010d). As mentioned in Section 1.1, with respect to watershed characterization, the Regional Municipality of Niagara (RMN), in partnership with the Niagara Peninsula Conservation Authority (NPCA) and the Ministry of the Environment (MOE) completed an entire watershed study in the NPCA's jurisdiction in 2009 (NPCA, 2009). Although this NPCA report provides an insight into the general description of the watershed physiography within the Region, there was no information provided as to measurement of surface water flow to the Welland Canal. What is unique about the current thesis is that it estimates the surface water outfalls to the Welland Canal by using the GIS program. In order to accomplish this, the Niagara Region's watershed has been divided into three focus areas of watershed to better facilitate analyzing hydrological connection to the Welland Canal.

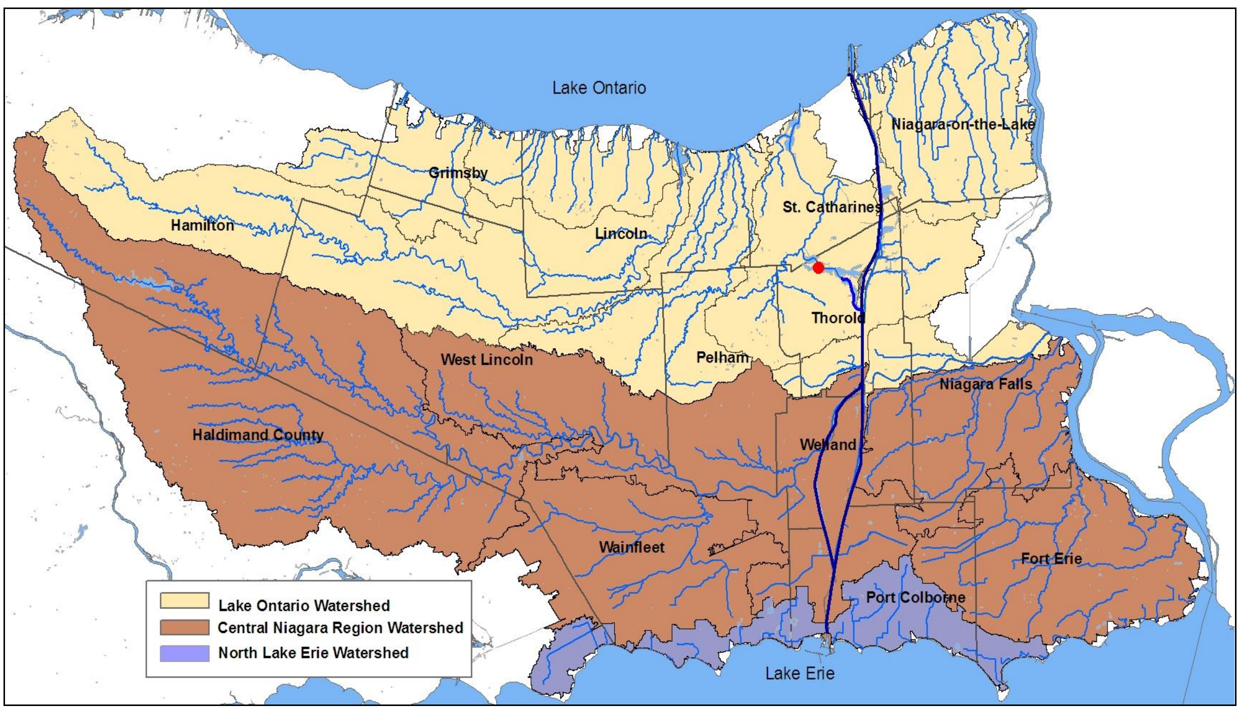


Figure 5. Niagara Region watershed, including the three focus areas variously referred to as the Lake Ontario Watershed, the Central Niagara Region Watershed and the North Lake Erie Watershed

2.1 Lake Ontario Watershed

Located in northern part of the Niagara Region, the Lake Ontario shoreline Watershed extends into the municipal boundaries of the Town of Niagara-on-the-Lake, City of St.Catharines, Town of Lincoln, Town of Grimsby, along with some portions of the City of Thorold, Town of Pelham, and Township of West Lincoln. Within this Watershed of the Niagara Region is situated the Feeder Canal and DeCew WTP. Thus, understanding any hydrological connection of this subwatershed to the drinking water source of the Welland Canal is critical. Major subwatersheds and their headwaters along this watershed are Twelve Mile Creek, Beaverdam Creek, Shrines Creek, Fifteen Mile Creek, Sixteen Mile Creek, and Eighteen Mile Creek. These Creeks rise above the Niagara Escarpment in a predominately agricultural area, then flow to Lake Ontario (Figure 6). In general all of the subwatersheds along the Lake Ontario Watershed meander through the northern portion of the Niagara Peninsula and ultimately outfall to the Lake Ontario (NPCA, 2009).

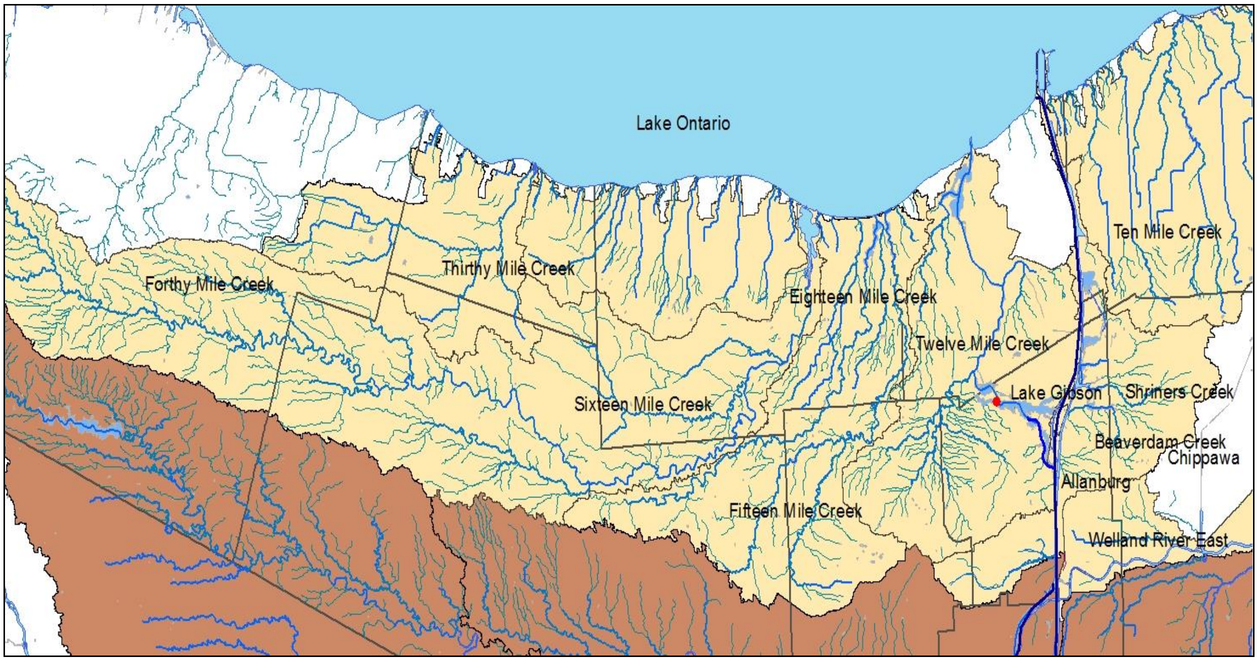
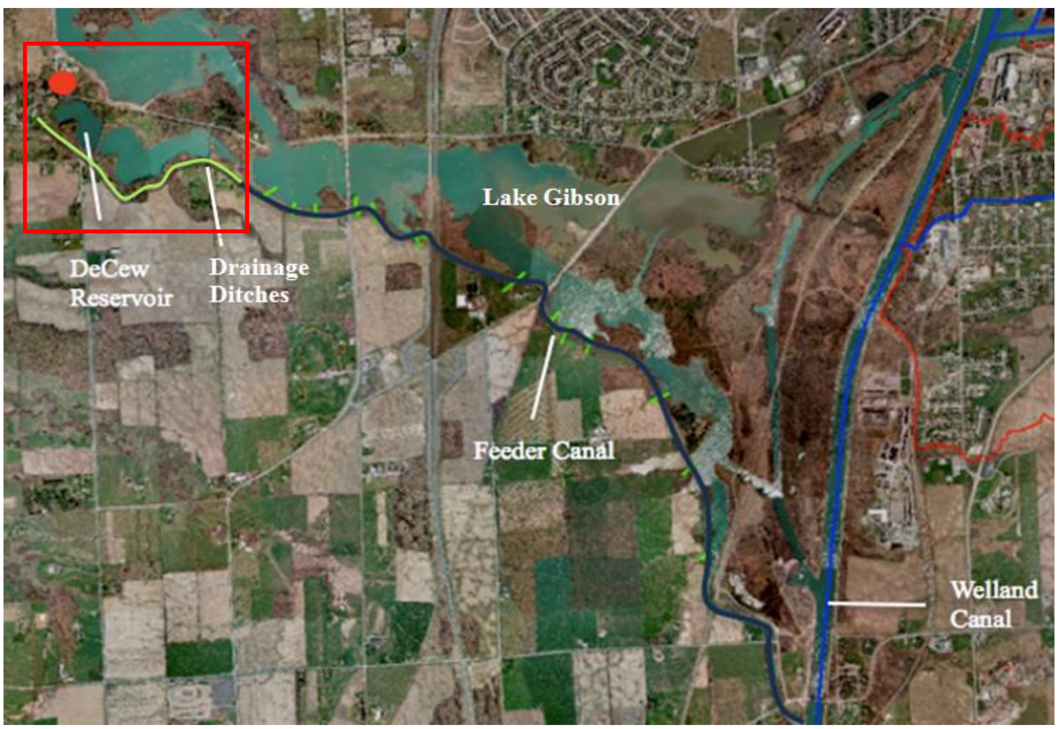


Figure 6. Lake Ontario Subwatersheds.

Within this Lake Ontario Watershed, the water for the DeCew plant is drawn from the Welland Canal via the Feeder Canal originating at Allanburg and stored in the DeCew Reservoir. In particular, at Allanburg, the Feeder Canal splits in two sections, one branch goes to Lake Gibson and the other leads to the Reservoir (Figure 7a) The water in Lake Gibson is discharged through two tributaries into Twelve Mile Creek with no hydrological connection to the Reservoir (Dr. Alun Hughes, personal communication, 2009). Additionally, diversion ditches surround the Reservoir to control and divert surface water runoff away from the Reservoir (Figure 7b). Thus, runoff from rain events goes into the drainage ditches alongside the Reservoir, with no interaction occurring with the Feeder Canal and Reservoir.

In conclusion, there is no hydrological connection between surface waters in the Lake Ontario Watershed and the Feeder Canal and the DeCew Reservoir. Thus, any contaminants from land use in this Watershed are not expected to have any impact on the drinking water quality of the DeCew WTP.

a)



b)

Figure 7. a) Location of the Feeder canal and drainage ditches alongside of the reservoir. b) A snapshot of the DeCew watershed area and flow of surface water into the ditch line.

2.2 Central Niagara Region Watershed

If there is no hydrological connection between the surface water runoff of the Lake Ontario Watershed and the DeCew WTP, it is now worthwhile examining whether any hydrological connection exists between the Central Niagara Region Watershed and the Welland Canal upstream of the Feeder Canal. This area includes the Township of West Lincoln, Town of Pelham, City of Welland, Township of Wainfleet, a small portion of the City of Port Colborne, Town of Fort Erie, and Thorold. The largest subwatersheds in this area are Welland River, Fort Erie Creek and Big Forks Creek (Figure 8).

The Welland River is the largest subwatershed in this area. Its headwaters originate south of Hamilton in Ancaster, and it flows eastward to the Niagara River. At the intersection where the Welland River crosses the Welland Canal, it becomes diverted beneath the Welland Canal by the construction of six concrete siphon culverts (NPCA, 2009). The constructed siphons allow water to enter the Welland River from the Welland Canal (Jayme D. Campbell, personal communication, 2009). The Welland River represents a main drainage basin for numerous subwatersheds in this area such as, Black Ash Creek, Parkers Creek, Unnamed Creek, Drapers Creek and Indian Creek Drain. Also, some portion of these waterways, on the east side of the Welland Canal, outfall to the Welland River as the land topography shows a slight slope toward this area (NPCA, 2009). The Fort Erie Creek Subwatershed receives water from Six Mile Creek, Beaver Creek and, Black Creek and drains into Lake Erie and the Niagara River via several outlets. The Big Forks Creek mainly falls within the Township of Wainfleet. It drains about 100 km^2 of land and drains to the Welland River.

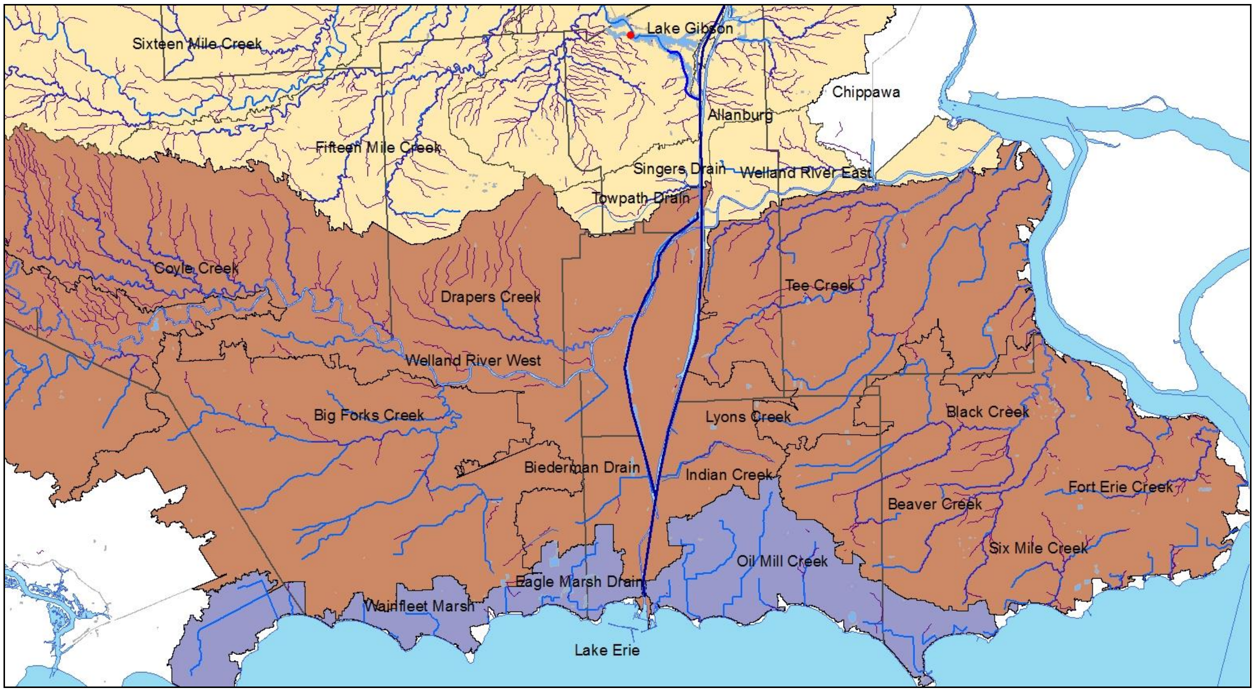


Figure 8. The Central Niagara Region Subwatersheds.

Aside from the Welland River that acts as the main natural drainage catchment for the majority of subwatersheds, the Welland Canal is a man-made drainage basin in the Central Niagara Region Watershed that receives inflow from approximately 64 square kilometers of land. Inflows enter from the Singer's Drain, the Towpath Drain, Lyons Creek, Biederman Drain and Indian Creek (Figure 8).

Located south of the Feeder Canal, Singer's Drain drains about 15 km^2 of land to the Welland Canal. This area of land is located in the municipalities of Thorold and Welland and the main branch of this Drain is designated as a municipal drain (Figure 9). An area of about 5 km^2 is drained by the Towpath Drain (Figure 9) which outlets to the Welland Canal just south of Singer's Drain.

Lyons Creek and Indian Creek (Figure 10) each drain about 13 km^2 of land from their headwaters in the cities of Welland and Port Colborne to the Welland Canal. Originally, Lyon's Creek flowed from southeast Welland and emptied into the Niagara River. In 1971, the Welland

Canal By-Pass severed Lyon's Creek, creating two separate watersheds: Lyon's Creek West, which empties into the Welland Canal By-Pass; and, Lyon's Creek East, which receives water that is pumped out from the Welland Canal By-Pass. Aside form the water that is poured into the eastern section of the Lyon's Creek, the amount of 13,000 m^3/day of water from 13 square kilometers of land naturally gravitates into the Welland Canal. Biederman Drain (Figure 11) drains a total land drainage of 18 km^2 to the Welland Canal. One branch of Biederman Drain originates from Wainfleet Bog located in the Township of Wainfleet and City of Port Colborne.

The flow rate and total land coverage by these subwatersheds are shown in Table 1. This table also provides the average percentages of agricultural and urban land uses within the catchment basins that drain into the Canal.

Table1. Summary of catchment flow to the Welland Canal

Catchment Names	Total Land Drainage (km^2)	Overland Runoff ( )	Agriculture Land Use %	Rural Land Use %
Singer's Drain	15	23,330	40	17
Towpath Drain	5	5,500	30	12
Biederman Drain	18	25,680	28	15
Indian Creek	13	8,330	33	36
Lyons Creek	13	13,000	55.5	21
Total	64	75,840	Average % 37.3	Average % 20.2

In addition to surface water discharges, dewatering of groundwater is actively occurring at two crossings of the Canal: East Main Tunnel operated by the Ministry of Transportation and Townline Tunnel operated by the St. Lawrence Seaway Corporation. The 330 meters long concrete Townline tunnel is located just south of the city of Welland and East Main Tunnel located in the north. Due to the substantial alterations in the regional ground water system, it was necessary to design a system for receiving and disposing of the water flowing towards the tunnel (Farvolden & Nunan, 1970). Also, Fraser Johnston from the St. Lawrence Seaway Management Corporation has confirmed that the general movement of groundwater is from the recharge areas at Port Colborne to the Townline tunnel (Fraser Johnston, personal communication, 2009).

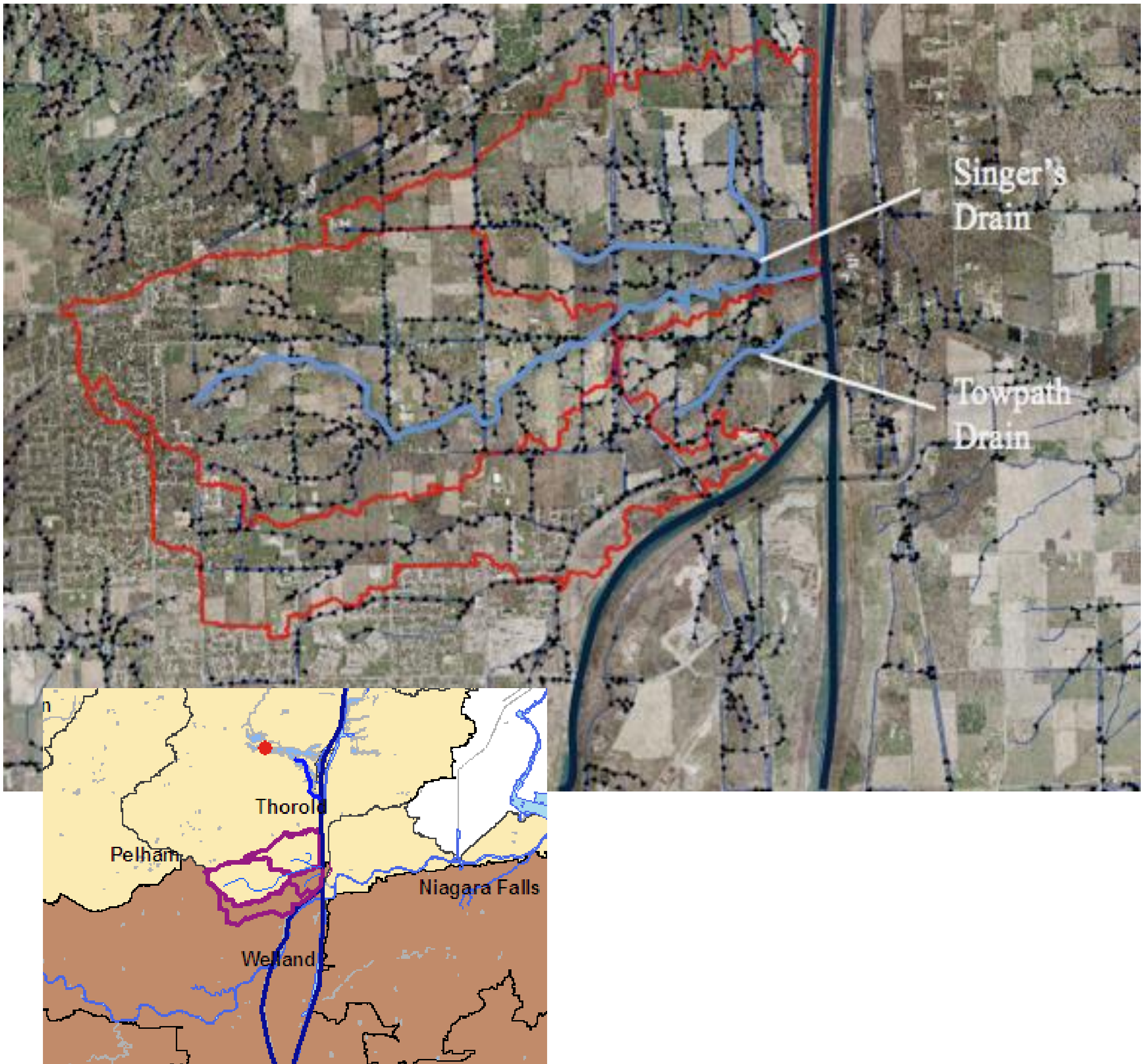


Figure 9. Location of Singer's Drain and Towpath Drain catchment basin.

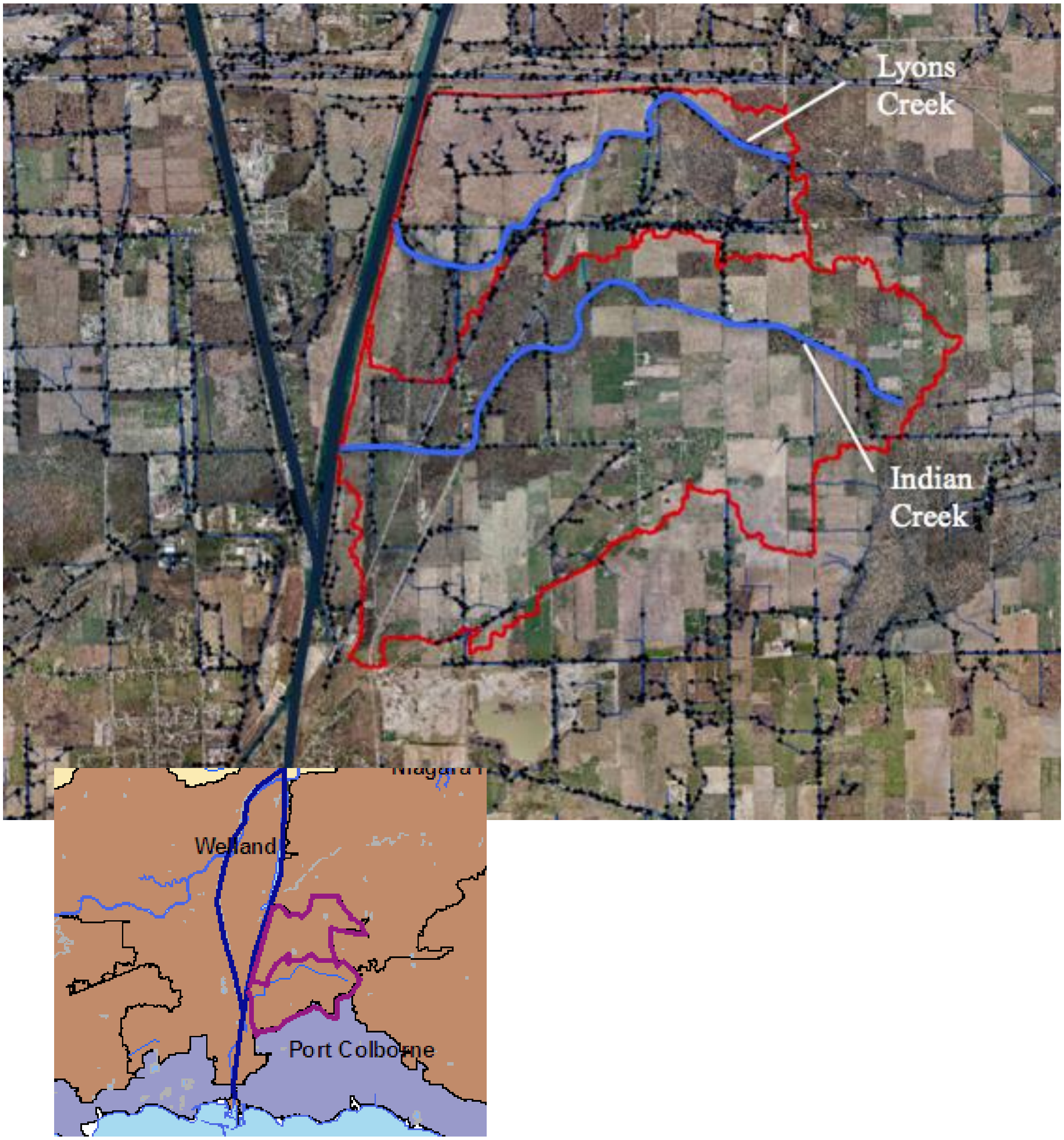


Figure 10. Location of eastern section of Indian Creek and Lyons Creek catchment basin.

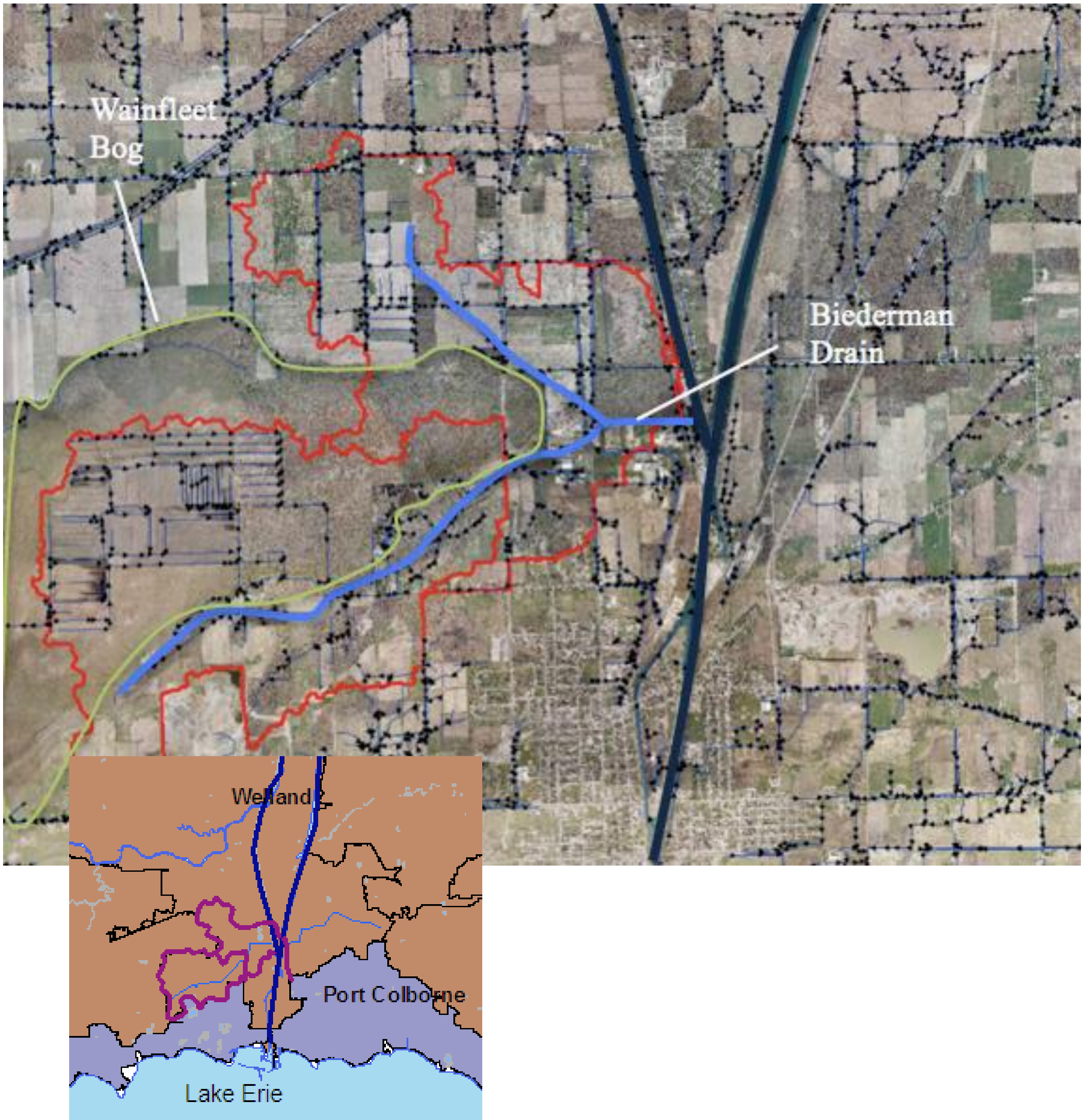


Figure 11. Location of Bidermans Drain and Wainfleet Bog.

2.3 North Lake Erie Watershed

This area of the broader Niagara Region Watershed extends from Haldimand County to Crystal Beach in Fort Erie including the City of Port Colborne, Township of Wainfleet, Town of Fort Erie and a section of Haldimand County. Major subwatersheds include Bay Beach Drain, Oil Mill Creek, Eagle Marsh Drain, and Wainfleet Marsh (see Figure 8). Aside from the industrial area surrounding the Welland Canal, land use in this watershed is primarily agriculture with focuses on egg and poultry production. Along the Lake Erie northshore, all of the catchments directly drain to Lake Erie with no hydrological connection to the Welland Canal.

In conclusion, the subwatersheds that fall within the Central Niagara Region Watershed have the most hydrological connection to the Welland Canal. Five catchment basins, ranging in size from 5 to 20 km^2, are estimated to have an average outlet of 75,840 m^3/day $(0.9\,m^3/Sec)$ to the Welland Canal, based on the calculated data from the ArcGis Spatial Analysis in this research. This number, compared to the 180 $m^3/\sec$ inflow from the Lake Erie, likely makes overland drainage a minor contributing factor to pollution of the Welland Canal.

Since agricultural drainage system is combined with the domestic sanitary system in municipalities upstream of the Feeder Canal, it was necessary to estimate pesticide application on farm fields as agricultural land make up an average of 37% land use within the Central Niagara Region Watershed. Therefore, the following sections are dedicated to estimate the type of agricultural activities and pesticide application on farm lands as overland runoff may find their way to this water system via the untreated Combined Sewage Overflow (CSO). Further, industrial activities that may contribute pollutions to the wastestream within these five catchment basins are indentified.

3.0 POTENTIAL SOURCES OF POLLUTION

3.1 Industrial and Municipal Activities

By the early 1960's, residential and commercial developments beside the Welland Canal had increased considerably (Gayler, 1994). Location of the Welland Canal was beneficial for the emergence of various industries including pulp and paper, metal mining and industrial machinery. All of these industrial activities produced vast quantities of wastes and with the inception of the Welland Canal, were directly dumped into it, diluted and dispersed (Gayler, 1994 & Jackson, 1997). Due to implementation of environmental regulation, the majority of metal and steel manufacturers such as United Steel in 1965, Union Carbide in 1999, Wabasso in 1984 were forced to close their doors (City of Welland, 2010). Although the amount of effluent discharges to the Welland Canal has been substantially reduced since its peak in the late 1960's, the wastewater emanating from the industrial activities are still impacting the quality of this water system (Darlene Suddard, personal communication, 2009). Thus, this section attempts to identify the current industrial activities adjacent to the Welland Canal and to examine the contribution of each industrial sector to water quality degradation upstream of the Feeder Canal.

Currently, there are a total of 38 industrial facilities located upstream of DeCew DWT within the municipalities of Thorold, Welland and Port Colborne. Locations of these facilities are mapped in Figure 12. The number of companies and their associated activities gathered through collaboration with Landry Blake at Niagara Economic Development Corporation and Darlene Suddard, Wastewater Compliance Coordinator at city of Port Colborne. Most of these industrial companies can be classified in three major categories of steel fabrication, manufacturing, concrete manufacturing; and ship repairs. The following sections discus how each major category contributes to the water pollution.

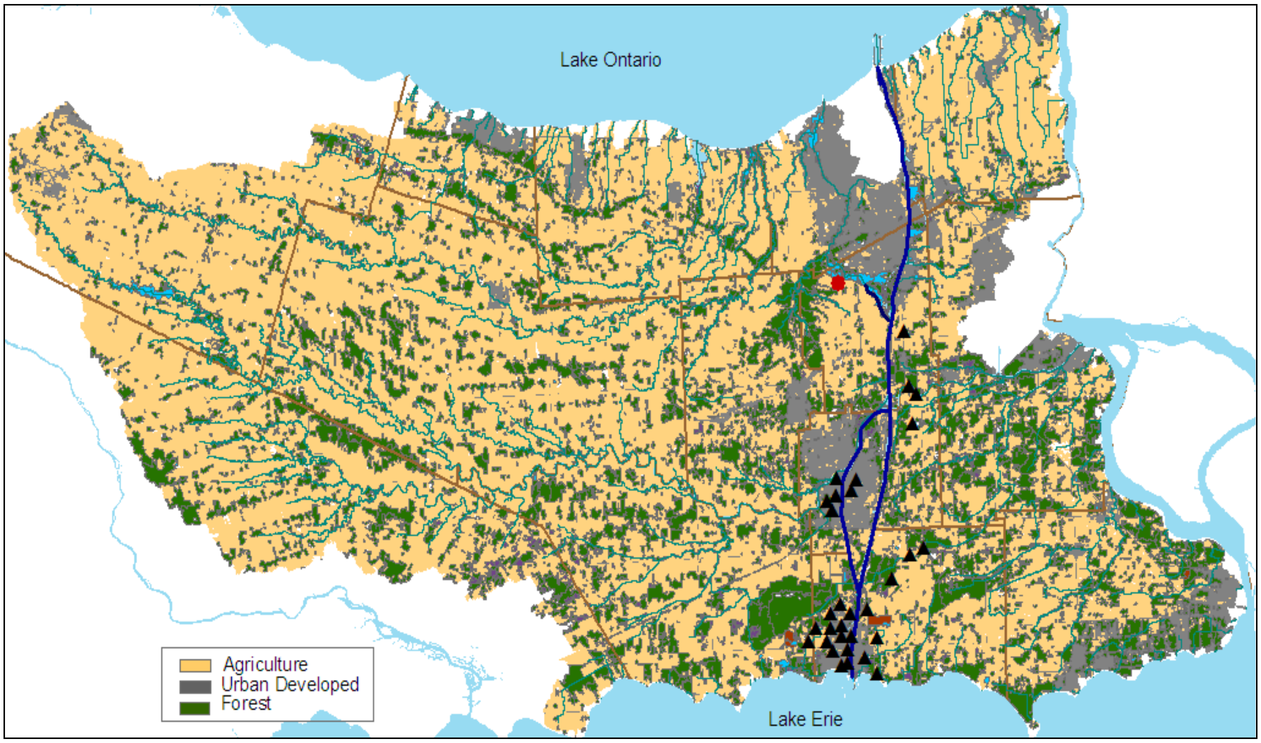


Figure12. Location of industrial companies alongside the Welland Canal.

Under the Ontario Water Resources Act (OWRA) any facility that discharges contaminants to ground or surface water is required to obtain the Certificate of Approval (COA) (OMOE, 2010). According to the COA, some operations are required to be equipped with industrial pre-treatment facilities to prevent the release of industrial pollutants to surface water (OMOE, 2010). Information obtained from industrial contacts, however, have confirmed that only 8 of the industrial companies in this study incorporate such treatment process before releasing their waste into the Welland Canal and the others discharge their waste into municipal sewer systems without any preliminary treatment. The companies which have the onsite wastewater treatment system are identified in Table 2.

Table 2. Industries along the Welland Canal. Companies are identified with asterix (*) operate onsite wastewater treatment facilities.

Company	Product
York-Ennis	Steel distributor
Shellby Sheet Metal & Mechanical	Metal manufacturing
H & S Heat Treating*	Meta heat treating and fabricating
St. Catharines Corrugated	Fiber box manufacturing
Welland Forge Division	Steel forging
Universal Resource Recovery	Material recycling
Henniges Automotive Canada	Automotive sealing manufacturing
Dufferin Concrete	Concrete manufacturing
Bradshaw Iron Works	Steel fabrication
Canada Forging	Ontario's largest die forging plant
Lakeside Steel Corporation*	Iron and steel pipe manufacturing
PanAbrasive*	Abrasive product and steel manufacturing
Arc Force	Steel fabrication
Berkwood Industries	Steel die
Hopkins Steel Works	Steel fabrication
P R W Fabrication	Steel Fabricator
Marr W.D	Machine forge and metal fabrication
Vesuvius Canada	Refractories
MMFX Steel of Canada	Steel manufacturing
Jungbunzlauer Canada*	Citric acid manufacturing
Taliscor Plastics Inc.	Plastic sheet manufacturing
Kwik Mix Materials	Concrete manufacturing
Canal Block	Concrete manufacturing
Vale Inco*	Metal casting
I M T Partnership*	Steel forging, metal fabricating
North American Tool & Die	Fabricated metal manufacturing
Hamilton Marine & Industrial	Steel fabrication
J. Oskam Steel Fabricators	Steel and alloy manufacturing
PowderCoat Niagara	Heat treating and allied activities
Westport Machining	Forge tooling, milling-cutters, tool holders and mold making. metal manufacturing
Barber Hymac Hydro	Machining and fabrication
Fraser Marine & Industrial	Ship repair and Industrial manufacturing
International Marine Salvage	Hazardous and non-hazardous waste recycling (battery and electronic waste)
Marine Recycling Corporation	Metal Recycling
R.J. Gillespie Enterprises	Ship repair and metal fabricating
Raw Materials	Hazardous and non-hazardous waste recycling (scrap metal)
Allied Marine & Industrial	Heavy industrial and ship repair
CASCO*	Starch manufacturing

3.1.1 Steel Fabrication and Metal Manufacturing

Almost 65% of the total industrial facilities located in this study area are involved in metal shaping and steel fabrication. Metal fabrication is a process of producing or creating metal components. The process may include various stages such as heat treating, coating, casting, shaping, welding, and cleaning metal parts. Most metal fabricating facilities generate a variety of wastewater streams. The resulting wastewater is treated as hazardous wastes due to the high content of hydrocarbons and chemical additives (USEPA, 1990). The largest wastestream in the metal fabrication process is comprised of oily disposal from machining operations. Additional contaminants present in wastestreams include solvents (alkaline and acid solutions) such as trichloroethane, methyl ethyl ketone and hydrochloric acid generated from cleaning, plating and stripping operations (USEPA, 1995). From a volume perspective, contaminants produced during the plating process account for the majority of waste, as it involves numerous rinsing steps. The primary inorganic wastes associated with metal cleaning and plating are alkaline cyanide, and cyanate and nitrate as well as organic pollutants such as petroleum hydrocarbons, dioxins and furans and phenols (USEPA, 1990; Water Environmental Federation, 2008). It appears that all 22 facilities in this study generate similar wastes as mentioned above with various composition levels (Shane Smith, Kevin Langerak, and Angelo Armenti, personal communication, 2009).

The majority of steel manufacturers in this study use the Basic Oxygen Furnace (BOF) process. The BOF input materials mainly include molten iron, scrap and oxygen which is used for high production of carbon steel (Vesuvius Canada Inc, personal communication, 2009). During the manufacturing of steel using a BOF, coke making and iron making are needed and the major pollutants in wastewater generated from this process include ammonia nitrogen, cyanides, benzene and hydrocarbons. They may also contain toxic metals such as antimony, arsenic, selenium and zinc (Wang *et al,* 2009). The recommended wastewater treatment systems for these facilities include sedimentation to remove suspended solids, chemical treatment to precipitate heavy metals; steam stripping to remove ammonia, and biological treatment (World Bank Group, 1998). Oil removal, ammonia distillation and secondary clarification are the most common types of treatment process among the steel and manufacturing operations in this study.

With respect to the substances that contribute to polluting the environment, it is important to mention that the most important significant court case dealing with contaminants in the Niagara Region recently occurred in Port Colborne. Port Colborne is home to major industrial activities, with a total of 19 metal refinery and processing industries. The residents of Port

Colborne, along with the Niagara Region Public Health, have been concerned with the amount of air and water emissions released by these facilities (OMOE, 2000). The Inco operation started refining of nickel, copper and cobalt in 1918. In 1999, a study was conducted by MOE to determine the soil concentration of Ni, Co and Cu in the area adjacent to the Inco Nickel refinery. This study indicated that the levels of Ni concentration in soil exceeded the MOE soil remediation criteria for Ni (200 μg/g) along a 3 kilometers gradient northeast of the refinery. Also, the soil remediation criteria for Cu (300 μg/g) and Co (50 μg/g) were also exceeded over areas of 0.2 and 0.8 km^2, respectively (OMOE, 2000). Following the OMOE report, a controversial lawsuit was brought forward by the residents of Port Colborne concerning the elevated levels of nickel found in the area. Eventually, after 10 years of court proceedings, the case was settled. In July 2010 The Superior Court of Ontario found Inco liable for the discharge of nickel emissions and the defendant was ordered to pay $36 million in environmental damages it had generated to residents of Port Colborne over the years of operation (Tyler, 2010). The Inco refinery disposes its pollution into Lake Erie. Although this is not directly discharged into the Welland Canal, there is a possibility for the pollutants to get carried into the Canal through the long shore currents.

3.1.2 Concrete and Cement Manufacturing

Concrete is basically a mixture of aggregates and paste. The aggregates are sand and gravel; the paste is water and portland cement which contains calcium, silica, and iron oxide (wang *et al*, 2009). According to the Canadian Environmental Protection Act, 1999, the concrete manufacturing process releases toxic chemicals including sulphur oxides, nitrogen oxides, VOC, particulate matter and carbon monoxide into air (Environment Canada, 2010). Contaminant wastewater is mainly generated through cooling and wet scrubbing. The main constituents of pollutants in the wastewater stream include Total Dissolved Solids (TDS) such as potassium and sodium hydroxide, chlorides and sulfates and Total Suspended Solids (TSS) including calcium carbonate. The main control and treatment methods for wastewater should involve segregation of dust and neutralization and settling ponds or clarifiers to remove TSS (Water Environmental Federation, 2008).

3.1.3 Ship Repair Operations

A total of five large ship repair operations actively service an average 3,671 vessels that annually pass through the Welland Canal (GLSS, 2007a). Common activities in these ship industries involved cleaning, abrasive blasting, sanding, mechanical repair and fuel change. All of these activities can impact the receiving environment by directly discharging contaminations to the water system. USEPA in 1979 indicated the presence of some chemical concentrations in the sediment of regions where ship repair and shipbuilding were performed (USEPA, 1979). In this study, substances including copper, lead, chromium, polyaromatic hydrocarbons, polychlorinated biphenyls, organotin, and dioxins and furans were recognized as having significant environmental impact to the receiving waterways in vicinity of shipyards.

3.1.4 Municipal Wastewater Treatment Plants (WWTPs)

Aside from industrial discharges to the Canal, effluent discharge from the sewage treatment plant to the Welland Canal is considered as one of the major significant factors threatening the quality of water. In Ontario, effluent from WWTPs has become one of the major point source of accidental spill of pollutants. In 1985, the International Joint Commission identified 17 locations within Ontario Great Lakes as Are of Concern (AOC). Effluent from municipal WWTPs was recognized as a major causes of water pollution at ten of these sites (IJC, 2007). In the Niagara Region, there are two WWTPs upstream of the Feeder Canal and the DeCew WTP. The Welland WWTP is located in City of Welland that receives the municipal waste water from cities of Thorold, Welland and some sections of Town of Pelham. Effluent from this plant discharges to the Welland River with no discharge to water in the Canal, as the river passes under the Canal.

The Seaway Wastewater Treatment Plant, however, which services Port Colborne, has final effluent discharging to the Welland Canal (OMOE, 2009). According to the 2009 COA, the average daily flow into the Seaway Plant is 15,120 m^3/d and during wet condition is 45,360 m^3/d. The wastewater inflow undergoes treatment processes within the plant including: primary clarifier, waste activated sludge thickening, aeration system, phosphorous removal, and UV disinfection. The total average treated sewage entering into Welland Canal is approximately 11,417 m^3/d, from which 132 m^3/d bypass the treatment processes (OMOE, 2009). This means they only undergo primarily clarification treatment before being discharged to the Welland Canal. Although the amount of bypassed wastewater accounts for 1.2% of the total sewage, it contains pathogenic organisms and toxic pollutants that present a health risk to the water system. The discharge of raw sewage occurs to prevent overloading treatment plant capacities during the rainy season. While it appears that the plant sufficiently manages the treatment process, effluent released from wastewater systems contain pollutants of concern. In this plant, flow from the primary clarifiers go into activated sludge process, where microorganisms are mixed with air. The activated sludge thickening system is a biological process that is designed to remove the biodegradable organic matter by providing a rich consortia of aerobic microorganisms that are able to break down the organic matter. Although secondary treatment may remove more than 85% of the organic matter and suspended solids, it fails to remove significant amounts of heavy metals, and persistent organic contaminants that resist degradation such as pharmaceuticals, antioxidants and pesticides and industrial chemicals (USEPA, 2004).

Several studies have confirmed that the discharge of untreated wastewater can result in elevated concentrations of chemical pollution in waters receiving wastewater effluent (Fono & Sedlak, 2005; Kolpin *et al*., 2004). Their results indicate that discharge of relatively small volumes of untreated combined sewage effluent and storm waters is a major source of bacteria, nutrients and organic pollutants in surface water samples collected downstream from the WWTPs. Among these chemical pollutants, various Pharmaceuticals and Personal Care Products (PPCPs) are a large class of organic waste contaminants that can originates from a variety of pathways entering domestic sewer systems including: human cosmetic products, hospital and veterinary medicine waste, disposal of outdated medications, industrial and agricultural waste (Ellis, 2006). Following usage, PPCP medical substances are usually excreted unchanged from human and animal bodies and pass through wastewater treatment plants. Treated sewage effluent have been shown to contain a variety of PPCP substances as the conventional treatment processes are not able to completely remove the residual substances. Advanced treatment of wastewater effluents using either ozonation or granulated activated carbon appears to be effective in degrading or capturing PPCPs (Ellis, 2006).

The occurrence and fate of PPCP in surface waters originating from municipal and commercial sources is one of the leading emerging issues in environmental toxicology. Recent studies have demonstrated the occurrence of PPCP at different concentrations at the sewage effluent of European and Canadian wastewater treatment plants (Boyd *et al.*, 2004; Buerge *et al.*, 2003). At least 80 PPCPs (e.g., analgesics, antibiotics, antiepileptics, antidepressants, and blood lipid regulators) have been identified in outflows from WWTPs and surface waters across Canada (Environment Canada, 2009). However, many PPCPs remain unidentified and number of research regarding the fate and quantification at drinking water intakes (Environment Canada, 2009). In Switzerland, elevated loads of caffeine were linked to combined sewer overflows during rainy seasons as it was concluded that untreated wastewater had been discharged into waters (Buerge *et al.*, 2003). Increased concentrations of ibuprofen and triclosan in storm water flow from New Orleans were attributed to untreated sewage after storms with rainfall of few inches (Boyd *et al.*, 2004). In Germany, pharmaceutical compounds such as diclofenac, choletrsol and coprostanol were measured at concentrations up to 7 μg/L in effluent samples and at the trace level concentrations in tap water (Hebere, 2003). Moreover, contrary to the common assumption that concentrations of pollutants might be lower during wet weather, evidence suggests dilution is not an effective method to remove the PPCP metabolites (Fono & Sedlak, 2005).

The only effective wastewater treatment technologies that have been recognized by the USEPA for removing pesticide active ingredients and other pollutants, are activated carbon adsorption, chemical oxidation, chemical precipitation, and hydrolysis which are not used in the Seaway STP plant (USEPA, 2009b; OMOE, 2009).

The government authorities have also recognized the need for improved wastewater treatment technologies and processes. To this end, the Regional Municipality of Niagara received a $7.3 million infrastructural loan as part of Canada's Economic Action Plan (Canada's Economic Action Plan, 2010). This project intends to expand the Seaway STP facilities in order to reduce the overflow of untreated sewage into the Welland Canal. This commitment from the federal government underlines the significant need to eliminate the combined sewer overflow problem and enhance the current treatment processes in an effort to minimize water pollution. However, to date, contaminant load to the Canal from Seaway STP still provides a potential risk to the DeCew WTP.

3.2 Agricultural Land Use

Diverse agricultural activities in the Niagara Region, reflect the unique nature of this area. The distinctive combination of geography and climate allow growth of a variety of agricultural products. In 2006, the Niagara Region had 231,728 acres of farm land which occupied 52% of the total regional land (RMN, 2003). To put this in perspective on a national scale, the Region generates more agricultural products than any of the Maritime Provinces (Statistics Canada, 2006). The high agricultural productivity in Niagara can be attributed to three main factors: physiography (natural features of land formation), soil capability (suitability of soils for cultivation) and climate. These physical parameters determine the extent to which agricultural products can be grown in a given area in the Region (RMN, 2003).

Niagara is comprised of three distinct physiographic sections including the lower area south of Lake Ontario, the Niagara Escarpment, and the area north of Lake Erie. The location above and below the Escarpment provides significantly different opportunities for agricultural production. The Lake Ontario Watershed area, above the Niagara Escarpment, is comprised of mainly course sandy loam and sand soils. This so called “vineland group soil” is suitable for most agricultural crops, but in this area it is commonly used for growing grapes and fruit tree production. Within the Central Niagara Region Watershed, between the Escarpment and Lake Erie, the Haldimand clay plain soil groups dominate the area (RMN, 2003; NPCA, 2009). This covers the most area of land within the Central Niagara Region Watershed which is exclusively used for the production of field crops.

Capability of soil is another important physiological factor that supports the vigorous agricultural growth production in the Region. The soil classification of the Niagara Region has been provided by Environment Canada (Environmental Canada, 1972). In this report the Canada Land Inventory (CLI) system was developed to measure the relative soil capability for agriculture land use. The system has categorized the Regional soils into different classes based on capability of areas for growing field crops. In this study, the soil is grouped into seven Classes with Class One considered the most productive area and Class Seven is the least capable soil for field crops. In Niagara, approximately 85% of land falls within Classes One to Three, representing the most productive agricultural lands (Environmental Canada, 1972). Agricultural soil classification in the Region is shown in Figure 13.

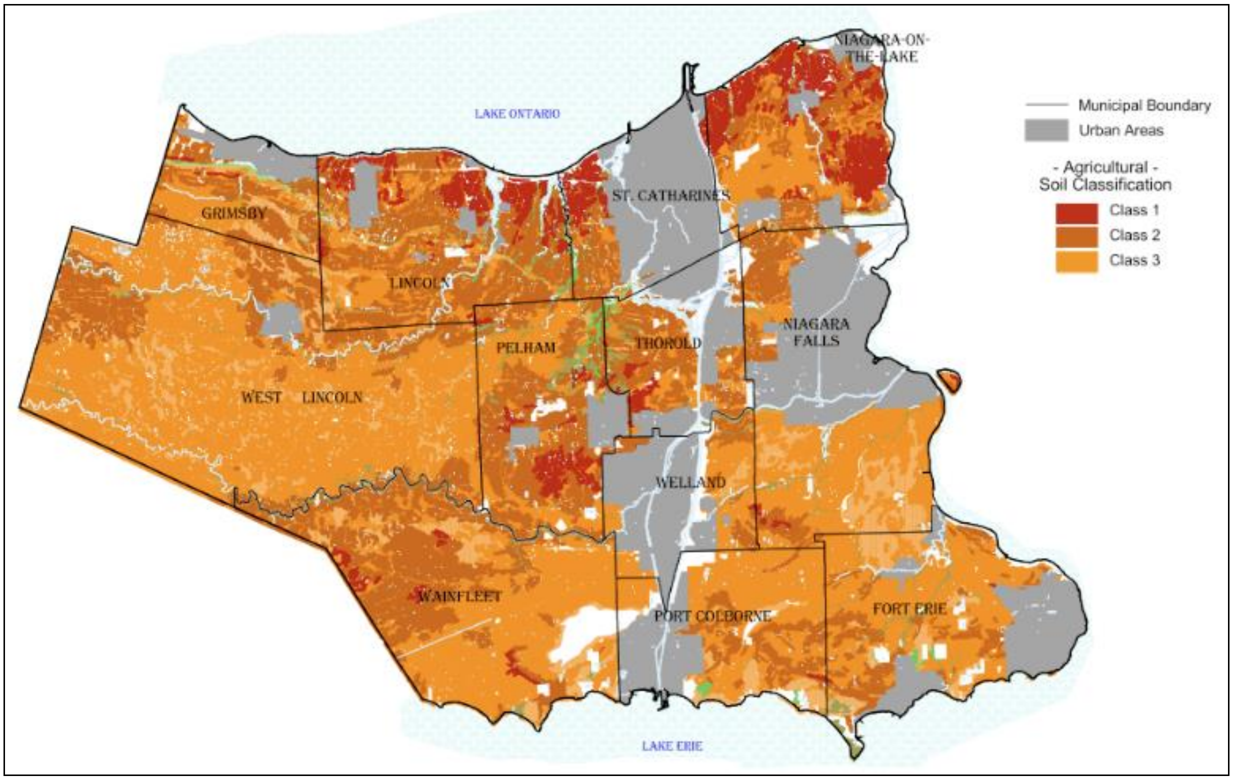


Figure 13. CLI for Soil classification (Source: RMN, 2003).

Lastly, Niagara Region's climate is the other important factor that elevates the opportunity for a wide range of agricultural activities. The northerly part of the Region along the Lake Ontario shoreline has a longer growing season compared to southern part of the Region. Due to the proximity to Lake Ontario, this area is the most suitable climate zone for fruit and grape crops. The area within the Central Niagara Region Watershed, along the Welland Canal is also located in an area with high Crop Heat Units (CHU). Crop Heat Units is a rating system developed to assist farmers in selecting the suitable area for planting seeds and grains based on the total accumulated crop heat units for the frost free growing season (Figure 14). The measured CHU value for the area Niagara Escarpment to Lake Erie is rated as 3300 showing a great flexibility of this area for growing a variety of grain crops and livestock production (OMAFRA, 1993; Gayler, 1994; RMN, 2003).

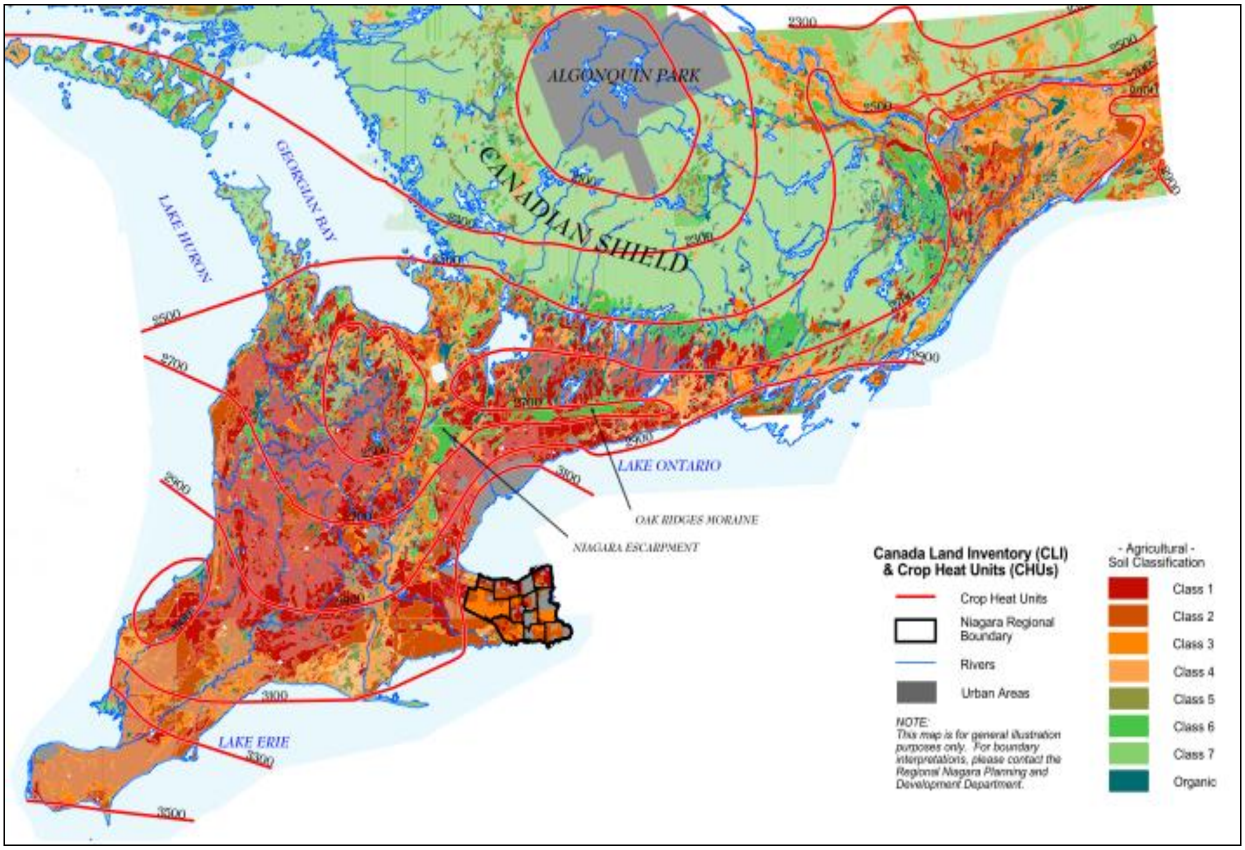


Figure 14. Agricultural Soil Classification (CLI) and Crop Heat Units (CHUs) for Southern Ontario (Source: RMN, 2003).

In addition to good soils and climate condition, the location of the Welland Canal also supports crop production due to close proximity to a source of water. According to Statistics Canada (2006), the major agricultural production in the whole Region was comprised of fruit (apples, berries, and peaches) green vegetables along with grain and oilseed (corn, wheat) products. The City of Lincoln, followed by Niagara-on-the-Lake, St Catharines and the township of Wainfleet have the highest number of fruit farms in the Region. Grain and oilseed production, with the second highest agricultural production in the Region, was more concentrated along the Welland Canal area in the cities of Port Colborne, Welland and Thorold (Statistics Canada, 2006).

Also, as determined by this study, the five catchment basins (Singer's Drain, Towpath Drain, Biederman Drain, Indian Creek, and Lyons Creek) which mainly fall within the municipalities of Thorold, Welland and Port Colborne, is comprised of 37% of farm land and drains approximately 0.9 cubic meters of overland water per second. Measuring the amount of pesticides entering the tributaries is difficult to do as the level of application and storm intensity can vary seasonally. Therefore, in order to assess the state of pesticides contamination in particular in runoff entering the Welland Canal, the following section provides a profile of agricultural land inventory along with the possible application of pesticides on field crops. The goal of this section is to make the best risk assessment of pesticides pollution into the Welland Canal water.

3.2.1 Agriculture Profile

The pattern of agricultural activities in the Niagara Region within the past decades represents a substantial change. A comparison of the status of Regional agriculture between the 1996 and 2006 reveals significant decrease in the number of farms, which can be attributed to the expansion of industrial activates within the Province (RMN, 2003). A review of the number of farms and the change in farmland acres shows a trend towards fewer farms and the rationalization of operations. However, the Niagara Region as a whole had an overall 1.6 % increase in total acreage of farms between 1996 to 2006 (Pond, 2009, RMN, 2003). The percentage change in both the number of farms and farmland acres over the years of 1996-2006 is depicted in Table 3.

Table 3. Comparison of total area of farms (acres) for the area municipality along the Welland Canal between 1996 and 2006 (Regional Municipality of Niagara (RMN), 2003; Environment Canada (EC), 2007a).

Geographic Location	**1996 (RMN, 2003)**		**2001 (RMN, 2003)**		**2006 (EC, 2007a)**	
	Number of Farms	Area of Land (ac)	Number of Farms	Area of Land (ac)	Number of Farms	Area of Land (ac)
Southern Ontario	20,756	4,100,912	18,649	3,985,132	18,665	3,934,766
Niagara Region	2,269	229,832	2,024	232,817	2,236	231,728
Thorold	60	8,029	43	11,537	49	10,799
Welland	14	1,660	22	2,123	23	1,525
Port Colborne	66	13,444	59	13,379	71	12,814

According to Statistics Canada data collected in 2006, the municipalities of Wainfleet, Lincoln, Niagara-on-the-Lake, and Pelham generated the highest level of agriculture production with over 70% farms of their total land area. In the same year, the total geographic area of farmland in Thorold, Welland and Port Colborne was 55%, 10% and 50%, respectively (Pond, 2009; Statistics Canada, 2007).

With respect to type of agricultural operation, Statistics Canada (2007) classifieds farms into different farm types. This classification is provided by estimating the gross farm receipts from the inventories of crops and livestock for each farm. In 2006, of the total 231,728 acres of the Regional farmland, 188,741 or 81.5% was in field crops. The data shows in the southern portion of the Region, grain and oilseed represented the largest number of field operations (Table 4). The diversity in farm type by number of farms is show in the Figure 15.

Table 4. Total farm acreage by products for the Regional of Niagara and the municipalities along the Welland Canal, 2006 (Statistics Canada database).

Geographic Location	Wheat	Corn	Soybeans	Green Vegetable	Apple, Berry and Grape	Total land in crops
Niagara Region	17,904	47,323	61,684	5,530	56,553	188,741
Thorold	1,355	4,176	4,210	100	521	10,362
Welland	50	0	800	100	40	1,000
Port Colborne	3,000	873	4,264	131	90	10,362

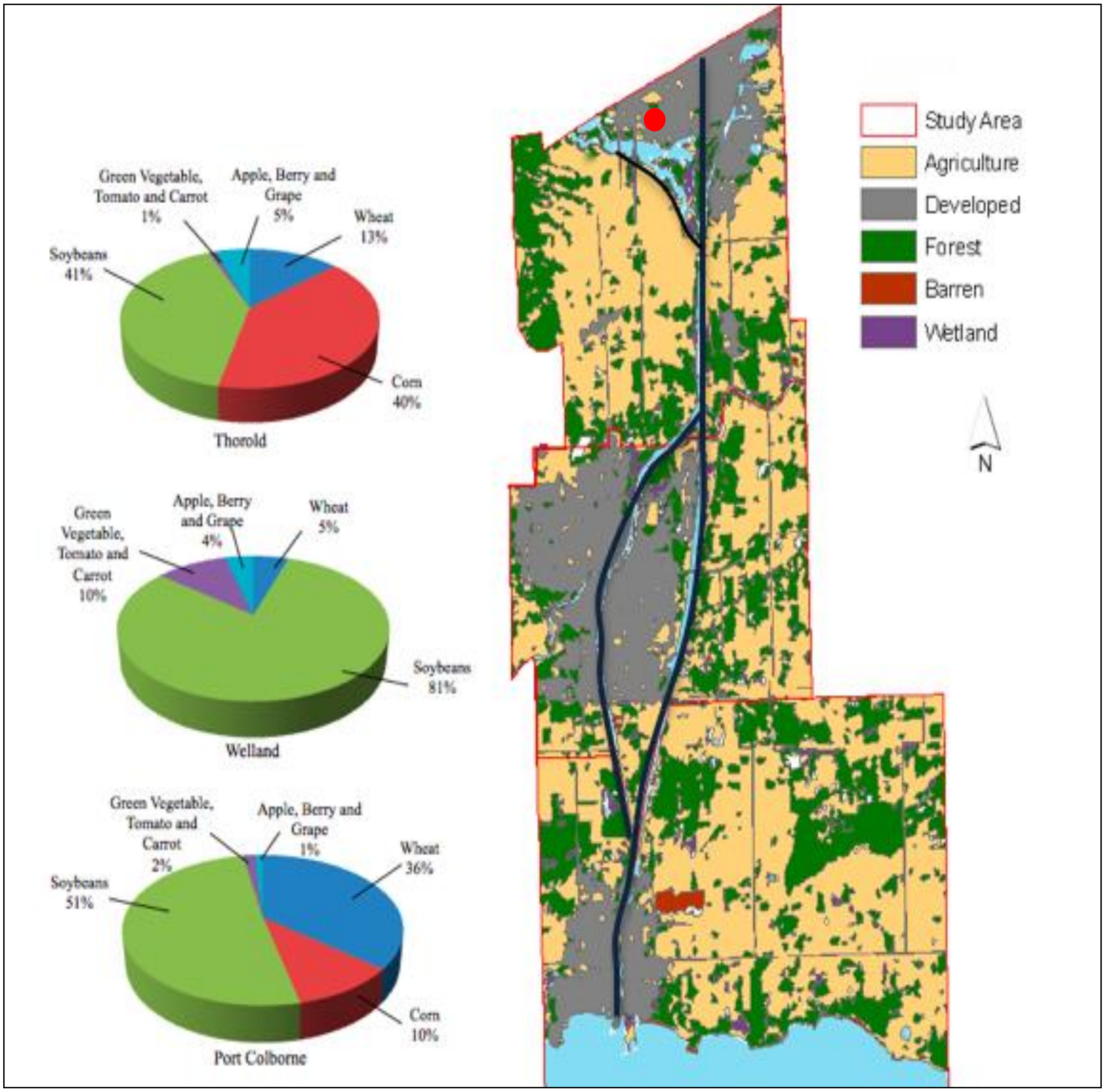


Figure 15. Percentage of number of farms within the municipalities of Thorold, Welland and Port Colborne (Statistics Canada, 2007).

3.2.2 Soil Texture

Type of soil is an important factor in specializied agriculture. The soil of the Niagara Region has been surveyed by the Ontario Instititute of Pedology in 1989 (Kingston and Presant, 1989). This study is still the most detailed survey conducted on geological and physiological features of soil in Ontario. Based on this data, in the northern boundary of the Central Niagara Region Watershed, lacustrine heavy clays of the Haldimand and Lincoln soil groups dominate the area of land in Thorold and Welland. In the southern portion of the Central Niagara Region Watershed (Port Colborne) lacustrine silty clays of the Beverly and Toledo soil groups dominate (Kingston and Presant, 1989). Both of these two types of soils are suitable for most agricultural crops but in this area, and are commonly used for growing soybeans, corn, and wheat (Figure 16). Both of these soils have slow to moderate permeability with high water holding capacity (NPCA, 2009).

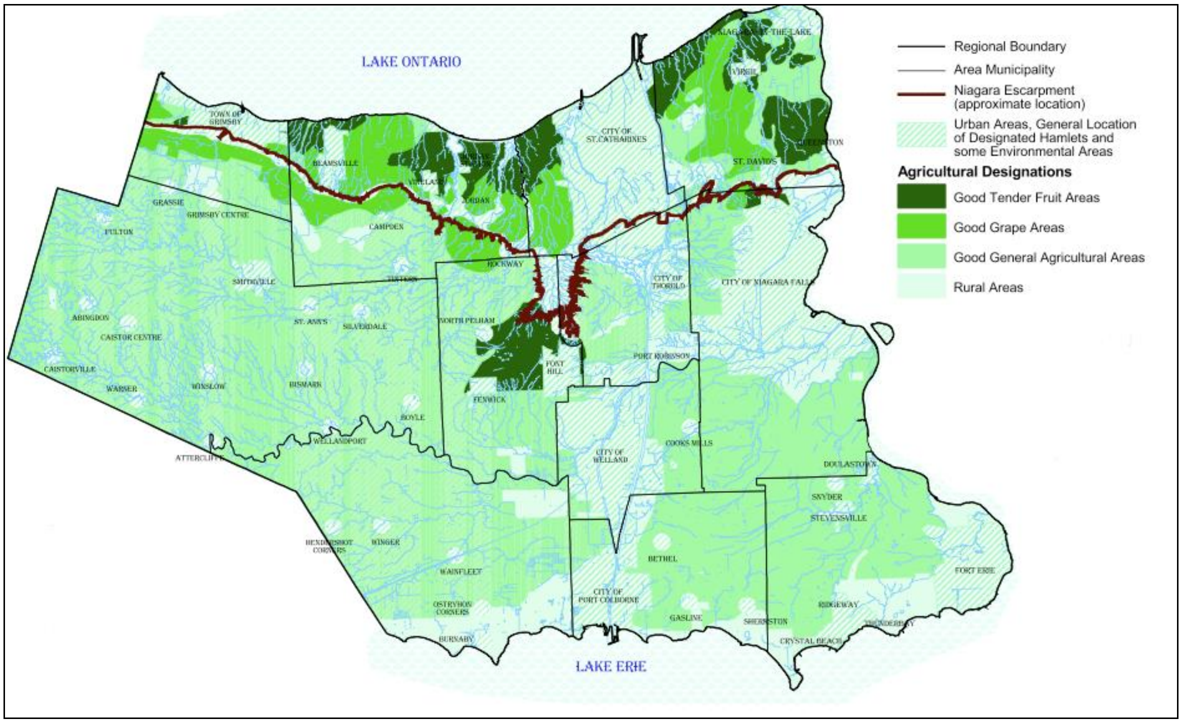


Figure 16. The Niagara Region soil capability (Source: RMN, 2003).

Type of soil also is a key property influencing the infiltration rate and the processes of water movement. The rate of infiltration is the velocity at which water penetrates the soil surface and thus, when water infiltration is slow, water does not enter the soil. Therefore, low rate of infiltration allows water to pond on the surface or wash off the land. The infiltration rate is usually measured by the depth of surface water in millimeters that can penetrate the soil within an hour (Arshad & Coen, 2009). With regards to the characteristics of soil infiltration in the Central Niagara Region Watershed, this area is currently being studied by the Niagara Peninsula Conservation Authority (NPCA) and has yet to be published. However, Jayme Campbell, the Hydrogeologist at NPCA indicated that the average soil infiltration rate within this subcatchment in the Central Niagara Region has been measured at 1.5 mm/hour, meaning that little agricultural runoff can penetrate to groundwater (Personal communication, May, 2010). The heavy clayey nature of soil as well as low levels of organic content result in decreasing water penetration because the space the soil occupies is relatively dense.

Soil slope is the other important effect on runoff since steep slopes accelerate water moving over land. A flat or no slope area does not act as a catalyst for the movement of water, allowing time for penetration. The subcatchments in the Central Niagara Region Watershed have an average slope of 3.5% toward the Welland Canal (NPCA, 2009). As such, it would be expected that water in this portion of the watershed would slowly transmit downward to the aquifer. However, with large natural areas surrounding the Welland Canal watershed being significantly developed for agricultural and urban use, the results are increased impervious surfaces that impede infiltration. This helps storm water move more quickly to receiving waters (Struger, 2007). As such, a combination of poorly structured soil, low levels of organic content, impervious surfaces, and slow infiltration rate are key factors in enhancing the potential for agricultural surface runoffs during the initial stage of rainy season to the Welland Canal via the major creeks such as Singer's Drain, Lyons Creek, and Indian Creek.

3.2.3 Pesticide Application

In the mid 1970's, organochlorine pesticides such as DDT and chlordane were first applied in Ontario to control insect pests (Frank *et al.*, 1997). Since then, pesticide formulations have gone through several changes including from inorganic substances to organochlorine insecticides, organophosphorous, and more recently, to sulfonyl urea and imidazolinone herbicides. Many of the earlier products, such as DDT, have been restricted in Canada due to their chronic toxic effects on indigenous organisms (Takacs *et al*, 2002). In general, new generations of pesticides have become less persistent, more water-soluble, and lower in toxicity to organisms (Kannan *et al.,* 2006).

Unlike most developed countries, Canada does not require pesticide manufacturers to provide public access to sales records, thus eliminating the ability to obtain accurate information on pesticide use (Takacs *et al*, 2002). However, every five years since 1973, OMAFRA has conducted a voluntary survey of Ontario farmers on pesticide use. In 2003, the estimated total pesticide active ingredients that had been applied to field crops, fruits and vegetables was 4,218.2 tonnes, from which 3217 tones was herbicides usage (McGee *et al.,* 2003). The previous survey of 1998 estimated a total pesticide use of 5,214.4 tonnes (Hunter & McGee, 1998). The 2003 and 1998 surveys represent an overall decline in pesticide use, with the largest decline including insecticides followed by fungicides for both fruit and vegetables. However, total herbicides used on grains increased by 14%: organophosphate herbicides, including glyphosate increased by 60%; triazine herbicides including atrazine and simazine have remained constants at 90% of their usage since 1998. The total estimates of pesticide application on field crops in Niagara Region is illustrated in Table 5.

Table 5. Quantities of active ingredients of each type of pesticide used on all surveyed crops in Ontario, 2003 (Source: McGee, 2003).

Crop	Herbicides				Total Herbicides (tonnes/year)
	Triazine	Phenoxy	Glyphosate	Other	
Field Corn	524.7	208.3	125.01	667.69	1525.7
Soybeans	30.9	4.5	861.98	298.62	1196
Dry Beans	-	0.9	10.5	44.6	55
Tobacco	-	0.1	0.22	1.88	2.2
Grains	-	221.1	102.8	304.2	407.1
Canola	-	-	9.06	1.53	10.6
Hay	-	3.7	16.98	3.82	20.8
Field Crops	**555.6**	**438.6**	**1126.55**	**1322.34**	**3217.4**

During the past two decades, atrazine has been the most common pesticides in term of mass application in Ontario (Zaruk *et al.,* 1998; Kannan, 2004;; Struger *et al.,* 2004), with around 500 tonnes applied to croplands every year (McGee *et al.,* 2003). It is most commonly used to spray on corn and soybeans, and enters surface water via runoff from rain or irrigation (Graymore *et al*, 2001). Health Canada regulates the Interim Maximum Acceptable Concentration (IMAC) for atrazine in drinking water at 5 µg/L, representing a total atrazine and its metabolites (Health Canada, 1993), while the USEPA advises that concentrations in drinking water not exceed 3 µg/L

(USEPA, 2003). The Canadian Water Quality Guidelines (CWQG), for protection of aquatic life, recommends the concentrations of atrazine to be at 1.8 µg/L (Canadian Water Quality Guidelines, 2008). However, atrazine and its metabolites are commonly detected in streams, river and lakes adjacent to agricultural and urban regions within southern Ontario, often above these recommended values (Takacs, *et al*, 2002). In 1992, Concentrations of atrazine in drinking water samples have been known to reach as high as 81 µg/L in Ontario (Graymore *et al.*, 2001).

Numerous studies have demonstrated that concentrations of atrazine in surface water exceed reregulated levels. Hall et al (1993) reported that surface water samples from watersheds in southern Ontario had atrazine concentrations up to 43 µg/L following the field application in spring. Between 1998 and 2002, Struger and Fletcher (2007) analyzed the surface water of Don River and Humber River watershed for one hundred and fifty-two active ingredient for pesticides and their metabolites. Of the total pesticides they sampled for, eleven pesticides and one metabolite were indentified. In all samples, the highest pesticide concentrations were measured for atrazine, which in 28% of detected samples its concentrations exceeded the CWQG. The highest concentration of atrazine detected in this study was 3.6 $\mu g/L$, which compared to the CWQG this amount was double (Struger & Fletcher, 2007).

Glyphosate is the second common dominant herbicide used, next to atrazine in Ontario. It is a weak organic acid used for weed control for planting of many crops including wheat, barely, corn, and flax. In 2003, surveys of agricultural pesticide use reported that the total usage of glyphosate was roughly 1,200 tonnes in Ontario. However, the total glyphosate usage is expected to be higher than these statistics suggest, as the survey did not include the urban and forestry usage (McGee *et al.*, 2003). In water, glyphosate is rapidly adsorbed to suspended particulate matter, and may be carried into other surface waters bound to sediments during precipitation events (Byer *et al*, 2008). Health Canada regulates IMAC for glyphosate in drinking water at 280 µg/L (Health Canada, 1987). Glyphosate is not regularly analyzed in pesticide monitoring programs of agricultural and urban landscapes in Canada, as it requires different analytical techniques from the pesticide scans used in most monitoring (Byer *et al*, 2008). Therefore, information is limited on its occurrence in most surface water in Ontario. Between the years 2004 and 2005 however, Struger et al (2008) examined the concentrations of glyphosate, on different location in rivers across southern Ontario and Niagara Region. In 500 surface water samples taken, neither glyphosate not its metabolites exceeded the Canadian guidelines for the protection of aquatic life of 65 $\mu g/L$. Although, all the samples were found below the CWQG for the protection of aquatic life, concentrations of glyphosate in surface water is not consistent and may vary during runoff events where high magnitude and short duration pulses may occur.

3.3 Atmospheric Deposition of Pesticides

There are three main processes by which atmospheric deposition of pesticides occurs: 1) wet deposition via precipitation, 2) dry deposition via particulates, and 3) gas absorption at the water interface (Kannan *et al*, 2006). Atmospheric deposition of persistent toxic chemical was first studied in the late 1970's under the Great Lakes Water Quality Agreement (GLWQA) (Kannan *et al*, 2006). Since then, the United States Environmental Protection Agency (USEPA) and Environment Canada have operated different monitoring networks to measure the occurrence and distribution of pesticides in the atmosphere of the Great Lakes regions (Kannan, 2005; Yao *et al*, 2007).

The Integrated Atmospheric Deposition Network (IADN), which is a joint venture of Environment Canada, the OMOE, and the USEPA was created in 1990 to determine deposition of toxic chemicals to the Great Lakes. Results of samples of air and precipitation is reported every two years through the IADN website, summarizing the measurement of several persistent organic pollutants and providing estimates for their atmospheric deposition. The IADN collects gas and particle-phase air samples for calculating the 13 polycyclic aromatic hydrocarbons (PAHs), 18 organochlorine pesticides (OCPs) including chlordane, dieldrin, endosulfan, and congeners of polychlorinated biphenyls (PCBs). These measurements have been conducted at a total of 15 stations within the Great Lakes basins. The recent published IADN report provides data from 2001 to 2005 for the station on Rock Point Provincial Park, (eastern end of Lake Erie 25 km west of Port Colborne), and indicates that the atmospheric loadings of PAHs, OCPs and PCBs reported in wet and gas absorption continued to decline (USEPA, 2005).

The Canadian Atmospheric Network for Currently Used Pesticides (CANCUP) is another pesticide-related air observation program which was developed in 2003. CANCUP aims to assess the atmospheric levels of the most commonly-used pesticides in the Canadian agriculture regions within the Great Lakes. In a recent report from CANCUP, distribution of different groups of pesticides including organochlorine, organophosphate, and neutral herbicides has been measured in vapour and particle samples collected from May to July of 2004 and 2005 (Yao *et al*, 2007). Samples were collected at three different locations including one in Vineland (Town of Lincoln), which is west of the DeCew WTP. Results show strong seasonal trends in both gas and particle phases, with the greatest number of detections occurring during the spring and early summer, which agrees with the usage of pesticides in the growing seasons. The fruit- and vegetable-growing region in Vineland exhibited the highest levels for several insecticides including the organophosphate chlorpyrifos and the organochlorine endosulfan. All these findings can be attributed to the fact that the area surrounding Vineland contains an intensive agricultural region where herbicides are widely used for fruits and vegetables.

Also in May to July 2004, the average concentrations of atrazine and its metabolite deethylatrazine in precipitation samples collected in Vineland were measured to be 190 ng/L and 25 ng/L. respectively. (Yao *et al*, 2007). The presence of atrazine in the gas phase is consistent with its physicochemical properties. For pesticides with high water solubility, such as atrazine with 33 mg/L @ 25^{o}C, precipitation input can be a major source of atrazine found in aquatic system next to runoff from tributaries (Kannan *et al*, 2005 & Stuger *et al*, 2004). Given that the West Lincoln contains the highest number of farmlands in the Region, it can be inferred that the source of atrazine at Vineland station may be attributed to the winds blowing from the agricultural fields crops located at the western portion of the township. John Struger, Aquatic Environmental Scientist at CCIW has also agreed with this hypothesis (Personal communication, 2009).

3.4 Lake Erie

Lake Erie, with its flow rate of 180 m^3/sec into the Welland Canal constitutes the largest amount of water draining into this shipping waterway. Additionally, currents at the mouth of the Canal bring water and potentially contaminants from both the eastern shores (from the Niagara River) and western shores (from the Detroit River) of Lake Erie. There is a considerable body of literature that has documented the adverse impact of persistent pollutants in Lake Erie (Frank *et al,* 1977; Painter *et al,* 2001; Marvin *et al,* 2004, 2007). Environment Canada in collaboration with United States Environmental Protection Agency (USEPA) regularly conduct survey on quality of water and sediment in Great Lakes to measure the occurrences and distribution of toxic substances (Painter *et al,* 2001; Marvin *et al,* 2004).

In 1971, Environment Canada conducted inclusive studies on Lake Erie to characterize the extent of bottom sediment contamination associated with metal and organochlorine contaminants (Thomas *et al,* 1976; Frank *et al,* 1977). Their report indicated that the highest concentrations of compounds included PCBs, DDT, and mercury in sediment of Lake Erie. These pollutants were apparent along the western and southern shore of the Lake. In 1995, samples from the same sites as the 1971 survey analyzed for the same compounds. Encouragingly, releases of PCBs and organochlorine pesticide pollutants had declined significantly from their peak period in 1971. However, numerous studies confirmed that the presence of persistent pollutants such as pesticides and heavy metals continue to adversely impact the sediments and quality of water in Lake Erie (Painter *et al,* 2001; Williams *et al,* 2003*;* Marvin *et al*, 2004; Struger *et al,* 2004; Marvin *et al*. 2007). Transport of these materials is of concern in this study because of their affinity to absorb to sediments that can later be transported into the Canal water. Since Lake Erie is the main source of water to the Welland Canal, the following summarizes the transport and chemical characterization of Lake Erie sediments in order to identify sources and potentially assess the pollution loads generated by point and non-point sources along the Lake Erie basin.

3.4.1 Lake Erie Hydrologic Setting

Lake Erie drainage basin covers 78,000 square kilometres which is surrounded by Ontario to the north, Michigan and Indiana to the west, Ohio, Pennsylvania and New York to the south (Figure 17). The drainage flow into the Lake from the five states is significant compared to drainage from the province of Ontario (GLIN, 2010). The Maumee, Huron, Raisin, Sandusky and Cuyahoga Rivers are the largest rivers in Michigan and Ohio that contribute the major stream flow to Lake Erie, with a total drainage of 46,000 square kilometres. Lake Erie drains 22,800 square kilometers of land in Ontario (Frey, 2001). However, in terms of volume of water flow, primarily inflow to Lake Erie is via the Detroit River with an average flow of roughly 6000 cubic meters per second, which represents nearly 80% of the total Lake Erie water (Marvin *et al*,2007).

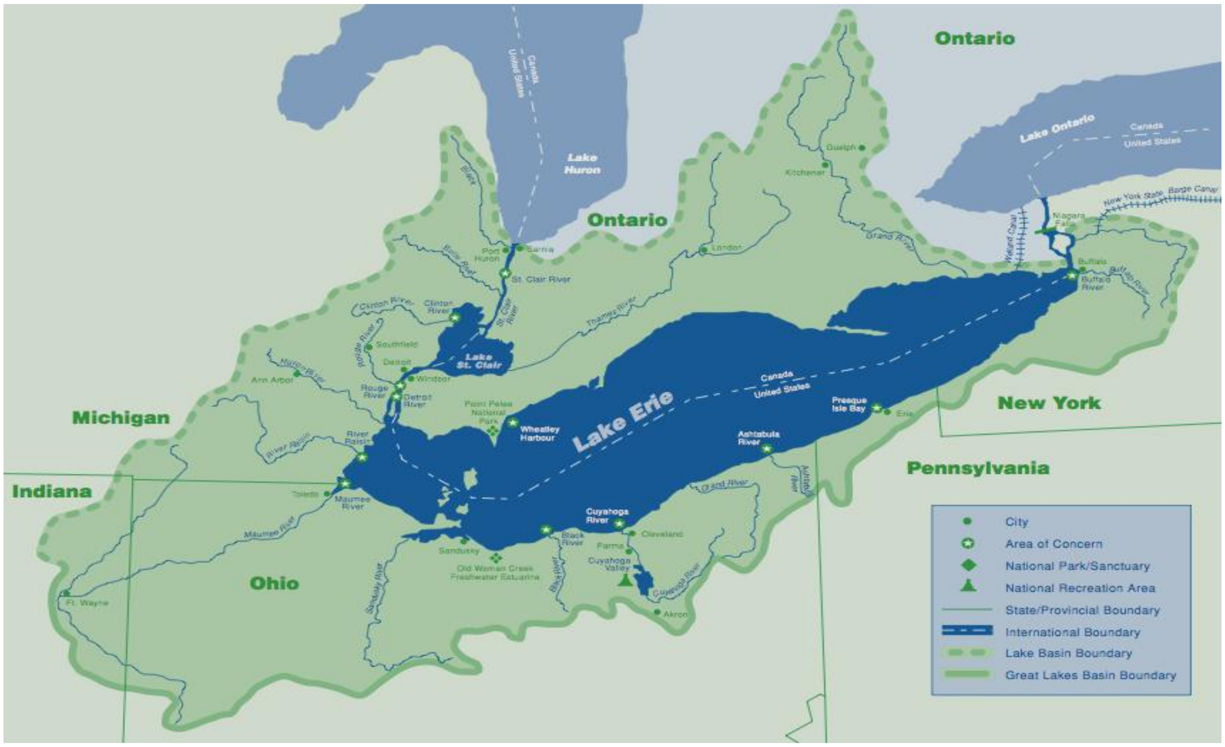


Figure 17. lake Erie drainage basin (National Oceanic and Atmospheric Administration (NOAA), 2009).

Lake Erie is comprised of three sections: a shallow western basin with an average depth of less than 10 m, a large central basin with maximum depth of about 24m and the eastern basin with a maximum depth of about 64 m (Figure 18). In general, the Western Basin of the Lake Erie receives the greatest tributary discharges and exhibits the highest degree of sediment contamination (Marvin *et al*, 2007). As mentioned earlier, the watersheds of the Detroit, Maumee, and Sandusky Rivers are major tributaries in the western basin through which the vast majority of pollutants, such as organic pesticides and metals enter the Lake (Carter & Hites, 1992; Marvin *et al*, 2004; Struger *et al* 2004; Marvin *et al*, 2007). The Western Basin also drains one of the largest agricultural regions in the Midwest.

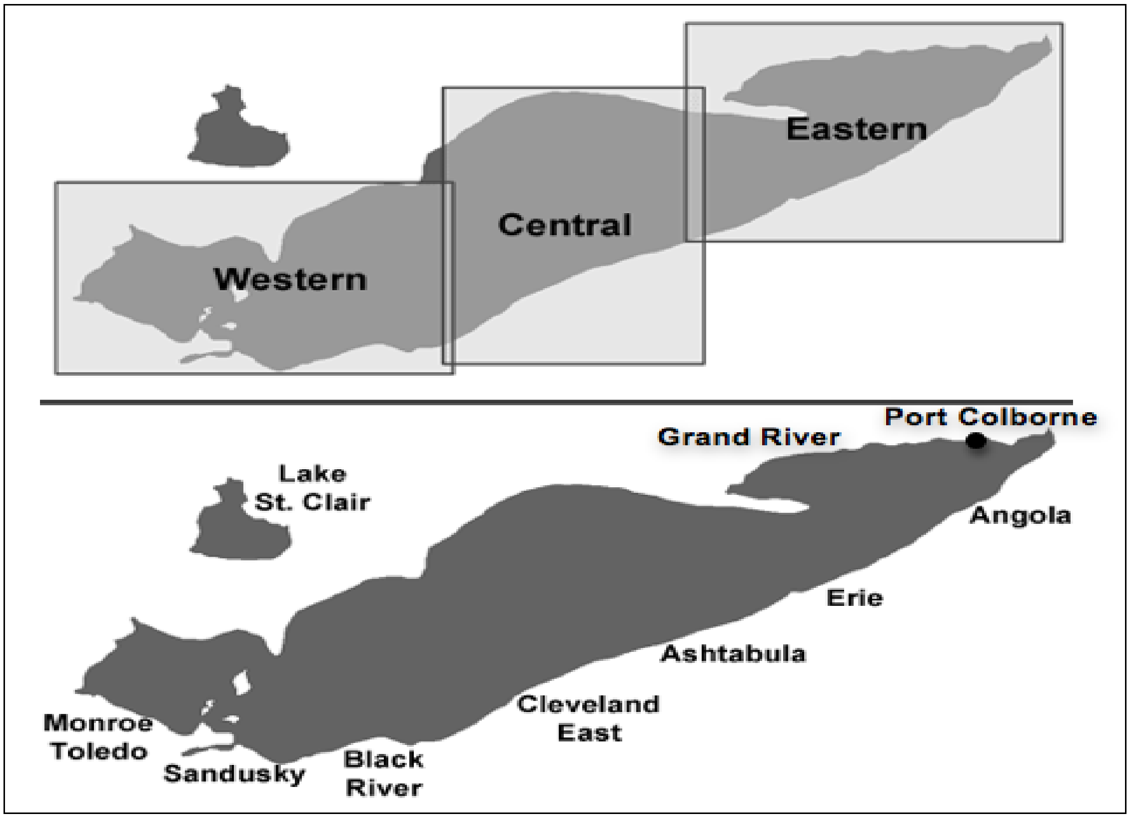


Figure 18. Three distinct basins within Lake Erie (Carter & Hites, 1992)

Lake Erie has the largest area of sediment accumulation of the Great Lakes, a characteristic that makes it particularly susceptible to pollution from environmentally-persistent organic compounds and metals, the majority of which are hydrophobic and tend to be absorbed onto sediments. In the case of Lake Erie, the transport of contaminants through sediment resuspension is the prominent factor in transport of pollutants to the water column (Hawley & Eadie, 2007; Marvin *et al*, 2007). As such, the present section will outline the elements influencing resuspension and deposition of sediment to understand the fate and transport of the hydrophobic chemicals along Lake Erie and to the Welland Canal.

3.4.2 Sediment Transport and Characterization

One of the major physical parameters attributed to the re-suspension phenomena is depth of water. Shallow depths and high tributary discharges in the Western Basin make it susceptible to the resuspension of bottom sediments as a result of wave action and boat traffic. In contrast, the eastern part of the Lake, which is by far the deepest part, experiences less or no re-suspension (Painter *et al*, 2001; Marvin *et al*, 2004; Marvin *et al*, 2007). In 1992, the mass balance of the hydrophobic pollutants accumulating in Lake Erie sediments was examined for each basin. This study indicated that 73% of the pollutants associated with the sediment of Detroit River accumulated in the Western Basin while the remaining 27% of the materials were transported to the deep sediment zone of the Eastern Basin (Carter & Hites, 1992).

Water circulation patterns and meteorological conditions are other responsible factors for sediment transport (Saylor & Miller, 1987; Carter & Hites, 1992). Between 1979 and 1980, the Lake currents and thermal stratification were studied in conjunction with the International Joint Commission (IJC) and USEPA. This study showed that surface currents appeared to have a constant eastward pattern with the prevailing wind stress. While close to the bottom, the Eastern Basin produced string-like currents that limited interaction with the other basins (Figure 19), this condition did not appear to remain the same all the time.

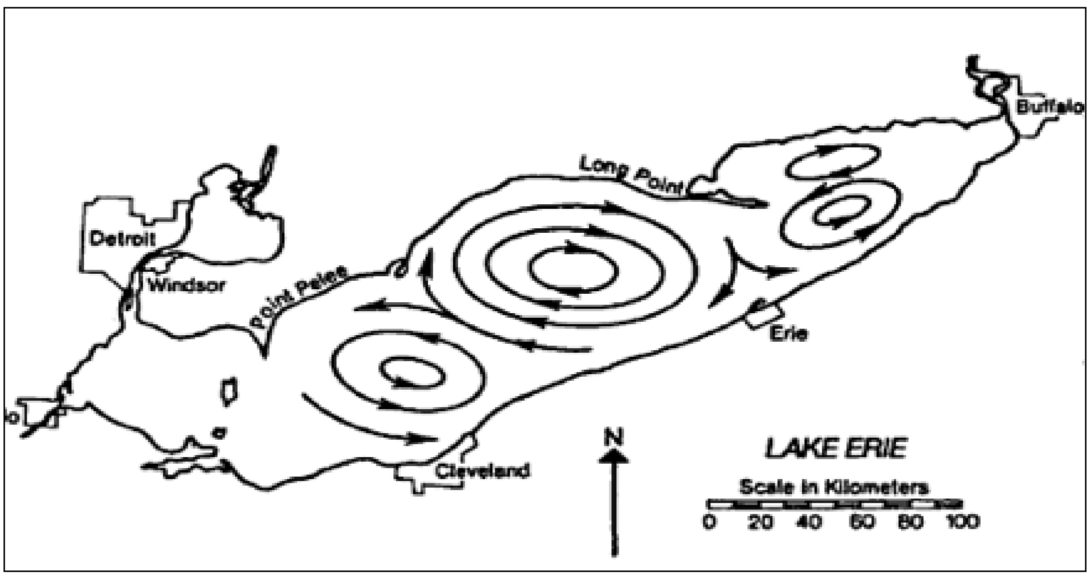


Figure 19. Lake Eire basins surface gyres (Saylor & Miller, 1983)

During the transition time from stratified to unstratified condition in late September, this pattern changed, resulting in clockwise flow from the Central Basin spilling over and surrounding the eastern basin (Saylor & Miller, 1987).

Thermal stratification or layering of water is also an important factor affecting the water quality and behaviour of pollutant transportation. In general, stratification occurs during the summer due to density changes as a result of solar radiation that heats the surface water (Hoover, 1997). As summer gives way to autumn, surface waters become denser and descends, mixing with deep waters causing turnover or non stratified conditions. In the deeper Eastern Basin, water is completely mixed during fall and remains as such through the winter months (September-November). Under this condition, the chance that bottom sediments enter the water column as suspended sediments becomes higher. Lick *et al* (1994) calculated the rate of resuspension and transportation of sediments in Lake Erie. Their results indicate that major storms are responsible for much of the contaminant resuspension while chemical diffusion seems to have lesser effects.

Although data analysis of both Hoover (1997) and Lick *et al* (1994) provide valuable insight into the physics of the Lake Erie, concluding one particular circulation patterns is not possible and the processes of resuspension and deposition are highly variable and can happen at very irregular intervals depending on the thermal condition (Saylor & Miller, 1987; Lick *et al*, 1994). Because of this, the net chemical flux from the bottom sediment to the overlying water that is associated with these resuspension processes is difficult to quantify over long period of time and predicting accurately which contaminants will enter the Welland Canal from the Eastern Basin is not possible.

3.4.3 Point Sources of Pollution

Industrial activities within the Great Lakes basin have introduced a variety of contaminants that result in subsequent degradation of surface water quality. These pollutants are primarily heavy metals and persistent organic pollutants due to the influence of anthropogenic activities (Frank *et al*, 1997; Marvin *et al*, 2004). In 1997 and 1998, Environment Canada, in partnership with the Ohio Environmental Protection Agency, conducted a survey in order to characterize sediment contamination of metals, PCBs, and dioxins and furans in Lake Erie (Painter *et al*, 2001). The above study indicated that the Western Basin exhibited the highest percentages of some elevated metals. High concentrations of total mercury, lead, zinc, copper and nickel were observed in more that 40% of the bottom sediment analysed in all samples of the Basin (Painter *et al*, 2001).

The Eastern Basin and the northeast portion of the Central Basin had the least contaminated levels of detected metals, exhibiting concentrations less than the Canadian Threshold Effect Level (TEL); level below which adverse biological effects are expected to occur. Concentrations of total mercury with an average of 0.65 $\mu g/g$ exceeded the Canadian Probable Effect Level (PEL); level above which adverse biological effects are expected to occur, in 6% of the samples, suggesting a major anthropogenic impact from the western watersheds (Figure 20).

Figure 20. Lake Erie total mercury concentration (μg/g) in 1997 and 1998 (Painter *et al*., 2001).

Total lead concentrations that exceeded the Canadian TEL were more extensively observed in the Central and the Western Basins and only one station in the Eastern Basin was found above the PEL level (Figure 21). Arsenic, cadmium, and zinc showed a similar trend as lead (Painter *et a*l, 2001). Dioxins and furans in all stations in the Eastern basin, with an average concentration of 2 pg/g, were higher than the Canadian TEL (0.85 pg/g), while 40% of stations exceeded the proposed PEL (21.5 pg/g). Figure 22 illustrates the pattern for bottom sediment total dioxins and furans.

Figure 21. Lake Erie bottom sediment total lead concentrations ($\mu g/g$) in samples collected in 1997 and 1998 (Painter *et al*., 2001).

Figure 22. Lake Erie bottom sediment dibenzo-p-dioxin and dibenzofuran concentrations (pg/g TEQ) in samples collected in 1997 and 1998 for (Painter *et al*, 2001).

Lakewide average levels of polychlorinated biphenyls (PCBs) were observed to decrease from its estimated value of 136 ng/g in 1971 by Frank *et a*l (1997) to 43 ng/g in 1997 (Figure 23). None of the samples collected for PCBs in 1997 exceeded the Canadian PEL.

Figure 23. Lake Erie bottom sediment PCBs concentration (ng/g) in samples taken in 1997 and 1998 (Painter *et al*, 2001).

Several studies have been conducted which show metals concentrations in suspended sediments of Lake Erie during the period of September to November to be substantially higher compared to the June and July sampling period (Marvin *et al*, 2004; Hawley & Eadie, 2007; Marvin *et al,* 2007). The most recent study on the concentrations of metals associated with suspended sediments in Lake Erie was by Marvin *et al* (2007) between 2001 and 2002. The findings reported in this study showed that all Western Basin samples exceeded the Canadian PEL value for mercury. Over the period September to October 2002, high concentrations of zinc in 20% of collected samples of the Eastern and Central Basins exceeded the PEL (Marvin *et al,* 2007). In this study, suspended sediment metals concentrations mirrored a similar trend in bottom sediment contamination observed from the bottom sediment survey conducted by Painter *et al* (1997). Therefore, suspended sediments were determined to have been heavily influenced by resuspended bottom sediments, implicating bottom sediments as a primary influence on water quality. As with the Lake Erie data, annual mean suspended sediment concentrations of mercury and zinc were statistically similar to bottom sediment concentrations (Table 6). Given that during winter time suspended sediment had higher associated concentrations of most metals than bottom sediments, it can be excepted that suspended sediments entering the Welland Canal via its entrance at Port Colborne contain significantly higher contaminant burdens than bottom sediment.

Table 6. The comparison of annual mean concentration of metals ($\mu g/g$) in suspended sediment and bottom sediment of Lake Erie.

Analyzed Parameters	**Bottom Sediment 1997-1998 (Painter, 2001)**		**Suspended Sediment 2001-2002 (Marvin, 2007)**		**Canadian Guidelines ($\mu g/g$) (CCME, 1999)**	
	Erie West	**Erie East**	**Erie West**	**Erie East**	**TEL**	**PEL**
Cadmium	2	1	2.1	0.98	0.59	3.53
Lead	57	35	70	26.12	35	91.3
Copper	47	35	51	69.7	35.7	196.6
Mercury	0.7	0.09	0.72	0.19	0.174	0.486
Nickel	50	40	63.7	43.6	18	35.9
Zinc	210	145	250	185.4	123.1	314.8

3.4.4 Non-Point Sources of Pollution

Agricultural practices that often result in pesticides runoff are a major source of pollution in Lake Erie (Struger *et al*, 2004; Kanan *et al*, 2005). In terms of specific pesticides, herbicides have been used more extensively than other pesticides including, insecticides and fungicides (OMAFRA, 1999). In particular, 50% of water draining into Lake Erie originates from the Maumee and Sandusky River watersheds which are massive agricultural areas (Marvin *et al*, 2004). With respect to land usage, agriculture is dominant in the lake Erie basin (Frey, 2001). Of the total agricultural land, corn and soybeans are the largest agricultural crops, accounting for more than 73% of total planted area within the Lake Erie watershed (Hoover, 1997; Frey, 2001). The coarse, poorly- drained Alfisols soils, with high clay and low organic content, encompasses the western part of the Lake Erie catchment and shows a pronounced effect on pesticide transport from field to watercourses (Frey, 2001).

In 1995, metolachlor and atrazine were the most heavily-used herbicide used on corn fields in the Lake basin (Figure 24). In 1998, herbicides applied on the field corn and soybeans with total usage of 3,669,337 kg, accounted for 70% of the total pesticides application in the Lake Erie region.

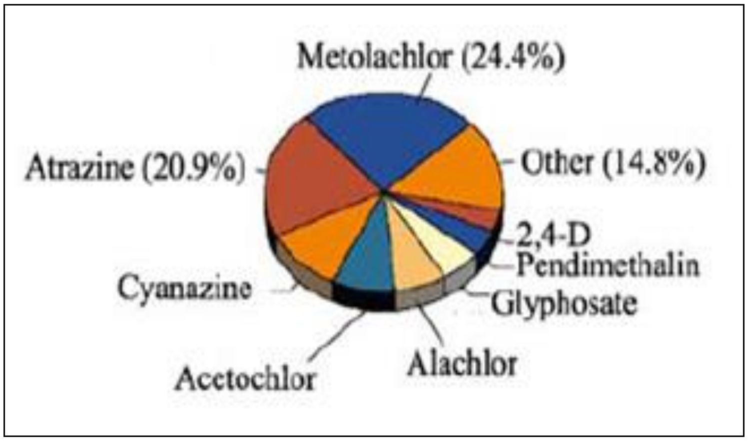


Figure 24. Pesticide usage in Lake Erie basin in 1995 (Kanna, 2004).

The most recent study on pesticide usage within Lake Erie was conducted by Environment Canada between 1994 and 2000. In this study, the highest concentrations of herbicides including atrazine, metolachlor, dicamba and 2,4-D were detected in 75% samples collected from Lake Erie in summer 2000 (Struger *et al*, 2004).

The most commonly used herbicides, atrazine and metolachlor have relatively high water solubilities and relatively low organic-carbon coefficients (Log $_{Koc}$), which is a predictor as to a chemical will sorb to soil or sediments (Wauchope, *et al*, 1992). Atrazine and metolachlor are chemically stable in the water phase and despite their high water solubility (33 and 530 mg/L, respectively) they persist in soil up to 90 days. Elevated concentrations of atrazine and metolachlor were found to persist for four to six weeks after the initial measurement in streams following application (Frey, 2001). Runoff and the timing of pesticide application are the major factors explaining the higher concentrations of these pesticide in early summer (Larson *et al*, 1997; Struger, 2004). For example, in spring 2000, median concentrations of atrazine and metolachlor in Lake Erie were 36 ng/L and 17 ng/L, respectively (Struger, 2004). However, the average concentrations of atrazine were observed at the highest level at 60.5 ng/L in July 1998 (Figure 25). Likewise, concentrations of metolachlor increased from 17 ng/L in April to 29 ng/L in July 1998 (Figure 26) (Kanan *et al*, 2005).

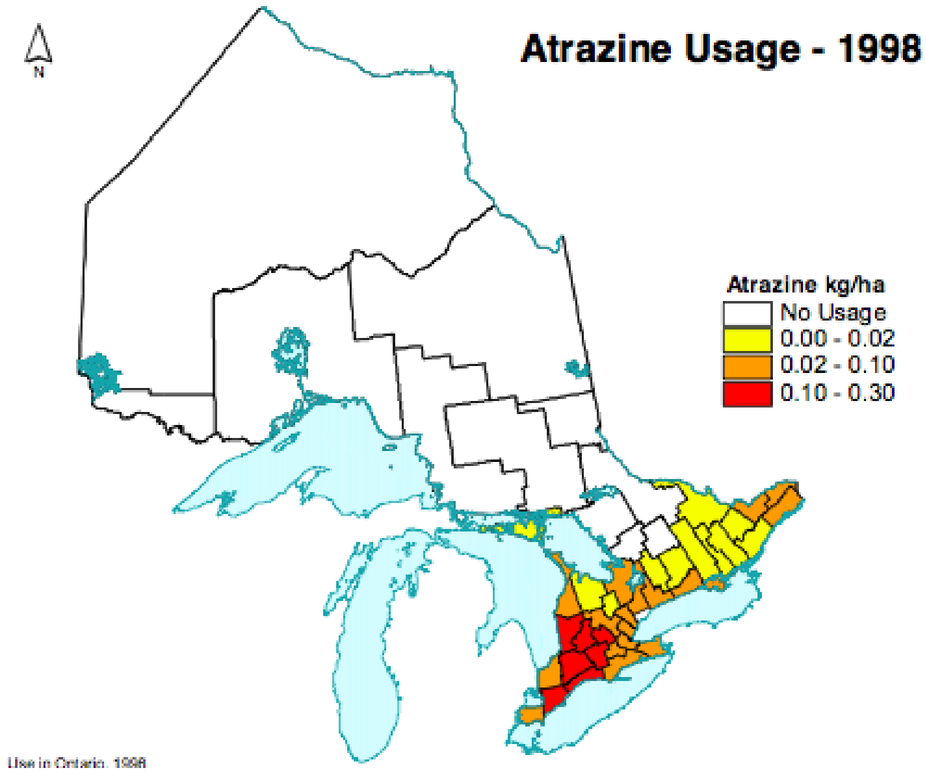


Figure 25. Atrazine concentrations in Lake Erie

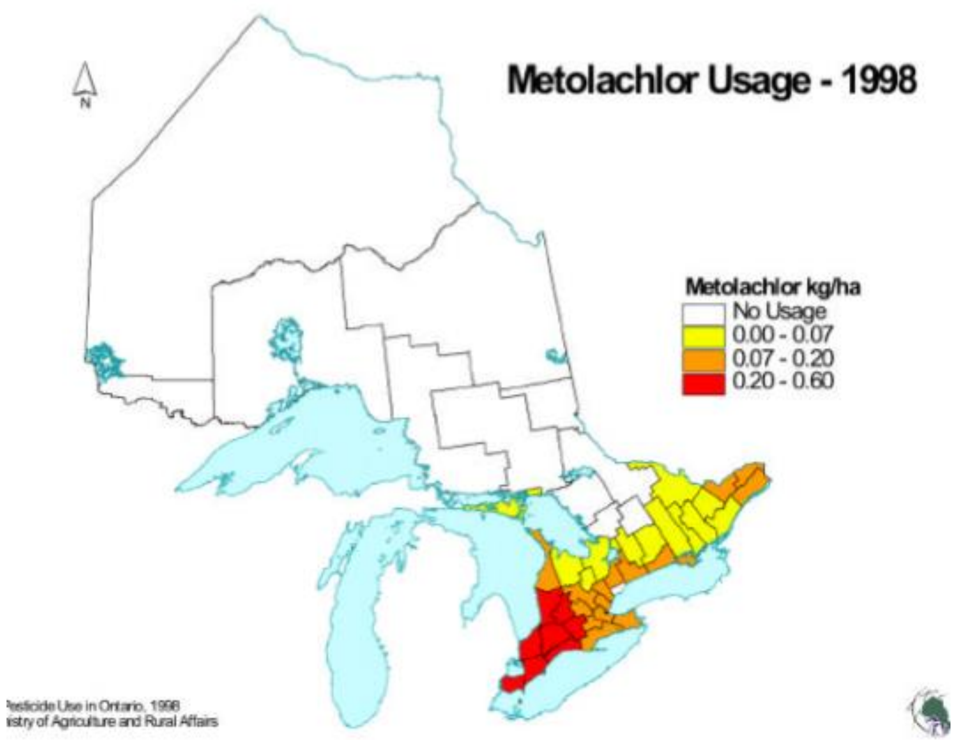


Figure 26. Metolachlor concentrations in Lake Erie

High concentrations of these pesticides in surface waters correlate with the timing of application of these herbicides following the month of May, explaining the seasonal differences observed in Lake Erie. Over the period of this study, concentrations of atrazine and metolachlor were at the highest in Lake Erie, compared to other lakes (Struger, 2004).

2,4-dichlorophenoxy acetic acid (2,4-D), MCPA and dicamba are phenoxy acid herbicides that have been extensively used in Ontario according to a recent survey (OMAFRA, 2003). 2,4-D can be used in different forms of esters, salts, and the acid formulation. In general, phenoxys have a high potential to travel in surface water and are comparatively resistant to biodegradation, hydrolysis, and volatilization. The acid form of 2,4-D, which is primarily used on wheat, corn and barley, is the most common form used in the Lake Erie basin. It has a relatively high water solubility of 900 mg/L and does not sorb strongly to soil (Larson *et al*, 1997; Struger, 2004). Published data on the concentrations of phenoxy herbicides in surface water are limited. In general, within the Great Lakes basin, the highest ranges of 2,4-D concentrations (0.5-84 ng/L) were observed in Lake Erie (Anderson, 1995). In 1998, samples collected in July had the highest concentrations of 2,4-D (85 ng/L) compared to samples in April (34 ng/L). Also, dicamba was detected in all samples ranging from 2-14 ng/L in July of 1994.

In conclusion, sediment contamination in many areas of Lake Erie still surpass the Canadian Sediment Quality Guidelines (Takacs *et al,* 2002) as defined by the threshold effect level (TEL). There is significant seasonal variation in suspended sediment flux rate and pollutant concentrations in the Eastern Basin of Lake Erie. In general, the rate of suspended sediment particles are higher in fall (September-November) due to unstratified conditions and increasing tributary discharges. These results indicate that release of metals, mainly mercury, zinc and lead contaminants into the water column over the period of un-stratified conditions and strong flow of runoff is highly probable. Although the concentrations of herbicides observed in surface water of recent studies have not surpassed the Canadian guidelines, their metabolites and synergic effects should be more examined as the elevated levels of herbicides including atrazine, metolachlor and phenoxy acid are expected to be higher during early summer and following their application. Therefore, ongoing monitoring programs should be in place to constantly trace the level of these pollutants in water resources at the drinking water intakes in Lake Erie and their transport to the Welland Canal.

4.0 THE NECESSITY FOR EARLY-WARNING BIOMONITORING SYSTEM (EWBS) IMPLEMENTATION

Above chapters have shown that the water of the Welland Canal is impacted by several point and non-point sources of pollution. Therefore, the following section will examined the regulatory guidelines that are currently in place to monitor the quality of sources for drinking water. In addition, given the results observed through this study, this thesis aims to emphasize the necessity of implementation of EWBS in the Niagara Region's DeCew WTP.

4.1 Industrial Effluent

With respect to facilities that directly discharge their pre-treated substances into the Welland Canal, there are no mechanisms currently in place in Ontario to categorize industries based on their discharges (Jason Oatley, personal communication, 2009). Consequently, there is no reporting system in place either to inform or alert the concerned authorities about presence of toxins. On the other hand, industrial effluent that are directly disposed into the sewer systems cannot be properly treated as the municipal sewer systems are only designed to remove the domestic and pathogenic pollutant (OMOE, 2010).

Environment Canada's National Pollutant Release Inventory (NPRI) is a federal organization that monitors final industrial effluent to the environment. Under the Canadian Environmental Protection Act 1999, the NPRI program requires large manufacturing and WWTPs to annually report their releases of certain pollutant, especially inorganic chemicals such as metals into air, water and land (NPRI, 2010). There are many limitations to the NPRI data report. Out of 23,000 toxic substances identified and published by Environment Canada's Domestic Substances List, only 300 parameters are included in NPRI monitoring (Environment Canada, 2007). It is also important to add that, there are industrial sectors such as finishing and metal fabricating, concrete manufacturing and ship repair that are exempt from reporting to NPRI. In the latest published reporting year in 2007, only 6 of the industrial facilities along the Welland Canal reported their pollutant release, five of which are located along the Welland Canal and upstream of the Feeder Canal. These industrial facilities include Lakeside Steel, Panabrasive, Casco, International Marine Salvage and Jungbunzlauer (Environment Canada, 2007). Although, the quantitative data in the 2007 report do not show any environmental or health risk issue, there is significant amount of toxic chemicals released by these facilities that have not been taken into consideration and there is a significant gap between the contaminants monitored under the NPRI and the extent of organic and inorganic pollutants that may be present in the effluents flowing out of such facilities. Comparing the regulated and non-regulated substances suggests that the federal monitoring programs should be geared towards the type of production and the processes involved in pretreatment processing facilities (Table 7). Also as municipal plants are not designed to treat industrial wastewater, pre treatment discharges should be regulated to prevent release of the organic pollutants into surface water via sewage treatment plants. This failure to update federal regulations has allowed Ontario’s approach to industrial wastewater regulation to fall behind other jurisdictions such as the United States; where for each specific industry there is a corresponding pre-treatment regulation is in place (MacDonald & Lintner, 2010).

Table 7. The gap between the regulated contaminants under the NPRI and non-regulated contaminates released by industrial facilities into water and sewer system.

Facility Name	Sector	Regulated pollutants into Water under NPRI	Not Regulated Pollutants
Lakeside Steel	Iron and steel Manufacturing	Hydrochloric acid	Ammonia, Nitrogen oxides, Dioxins and furans, Phenols, Hydrocarbons (WEF, 2008)
Panabrasive	Steel and Abrasive Products Manufacturing	Dioxins and furans, Hexachlorobenzene, Manganese	Ammonia, Nitrogen oxides, Benzene, PAHs, Mercury (CCME,2002)
Casco	Starch Manufacturing	Ammonia, Hydrochloric acid, Phosphorous	Nitrate, Pathogenic organisms (WEF, 2008)
International Marine Salvage	Battery and Electronic Waste Recycling	Asbestos	PCBs, Mercury, Cadmium, Cadmium, Copper (Cui & Forssberg, 2003)

Under the provincial jurisdiction, the Municipal Industrial Strategy for Abatement (MISA) monitors levels of persistent toxic substances that are directly discharged into waterways. In 1986, MISA was put in place under the Ontario Effluent Monitoring and Effluent Limits (EMEL) Regulations, with the intention to monitor nine industrial facilities sectors including organic chemicals, inorganic chemicals, iron and steel, electrical power generation, petroleum, metal mining, industrial minerals, sewage treatment, and pulp and paper (OMOE, 2008a). The MISA regulations were supposed to be upgraded every five years with more stringent guidelines put in place as technology improves. The goal of the MISA project was to apply the use of the

Best Available Technology (BAT), and it was expected that the acceptable effluent levels become lowered as technology improved. In fact, since the early years of implementation of MISA in the 1990s, little amendments occurred and guidelines have not been upgraded based on recent scientific findings and technologies on water pollution (MacDonald & Lintner, 2010). The latest data published by MISA in 2004, suggest a total of 140 facilities (OMOE, 2008b). From the total industrial facilities along the Welland Canal area, only Vale Inco in Port Colborne and two pulp and paper mills: Georgia-Pacific and Abitibi-Consolidated located in Thorold are monitored based on the 2004 list. Given the absence of many industrial facilities that discharge their pretreatment sewage effluent to surface water, it is apparent that update and review of the MISA regulation is long overdue.

With respect to industrial facilities that directly dispose their wastewaters to municipal sewer systems, it is the mandate of municipal authority to regulate the quality of inflows into municipal sewer systems (RMN, 2010b). To this end, under Ontario's Municipal Act, municipalities have the power to pass sewer use by-laws. The sewer-use-by-laws allow municipalities to control discharge of pollutants into the sewer system and may vary from one municipality to another. However, according to the 2007 report by the Environment Commissioner, the MOE does not require municipalities to implement a sewer- use bylaw. However, the Regional of Niagara is among the 50% municipalities in Ontario that enforce the bylaw (MacDonald & Lintner, 2010).

The regional Municipality of Niagara Sewer Use By-Law 47/08 monitors discharges into the Seaway WWTP in Port Colborne which is operated by the Region of Niagara (RMN, 2010b). The Regional sewer bylaw requires wastewater discharges into sewer systems meet the set threshold limits for the chemical parameters outlined in the bylaw (Table 8). Jason Oatley, Manager of wastewater division in Niagara Region, claimed that officers of environmental enforcement section of the Region are primarily responsible for monitoring pollutant being discharged into the Port Colborne WTP. He added that there is not set routine for collecting and analyzing samples for pollutants. However, their analysis is only limited to some metals and conventional pollutants. Table 8 lists the allowable concentrations of selected chemicals monitored under the Niagara Region bylaw into the sanitary and combined sewers (RMN, 2010b). In fact the provincial regulatory body underestimates the large quantities of toxic substances that continue to flow into waterways. The Ontario Ministry of the Environment (OMOE) is the regulator for Ontario sewage treatment plants and should be acting on its existing policies to promote municipal sewer use bylaws. Instead, although recognizing the need for stronger sewer use bylaws and stringent guidelines, they have made little progress over the past decade (ECO, 2004).

Table 8. Number of parameters and their associated allowed concentration levels that can be released into the sanitary and combined sewers under the Niagara Sewer Use By-Law 47/08.

Parameter	Limit (mg/L)	Parameter	Limit (mg/L)
Aluminum, Total	50	Ethylbenzene	0.16
Antimony, Total	5	Fluoride	10
Arsenic, Total	1	Iron, Total	50
Barium, Total	5	Kjeldahl Nitrogen, Total	100
Benzene	0.01	Lead, Total	2
Biochemical Oxygen Demand	300	Mercury, Total	0.05
Cadmium, Total	0.7	Methylene Chloride	0.21
Chloride	3000	Molybdenum, Total	5
Chloroform	0.04	Nickel, Total	3
Chromium, Total	5	O-Xylene	0.52
Cobalt, Total	5	Phenolics (4AAP)	1
Copper, Total	3	Phosphorus, Total	10
Cyanide, Total	1	Selenium, Total	5

4.2 Sewage Treatment Plants Effluent

The Ontario Ministry of the Environment (OMOE) regulates the quality and quantity of effluent discharged by WWTPs under the Certificate Of Approval (COA) system. The Certificate is obtained from the Ministry of the Environment and basically represents a license for the operators of the plants to discharge substances in accordance with the terms of the COA (ECO, 2007). The content of the certificate is negotiated on a case-by-case basis between the operator and the ministry officers. As noted in the 2009 amended COA report of Seaway WWTP in Port Colborne, OMOE only regulates a few conventional parameters which include: biochemical oxygen demand (BOD), total suspended solids, total phosphorus, total nitrogen, *E Coli*, total chlorine residual and pH (OMOE, 2009). Metals and other toxic contaminants that are commonly found in sewage effluent are not regulated in COA, and are hardly ever monitored. The lack of regulation with respect to sewage discharges gives the impression that the province has given less priority in regulating this source of pollution. In this regard, in 2007 Gord Miller, the Environmental Commissioner of Ontario, acknowledged that sewage certificate of approval system is outdated and contains standards that are not compliant with relevant environmental requirements (ECO, 2007). He also noted that there is no data available to show the performance and operating standards regarding WWTPs. In fact, due to having inadequate laboratory analytical resources and lack of available expertise, OMOE has not reported data on the performance of the WWTPs since 1993. Currently, OMOE has enough staff members to conduct technical inspections on only 4% of all regulated facilities annually. Thus, the 96% remaining facilitates (including the Seaway WWTP in Port Colborne) will generally work years without inspections. Besides, OMOE has not published any current analysis of the relationship between contaminant levels in WWTP effluent and potential environmental problems (ECO, 2007).

In addition, as mentioned earlier, another issue is OMOE's failure to properly address the combined sewer overflow problem. Every year, many litres of untreated raw sewage are discharged from sewer systems into waterways and the Welland Canal is not an exception. To address this overflow problem, OMOE's guidelines require all municipalities served by combined sewer systems to implement Pollution Prevention and Control Plans (PPCPs). However, there is no evidence that OMOE has reviewed the PPCP for the Niagara Region, nor do there appears to be any plans to conduct such control in the near future.

Continuous progress in WWTPs technologies is even more important in such waterways like the Welland Canal located upstream of the intake of a WTP. Also, there is an urgent need, for updating regulations as all WWTPs are currently operating under the certificate of approvals that have been in place for over twenty years. The current certificate mainly outlines information on capacity limits and concentrations of short listed pollutants in the treated effluent. Thereby, OMOE must update the guidelines and implement tighter control for obtaining the COA to limit the contaminants discharged into surface water. More importantly, without firm and ongoing inspections, municipalities are unlikely to be able to target the unpredictable spill of contaminants into surface water.

4.3 Pesticides Input

The last decade has been one of intense focus on pollutants that may affect the function of the endocrine system in humans, fish and other wildlife. The events that moved the ecological impacts of pesticides to the forefront of ecotoxicology were reports of reproductive abnormalities in American alligators from Lake Apopka, Florida following a major DDT spill in 1980 (Kavlock, 1999; Vonier, *et al,* 1996). Another example is driving the population of trout in Lake Ontario during the 1960 to near extinction due to exposure to dioxin-like compounds in the sac-fry stage. Eggshell thinning and impaired incubation in nesting grebes in Clear Lake, California, is yet another example in 1971 (Kavlock, 1999; Cook *et al,* 2003). Although many of the adverse physiological effects of chemicals affecting the neuroendocrine system have been known for over the past decades, widespread attention to this issue from regulatory perspective became visible in the early 1990s (Takasc, 2002).

With respect to pesticides in drinking water, several researches have pointed out the limitations of current guidelines on evaluating the presence of pesticides and their potential effects in surface water (Struger *et al*, 2004; Struger *et al*, 2007 Byer *et al*, 2008). Currently the *Safe Drinking Water Act, 2002* regulates drinking water systems to provide drinking water system in compliance with drinking water quality standards and guidelines (OMOE, 2006). Under this Act, the Drinking Water Systems Regulation O. Reg.170/03, describes the type and frequency of microbiological and chemical parameters required to be tested at residential drinking water systems. According to this regulation, large municipal residential systems must sample for inorganic and organic parameters at least once every year (OMOE, 2006). According to 2009 Annual Water Quality Report for DeCew WTP, organic chemicals were sampled in the beginning of November (RMN, 2010a). Thus, it is apparent that measurement of high concentrations of pesticides following their application in early summer could be missing from monitoring intervals. Also, standards and analytical methods are not available for all organic pollutants. Of the total 56 organic parameters listed on Schedule 24 of O. Reg.170/03, the Interim Maximum Acceptable Concentration (IMAC) standards have only been developed for 11 parameters (MOE, 2006). Besides, there are no guidelines to address the endocrine effects of pesticides on humans. Therefore, active and synergistic effects of pesticide mixtures and their degraded products should be monitored more strictly and their potential occurrence should be examined in a more timely manner.

With respect to the most commonly used herbicide, atrazine, numerous health risk issues have been linked to its presence in drinking water. The real risk occurs with chronic exposure to low concentrations of atrazine. The increased risk of ovarian cancer, uterine and breast malignancies, as well as non-Hodgkin's lymphoma have been associated with atrazine exposure among farmers and workers in rural areas (Donna *et al.,* 1984; Health Canada, 1993). Disruptive effect on hormonal systems and steroid metabolism appear to be induced by atrazine and its metabolites. Exposure to atrazine has been shown to increase follicle stimulating hormone and luteinizing hormone and to cause abnormalities in the body's ability to properly metabolize testosterone (Health Canada, 1993). Although atrazine in several analytical studies provided evidence for increasing risk of cancers, the evidence was considered inadequate by Health Canada and as such it classified as a Group 3 carcinogen representing "possibly carcinogenic to humans" (Health Canada, 1993). Also, the Canadian guidelines were originally created based on data from short term toxicity and did not consider effects of endocrine disruption (Takascs, *et al*, 2002).

It should be noted that the Niagara Region Public Health has done a comprehensive epidemiological study in which the primary reason of hospitalization and deaths are reported. In general, it can be seen from the data that the rate of death as a result of cancer in the Niagara-on-the-Lake, St Catherine and Thorold compared to other municipalities is higher. Data shows breast, ovarian and colorectal cancers are major causes of death among the residents who are consuming DeCew drinking water. Also number of females hospitalized with complications of pregnancy (labour and delivery) is significantly higher in those municipalities compared to the Niagara Region (RMN, 2010c). Numerous studies have confirmed the endocrine disruption effect of the most common herbicides used along the Welland Canal area and the Lake Erie Basin, including atrazine, glyphosate, and metolachlor (Donna *et al.*, 1984; Health Canada, 1993; Hardell & Erikson, 2000; Takacs *et al*, 2002). However, there is no evidence to prove the link between the presence of herbicides (or other organic persistent pollutants) in their drinking water and the type of diseases among the consumers. Therefore, further research on the occurrence of pesticide is prudent. Furthermore, a revision of guidelines and ongoing monitoring programs on drinking water sampling should be considered due to potential risks associated with human errors.

4.4 Ship Related Pollution

The Welland Canal plays an important role in supporting significant cargo traffic, which can introduce a wide range of chemical pollutants, such as marine organotin antifouling agents. One of the major pollutants to the aquatic environment from shipping routes is from leaching of antifouling paints from carrier vessels and lakers (Alzieu, 1998; Konstantinou & Albanis, 2004) Trybutyltin (TBT) is the most common organotin compound that has been applied since 1970s to the hulls of ships to protect them against the attachment of algae and other fouling organisms (Michaud, 2006; Regloi *et al*, 2001). TBT is highly hydrophobic and in sediments has the potential to be resuspended in the water column and thus poses a continued threat to water quality (Chau *et al.*,1997). At extremely low concentrations, TBT has been linked to endocrine disruption in several organisms at sub-lethal concentrations (Horry *et al.*, 2004).

Due to the hazardous environmental impacts of TBT, several restrictions were placed on the usage of TBT and other organotins in antifouling paints. In 1989, many countries, including

Canada regulated the application of TBT-based paints prohibiting their use on vessels less than 25 meters in length (Chau *et al.*,1997; Alzieu, 1998). A survey of Canadian harbours indicate the effectiveness of the 1989 regulation in the overall reduction of TBT in Canadian waterway. However, TBT contamination is expected to be present in the Welland Canal that annually handles 3,671 lake and ocean vessels with the average size of 100 meters (GLSS, 2007a).The minimum and maximum length of vessels are 30 and 222.5 meters, respectively (GLSS, 2010). The most recent international conference for TBT application was in 2001 in order to adopt the International Marine Organization's Anti-fouling Systems known as AFS. The AFS Convention is proposed to ensure a global ban on the usage of TBT on large ships. As of January 2010, the Convention was not in place and it currently only applies to non-Canadian ships pending the AFS being approved and implemented in Canada (Transport Canada 2010). Because of the persistence of the contaminant, the introduction of more TBT from ships not restricted by international bans and because of its potential to be resuspended in the water column, TBT remains an important environmental contaminant in shipping routes.

In general, reductions in concentrations of TBT in freshwater environments have been seen since the bans were enacted in Canada and throughout the world (Chau *et al.*,1997). In Canada, TBT and its metabolites are found in freshwater much less frequently and in lower concentrations compared to levels prior to consideration of restrictions starting in the 1980s (Chau *et al.*,1997). However the regulatory controls on antifouling paints have not been effective in reducing concentration of TBT in areas like the Welland Canal with high shipping traffic and with large ships and vessels that have been painted prior to 1989. Therefore, the development of a reliable system for detection of TBT would be highly beneficial in order to help water treatment plant operators detect the presence and concentration of the organotin contaminant.

5.0 CONCLUSIONS AND FUTURE APPLICAITONS

The following outline the chemicals of concern and the possible sources of contamination impacting the Welland Canal water system in an attempt to provide a more reliable and effective way for the DeCew WTP to detect potentially dangerous aquatic contaminants before they enter the drinking water supply.

1. The subwatersheds that fall within the Central Niagara Region Watershed only have hydrological connection to the Welland Canal within the Niagara Region. A total of five catchment basins is estimated to have an average outlet of 75,840 m^3/day to the Welland Canal. Agriculture land use within this watershed is 37% on average, representing a source of pesticides runoff moved from field to the Welland Canal.
2. The NPRI has reports on only eight out of a total thirty eight industrial facilities upstream the Welland Canal. There are significant amount of toxic chemicals released by the remaining facilities that have not been taken into consideration by federal and provincial authorities.
3. Port Colborne WWTP is considered the most significant factor threatening the quality of water in the Canal. It discharges nearly 12,000 m^3/day treated and non-treated sewage into the Welland Canal. The current treatment facilities that operate in the Seaway WWTP are not able to remove significant amounts of heavy metals, nor are they able to remove persistent organic contaminants that resist degradation such as pharmaceuticals, antioxidants and pesticides and industrial chemicals.
4. Atrazine and glyphosate are the two most common herbicides used on the field crops (corn, wheat and soybeans) along the Welland Canal area. Although atrazine and glyphosate in several epidemiological studies provide evidence for increasing risk of cancers, there are no guidelines for drinking water to address the endocrine effects of pesticides on humans. Also, it is apparent that measurement of high concentrations of pesticides following their application in early summer could be missing from sampling monitoring intervals.
5. Agricultural drainage flow from the largest rivers in Michigan and Ohio contribute to the major storm runoff to Lake Erie. Atrazine and metolachlor have been found to be the most heavily used herbicides within the Lake Erie basin. The highest concentrations of these herbicide were observed in July after their application on field crops. These herbicides can be transferred to the Welland Canal bound to sediment or under strong storm and

precipitated material can be resuspended in the water column and enter the Welland Canal.

6. High levels of mercury and zinc concentrations in suspended sediments of Eastern Lake Erie during the period of September to November, over the period of un-stratified conditions are highly evident.
7. Non regulated antifouling paints on ship vessels are the major source of TBT entering into the water system. Although the potential exists for pulse introductions of TBT to the source of water for the DeCew WTP, it is not specifically tested for at drinking water intakes due to the cost and time involved.

This thesis contributed to the overall project goal of developing an EWBS technology to provide timely response to contamination events at the intake of Niagara Region's DeCew WTP. This research was the fist attempt in proving the comprehensive risk assessment report of the sources of contamination to the DeCew WTP since its inception in 1925. Hhowever, in order to build a holistic response bioassay, further analytical assessments using direct chemical analysis is required to accurately determine the presence of organotin compounds, endocrine disruptors and other potential contaminants of concern in the Welland Canal.

Team members of bioassay in this project have been conducted the used of EWBS for several classes of contaminants including heavy metals, pesticides, and organotin TBT. In order to bring the EWBS research to the next level, behavioural response data is required to gathered and statistically processed to build a library of response to contaminants of concern in this water system. The next step will be the field application of the proposed EWBS, as a detection system for contaminants and pathogens, at locations with highest probability for presence of contaminations. In addition to drinking water system implementation, suggesting locations for the use of the system in Niagara Region will include: the point where water is drawn from the Welland Canal to the Reservoir; about 700 meters north of Port Robinson where Singers Drain and Towpath drain flows to the Canal; the point at Port Colborne where effluent of Seaway WWTP and metal manufacturing discharges; at the entrance of Lake Erie to the Canal neat Lock 8. The EWBS eventually is useful in both developed and developing countries where drinking water sources tend to cause adverse health issues due to inadequate technologies, expertise, and timely monitoring systems.

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