1-1-2002

Control of oil spills in urban areas

Jenny King-Lai Chui
Ryerson University

Control of Oil Spills in Urban Areas

by

Jenny, King Lai Chui,
BEng, Ryerson University, 2000

A thesis

presented to Ryerson University

in partial fulfillment of the

requirement for the degree of

Master of Science

in the Program of

Environmental Applied Science and Management

Toronto, Ontario, Canada, 2002

0-612-85314-4

AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis

I authorize Ryerson University to lend this thesis to other institutions or individuals for the purpose of scholarly research.

____

I further authorize Ryerson University to reproduce this thesis by photocopying or by other means, in total or in part, at the request of other institutions or individuals for the purpose of scholarly research.

____

BORROWER'S PAGE

Ryerson University requires the signatures of all persons using or photocopying this thesis.

Please sign below, and give address and data.

ABSTRACT

Jenny, Chui King-Lai, 2002. *Control of Oil Spills in Urban Area.* A thesis presented to Ryerson University in partial fulfillment of the requirements for the degree of Master of Applied Science in the Program of Environmental Applied Science and Managemnt

The City of Toronto has experienced about 300 oil spills per year (Li 1997). Traditionally, the city recommends that businesses and industries practise pollution prevention and install on-site oil separators. Currently, the sizing criteria for these devices are not well defined and the draft code of practices for oil separators by the Canadian Petroleum Product Institute (1994) has not yet been approved by the Ministry of the Environment (Li 2000). Thus, the city is currently investigating the possibility of installing oil separators at spill prone sewer outfalls. The new application of oil separators at sewer outfalls requires that the devices be operable under high flow conditions and that their capacity should reflect the land use characteristics in the associated sewershed.

This study has developed an innovative spill control device for the Humber Creek outfall and a Geographic Information System (GIS)-based analysis technique for urban oil spill management. First, a flow diversion structure was designed to capture the dry weather flow at the outfall and to transport the captured flow into an oil/water separator designed in accordance to the American Petroleum Institute's manual (1990). The designs of the flow diversion structure and the oil/water separator were evaluated by a physical model study using the National Water Research Institute's Hydraulics Laboratory at the Canada Centre for Inland Waters in

Burlington, Ontario. Then, the GIS-based analysis technique was used to identify potential treatment options for spill-prone sewer outfalls in the Town of Richmond Hill.

It was found that (1) the spill event characteristics should be analyzed in order to develop design criteria for oil spill control systems; (2) the preliminary design of the oil spill control system at Humber Creek was different from the API's methodology; and (3) the physical model investigation confirmed the conveyance capacity of the diversion channel and the general behaviour of the tilted-plate separator.

A database of oil spill records in the Greater Toronto Area from 1988 to 2000 were compiled and geo-referenced. By overlaying the spill characteristics and other GIS data layers, such as woodlots, wetlands and watercourses, spill prone areas were identified. In order to increase the accuracy of the analysis, the percentage of geo-reference oil spill locations should be increased.

ACKNOWLEDGMENTS

The author would like to thank Dr. James Li, of Ryerson University for providing his encouragement, support and expertise throughout this thesis.

Appreciation is extended to the following agencies for their funding and services, City of Toronto, Great Lake Sustainability Fund, MOE Spill Action Centre, Compusearch, Toronto and Region Conservation Authority, Town of Richmond Hill and Natural Science and Engineering Research Council.

The author would like to thank the Wildness Preservation Committee of Ontario for a graduate scholarship to support this research achievement.

Thanks are also extended to Dr. Jiri Marsalek, Mr. Brian Taylor and Mr. Bill Warrender of National Water Research Institute for their advice and assistance in the construction of the physical model, the Canada Centre of Inland Waters for providing space for the experiments, and Dr. Doug Banting of the School of Applied Geography for technical support.

TABLE OF CONTENT

AUTHOR'S DECLARATION........ii
BORROWER'S PAGE........iii
ABSTRACT........vi
ACKNOWLEDGEMENTS........ix
LIST OF TABLES........xiii
LIST OF FIGURES........xiv

CHAPTER 1: INTRODUCTION

1.1 Background........1

1.2 Objectives and Scope........4

CHAPTER 2: LITERATURE REVIEW

2.1 Oil Spill Overview........7

2.1.1 Cause of oil spills........7

2.1.2 Transport of spilled oil in urban areas........7

2.1.3 Control options for urban oil spills........8

2.1.3.1 Oil spills on land........8

2.1.3.2 Oil spills on water........9

2.2 Best Management Practices........11

2.2.1 Oil spills in stormwater........11

2.2.2 Oil and grease in stormwater runoff........12

2.2.3 Structural practices........13

2.2.3.1 Cleaning of surface material........13

2.2.3.2 Porous pavement........14

2.2.3.3 Oil sorption material........14

2.2.3.4 Greenbelt........14

2.2.3.5 Dispersion devices........14

2.2.3.6 Constructed wetlands........15

2.2.4 Non-structural practices........15

2.2.4.1 Sewer e by-law........15

2.2.4.2 Pollution prevention plan........................16
2.2.4.3 Oil recycling.....................................17

2.3 **Oil Water Separators**..18
2.3.1 Gravity Separation...................................... 18
2.3.1.1 Spill Control Separators.........................19
2.3.1.2 American Petroleum Institute Separators..... 21
2.3.2 Coalescence Plate Separators...........................24
2.3.2.1 Inclined Plate Separators........................25
2.3.2.2 Flat Corrugated Plate Separators.............. 25
2.3.2.3 Multiple Angle Plate Separators............... 29
2.3.2.4 Coalescing Tube Separators.....................29
2.3.2.5 Modified Crossflow Pack Separators..........33
2.3.3 Dissolved Air Flotation.................................34
2.3.4 Enhanced Gravity Separation.......................... 35
2.3.5 Filtration..36
2.3.5.1 Fixed Media..................................... 36
2.3.5.2 Loose Media.....................................36
2.3.5.3 Cross Flow Membrane Filters..................36
2.3.6 Absorbents.. 38
2.3.6.1 Inorganic Sorbents.............................. 38
2.3.6.2 Natural Organic Sorbents.......................39
2.3.6.3 Polymeric Sorbents............................. 39
2.3.6.4 Miscellaneous Sorbents........................ 40

2.4 **Oil Spill Legislation**.. 41
2.4.1 Ontario Environmental Protection Act................ 41
2.4.1.1 Classification of spills..........................42
2.4.2 Regulations associated with spills..................... 48
2.4.2.1 Fire Protection and Prevention Act............48
2.4.2.2 Technical Standards and Safety Act.......... 50
2.4.3 Spill Action Centre.................................... 51
2.4.3.1 Spill action centre function..................... 51
2.4.3.2 Appropriate Response Action.................51

2.4.3.3 Spill Record.....53
2.4.3.4 Contingency Planning.....53

2.5 Overview of Geographic information System.....57
2.6 Summary.....60

CHAPTER 3: DESIGN OF AN OIL SPILL CONTROL SYSTEM FOR STORM OUTFALL STRUCTURES

3.1 Introduction.....61
3.2 Design Concept.....64
3.2.1 Flow Diversion Channels.....64
3.2.2 Off-Line Oil/Water Separators.....65
3.3 Design of diversion channel.....66
3.3.1 Design for a testing Rectangular Diversion Channel.....69
3.3.2 Design for a Triangular Diversion Channel.....73
3.4 Off-line oil/water interceptor.....76
3.4.1 Design Calculations for an API Separator.....77
3.4.2 Design Calculations for a tilted plate separator.....81
3.5 Summary.....86

CHAPTER 4: PHYSICAL MODEL STUDY OF THE OIL CONTROL SYSTEM

4.1 Introduction.....89
4.2 Design of physical model.....90
4.2.1 Design of flow diversion channel experiments.....90
4.2.1.1 Rectangular diversion channel.....91
4.2.1.2 Triangular Diversion Channel and titled plate separator.....96
4.3 Experiment Result.....100
4.3.1 Rectangular diversion channel.....100
4.3.1.1 Inflow to the separator.....100
4.3.1.2 Water profile.....106
4.3.2 Triangular Diversion Channel and Title Plate Separator.....108

4.3.2.1 Inflow to the separator........................... 108

4.3.2.2 Water profile.................................. 110

4.4 Disscussion and Observation.................................. 112

4.4.1 Hydraulic Jump.. 112

4.4.2 Visual Observation of Floatable and Sediments....... 113

4.4.3 Backwater effect...................................... 115

4.5 Summary.. 118

CHAPTER 5: SPATIAL ANALYSIS OF OIL SPILLS IN THE GTA AREAS

5.1 Introduction.. 121

5.2 Data Preparation... 122

5.2.1 Oil spill location.. 122

5.2.2 Digital data layers..................................... 123

5.3 GIS Analysis Procedure 125

5.4 Case studies of Richmond Hill.................................. 128

5.4.1 Types of impact.. 128

5.4.2 Locations of spills..................................... 128

5.4.3 Types of Roads.. 129

5.4.4 Types of Oil... 129

5.4.5 Volume of oil spills.................................... 129

5.4.6 Environmental Significant Area........................ 135

5.4.7 Downstream Outfall Control........................... 135

5.5 Summary.. 140

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions... 141

6.2 Recommendations.. 143

APPENDIX

REFERENCE AND BIBLIOGRAPHY

List of Tables

TABLE 1 Classification of oil/water mixtures....................................18

TABLE 2 Wincott gauge baseflow 63

TABLE 3 Storm outfall H-632 baseflow...63

TABLE 4 The basics geometry of the triangular diversion channel...........74

TABLE 5 Comparisons between inlet and outlet................................83

TABLE 6 Scales for basic hydraulic quantities..................................90

TABLE 7 Different combinations of the model in single flow rate.......... 92

LIST OF FIGURES

FIGURE 1 A Spill Control Separator... 20

FIGURE 2 An American Petroleum Institute (API) Separator................ 23

FIGURE 3 A Inclined plate separator... 26

FIGURE 4 A Flat Corrugated (Horizontal Sinusoldal)
Oil/Water Separator... 27

FIGURE 5 A Flat Corrugated (Horizontal Sinusoidal) Plate Pack............ 28

FIGURE 6 A Multiple Angle (MPack) Separator, The HEROWS unit...... 31

FIGURE 7 A Coalescing tube separator.. 32

FIGURE 8 Data Overlays in a Geographic Information System 59

FIGURE 9 A perspective view of a typical diversion structure............... 67

FIGURE 10 Plan and Profile View of a rectangular diversion channel....... 69

FIGURE 11 Top View of the rectangular horizontal
diversion channel model.. 71

FIGURE 12 Side View of the rectangular horizontal
diversion channel model.. 71

FIGURE 13 Side View of the elevated rectangular horizontal
diversion channel model.. 72

FIGURE 14 3-D view of the 45-degree triangular
sloping diversion channel 74

FIGURE 15 Top and side view of the 45-degree
triangular sloping diversion channel............................ 75

FIGURE 16 Design Equations for the triangular diversion channel...........74

FIGURE 17 Preliminary design of an API separator............................ 80

FIGURE 18 Side View of the tilted-plate separator............................ 84

FIGURE 19 Top View of the tilted-plate separator............................ 85

FIGURE 20 The diversion weir in relation to the diversion channel......... 92

FIGURE 21 Locations of the water depth measurement
at the rectangular channel.. 94

FIGURE 22 The experiment setup of the rectangular channel................ 94

FIGURE 23 The experiment setup of downstream
weir measurement box... 95

FIGURE 24 Locations of Water Depth Measurement
at the 45 degree channel...98

FIGURE 25 Calibration cure for the overflow rate
at the diverion channel (Low parition).........................98

FIGURE 26 Calibration curve for the overflow rate
at the diversion channel (High parition)........................ 99

FIGURE 27 Total Flow (Qt) Vs Pipe Discharge (Q1),
Channel Width = 60 cm... 101

FIGURE 28 Total Flow (Qt) Vs Pipe Discharge (Q1),
Channel Width = 45 cm... 102

FIGURE 29 Total Flow (Qt) Vs Pipe Discharge (Q1),
Channel Width = 30 cm... 102

FIGURE 30 Water Profile for a Channel width of 60 cm
and no diversion weir installed.................................. 103

FIGURE 31 Water Profile for a Channel width of 60 cm
and 2 cm height diversion weir installed....................... 103

FIGURE 32 Water Profile for a Channel width = 60 cm
and 6 cm height diversion weir installed....................... 103

FIGURE 33 Total Flow (Qt) Vs Pipe Discharge (Q1),
No diversion weir installed....................................... 104

FIGURE 34 Total Flow (Qt) Vs Pipe Discharge (Q1),
Diversion weir height = 2 cm.................................... 104

FIGURE 35 Total Flow (Qt) Vs Pipe Discharge (Q1),
Diversion weir height = 6 cm.................................... 105

FIGURE 36 Water Profile for a Channel width of 60 cm, and no
Diversion weir 106

FIGURE 37 Water Profile for a Channel width of 60 cm, and a
2 cm diversion weir 107

FIGURE 38 Water Profile for a Channel Width of 60 cm, and a
6 cm diversion weir 107

FIGURE 39 Flow distributions through the
spill control system (Low partition)..........................109

FIGURE 40 Flow distribution through the
spill control system (High partition)..........................109

FIGURE 41 Water Profile for total flow equal 18 L/s..........................110

FIGURE 42 Water Profile for total flow equal 38 L/s..........................110

FIGURE 43 Water Profile for total flow equal 162 L/s..........................111

FIGURE 44 A Hydraulic Jump at the Diversion Channel..........................112

FIGURE 45 Reasons for Sedimentation in the Diversion Channel..........................114

FIGURE 46 Vortex action inside the separator..........................114

FIGURE 47 Water profiles along the culvert and the separator
at Qt equal to 18 L/s..........................115

FIGURE 48 Water profiles along the culvert and the separator
at Qt equal to 38 L/s..........................116

FIGURE 49 Water profiles along the culvert and the separator
at Qt equal to 71 L/s..........................116

FIGURE 50 Water profiles along the culvert and the separator
at Qt equal to 162 L/s..........................117

FIGURE 51 Impacts of oil spills in Richmond Hill..........................130

FIGURE 52 Locations of spills in Richmond Hill..........................131

FIGURE 53 Types of road for oil spills in Richmond Hill..........................132

FIGURE 54 Types of Oil Spills in Richmond Hill..........................133

FIGURE 55 Volumes of Oil Spills in Richmond Hill..........................134

FIGURE 56 Oil Spills Near Environmental Significant Areas
in Richmond Hill..........................136

FIGURE 57 Potential retrofit ponds 24-2 and 26-2
or oil spill control in the Don Watershed..........................137

FIGURE 58 Potential Retrofit Pond 28-2 for Oil Spill Control
in the Rouge Watershed..........................138

FIGURE 59 Potential Downstream Control Locations
in Humber Water Watershed.................................... 139

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

We live in a society where petroleum and its products are used everywhere. Oil not only provides energy and lubricantion for automobiles but it is also important ingredients for clothes, footwear, furniture and appliances. Since the demand for oil is so large, the world production of crude oil is more than three billion tons per year (Harayama et al., 1999). As more oil fields on land are depleted, more offshore oilfields have to be developed. Nearly half of this oil is transported by sea. As a result, spilled crude oil is one of the most important and publizied organic pollutants in marine environments. It has been estimated that worldwide between 1.7 and $8.8*10^6$ tonnes of petroleum impact marine waters and estuaries annually (Head and Swannell, 1999).

Unlike major tanker oil spills in oceans, oil spills in urbanized areas seldom catch people's attention unless they are in large quantity. Numerous oil spills occur daily in major cities across Canada and the total quantity entering into our fragile urban environment is significant. For instance, it was estimated that 3.8 million litres of oil has been spilled to Lake Ontario from the Golden Horseshoe area between 1998 and 1997 (Li and McAteer, 2000). These large quantities of spilled oil might have detrimental effects on the urban environment in several ways. First of all, the volatile fractions of oil are acutely toxic to most living organisms (Shales et al. 1989). The toxicity of the oil itself can poison exposed organisms, posing serious threats to surface water resources. Secondly, spilled oil can have catastrophic effects on wildlife and their habitats resulting, for instances, in fish kill due to algal bloom and destruction of freshwater invertebrates and vertebrates. Thirdly, the spilled oil which enters sanitary sewers not only causes deleterious effects, but also makes sewage treatment difficult, causing turbidity, objectionable tastes and odor. Last but not least, spilled oil which enters storm sewers could pose a major fire hazard if ignited because fire and smoke can spread throughout the whole neighborhood.

There is no doubt that spill prevention and control at the source is the most cost-effective method for managing oil spills in urban areas. However, accidents do occur and municipalities should prepare for spill accidents with engineered control systems at strategic locations. Oil spills are non-point pollution sources (Li and McAteer 2000) and it is expensive to install control devices indiscriminately at every potential location. Thus, it is imperative that a new approach to control oil spills in urban areas be developed.

The City of Toronto has experienced about 300 oil spills per year (Li 1997). Traditionally, the city recommends that businesses and industries practise pollution prevention and install on-site oil separators. Currently, the sizing criteria for these devices is not well defined and the draft code of practices for oil separators by the Canadian Petroleum Product Institute (1994) has not yet been approved by the Ministry of the Environment (Li 2000). Thus, the city is currently investigating the possibility of installing oil separators at spill-prone sewer outfalls. This is different from the conventional application of oil separators at individual commercial and industrial establishments. The new application of oil separators at sewer outfalls requires that the devices be operable under high flow conditions and that their capacity should reflect the land use characteristics in the associated sewershed. Recognizing this need, the Environment Canada's Great Lakes Sustainability Fund (GLSF), the City of Toronto, and the Ministry of the Environment's Spill Action Centre (SAC) are sponsoring this research on the design of oil separators for urban applications.

1.2 Objectives and Scope

The objectives of this research are to develop an innovative spill control device for storm outfall applications and a Geographic Information System (GIS)-based analysis technique for urban oil spill management. Preliminary investigations by Lin (2001) indicated that oil spills occur frequently near the Humber Creek, a tributary of the Humber River. Thus, a case study of the Humber Creek's storm outfall was be the focus of this research. To demonstrate the application of the GIS-based analysis technique, a case study of the southern York region was conducted.

The research is made up of two major components. The first component is the development of an innovative spill control device for storm outfall applications. A flow diversion structure was designed to capture the dry weather flow at the Humber Creek's outfall and to transport the captured flow into an oil/water separator designed in accordance to the American Petroleum Institute's (API) manual (1990). The designs of the flow diversion structure and the oil/water separator were evaluated by a physical model study using the National Water Research Institute's Hydraulics Laboratory at the Canada Centre for Inland Waters in Burlington, Ontario. The second component is the development of a GIS-based analysis technique which can be used to identify potential treatment options for spill prone sewer outfalls.

The thesis is organized in the following manner. Chapter 2 reviews the basic control options for oil spills and the related legislation and regulations in Ontario. The designs of the flow diversion structure and the oil/water separator are described in Chapter 3. Chapter 4 presents the experimental results of the physical model study.

Chapter 5 presents the GIS analysis of oil spills in York Region. The last chapter concludes the thesis with recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW OF URBAN OIL SPILLS

2.1.1 CAUSE OF OIL SPILLS

The Spill Action Centre (SAC)'s Summary Report of 1995 Spills has indicated that equipment failure and operator error are the major causes of spills in urban areas. Oil spills can be caused by errors during the filling operation of storage tanks at factories, at domestic heating plants, or at inland oil-fired power stations. Oil spills can also be caused by equipment failure such as accidental damage or malicious damage to oil storage tanks, roads or rail tankers carrying fuel oil or other hydrocarbons.

2.1.2 TRANSPORT OF SPILLED OIL IN URBAN AREAS

When oil is spilled on the ground, it spreads out and almost inevitably sinks through the surface if the ground is permeable. The depth to which it sinks, is dependent on the following factors:

- soil texture;
- soil structure;
- volume of a spill; and
- viscosity of the oil

For example, a low viscosity oil sinks rapidly into a dry sandy soil which is highly porous, but spreads slowly through clay. Waterlogged ground will resist penetration longer.

When oil penetrates the sub-soil, it will move slowly downwards until it reaches water or an impermeable layer. When it reaches ground water levels, it will usually flow along with the ground water and move a considerable distance below the ground (Environment Canada 1976).

The problem with movement of spilled oil in the ground is not the presence of oil but rather that the slow migration of oil in the direction of ground water flow and its reappearance in springs a long way from the spills, resulting in the contamination of the well and streams as well.

If oil is spilled on impervious areas such as parking lots or roads, it will move along the road and enter the associated storm sewer. It may pose a major fire hazard if ignited and the associated fire and smoke may spread throughout the whole neighborhood (Li 2000).

2.1.3 Control options for urban oil spills

2.1.3.1 Oil spills on land

In the event of an oil spill on land, immediate action must be taken to stop the movement and spreading of oil. In particular, all possible actions should be taken to prevent oil from reaching a watercourse or entering a sewer or drain. Several control options are listed below (Environment Canada 1973):

1. Embankments of earth or sand around the spill to close access to road drains and sewers, should be put up as soon as possible, while inlets to drainage systems can be covered by materials such as tarpaulins, blankets and plastic sheets.
2. If possible, any visible oil should be picked up by means of a gulley emptier, or some other similar type of pump.
3. Simple reservoirs, made of holes dug in the earth and lined with plastic sheets, can be prepared to act as temporary storage.

2.1.3.2 OIL SPILLS ON WATER

Spilled oil that enters a stream, river or lake can be dealt with by the following methods (Environment Canada 1973):

1. Absorption

Absorption is a practical solution for oil spills. If an absorbent is finely divided, it can be thrown or shovelled on to small patches of floating oil in a river or pond. Then, it can be removed either by an improvised downstream dam which collects the oil-soaked material, or by a simple scoop system that removes the oil absorbed material from the water surface. Generally, the whole operation is small and it is easy to produce a very good clean-up.

2. Booms

Booms, either production ones, or improvised booms made out of floating logs or bales of straw, can be set up at a sufficiently oblique angle at a slow flowing river to intercept the oil.

3. Dispersant

When an oil spill occurs on an inland water such as lake and rivers, dispersants and chemicals should not be used. Dispersants increase the surface area of the oil and bacterial degradation can take place more rapidly. Bacterial degradation of oil requires significant dissolved oxygen and may impact on the survival of aquatic organisms. Many rivers are already rather short of oxygen due to the discharge of industrial and sewage effluents, and any additional depletion of dissolved oxygen should be avoided. Chemicals, which are used as emulsifying agents, usually have some degree of toxicity and their chronic effects may be sufficient to kill sensitive aquatic organisms.

4. Oil/water separators

Oil/water separators are devices generally used to remove oil and other petroleum products from industrial wastewater and/or storm water systems. The application of oil/water separators in inland water is only feasble if the spilled oil can be captured and sent for treatment at a controlled rate. Liquid wastes contaminated with hydrocarbon or oil-like pollutants are found in many industries. Some common sources of oily wasterwater are petroleum refineries, metal fabrication facilities, utility operations, surface runoff in fueling or transportation operations and groundwater recoverd in remediation projects.

2.2 Best Management Practices

Oil can pollute stormwater in two ways. Oil residue on impervious surfaces can be washed off by storm runoff and become a stormwater pollutant. Oil spills which occur during storm events can be transported by storm runoff. Best Management Practices (BMP) is an approach in which optimal the solution for controlling oil and grease in storm runoff are identified. However, spilled oil that becomes mixed with stormwater is very difficult to control due to the high flows and the uncertainty of knowing ahead at time where the spill might occur.

2.2.1 Oil spills in stormwater

Oil spills can occur during wet or dry weather. Oil spills which occur during storm events can be termed "wet weather spills". This is the worst case of oil spills because the storm runoff picks up the spilled oil and enters the storm inlets quickly. Even if there is an oil/water separator at the storm inlet, it is almost impossible to treat such a large volume of stormwater. If oil spills enter a combined sewer system, the wastewater treatment plant may be forced to shut down or bypass the flow completely.

Oil spills which occur during dry weather can be termed "dry weather spills". The spilled oil is normally controlled by putting absorbent material on the spills or by building a dike around the spills. If the spilled oil enters the sewer system, it can be captured either by on-site oil/water separators or by placing a boom at the sewer outlet. However, many on-site oil/water separators in industrial and commercial areas are undersized and cannot handle large quantity of spilled oil (Li 2000). As a result, municipalities may consider the installation of oil spill control devices at spill prone outfalls.

Fortunately, thesis show that about 80% of the oil spills in Toronto occurred during dry weather. If dry spills can be captured by spill control devices at storm outfalls, most of the adverse effects of the spills can be eliminated.

2.2.2 OIL AND GREASE IN STORMWATER RUNOFF

In general, the concentration of oil and grease in stormwater runoff increase with urbanization and technological development. A study of an urban watershed in Richmond, California showed that the oil loading from industrial and commercial areas was much greater than from other land uses (Silverman 1986). If the oil and grease discharged from parking and commercial properties, which represents only 11% of the land area, were reduced by 90%, the total oil and grease emission from the whole watershed could be reduced by over 50%. If reductions of only 60% could be obtained form commercial and parking areas, the overall watershed reduction could still be over 35%.

Unfortunately, traditional technologies designed for industrial settings and municipal wastewater treatment do not have the capability to remove oil and grease from storm water on a cost-efficient basis given the sporadic nature of discharge and relatively low pollutant concentration (Silverman 1986). The major sources of pollutants in runoff can be scattered throughout a watershed, making detection and prevention of pollutant discharge difficult. The problem of controlling oil and grease in storm water runoff is exacerbated by the stochastic nature of the discharge. Runoff rates may be extreme, highly variable, and are both short-and long-lived. Technology capable of handling the wide range of runoff levels normally expected would have to be extremely versatile. As a result, pollution prevention for oil and grease in stormwater should be started at the source while BMP is the solution.

Best Management Practices (BMP) can be defined as

"*The processes, procedures, human actions or actual construction activities that prevent toxic pollutants or hazardous substances from damaging the environment*" (Silverman 1986)

Thus, BMP can be categorized into structural and non-structural measures. Structural practices are human actions or actual construction activities that control pollution. Non-structural practices are processes or procedures that prevent pollution. Some of the structural and non-structural practices for oil and grease in urban runoff are reviewed in the following sections.

2.2.3 STRUCTURAL PRACTICES

2.2.3.1 CLEANING OF SURFACE MATERIAL

Since over 80% of the hydrocarbons in runoff are typically found associated with particulates (Li 2000), regular cleaning of parking lots, commercial streets, and other heavily used areas will remove pollutants before they are entrained in runoff(Silvemen 1986). However, studies show that hydrocarbons only associate with very fine particles, which are most likely to be left behind by traditional sweeping techniques (Silverman 1986). In order to remove these fine particles, a wet-sweeping technique is specially designed for street sweepers. First, the street sweeper sprays a small area with water containing biodegradable soaps or detergents which solubilizes the oil and grease deposited on pavement surfaces. Then, the sweeper removes the water using a combination of sweeping and vacuum actions (DiSalvo 1975).

2.2.3.2 Porous pavement

Porous asphalt pavements allow a high rate of rainfall infiltration by omitting fine particles during pavement construction. Water is retained in the base and pavement materials, providing an opportunity for pollutant adsorption and degradation. This pavement also reduces the magnitude of total peak runoff and provides flood control benefits. Oil can be trapped in the porous media and be degraded by soil bacteria (Diniz 1980).

2.2.3.3 Oil sorption system

Oil sorption systems have been developed using various types of materials in order to cleanup spilled oil in open waters. The same strategy may be applied in urban runoff by installing adsorbents at all sewer inlets in parking areas and commercial streets. However, the adsorbents may block the inlets and cause local flooding. Also, routine maintenance such as replacing sorbent and removing debris required. (Cochram 1973).

2.2.3.4. Greenbelt

Vegetative areas (e.g. Grass strip filter) can be designed to catch runoff with relatively high oil and grease concentrations from large paved areas such as parking lots. Percolation through soil and underlying layers results in hydrocarbon filtration and adsorption, encouraging degradation by naturally occurring soil bacteria. The greenbelt consists of an upper layer of topsoil supporting plant life resting on a layer of sand, which in turn lies on a thick bed of gravel. Runoff percolates through the top layers. This percolation removes essentially all suspended solids and reduces hydrocarbon concentration. The gravel layer acts both as a drain, keeping the upper layers from saturation, and as a reservoir where stormwater is stored while it percolates into the surrounding soils at depth (Rich 1980).

2.2.3.5 Dispersion devices

Diffusers can reduce the impact of oil and grease from runoff without reducing mass emissions. A diffuser does not reduce the amount of pollution discharged to the receiving body, but dilutes the concentration of pollutants (Silverman 1986).

2.2.3.6. Constructed wetlands

Wetlands offer a mechanism for treating storm runoff, so constructed wetland are employed to confine waters contaminated with oil and grease. Since the majority of oil and grease in runoff is normally found to be associated with fine particulates, it is reasonable to assume that wetlands act primarily as a sedimentation trap. Pollutant removal from the water column occurs as the particulates settle, with degradation responsible for their ultimate elimination. Unfortunately, this technique is site-specific and the capital cost is high.

2.2.4 Non-Structural Practices

2.2.4.2 Sewer e by-law

A Sewer e by-law could minimize oil and grease loadings at the source. In Toronto, all wastewater is subject to the City of Toronto Municipal Code Chapter 681 (Sewer Use By-law 457-2000). All kinds of wastewater that discharge into sanitary, combined, and storm sewers and watercourses should fulfill the requirements in this code.

For example, if sewerage has one or more of the following characteristics, it cannot be discharged into sanitary and combined sewers,

- A temperature greater than 60 degrees Celsius;
- Two or more separated layers; or
- A pH less than 6.0 or greater than 11.5.

If sewerage has one or more of the following characteristics, it cannot be discharged into storm sewers and watercourses,

- Visible film, sheen or discolouration.
- Two or more separate layers.
- A pH less than 6.0 or greater than 9.5
- A temperature greater than 40 degrees Celsius.

For the rest of the requirements, please refer to the City of Toronto Municipal Code Chapter 681, Section 2 and 4 (http://w3.city.toronto.on.ca/involved/wpc/nbylaw.htm).

2.2.4.3 Pollution prevent plan

A Pollution Prevent (P^2) plan is a comprehensive way to eliminate the pollutants in sewers. P^2 is the maximum feasible reduction, preferably elimination, of all toxic wastes and the wastes generated at production, usage, or storage sites. It involves judicious use of resources through source reduction, energy efficiency, reuse of input materials, and raw material substitution with more environmentally friendly products. There are two general methods of source reduction that are advocated: product and/or production process change to reduce pollution at the source and redesign products to minimize their environmental impacts.

Every industry that discharges pollutant into the sewer should prepare a P^2 plan and submit it to the city of Toronto. In the plan, they should state all the pollutants that are generated during the production, the current waste reduction or waste treatment for the pollutant, as well as, a list of possible three- and six-year targets to reduce the discharge of pollutant to the City's sewers.

2.2.4.1 Oil recycling

Vehicular oils have been shown to be the main source of oil and grease typically found in urban storm runoff (Stenstrom et. al. 1984). These oils can be introduced to the watershed through tailpipe emissions, leakage, or dumping. Promoting oil recycling provides the possibility of reducing the input, thus reducing oil and grease concentrations in stormwater.

2.3 Oil Water Separation

Typical industrial processes to remove oil and grease from wastewater include skimming, gravity differential systems, filtration, dissolved air flotation, coalescence, and sorption. Some of these oil/water separators are not designed to handle large variable flows while others are too either expensive or maintenance intensive. The basic principles of oil/water separators are reviewed in the following sections.

2.3.1 Gravity Separation

The design of gravity-type oil separators is based on the principle of Stokes' Law. The larger the oil droplet, the faster it rises through the water. Thus, the degree of separation of an oil/water mixture is a function of the distribution of oil droplets. Oil/water mixtures can be classified into four classes as indicated in Table 1

Table 1 Classification of oil/water mixtures (American Petroleum Institute 1990)

Oil Classification	*Size of Oil Droplets*
Free Hydrocarbon	150 microns or greater
Dispersed Oil	20 to 150 microns
Emulsified	<20 microns
Dissolved-Phase Hydrocarbons	Not typically removable by physical treatment

The predominant approach in designing gravity-type oil/water separators is to retain the oil/water mixture for a long enough period to allow natural separation of oil and water to occur. This natural separation is called gravity separation and is based on the difference between the density of water and hydrocarbon compounds. Lighter oil rises up to the water surface and separates itself from the water. This approach is limited to removal of free oil globules larger than 150 microns (API 1990).

2.3.1.1 SPILL CONTROL SEPARATOR

The simplest possible separator is an storage chamber with sufficient volume to contain spills, such as a typical spill control separator. A spill control separator is essentially a catch basin, but it is designed to retain oil (Figure 1). Wastewater flows into a cylindrical chamber through the inlet pipe and clean effluent enters the downstream sewer through the submerged outlet pipe. It has also an emergency overflow outlet that is connected to the submerged outlet pipe. A spill control separator is only suitable for intercepting typical spills of oil or grease in Toronto (average spill event volume) because the cylindrical size chamber is too small to intercept small oil droplets in industrial wastewater. Also, spill control separators are only effective if the accumulated oil is removed regularly. If the trapped oil is not removed regularly, a storm event may flush the accumulated oil out of the separator into the downstream sewer (Romamo, 1990).

Due to washout problems, spill control separators have been modified into manhole separators where a weir is designed to bypass excess stormwater. The height of the weir is designed to convey the overflow of a design storm ranging from 2 to10 years. The modifications increase the effectiveness of the separator, while reducing maintenance requirements (Zhen 1998).

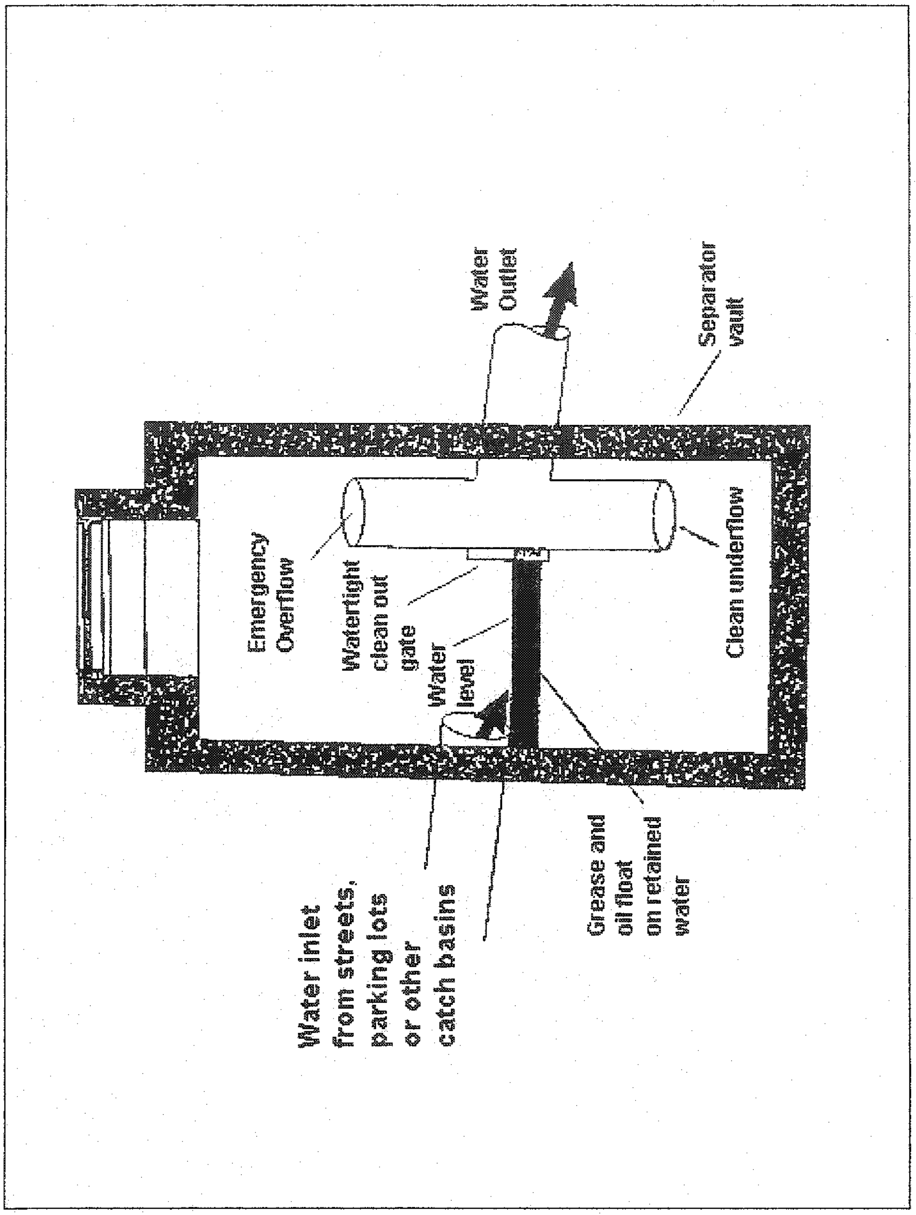

Figure 1 A Spill Control Separator (Romano, 1990)

2.3.1.2 AMERICAN PETROLEUM INSTITUTE (API) SEPARATOR

The API separator is a conventional oil-water separator that is based on the criteria developed from a 3-year, API funded research study initiated in 1948 at the Engineering Experiment Station at the University of Wisconsin. Since then, numerous oil-water separators based on the API's design criteria have been designed and put into operation throughout the petroleum industry. The criteria were developed as voluntary guidelines for designing conventional oil-water separators. Many other separators, based in part on the API-developed design criteria, have been adapted for a variety of other industrial wastewater treatment applications (API 1990).

Figure 2 shows a typical API oil-water separator. There are three chambers separated by 2 baffles. The baffles are placed within the chamber to block oil from flowing out of the separator and to reduce turbulence. Oil-water separation occurs in the first and centre chambers. Oil floats to the top of the chamber while sludge sinks to the bottom. Another baffle or weir is fastened to the bottom to trap the sludge at the bottom of the separator. An oil skimmer device should be installed to remove the trapped oil(API 1990). It should be connected to a remote waste oil tank,allowing for gravity separation of the oil to the top of tank.

Since the oil-water separation theory is based on the rate at which an oil globule rise and its relationship to the surface loading rate of the separator, any oil globule with a rise rate greater than or equal to the surfaceloading rate will theoretically reach the separator surface and be removed. Therefore, the API guidelines (1990) recommend that the maximum allowable mean horizontal velocity for the API separator be limited to approximetely 1m/min (3 ft/min). By comparing this horizontal velocity with the flow rate in the sewer system, minimum velocity of sanitary flow in sewer is much slower than the allowable horizontal velocity. In order to satisfy the maximum allowable velocity specified by API in a sewer system, the size of the API separator is maybe in the order of tens of metres. The lengthy treatment process and the enormous size of the separators limit the application of API separators in urban sewer systems.

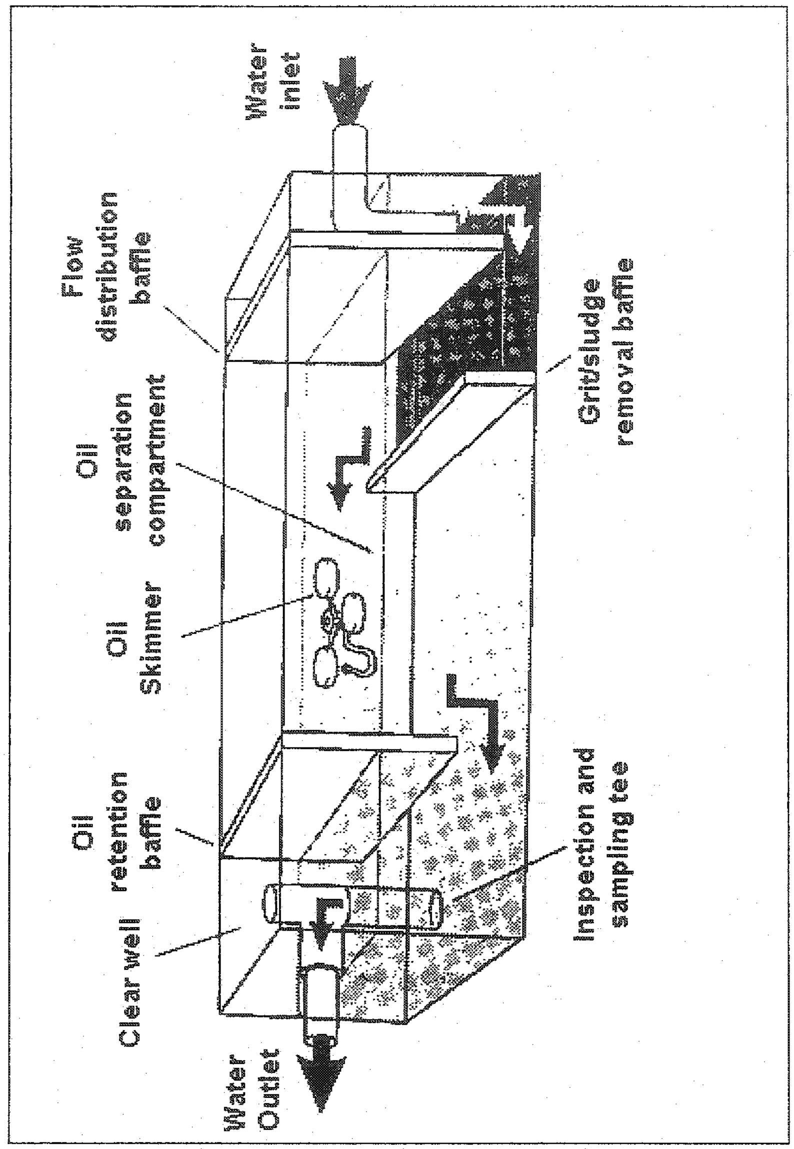

Figure 2 A American Petroleum Institute (API) Separator (Romamo, 1990)

2.3.2 Coalescence Plate Separation

Since the API separator has many limitations, the Royal Dutch Shell Group investigated these problems and developed the coalescing plate separator (Iggleden 1978).

Why coalescence cannot happen in a simple API separator?

Coalescence means forming large oil droplets from very small oil globules. In the dispersion of two immiscible liquids, immediate coalescence seldom occurs as two droplets collide. If the droplet pair is exposed to turbulent pressure fluctuations, and the kinetic energy of oscillations induced in the coalescing droplet pair is larger than the energy of adhesion between them. As a result, contact may be broken before coalescence is completed.

However, coalescence can be achieved by providing sufficient energy in the system to allow the oil droplets to be brought together. By installing a series of parallel flat plates at an angle of 45 degree to the direction of flow, the coalescing action was found to be maximized (Iggleden 1978). The parallel plates provide solid surfaces on which the small oil droplets to accumulate. These accumulated oil droplets form a thick oil film, which becomes a source of large drops. When other mechanical forces, such as gravity or fluid forces, overcome the cohesiveness of the oil film, these accumulated oil droplets break loose from the solid surface. According to the Stokes Law, these large oil droplets separate from the water phase much faster than the original small droplets.

Also, the flow through a parallel-plate separator can be two to three times that of an equivalent conventional separator. Thus, the spatial requirements of oil-water separation can be reduced up to twofold on width and tenfold on length when a parallel-plate separator is used in place of a conventional one (Iggleden 1978).

2.3.2.1 INCLINED PLATE SEPARATORS

Figure 3 shows a schematic of a typical inclined plate separator. These separators, usually made in large modules, are constructed of fiberglass-corrugated plates packaged in steel or stainless steel frames. The plates, installed in an inclined position, encourage oil droplets collected on the undersides of the plates to move toward the surface of the separator, and sludge collected on the plates settles toward the bottom of the separator by gravity. The advantages of this system include improved removal efficiency of both solids oil, and resistance to plugging with solids.

2.3.2.2 FLAT CORRUGATED PLATE SEPARATORS

The plate unit of flat corrugated plate separators is a series of horizontal oleophilic polypropylene plates stacked on top each another in vertical stacks and fastened into packs with rods or wires. Figures 4 and 5 show a typical flat corrugated plate separator system. According to Stokes law, large oil droplets rise faster than small ones and thus separate better. However, turbulence causes mixing of oil and water and reduces oil droplet sizes. Therefore, the vertical stacks are designed to slow down the flow such that a laminar flow regime exists. Also, the oleophilic nature of the plate attracts oil droplets and encourages them to coalesce into larger ones.

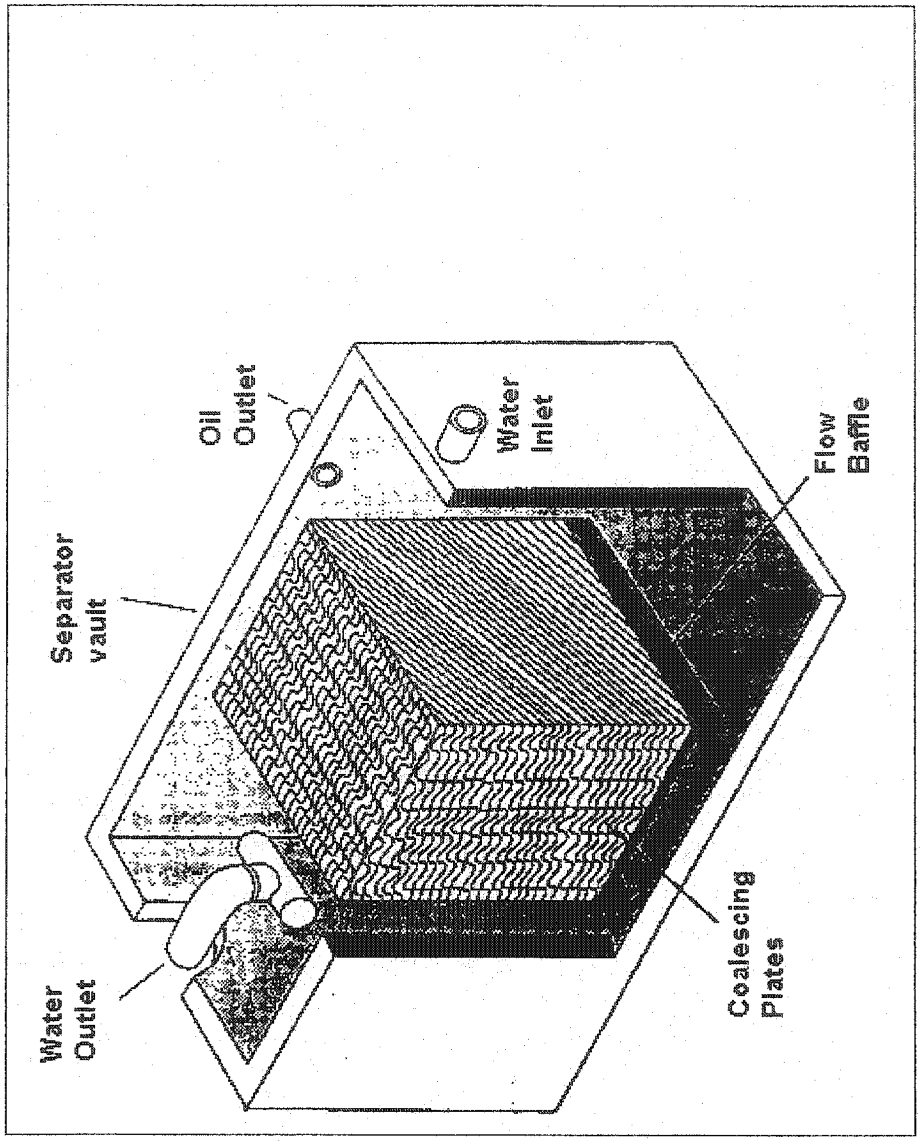

Figure 3 A Inclined plate separator (Romano, 1990)

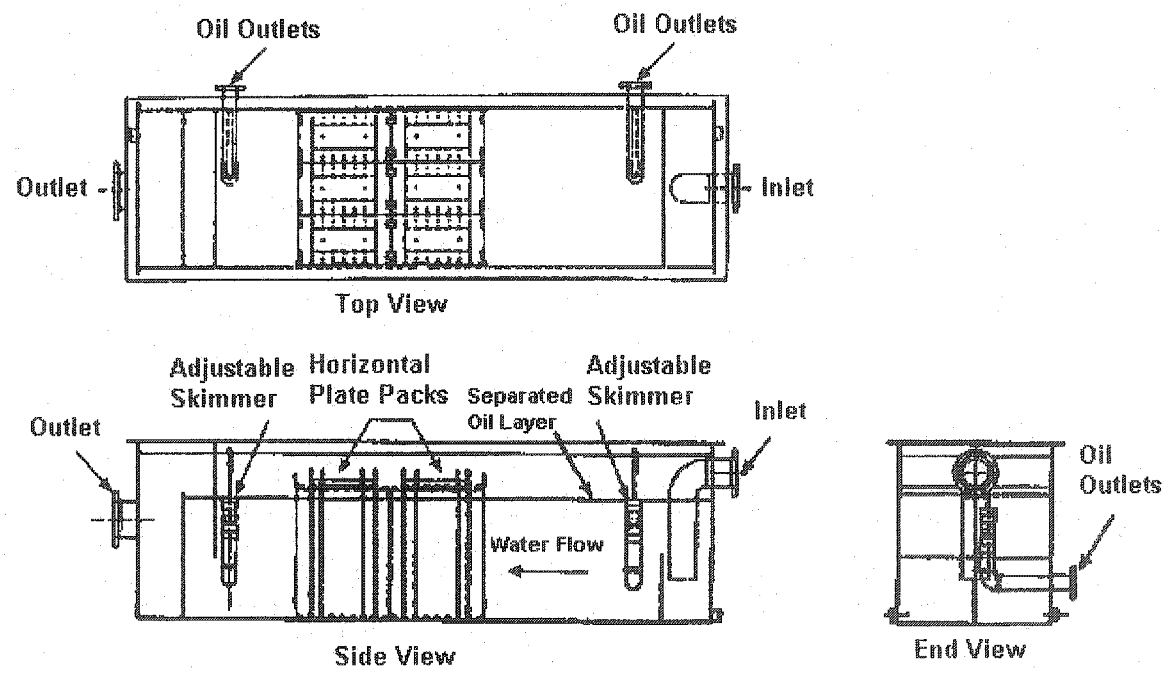

Figure 4 A Flat Corrugated (Horizontal Sinusoidal) Oil/Water Separator (Mohr, 1992)

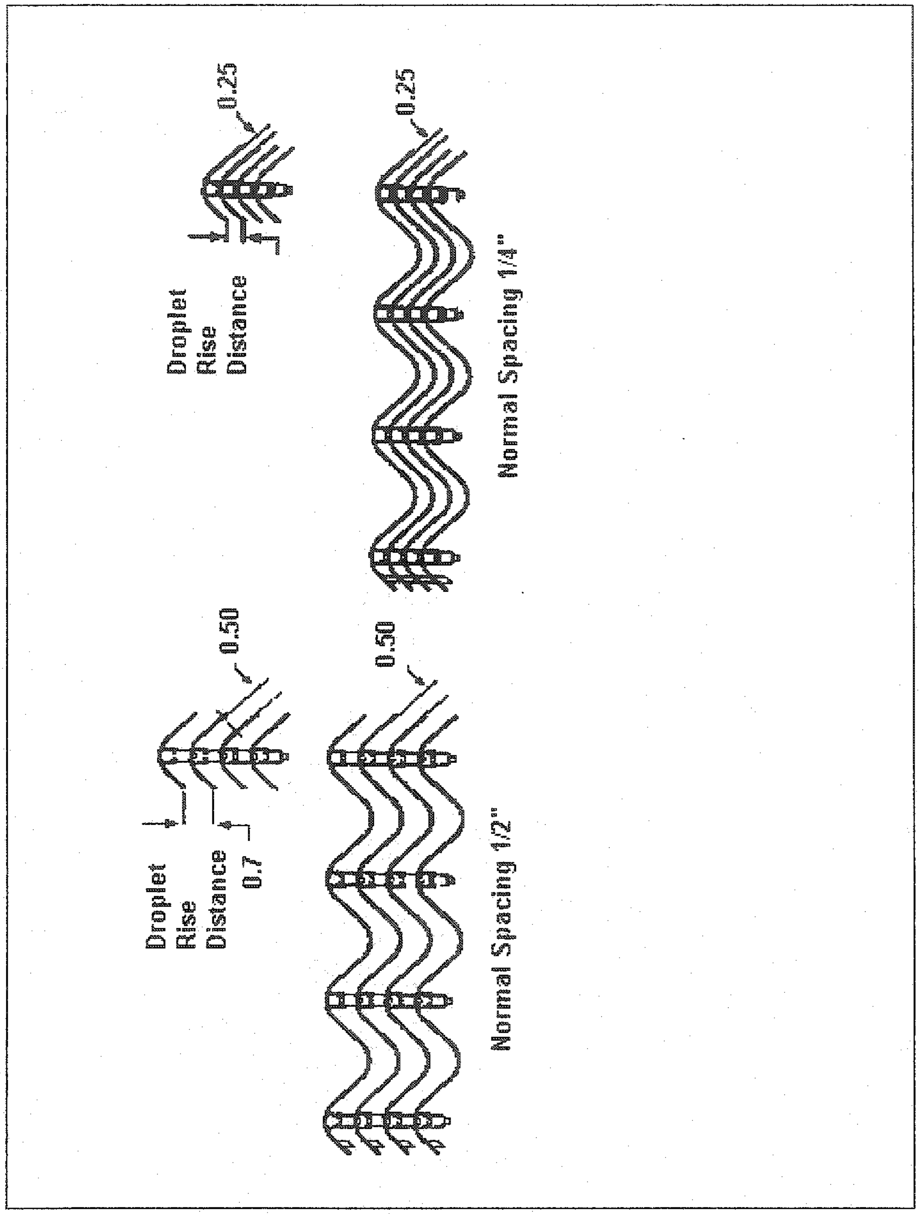

Figure 5 A Flat Corrugated (Horizontal Sinusoidal) Plate Pack (Mohr, 1992)

The advantages of this system are that the plate packs are modular and relatively small in size compared to the inclined plate modules. Corrugated plates in this type of system are spaced a nominal 0.63 cm to 1.27 cm apart. Because the plates are corrugated, the rising distance of droplets in the vertical direction is made to be greater than the perpendicular distance between plates. The disadvantages of this system are that the plate packs can be clogged by solids and the polypropylene plates can be damaged by solvents (Mohr 1992).

2.3.2.3 MULTIPLE ANGLE PLATE SEPARATOR

Figure 6 shows the "MPak®" multiple angle plate separators. The separator plate has an "M" shape when seen from the end and thus the system is referred to as the "M Paks". The plates are corrugated in both directions, making a sort of "egg-carton" shape. The "M" shaped plates are designed to shed solids to a solids collection area at the bottom of the separator and therefore to avoid plugging the device. In inclined plate systems, solids must slide down the entire length of the plates. However, in the "M" shaped plate, solids only slide a few centimeters before encountering one of a multitude of solids removal holes. The solids drop directly to the bottom of the separator. The double corrugations also provide surfaces (sloping at a forty-five degree angle in all directions) to facilitate upward movement of coalesced oil.

2.3.2.4 COALESCING TUBE SEPARATORS

Figure 7 shows a coalescing tube separator. This separator utilizes perforated plastic tubes for separation. The advantages of this separator are its low cost and enhanced separation due to the oleophilicity of the packing (Mohr 1992). The disadvantage is that the oil separation from the tubes is uncertain and therefore not optimized.

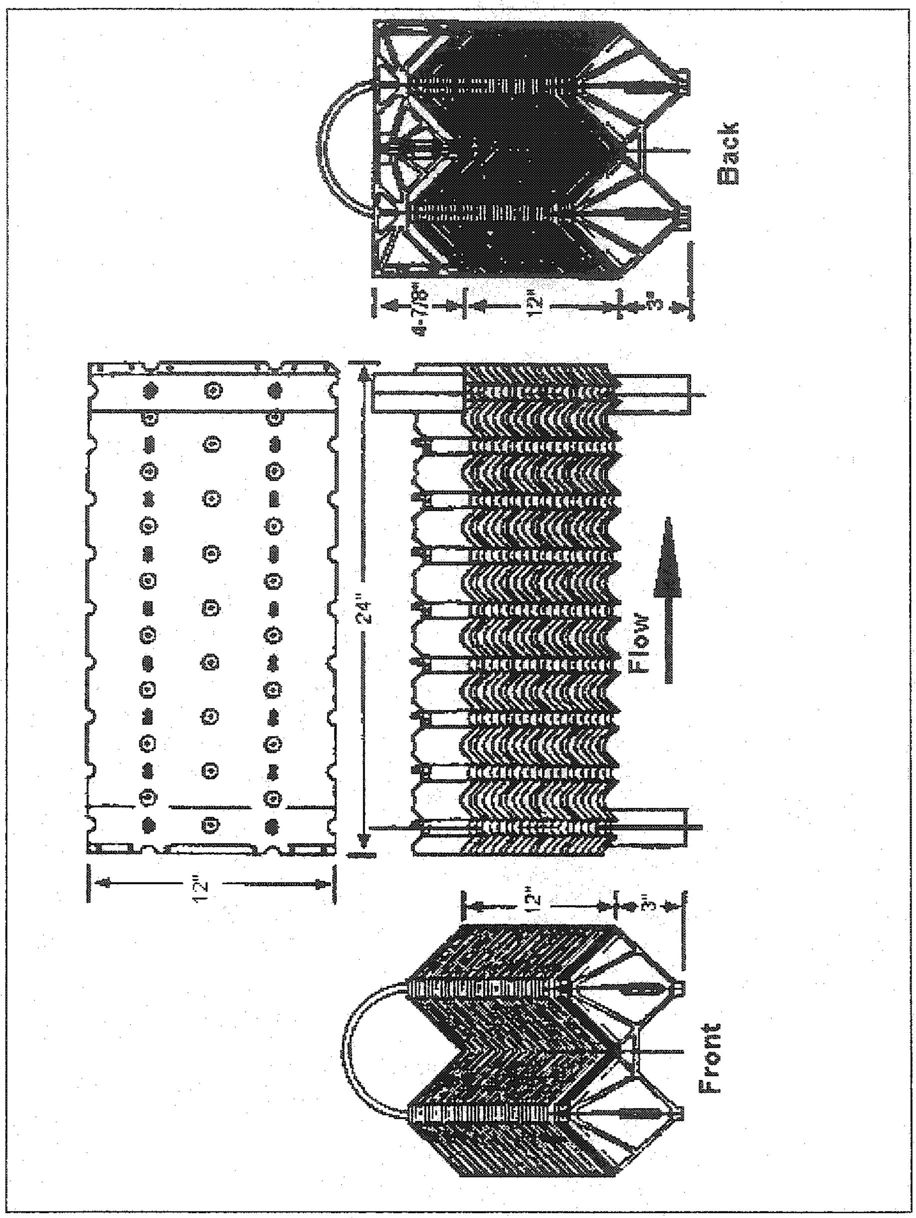

Figure 6 A Multiple Angle (MPack) Separator, The HEROWS unit (Mohr, 1992)

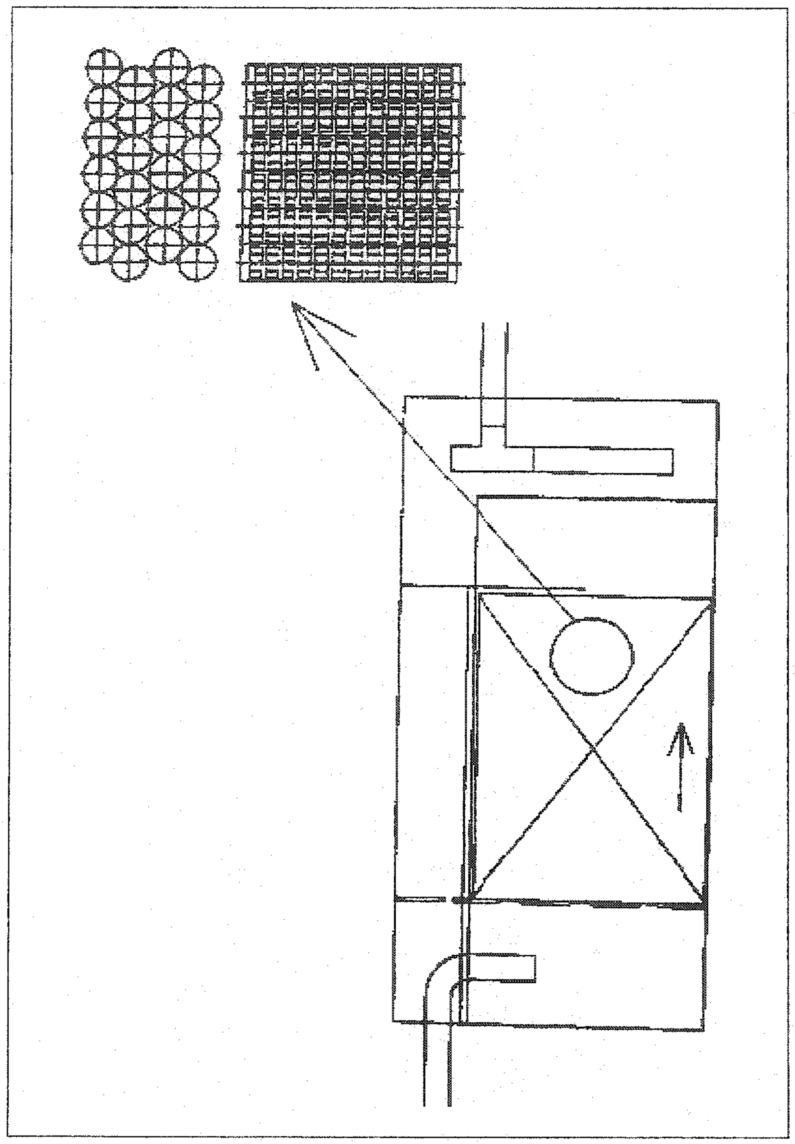

Figure 7 A Coalescing tube separator (Mohr, 1992)

2.3.2.5 MODIFIED CROSSFLOW PACK SEPARATOR

Since the traditional plate coalescence separator is prone to plugging by solids or biological flocs, a modified plate coalescence is designed to overcome this limitation. Although it is designed for a Crossflow Pack separator, it still can be applied to other plate coalescence separators. In order to increase the coalescence rate, additional energy must be provided to the system to create an oscillatory flow. This type of flow will create turbulence just enough to promote coalescence but not so great as to avoid shearing oil droplets. This flow action can be achieved by applying the shaking-induced flow technique. When the plate pack experiences a vertical motion with 1 cm displacement, it is possible to have different oscillatory flows with Reynolds numbers ranging from 1,500 up to 4,500. Since the Reynolds number of the original laminar flow through a standard CFP separator was 930 (Morhn 1992), the additional shaking motion accelerates the removal of sediments and solids from the plate pack.

2.3.3 DISSOLVED AIR FLOTATION

Flotation is a process in which tiny gas bubbles are introduced into the water phase and small oil droplets and fine solid particles adhere to the gas bubbles as they rise. Separation is enhanced because the rising velocity of the gas bubble is much higher than that of an oil droplet of comparable size.

Flotation units are commonly used in the oil industry because of their effectiveness in removing oil-coated solids. The most common gases used for flotation are air, CO_2, N_2 and natural gas. Two major types of gas flotation systems are listed below.

- Dispersed gas system

In this system, a fine dispersion of gas bubbles is mechanically created with an impeller or with a combination centrifugal pump and eductor. As a result, this system can be further subdivided into rotor-dispersed and pump-eductor dispersed.

- Dissolved gas flotation system

In this system, the gas and oily water are combined under a pressure of about 45-50 PSI. Tiny bubbles are formed when the water flows through a pressure control valve and discharges into an atmospheric pressure flotation tank. This system has a high oil removal efficiency but it is relatively expensive and requires lots of space (Armold 1985).

2.3.4 Enhanced Gravity Separation

By replacing gravity force with centripetal force, oil/water separation can be enhanced. When a water stream is spun at high velocity, oil droplets migrate to the centre by centripetal force whereas the water is flung to the outside by centrifugal force (Aromld 1995). Water is introduced tangentially through a rectangular port into a conical-shaped chamber. The water rotates rapidly around the chamber and moves downward, exiting at the small end of the cone. As the water moves down the cone, the decreasing diameter causes the water's rotational velocity to increase which in turn, increases the centripetal acceleration of the lighter oil droplets towards the centre of the cone and the centrifugal acceleration of the denser water to the outer wall of the cone. A slender core, typically 1 to 2 mm in diameter, of concentrated oil forms at the centre of the cone and floats to the top of the hydro cyclone. A water stream, concentrated in oil, is removed at the top of the hydro cyclone while the clarified water stream exits at the bottom.

Centrifugal separators such as centrifuges and hydro cyclones have traditionally been used for removing solid particles or for de-watering sludge. Use of centripetal force for de-oiling water is a relatively new technology. Preliminary results indicate that the oil-removal efficiency may exceed 90% (Armold 1985). However, large amount of energy is required to produce the high velocities within the hydro cyclone. The operation and maintenance cost for this system is also relatively high compared to that of the traditional gravity separator (Armold 1985).

2.3.5 FILTRATION

Filtration is another type of oil-water separation other than gravity separation. It is usually applied when the treated water is to be reused. Several filtation systems are reviewed below (Romano 1990).

2.3.5.1 FIXED MEDIA

A fixed media filter is a device that processes oily water by passing it through a highly porous oleophilic coalescing media. Oil is removed from the water by wetting the surface of the coalescing media, or by coalescing within the media with other droplets to form larger droplets. After passing through the media, these enlarged drops are separated by gravity in the separation chamber of the vessel. The media require cleaning when they are saturated with oil (Armold 1985).

2.3.5.2 LOOSE MEDIA

Walnut shells, gravel, crushed anthracite and sand are the typical filters for loose media. These materials provide a large surface area upon which tiny oil droplets in the wasterwater or oily water can coalesce. Oil coalesces on the grains and accumulates in the bed, starting on the inlet side of the filter, and gradually progressing to saturate the media (Armold 1985).

2.3.5.3 CROSS FLOW MEMBRANE FILTERS

Cross-flow membrane filtration refers to a system in which the fluid, to be filtered, flows across the membrane surface, perpendicular to the direction of permeate flow. These filters have potential advantages for filtration of oily water . In general, they are capable of producing highly treated water compared to conventional de-oiling systems.

2.3.6 ABSORBENTS

Absorption techniques are primarily used to clean up oil spills. They are used to remove oil and grease in relatively high concentrations. As a result, these techniques have been used for industrial wastewater clean up for a long time.

Each absorbent has three distinct properties which determine its performance: sorption capacity, maximum sorption capacity and oil/water ratio. Sorption Capacity is the amount of oil that a particular material is capable of picking up, usually given as grams of recovered oil per gram of absorbent. Maximum sorption capacity is the total oil pick-up capacity of an absorbent for a number of material, expressed as gram of recovered oil per gram of absorbent. The oil/water ratio is the weight of oil versus the weigh of water in the liquid recovered by the absorbent. The performance of an absorbent depends on these three distinct properties. However, these are several factors which also affect these three properties.

- water and air temperature,
- thickness of the oil slick,
- physical state of the oil (i.e. emulsification, aging, etc.),
- the presence of debris and
- the mode of absorbent selection for use (i.e. chips, pads, sweeps, etc.)

Absorbent can be divided into three classes: natural products, modified natural products and synthetic products. Each class of absorbents is described below.

2.3.6.1 INORGANIC SORBENTS

This class of sorbents consists of naturally-occurring materials (e.g. perlite, vermiculite, glass wool and volcanic rork) that have been mined or otherwise harvested. Often this material may be rendered more oleophic and hydrophobic by treatment with silicones, etc. These sorbents generally have low oil-pick-up capacities and are difficult to use. In addition, protective wear for eyes and lungs may be necessary when handing them (Environmental Canada 1973).

2.3.6.2 NATURAL ORGANIC SORBENTS

Natural organic sorbents such as straw, peat moss and sawdust have been used in the recovery of spilled oil. These products are readily available and relatively inexpensive compared to other sorbents. Oil sorption capacity of this class of sorbents is higher than that of many inorganic sorbents (Environmental Canada 1973). However, if these materials are indiscriminately utilized, a sorbent retrieval problem may develop.

2.3.6.3 POLYMERIC SORBENTS

Polyurethane, polyethylene, polypropylene and other organic polymers have been used to treat oil spills with varying processes. Most polymeric sorbents are those that are highly oleophilic and hydrophobic and their sorption capacities are relatively high. However, they are sparsely available and relatively expensive (Environmental Canada 1976). The application of these materials has been greatly facilitated by the formats in which these materials are available, i.e. bags, pads, sheets, boom, etc. Although this class of sorbents has a high initial cost, it can be offset by their large sorption capacities and the potential to reuse.

2.3.6.4 MISCELLANEOUS SORBENTS

There are several sorbents that are mixtures of the above types. Typically they are cellulose fibre – perlite mixtures which are marketed under a variety of trade names and in several different physical configurations (e.g. granules, sheets and sausage booms). In general, their sorption capacities and costs are on a par with the natural organic sorbents.

2.4 Oil Spill Legislations

2.4.1 Ontario Environmental Protection Act

In the Part X of the Environmental Protection Act, a spill is defined as following;

" A discharge of pollutant from a structure, vehicle or other environment into the natural environment with abnormal in quantity or quality in light of all the circumstances of the discharge." (Part X, Section 91(1))

Whom to contact?

If a person causes a spill of a pollutant and the pollutant causes an adverse effect to the environment, he or she should immediately notify the Ministry; the municipality; the owner of the pollutant; the person having control of the pollutant with the information about the spill and the action they intend to take.

What and When do duty effect?

The owner of a pollutant and the person who causes the spill should do everything practical to prevent, eliminate and ameliorate the adverse effect and to restore the natural environment. His or her duty is in effect immediately upon knowing that the spill has pollutants and that it has adverse effect.

In order to carry out the duty in response to a spill, any person subject to the duty may 1) enter any places, 2) construct structures and use machinery, structures, materials and equipment, 3) remove the pollutant or any matter, thing, plant or animal or any part of the natural environment that is affected by the pollutant.

The owner also should not dispose of any pollutant, as well as all the things; plants, animals or the natural environment that is affected by the pollutant, unless they have received an order from the Minister or the approval of the Director.

Who has the right for compensation?

Any person has the right to claim compensation from the owner of the pollutant and the person having control of the pollutant, if they have losses or damages due to the adverse effect cause by the spill of a pollutant, due to the action of recovery of spill or due to the owner's negligence to carry out a recovery action for the spill. Losses and damages include personal injury, loss of life, loss of use or enjoyment of property and loss of income.

However, an owner of a pollutant or a person having control of a pollutant are not liable for compensation if they take all reasonable steps to prevent the spill of the pollutant or iff they can show the spill is caused by an act of war, insurrection and terrorism, or caused by a natural phenomenon of an exceptional character, or caused by a person other than the owner of the pollutant who intends to use the pollutant to harm other people.

2.4.1.1 CLASSIFICATION OF SPILLS

Under the Ontario regulation 675/98 of the Environment Protection Act, there are eleven classes of spills.

Class 1: Approved Discharge

The class 1 spill is a discharge that is authorized by the certificate of approval, order, licence or permit issued under the Ontario Water Resources Act, the Pesticides

Act or a predecessor of either of them. Since this spill is authorized, it is exempt from Part five of the EPA Act. However, this spill should comply with all the orders, requirements and directions made under the Act and the spill should not contravene any other federal or provincial acts, regulations or municipal by-laws.

Class 2: Water from Reservoirs and Water Mains

A Class 2 spill is a discharge of water from reservoirs formed by dams where the discharge is caused by natural events or potable water from municipal water mains. Therefore, this class is exempt from Part five of the EPA.

Class 3: Household Fires

A Class 3 spill is a discharge of pollutants from a fire. These pollutants should be the products of combustion of materials. The quantity of these pollutants should not be greater than the total quantity of these materials normally found in 10 residential households.

Class 4: Planned Spills

There are two different kinds discharge that are classified as Class 4. One kind of discharge is those planned for research or training purpose while the other is a direct and unavoidable result of a planned maintenance procedure to water or waste water systems. These two kinds of discharge should be consented by the Director. The person having control of the pollutant should apply for the Director's consent not less than 15 days before the spill. In the application, he or she should set out the time, place and potential adverse effects of the spill. He or she should also monitor the adverse effects of the spill and report them in writing to the Director within five days after the spill.

Class 5: Refrigerants

A Class 5 spill is a spill of refrigerant to which Ontario Regulation 189/94 applies. This spill is exempt from section 92 of EPA act if there are no adverse effects occur at the spill location and the quantity of the spill is less than 100 kilograms.

Class 6: Motor Vehicles

If the quantity of spill is less than 100 litres and the fluid is from the fuel system or other operating system of a motor vehicle, it is classified as Class 6. A Class 6 spill is exempt from section 92.1.a and subsection 92.3 and 92.4 of the EPA under following conditions: A) the spill does not enter any water through a drainage system; B) the spill does not cause any adverse effects, other than those that are remediated through cleanup, and restoration of surface that are prepared for vehicular traffic.

Class 7: Electrical Utilities

When an electrical transformer owned by a municipal or provincial electric authority is leaking less than 100 litres of mineral oil, this spill should classified as Class 7. A Class 7 spill is exempt from sections 92.1.a and and 92.4 of EPA under following conditions: A) the spill does not enter any water through a drainage system. B) the spill does not cause any adverse effects, other than those that are remediated through cleanup, and restoration of surface that are prepared for vehicular traffic.

Class 8: Petroleum Sector

A Class 8 spill is a spill of a fluid petroleum product at a location defined in the *Gasoline Handing Act* as a bulk plant, marina, private outlet or retail outlet. However, the quantity of the spill should be less than 100 litres in areas restricted from public assess or less than 25 litres in areas with public assess. A Class 8 spill is exempt from sections 92.1.a, subsection 92.3 and 92.4 of EPA under following conditions: A) the spill does not enter any water through a drainage system. B) the spill does not cause any adverse effects, other than those that are remediated through cleanup and restoration of surface that are prepared for vehicular traffic.

Class 9: Transportation of Dangerous Goods

A Class 9 spill is subject to immediate notification requirements under the *Transportation of Dangerous Goods Act*, 1992 or the *Dangerous Goods Transportation Act* and the regulation under those acts. If the quantity of the spill is less than the minimum reportable quantity specified in the Transportation of Dangerous Goods Regulations under the *Transportation of Dangerous Goods Act*, it would still be classified as Class 9 spill. A Class 9 spill is exempt from section 92.1.a, subsection 92.3 and 92.4 of EPA under following conditions: A) the spill does not enter any water through a drainage system. B) the spill does not cause any adverse effects, other than those which are remediated through cleanup.

Class 10: Contingency Plans

A Class 10 spill is a spill that is described in a spill contingency plan as "not reportable" if, the spill contingency plan adheres to the Canadian Standard

CAN/CAS-N731-95, Emergency Planning for Industry, and the spill contingency plan has been provided to the Director for review.

The Class 10 spill is exempt from Ontario EPA, Part X, section 92.1.a and subsection 92.3 and 92.4 if the plan has been in effect before the spill; the spill is a material specified in the plan; the quantity of a spill is less than the reportable quantity specified in the plan; the plan has described the spill as one which is not likely to cause an adverse effect based on experience; and the spill is not deliberate on the part of the owner or person in control.

Class 11: One Window Reporting

A Class 11 spill is a spill that is reportable to a provincial or federal agency. This spill will be exempt from section 92.1.a and 92.4 of the EPA, only if a memorandum of understanding exists between the Ministry of the Environment and the other agencies with respect to resolving duplicate reporting of spills. Also, the spill should meet all conditions specified in the memorandum of understanding.

Recording the Spill

For Classes 5,7,8,9,10 and 11, the person having control of the pollutant should record the details of the spill. He or she should keep the record for two years after the spill. During these two years, he or she should make the record available for inspection upon the request of a provincial officer.

The record should include the date, time location and duration of the release of the pollutant; the identity of the pollutant released; the quantity of the pollutant released; the circumstances and causes of the spill; details of the containment and clean-up efforts; as well as the method used to dispose the pollutant and any matter that is affected by the spill and the location of the disposal site. Finally, any adverse effects as a result of the spill should be included in the record.

2.4.2 Regulations Associated With Spills

2.4.2.1 REGULATION UNDER FIRE PROTECTION AND PREVENTION ACT

Under *Fire Protection and Prevention Act*, there is one regulation related to spills.

Fire Code, Ontario Regulation 315/01, Part 4 Flammable and Combustible liquids

This part of the regulation covers the handling, processing, storage and use of flammable or combustible liquids. Liquids with a flash point greater than 93.3°C are also included in this part of the regulation.

Spill Control

Under the subsection 4.1.6 are specific details relating to spill control for flammable or combustible liquids. In order to prevent the spilled liquids from reaching waterways, sewer systems and potable water sources, a non-combustible barrier with sufficient capacity to contain the spill should be constructed, or grading of the site is to be graded to divert the spill from a drainage system. However, this drainage system should be terminated at a location where such a spill will not create a fire hazard or any risk to health or safety or the natural environment, and this drainage should divert the spill away from buildings, fire department access roadways, or valves controlling the flow of flammable liquids or water supplies for fire fighting. If it is a close drainage system, it should be equipped with a trap.

Spills and Leaks

In order to prevent spillage and leakage of flammable liquids, proper maintenance and operating procedures should be established. Those flammable liquids should not enter areas where they could create a fire or explosion hazard. If a spill or leakage occurs, all reasonable steps should be taken to recover escaped liquid and remove all contaminated soil, surface water, ground water or aquatic system. These escaped liquids can be removed with the aid of an absorbent. These absorbents should be non-combustible or conform to ULC/ORD-C410A, "Absorbents for flammable and Combustible Liquids". The clean up of the spill or leakage should conform to Part X of the Ontario *Environmental Protection Act.*

Spill Procedure

A spill control procedure should be implemented if there are flammable liquids stored, handled, processed or used. The spill control procedure should include an operating procedure to prevent leaks and spills from piping, pumps, storage tanks or process vessels. A safety control of ignition sources (e.g. fire or heating source), a comprehensive spill clean up kit, and dikes and spill control agents should be available. People working with the flammable liquids should have their own protective clothing or equipment (e.g. rubber gloves, rubber boots and self-contained breathing apparatus). All wastes that are produced from the flammable liquids should be disposed of in accordance to the Ministry of Environment and Energy's requirements. The spill control plan should include a chain of command including notification of affected agencies and management and a preventive maintenance program. Training should be provided to new staff within 3 months after they are hired. If a staff already has experience with handling flammable liquid, training should also be provided within six months after they are hired. The spill control procedures should be posted where flammable liquids are stored, handled, processed or used.

2.4.2.2 TECHNICAL STANDARDS AND SAFETY ACT

Under *Technical Standard and Safety A*ct, there are three regulations related to spills.

Liquid fuels, Ontario Regulation 217/01, Section 13(2)

If a person discovers that a petroleum product has escaped into the environment, or he or she discovers a spill or leak inside a building, he or she should report to the operator of the facility or the licence holder.

Oil and Gas Pipeline System, Ontario Regulation 210/01, Section 14.1

The section only applies to oil and gas pipeline systems. If there is carbon monoxide poisoning, asphyxiation, explosion or fire occurring due to the handling or storage of oil or gas, the licensee shall notify an MOE's inspector of the occurrence in accordance to a notification procedure.

Propane storage and handling, Ontario Regulation 211/01, Section 15.1

The section is the same as regulation 210/01, section 14.1. The only difference is that this section applies to propane storage and handling.

2.4.3 SPILL ACTION CENTRE

2.4.3.1. SPILL ACTION CENTRE FUNCTION

The Spills Action Centre (SAC) commenced operations on November 29, 1985, the same day Part X of the *Environmental Protection Act* came into force. The main function of SAC is to maintain a province-wide, toll-free service for receiving, evaluating and initiating responses to notifications of spills and other urgent environmental matters on a 24-hour basis. It also serves as a provincial focal point for activities dealing with spills and related emergencies and liaises with other agencies on spills and related emergencies. The centre is to keep all the reported spills in a spill database for the Ministry. The centre also provides contingency planning functions and related response training.

2.4.3.2. APPROPRIATE RESPONSE ACTION

When a SAC staff member receives a report of a spill, he or she is required to evaluate the occurrence and to decide on the appropriate actions to be taken, with the assistance of SAC Operating Procedure Cards. Typical actions that will be taken when a spill is reported are:

- Contacting the owner of a suspected pollution source in an attempt to verify and resolve the problem;
- Initiating Ministry field response by contacting Environmental/Emergency Response Staff if required;
- Contacting other agencies as required (e.g., fire department, ambulance, Coast Guard, Canutec, municipalities, U. S. authorities);
- Establishing contact with the Minister regarding major spills and preparing direction and orders for the Minister's consideration, and conveying directions or orders from the Minister as necessary;

- Ensuring that potentially affected parties are notified or warned;
- Liaising with, and providing support for, agencies in charge when a spill involves an emergency situation;
- Recording details of complaints or incidents and forwarding them to relevant District Offices or other agencies for response during normal business hours.

Typically, SAC receives 4,000 to 5,000 reports of spills each year (Spill Action Centre 1997). Most of the spills can be dealt with by those responsible for the spill, or by municipal agencies, without the on-site presence of ministry staff. Depending on the size and nature of an incident, SAC can activate three levels of ministry field response listed below (Spill Action Centre 1997).

- Level 1 – District Response

Environmental officers working in district offices provide the ministry's first level of field response. An example that could trigger a Level 1 response may be a tanker truck that has an accident, spilling its load onto the highway. In this case, an environmental response person can be called in. He or she will make sure the contaminants are contained and removed for disposal by the owner who has control of the material at the time it is spilled. At this level, staff can conduct an initial assessment and determine the extra resources required, also the actions need to be taken next. If necessary, they can trigger the next level of environmental response.

- Level 2 – Regional Response

The Level 2 ministry response will typically be triggered two or three times in a year. The level is provided through resources available at the ministry's five regional offices. For example, the Level 2 action may be required to assist first response agencies during a chemical fire. SAC can activate a Level 2 response by contacting one of the regional offices. The office will provide back-up staff, equipment and technical expertise for complex incidents. It also provides air or water monitoring or modelling (a picture of existing, and possible projected, conditions). It will provide support, guidance and approval to initiate directions, approvals or orders under the *Environmental Protection Act*. If necessary, SAC can trigger the third level of environmental response.

- Level 3 – Head Office Response

The Level 3 response is usually triggered only once a year. This level will use additional ministry expertise and resources beyond the regional level. This may include on-site assistance from other branches, such as the Environmental Monitoring and Reporting Branch, Standards Development Branch and Laboratory Services Branch. For example, a large fire burning after a spill for an extended time close to a populated area will require a Level 3 response.

2.4.3.3. SPILL RECORD

Since SAC is responsible for maintaining spill records for the Ministry, all occurrences reported to SAC will be documented in the Ministry's Occurrence Reporting Information System (ORIS). Each year, SAC will prepare a summary for the spill database.

2.4.3.3. CONTINGENCY PLANNING

The Prime Minister of Canada and the President of the United States signed the Great Lakes Water Quality Agreement and agreed to establish mechanisms to deal with spills, pollution monitoring and pollution abatement in waters shared by the two countires. The Agreement called for a joint contingency plan which organizes the national, provincial/state, and local resources to deal with spills.

One of the SAC functions is to provide contingency planning. The main activities are to provide: advisory services for municipal and industrial spill contingency planning; spill response advisory services; and staff training and participation in spill training course and exercises. Several contingency plans are outlined below.

The Canada/United States Joint Marine Pollution Contingency Plan

This plan establishes the mechanism as required under the Canada/United States Water Quality Agreement. The plan is dependent on the supporting plans at the federal, provincial/state, and municipal levels. Under this plan, the Coast Guard of the country in which the spill originates is in charge. However, the MOE acts as a supporting role and gives advice on environmental matters through the Province of Ontario Spill Contingency Plan. The Ministry's field support is provided by the Regional Offices. SAC provides an International Joint Response Team under the MOE's executive support. This team is made up of representatives of the responding agencies from both countries and provides an advisory service to the Coast Guard in charge.

The Canadian Marine Contingency Plan

This plan deals with spills from ships in lakes or rivers which do not cross the international border. Therefore, the Canadian Coast Guard is in charge under this plan. Again, MOE will provide a supporting and advisory role similar to that outlined under the Joint Plan.

The Province of Ontario Contingency Plan for Spills of Oil and other Hazardous Materials

The main purpose of this plan is to establish a reporting and notification protocol for all spills. It also provides a mechanism to deal with major spills which threaten the environment under provincial jurisdiction. This plan mainly deals with containment, clean up, and disposal phases of spills and is subordinate to plans which deal with contingencies where the threat to life and property is of primary concern. If a major spill occurs within the MOE's mandate, this plan will place MOE in charge and MOE will work with the Ministries of Natural Resources, Northern Development and Mines, Health, Labour, Solicitor General and Correctional Services, Consumer and Commercial Relations, and Transportation. Two federal agencies, Environmental Canada and the Canadian Coast Guard, are also signatories.

The Province of Ontario Nuclear Plan

This plan is designed to coordinate response to major events involving nuclear generating facilities. The Plan establishes several groups and organizations in which MOE participates. The role of MOE is to sample under the direction of the Ministry of Labour, and participate in the Provincial Ingestion Monitoring Control Group, and the Provincial Restoration Committee established under the Plan.

The Canada-Ontario Agreement (COA) Spill Reduction Commitment

This spill reduction commitment initiated by federal and provincial government under the *Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem* (1994). In order to reduce pollutant loadings in the main concern area (such as the St. Clair River), this commitment focuses on the prevention and control of spills by improving federal and provincial spills prevention, preparedness and response programs in the main concern area. There are five educational workshops for industrial and municipal groups in the priority areas to promote awareness of the environmental consequences of spills.

2.5 Overview of Geographic Information System

The use of the term *Geographic Information Systems* (GIS) dates back to the mid-1960s (Goodchild, 1993). During that period, there were only two main purposes for GIS. The Canada Land Inventory used GIS to determine land use by overlaying two different maps. In the U.S., GIS was used to conduct a large-scale transportation modelling analysis. They used GIS to combine information on population distributions with other spatially distributed information, like employment and transportation routes. More recently, GIS has been widely used in various fields, by local government officials, urban and regional planners, land records administrators, the oil and gas industry, stormwater management (Li and Banting 1998), etc.

Environmental problem solving is one of the strongest and most successful application areas for GIS. Many forest resource companies and regulatory agencies used GIS in the early 1980s, as did environmental agencies such as the U.S. Environmental Protection Agency, the National Park Service, and the Bureau of Land Management (Goodchild, 1993). GIS also has been widely used for environmental modeling because it provides a processing environment for the capture, manipulation and analysis of spatial distribution data. For example, GIS has been used in atmosphere modelling (Fedra, 1993). In order to estimate the effect of source pollution from factory or highway sources, GIS was used to create a buffer area around the source pollution, and then compare the population distribution with buffer areas to find out how much the population would be affected by the source pollution.

GIS also has been used in hydrological modelling such as lake models, river models, runoff models and erosion models (Fedra, 1993). Spatially distributed data such as watershed parameters, such as slope, soils, land cover and channel characteristics are the most important inputs in these models. GIS can model the surface and subsurface flows in a 3D structure. GIS users can visualize the flooding or erosion of a river.

GIS can also be used in biological and ecological models because spatial pattern is an important factor in the analysis of plant sociology, forestry and plankton studies (Fedra 1993). These spatial patterns can easily be visualized by mapping spatial data in GIS and the user can use the geostatistic function of GIS to conduct a statistical analysis of these spatial data. As a result, GIS is an appropriate tool for analysis of spill prone areas and remedial actions.

Traditional numerical or regression analyses only compare the attributes data between two subjects. However, GIS can compare data in a spatial format by displaying two or more layers of map at the same time and providing an opportunity to visualize the spatial pattern (Figure 8). For example, by overlaying the oil spill locations with the street map, the pattern of the oil spills in the urban area can be visualized. In a similar manner, oil spills near or inside an Environmentally Sensitive Area can be identified.

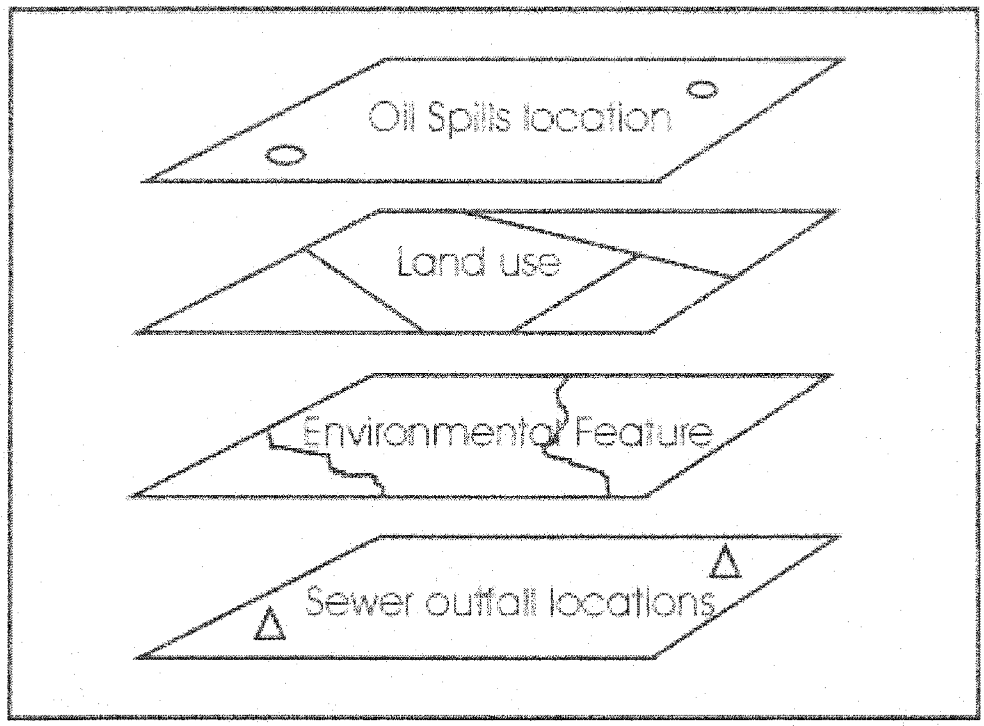

Figure 8 Data Overlays in a Geographic Information System

2.6 Summary

Urban oil spills have the potential to cause serious impacts on surface and groundwater, soil and air. In order to management these spills, the environmental pathways of oil spills should be identified. Although non-structural and structural measures are available for spill control, there is an acute need to develop new applications of these control measures. For instance, the application of oil-water interceptors for spill control in storm drainage systems should be investigated further. A review of spill legislations and regulations in Ontario and Canada also reveals that most of these legislations and regulations are developed primarily for spill response. A proactive approach to spill management should focus on pollution prevention. For instance, the recent city of Toronto's sewer use bylaw was developed to address both pollution prevention and discharge of pollutants to sewer systems.

CHAPTER 3

DESIGN OF AN OIL SPILL CONTROL SYSTEM FOR STORM OUTFALL STRUCTURES

3.1 INTRODUCTION

Humber Creek is a tributary of the Humber River. It is located in the northwest part of Toronto. The total length of the stream is approximately 4 km. The width of the Creek varies from 5 m at the upstream end to about 10 m near the mouth. The total drainage area is about 815 ha and the subwatershed has been highly urbanized since the 1970's. There are 20 stromsewer outfalls which discharge directly to Humber Creek. The storm sewer outfalls range in size from a diameter of 250 mm to an crose-section area of 2.7 m by 5.2 m. The largest storm sewer services a total drainage area of more than 200 ha, including industrial lands located northwest of Highway 401 and Kipling Ave.

In 1999, the City of Toronto together with the Toronto and Region Conservation Authority (TRCA) realized the potential impacts of urbanization on Humber Creek and downstream bodies of water. Thus, they commissioned a study to assess and characterize the current state of physical, biological and environment conditions within the Humber Creek subwatershed, develop a preliminary natural channel design for the Humber Creek and develop a pollution and stormwater quantity control strategy which incorporates the implementation of structural and non-structural stormwater best management practices within the entire subwatershed.

In the mid 1980's, the degradation of water quality within Humber Creek was identified as a result of spills from the industrial area located northwest of Highway 401 (Aquafor Beech Limited 1999). Therefore, part of the subwatershed study assessed the frequency and composition of spills. The study results showed that spills were frequent in Humber Creek. There were 53 reported spills located in the Humber Creek subwatershed between 1994 and 1996. The maximum size of the spill was 5,940 gallons and the average size of a spill was 95 gallons. About half of the spills were petroleum products.

The main purpose of the subwatershed study was to rehabilitate the Humber Creek channel by creating a physical environment suitable for aquatic organisms. However, one of the problems was the degraded water quality in the stream due the algal blooms, oil residuals and noxious odours from frequent spills. If the water quality will not improve, the rehabilitation of the channel cannot be successful even with a perfect physical environment. As a result, the City of Toronto had decided to install an oil spill control structure at the Humber Creek near Dixon Road to capture oil spills and improve the water quality in the creek.

The proposed location for this oil spill control structure is the 12 ft x 9 ft box culvert under Dixon Road. As previous spills occurred mostly during dry weather, the design capacity of the control structure is based on the dry-weather flow rate in this culvert. Table 2 shows the baseflow upstream of the box culvert monitored by Aquafor Beech Ltd. in 1993. In the summer of year 2001, the author conducted field measurements at the downstream end of the box culvert and the results are shown in Table 3. By measure the flow velocity and the cross-section area of Humber Creek at the downstream end of the box culvert, and using the following two equation, the discharge of at the box culvert was found.

Q =V * A which Q = discharge

V = flow velocity

A = Cross –section area

It is noted that the baseflows in both tables are consistent and the maximum baseflow is 120L/s. As a result, the design flow for the oil spills control structure is set at 120L/s

Table 2 Wincott gauge Baseflow (Aquafor Beech Ltd, 1999)

Date	Flow Rates from Aquafor Beech Ltd
May 16, 93	120 L/s
July 14, 93	40 L/s
Aug 30, 93	70 L/s
Oct 4, 93	50 L/s

Table 3 Storm outfall H-632 Baseflow

Date	Field Measured Flow Rates
May 16, 01	92 L/s
July 14, 01	50 L/s
Aug 30, 01	75 L/s
Oct 4, 01	55 L/s

3.2 Design Concept

The spill control structure is designed to capture dry spills and baseflow that enter the box culvert and divert them to an off-line oil/water interceptor. Oil is to be trapped at the oil/water interceptor while baseflow is to be released back to the box culvert. During wet weather conditions, the flow diversion channel limits the storm flow from entering the oil/water interceptor and prevents the washout of the trapped oil.

3.2.1 Flow Diversion Channel

In the ideal case, an oil/water separator should be sized to capture wet and dry spills. Unfortunately, the size of the oil/water separator will be very large in order to handle the large quantity of storm water during wet spills. Moreover, the cost will be extremely high. Previous study has showed that 80% of the oil spills in Toronto occurred during dry weather (Li, 2000). Thus, the treatment rate of the oil/water separator is designed for dry weather flows.

The flow diversion channel is designed to limit high flows to the oil/water interceptor during wet weather. During a storm event, the flow rate in the sewer will increase dramatically in a short period of time. These large quantities of storm runoff can enter the oil/water separator at a very high velocity and drag out oil that is already trapped in the separator. If the inflow to the oil/water separator is controlled by the diversion channel during a storm event, the overall effectiveness of the oil/water separator can be increased dramatically.

3.2.2 Off-Line Oil/Water Separator

The traditional American Petroleum Institute (API) gravity-type oil/water separator was chosen for this oil spills control structure because the most frequent types of oil spills in Toronto are diesel oil and gasoline, (Li 2000). The larger the oil droplet, the faster it rises through the water in an API separator. Therefore, it can be installed underground and no electricity is needed. For maintenance, all the floatables and sediments must be cleared out and the trapped oil should be removed frequently using absorbents or skimming devices.

3.3 Design of the diversion channel

Weirs are typically used to divert flow in a storm drainage system. For instance, the first flush of runoff is usually diverted to stormwater quality ponds for treatment. A typical diversion structure is shown in Figure 9. This system is commonly referred to as a "dual pond system". The height of the weir equals the height of the water in the stormwater treatment facility. When the storm runoff is greater than the storage of the treatment facility, the extra runoff will spill over the isolation/diversion weir to the detention facility for flood control or exits directly into the downstream stormwater collection system. However, the weir cannot control the flow entering the treatment facility at high flows. If the diversion weir is used to divert the stormwater into the oil/water separator, the stormwater will fill the separator completely and flush out all the trapped oil in the separator.

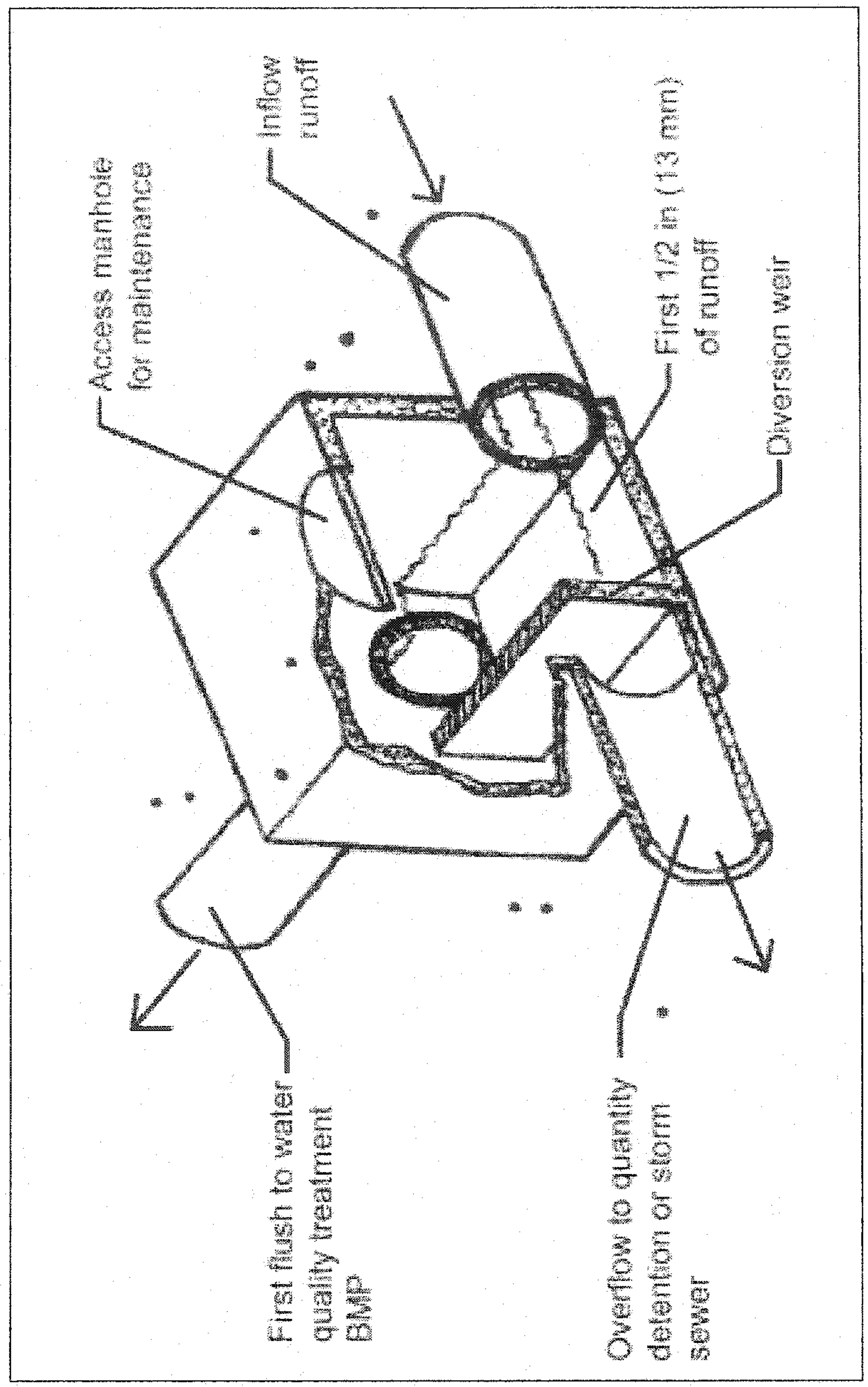

Figure 9 A perspective view of a typical diversion structure[1]

[1] http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/water/volumes/sodivstructure.pdf.

In order to limit the inflow into the oil/water separator, a lateral diversion channel is used. This diversion channel will be built across the sewer as indicated in Figure 10. It consists of three parts, an upstream ramp, a lateral diversion channel and a downstream ramp. The lateral diversion channel is connected to the oil/water separator through a pipe. During dry weather, the base flow in the sewer will drop into the diversion channel and enter the oil/water separator. Later, the clear treated effluent will re-enter the box culvert downstream of the separator. During wet weather, storm runoff will exceed the capacity of the diversion channel and spill over to the downstream storm system. The drop diversion channel will limit the flow into the oil/water separator and prevent washoff of trapped oil.

The design of the diversion channel is based on the theory of side-channel spillway or a spatially varied flow with increasing discharge. When the storm runoff drops into the channel, a certain amount of energy will be lost due to turbulent mixing. Since the magnitude of this energy loss is relatively high and uncertain, the momentum equation is more suitable to solve this problem than the energy equation (Chow 1959). Hinds developed the first fundamental differential equation for spatially varied flow with increasing discharge in year 1926 (French 1994). Several studies have since modified the equation. For example, Camp *et al.* (Chow 1959) had integrated this equation for prismatic rectangular channel with uniform inflow throughout the channel length. In this thesis, the design of the diversion channel will be based on the standard differential equations in Chow's hydraulics textbook (1959).

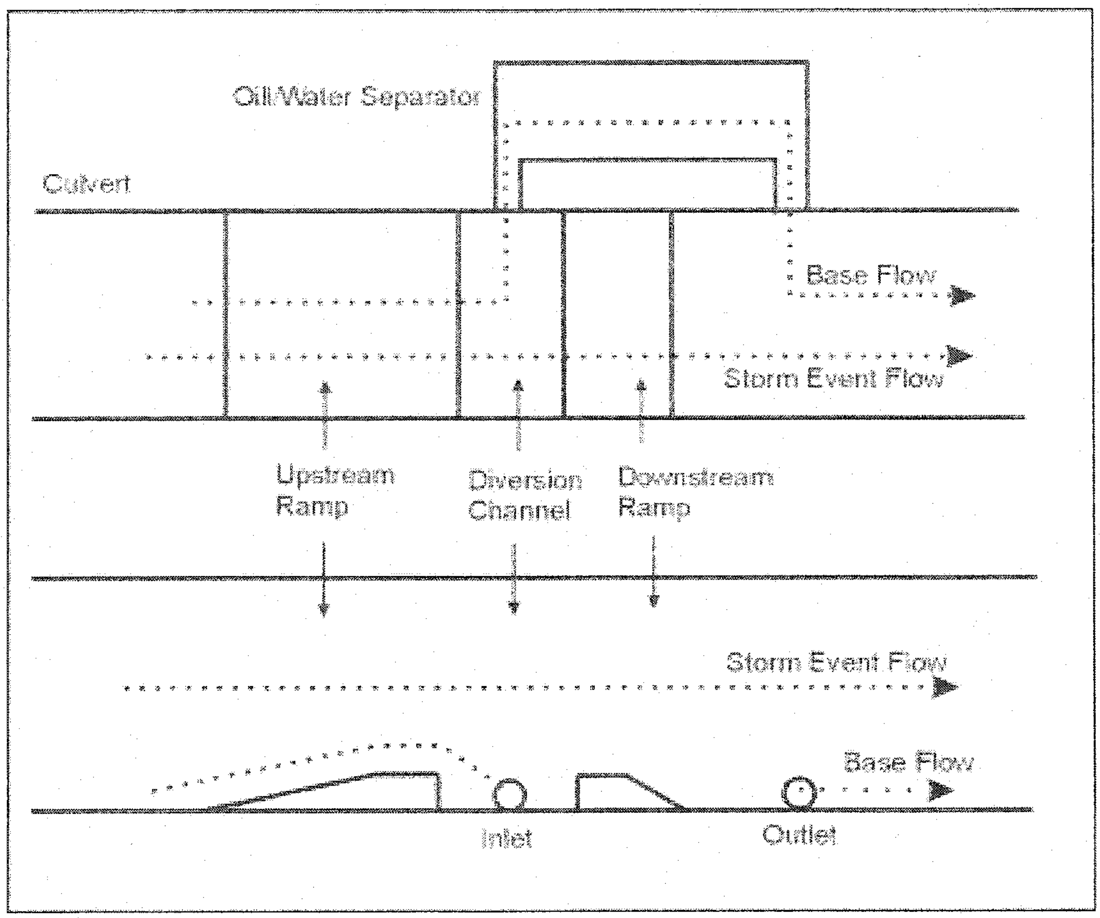

Figure 10 Plan and Profile View of a Rectangular Diversion Channel

3.3.1 Design for testing Rectangular Diversion Channels

Since the theory of side-channel spillways was developed for a rectangular drop channel, it was felt that an arbitrarily sized physical model should be constructed to study the flow conditions. Two 1:5 physical models were tested at the National Water Research Institute's Hydraulics Laboratory at the Canada Centre for Inland Water in Burlington, Ontario. The first physical model consists of three parts: a flume which acts as the box culvert, a pipe which acts as the inlet of the separator, and a lateral rectangular drop channel, which is the main focus of the experiment. The physical model was built inside a one-metre flume (Figures 11 and 12). Since the size of the box culvert is 3.75m by 2.7m, the size of the model should be 0.75m by 0.54m. However, the interior width of the flume is 1.0m. Therefore, several plywood boards were used to narrow down the width of the flume to a measurement of 0.75m (Figure 11 and 12). The inlet of the separator was modelled by a 2-inch PVC pipe and the lateral drop channel was constructed from a plywood board. To study the effect of diversion weir size, the downstream ramp of the rectangular channel was also designed to accommodate various sizes of weirs.

Since a lateral drop channel might be expected to trap sediments, an elevated drop channel was investigated (Figure 13). This physical model is similar to the first one except the whole device was elevated by 75 mm above the base of the channel. Sediments are expected to move as bed load beneath the drop channel so maintenance can be minimized.

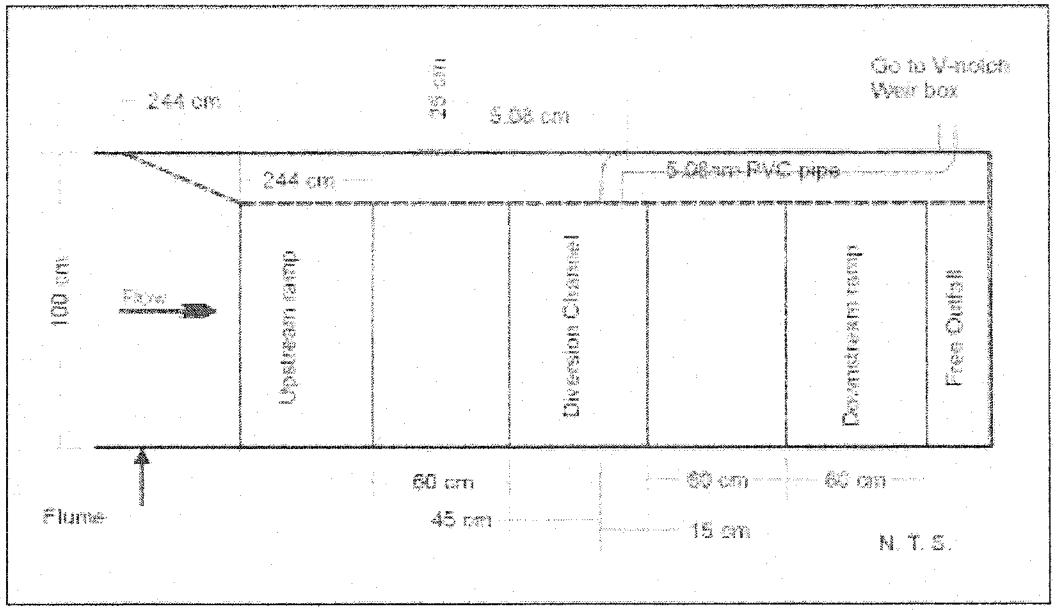

Figure 11 Top View of the rectangular horizontal diversion channel model

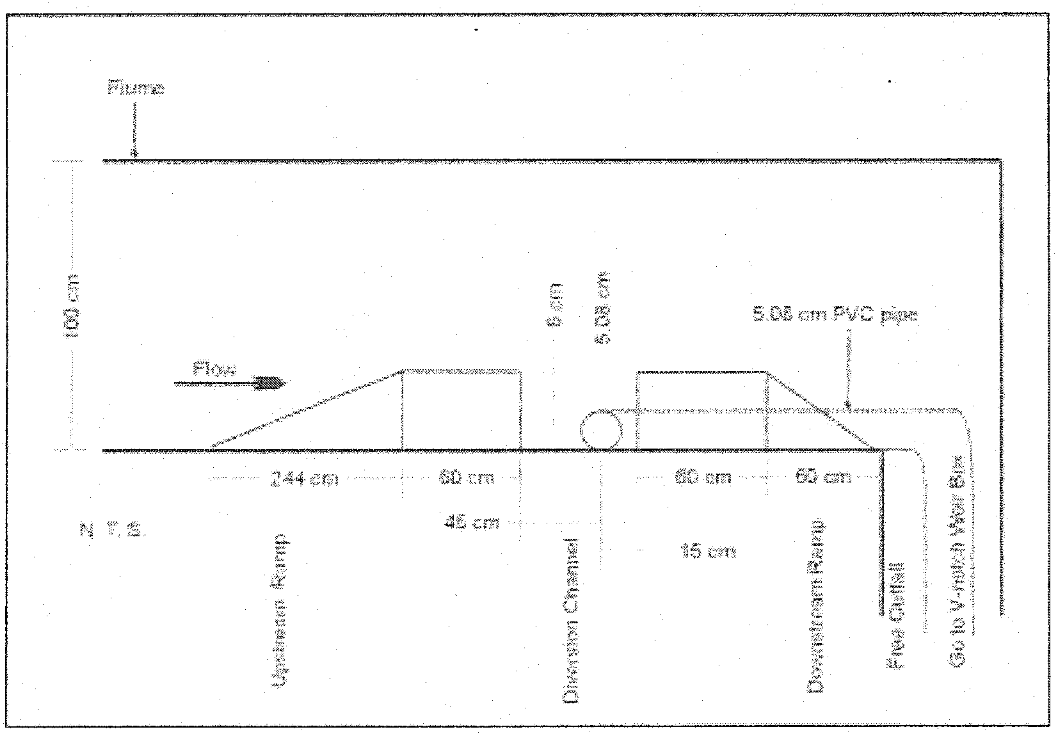

Figure 12 Side View of the rectangular horizontal diversion channel model

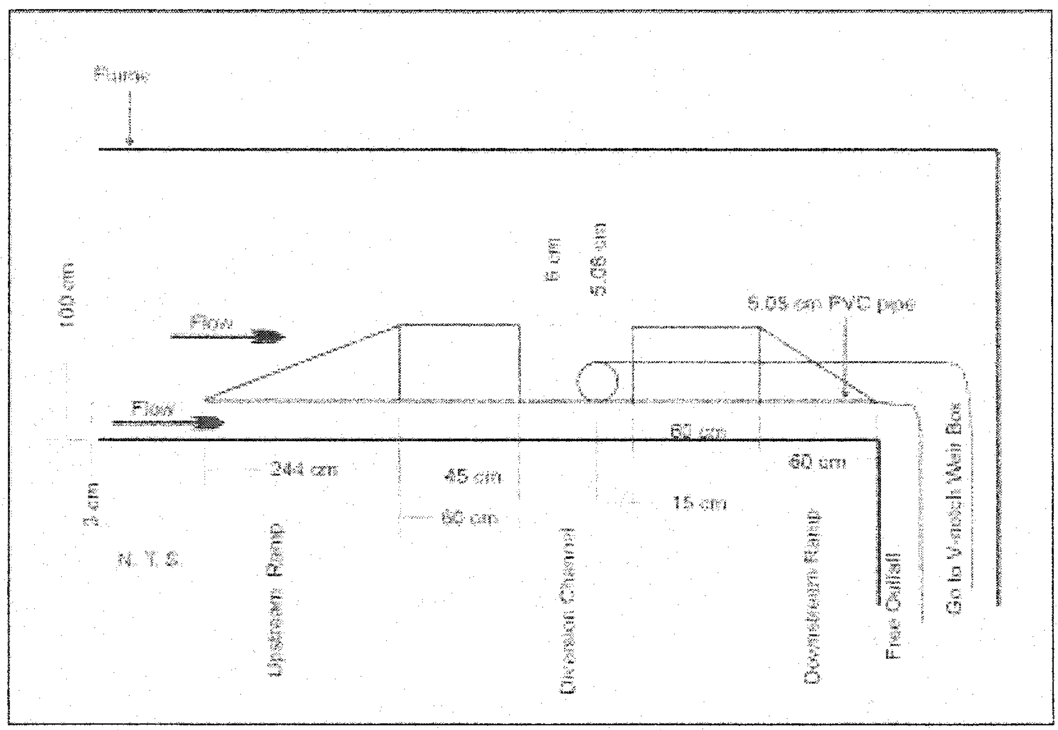

Figure 13 Side View of the elevated rectangular horizontal diversion channel model

3.3.2 DESIGN FOR A TRIANGULAR DIVERSION CHANNEL

The diversion channel is designed to convey the dry weather flow of Humber Creek to the proposed oil/water interceptor. To minimize any maintenance works at the diversion channel, floatables and sediments in the dry weather flow should also enter the separator where the trapped oil, floatables, and sediments can be removed frequently. To facilitate the transport of floatables and sediments, a sloping triangular channel at 45 degree diagonal to the storm water flow was designed (Figure 14). Similar to the testing rectangular channel, there are two ramps connecting to the triangular diversion channel (Figure 15).

By using the law of conservation of linear momentum, flow in the diversion channel is completely determined by making the momentum after impact equal to that before impact plus any acceleration due to external forces. The water profile of the side-channel spillway can be described by the following equation (Chow 1959).

$$dy/dx = (S_0 - S_f - 2\,Q\,q_*/\,g\,A^2\,) / (\,1 - Q^2 / g\,A^2\,D\,)^2 \qquad (1)$$

Which q = total discharge per unit length

S_0 = Slope of the side-channel spillway

S_f = the frication slope = $Q^2\,n^2 / 2.22\,A^2\,R^{(1/3)}$

D = hydraulic depth

A = Cross-section area of the channel

g = acceleration of gravity

R = Hydraulic RadiusIn order to find the maximum height of the channel, Eq (1) is set to be zero.

$$0 = \{\,S_0 - S_f - 2\,Q\,q_*/\,g\,(y^2)^2\,\} / \{\,1 - Q^2 / g\,(y^2)^2\,(0.5y)\,\} \qquad (2)$$

[2] V. T. Chow 1958 "*Open Channel Hydraulic*" McGraw-Hill, New York

After substituting the basic geometry of the diversion channel and design flow (see table 3) into Equation 1 and solving by the trial and error method (Figure 16), the maximum height of the triangular diversion channel is 0.33 m and the width of the diversion channel is 0.66 m. In order to ease the model construction, the height and width of the diversion channel are set to 0.35 m and 0.70 m.

Table 4 The basics geometry of the Triangular Diversion Channel

Total Discharge, Q	0.12 m^3/s
Total length of channel, L	5 m
Total length per unit length, q	0.024
Hydraulic depth for Triangle, D	½ * y
Estimate Manning's *n* for concrete, *n*	0.015
Slope of the side-channel spillway, S_0	0.05
Area of the channel, A	y^2
Hydraulic Radius for Triangle, R	0.354 y

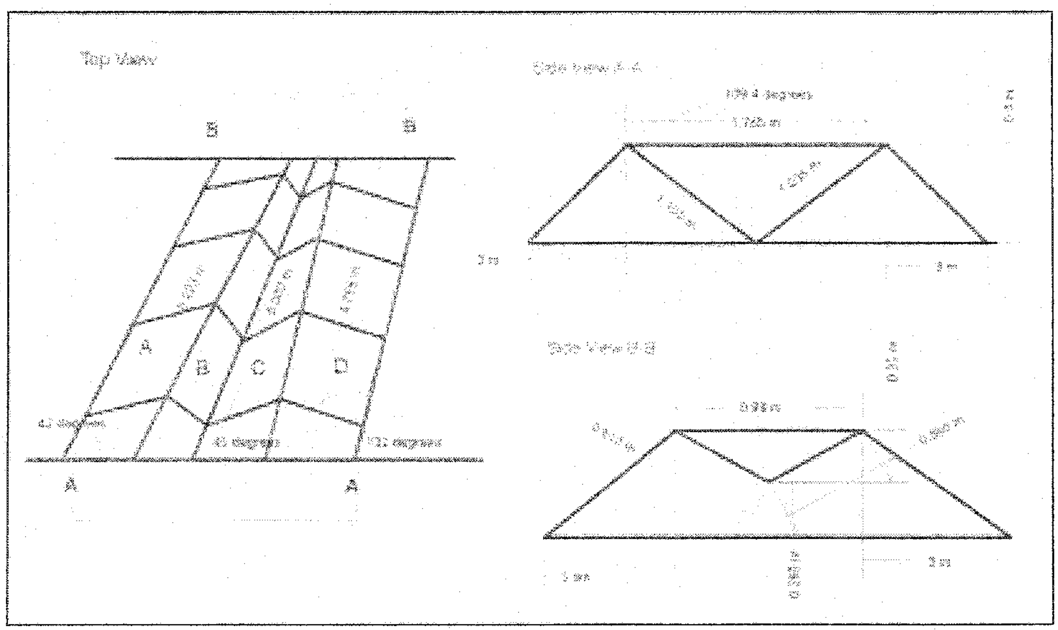

Figure 14 Top and side view of the 45-degree triangular sloping diversion channel

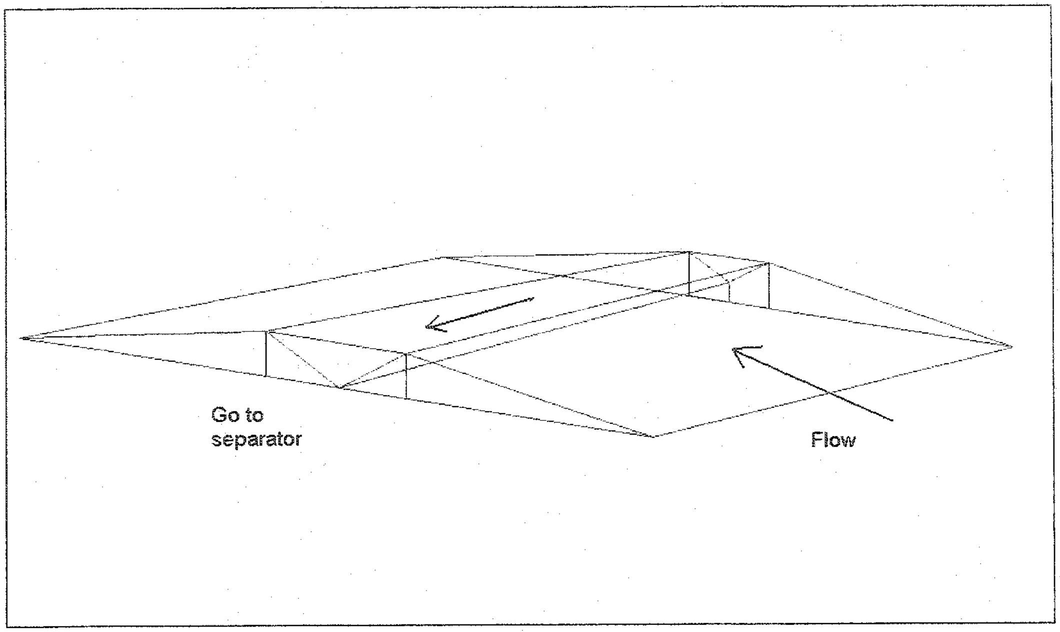

Figure 15 3-D view of the 45-degree triangular sloping diversion channel

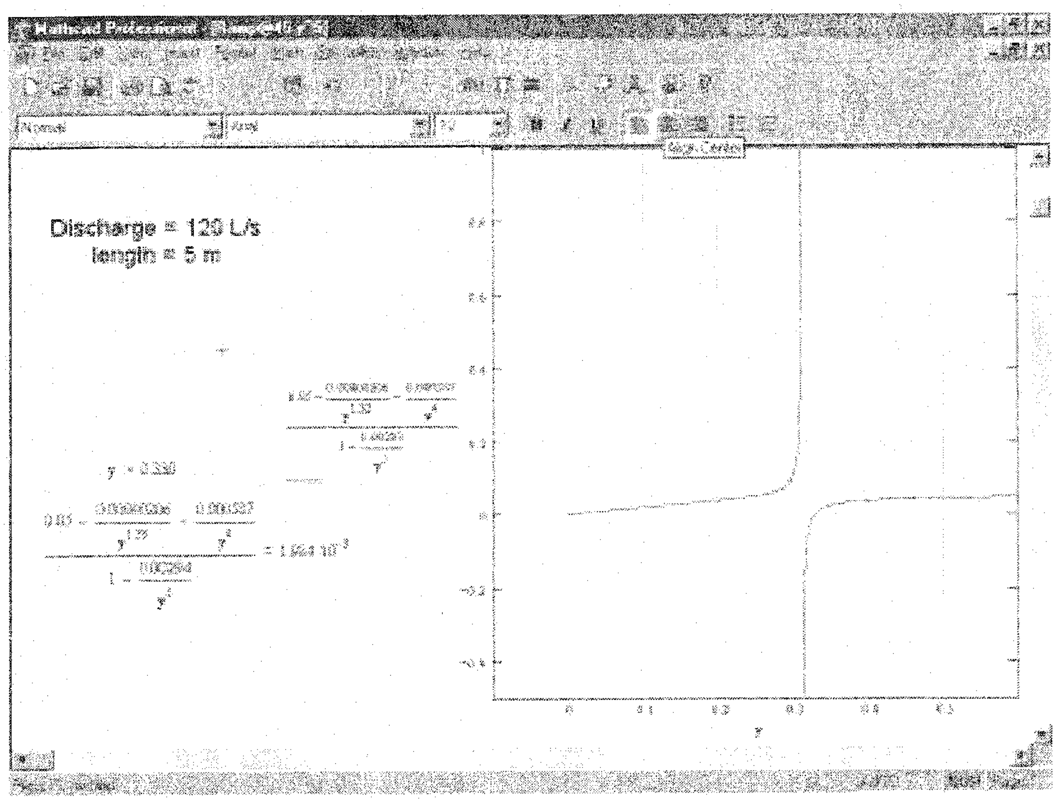

Figure 16 Design Equations for the triangular diversion channel

3.4 OFF-LINE OIL/WATER INTERCEPTORS

In 1990, the American Petroleum Institute (API) published a design and operation manual for oil/water separators. In the manual, it was presented the background theory of the separator, the construction details of the separator and a series of step-by-step design calculations for API separators and parallel-plate separators. Since the API separator has been adapted for a variety of industrial wastewater treatment applications over a long period of time (API 1990), the design of the oil/water separator for the Humber Creek project will follow this manual.

In the manual, API states

"The performance of gravity oil-water separators varies with changes in the characteristics of the oil and wastewater, including flow rate, specific gravity, salinity, temperature, viscosity, and oil-globule size."

The API separator is designed for wastewater treatment process which has a steady flow rate. In order to accommodate this requirement, the diversion channel was designed to provide a steady flow condition for the separator.

3.4.1 DESIGN CALCULATIONS FOR THE API SEPARATOR

The oil/water separator theory is based on Stokes' Law of gravity separation (API 1990) where lighter oil rises up the water surface and separates itself from the water. If an oil globule has a rise rate greater than or equal to the surface-loading rate, it will rise to the surface and be removed. The rise rate of the oil globule can be caculated using the Stokes' Law .

$$V_t = (g / 18 \mu) (\rho_w - \rho_o) D^2 \qquad (3)$$

Where V_t = rise rate of the design oil globule, in cm/s

g = acceleration due to gravity, 981 cm/s

μ = absolute viscosity of wastewater at the design temperture, t, in poise

ρ_w = density of water at the design temperature, t, in g/cm^3

ρ_o = density of oil at the design temperature, t, in g/cm^3

D = diameter of the oil globule to be removed, in cm

Using Eq (3) and the design flow rate of 120 L/s, the size of the separator can be determined.

Before the calculation, the following parameters are required.

- Maximum wastewater flow or design flow,

  The maximum baseflow in the creek is 120 L/s, thus the design flow for the separator will be 120 L/s.

- Wastewater temperature,

  The usual temperature for stormwater is around 10°C to 15°C in the summer, and the design temperature is assumed to be 10°C.

- Wastewater specific gravity,

  Ideally, the stormwater is just rainfall which is clear water. Thus the specific gravity of water will be used in the design.

- Wastewater absolute viscosity

At the design temperature, the absolute viscosity of clean water can be found in the manual.

- Wastewater oil-fraction specific gravity.

Since most of the spills in the Humber creek were related to gasoline, the oil-fraction specific gravity was set as 0.72 which is the specific gravity for natural gasoline (Delta Control Corporation 1999).

A step-by-step design procedure for the API separator is listed below.

Step one: Determine the rise rate for the oil globules (V_t)

Since the API separator is designed to treat free oil globules of 150 μm diameter, the rise rate of these globules is determined by

$$V_t = 0.0241*(S_w - S_0)/\mu \qquad (4)$$

Where S_w = specific gravity of fresh clean water at 10 °C
S_0 = specific gravity of gasoline
μ = absolute viscosity of fresh clean water at 10 °C, in poise

Step two: Determine the maximum allowable mean horizontal Velocity (V_H)

The design mean horizontal velocity (V_H, in feet per minute) is determined by the smaller value of two constraints. One is 15 times of the rise rate for the oil globules, or 3 feet per minute, which is recommended as the upper limit for conventional refinery oil/water separators.

Step three: Determine the minimum vertical cross-section area (A_C)

Given the design flow rate and the horizontal velocity, the cross-section area can be determined by the following equation.

$$A_C = Q_m / V_H \qquad (5)$$

where A_C = minimum vertical cross-section area
Qm = design flow to the separator
V_H = horizontal velocity

Step four: Determine the channel width and depth

Given the total cross-sectional area of the channels, the width and depth of the channel can be determined by the following equation.

$$d = A_C / B \quad (6)$$

where d = depth of channel
A_C = cross-section area
B = width of the channel

Since there are two unknowns in this equation, the width and the depth of the separator will be determined by trial and error until the depth-to-width ratio is between 0.3 to 0.5.

Step five: Determine the separator length, L

After the separator depth and width have been determined, the length of the channel can be calculated by the following equation.

$$L = F * (V_H/V_t) * d \quad (7)$$

Which L = length of channel
F = turbulence and short-circuiting factor
V_H = horizontal velocity
V_t = rise rate for the design oil globule
d = depth of channel

The turbulence and short-circuiting factor (F) is determined by a short-circuiting factor of 2.1 and a turbulence factor which depends on the ratio of V_H and V_t. A graph of F versus the ratio V_H/V_t can be found in the API manual.

The preliminary dimensions of an API separator that could treat 120 L/s of wastewater are 4 m by 16 m by 2 m (Figure 17). Detailed calculations can be found in Appendix A. Since the size of this separator may be too large for the Dixon Road's site, an alternative design of the API separator is presented in the next section.

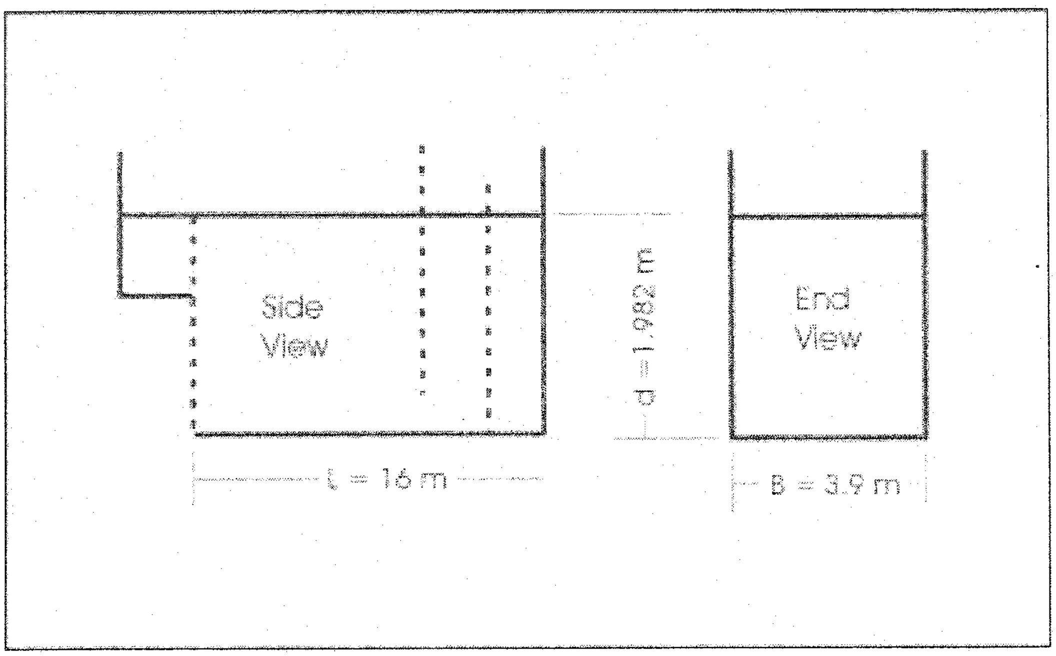

Figure 17 Preliminary design of an API separator

3.4.2 Design Calculations for a Tilted Plate Separator

Studies (Iggleden 1973) indicate that smaller tilted plate separators provide oil/water separation similar to that of API separators. The API separator described in the last section requires 280 m^2 plan area to remove 60 μm globules of 0.9 sg oil from a flow of 120 m^3/h oily water at 20^{0}C. However, the tilted plate separator only requires 16 m^2 plan area to achieve the same result. By installing a series of tilted parallel flat plates at an angle of 45 degree to the direction of flow, the tilted plate separators maximize the coalescing action of the oil globules. The tilted parallel plates provide a solid surface for the small oil droplets to accumulate upon. These accumulated oil droplets will form a thick oil film and become a source of large drops which rise faster to the surface of the separator. As a result, tilted plate separators maybe able to capture smaller diameter oil globules. A traditional API separator is designed to capture 150 μm diameter globules or bigger while a tilted plate separator is designed to capture 60 μm diameter globules or bigger.

Iggleden's study (1973) provides the following procedure to calculate the number of titled plate packs in a separator given that a design flow is known.

Step one: Determine the rise rate of the oil globules (V_S)

Since the tilted plate separator can capture 60 μm diameter globule or bigger, the rise rate for the 60 μm diameter oil globule can be calculated by

$$V_s = 0.00386 * [(S_w - S_0) / \mu] \qquad \textbf{(8)}$$

Which S_w = specific gravity of fresh clean water at 10 ^{0}C
S_0 = specific gravity of gasoline
μ = absolute viscosity of fresh clean water at 10 ^{0}C, in poise

Step two: Determine the total surface area required (A)

Same as before, the total surface can be calculated by using following equation.

$$A = Q / V_s \tag{9}$$

Which Q = design flow rate

V_s = rise rate of 60 μm diameter globule

Step three: Determine the total number. of TPS pack required

The standard TPS pack consists of 47 corrugated plates in a unit of 1750 mm long by 1000 mm wide by 1000 mm high. The plates are held at a spacing of 20 mm by supporting combs at each end of the pack. There are thus 46 compartments for bulk flow and oil globule separation, with a total plate surface area of 69 m^2. However, the total plate surface area cannot be fully utilized due to hydraulic turbulence. The effective surface area available for separation is 43.5 m^2 after the hydraulic factor is taken into consideration (Iggleden 1973). The required number of packs is determined by the ratio of total surface area and the effective area of one pack. It is determined that an oil/water separator that can treat 120 L/s of wastewater will need 7 packs of TPS plates. Detailed calculations are shown in Appendix A.

When the 7 packs of tilted plates are installed at the separator, there are several issues to be considered. First, the last chamber of the separator may trap fine sediments. Since sediments are typically removed using vertical suction vacuum devices, an extension ramp below the tilted plates should be installed under the titled plates to allow sediment to slide down the last chamber (Figure 18).

Second, the largest suction head that vacuum devices can reach is about 7 metre and the depth of the separator should be smaller than 7 m. In order to have a shallowest separator, the 7 packs of tilted plates are arrangd in one row to keep the depth of the separator under 7 m.

Third, in order to prevent floatables from plugging the inlet of the separator, the partition between the first and second chamber should be lower than the inlet of the separator. This will also create more storage room for the floatables. However, this design may reduce the performance of the separator because it will allow more turbulence in the separator.

Fourth, the outlet of the separator should not restrict the flow through the oil/water separator. In order to ensure the inlet and outlet of the oil/water separator have the similar discharge rate, the normal depth of the two openings should be comparable. By setting the discharge rate at 120 L/s, the normal depths for the inlet and outlet are computed (see table 4). Thus, the diameter of the outlet is set to be 0.762 m or 30 inches.

After all the issues are taken into consideration, a final design of the tilted plate separator is obtained (Figures 18 and 19).

Table 5 Comparisons between Inlet and Outlet

	Inlet	**Outlet**
Area	0.336 m^2	0.456m^2
Height	0.35 m	0.762 m
Normal Depth at 120 L/s	0.33 m	0.328 m

(For detailed calculation, see Appendix A)

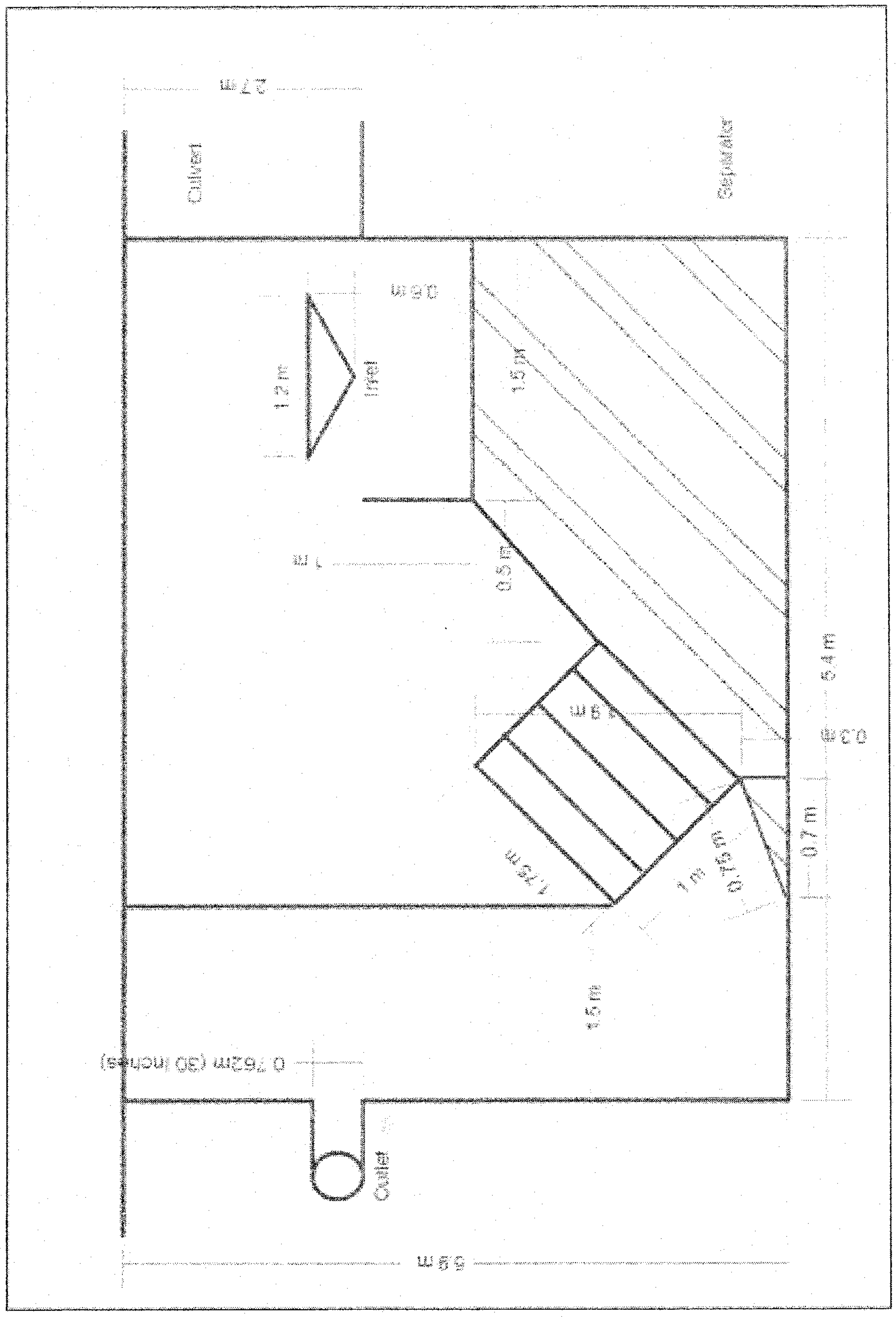

Figure 18 Side View of the tilted-plate oil spearator

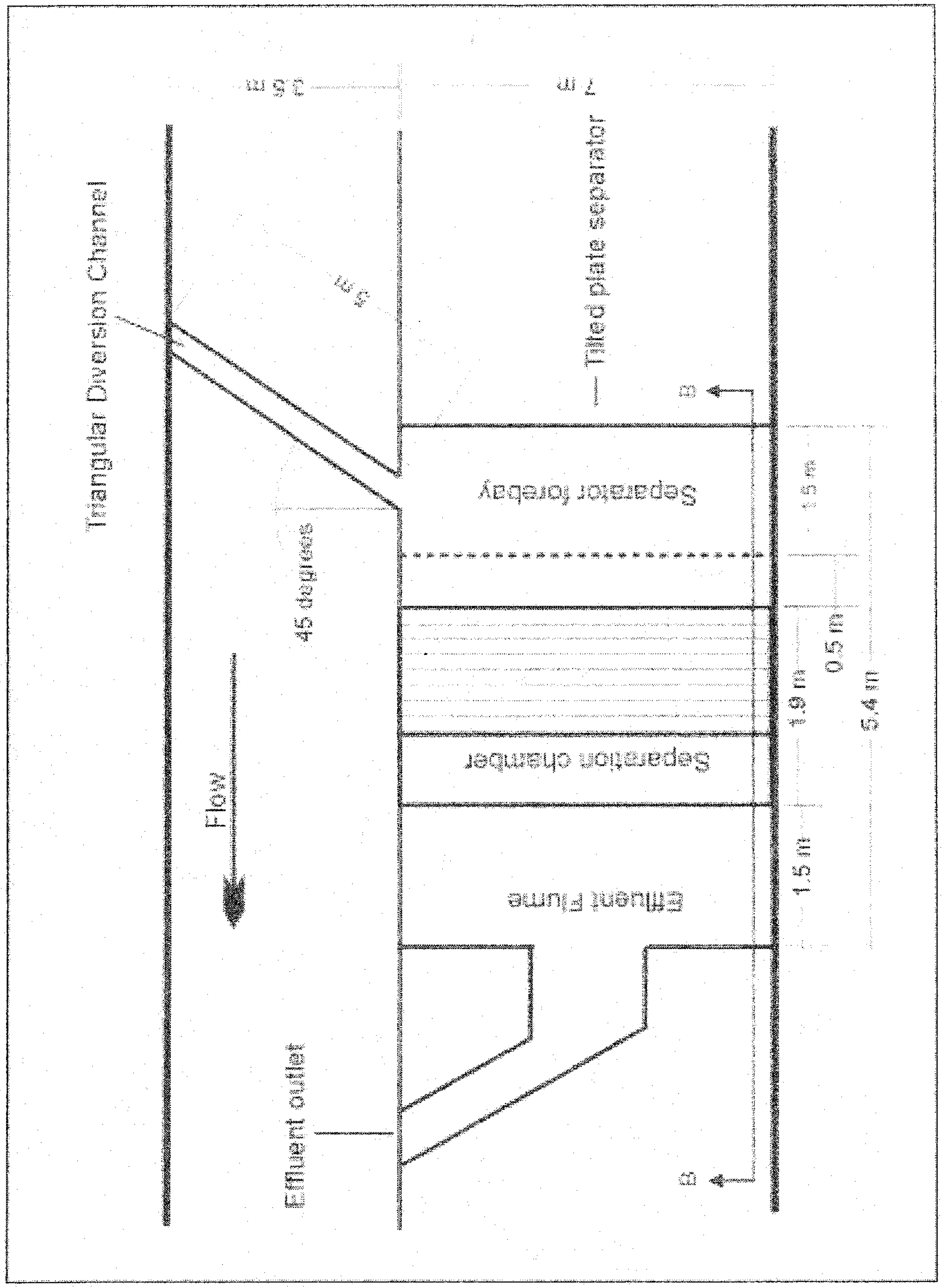

Figure 19 Top View of the tilted-plate oil spearator

3.4 SUMMARY

In 1999, the City of Toronto together with the Toronto and Region Conservation Authority (TRCA) realized that urbanization had degraded the environment in Humber Creek and the downstream water bodies. In order to rehabilitate the environment in Humber Creek, the physical environment of the Humber Creek should be rehabilitated and the water quality in the Humber Creek should be improved. Studies showed that the degradation of water quality within Humber Creek was in part a result of spills from the industrial area located northwest of Highway 401. As a result, the City of Toronto desires to install an oil spill control structure in the Humber Creek sewer outfall to capture spills and improve water quality in the creek.

This oil spill control structure has two components: a flow diversion channel and an oil/water separator. As most of the spills occur during dry weather, the design of oil spill control structure should be based upon the dry weather flow. When the spilled oil enters the sewer, the mixture of oil and baseflow should be diverted into the separator by the flow diversion structure. After the spilled oil is separated from the baseflow in the oil/water separator, the treated water will re-enter the sewer. During wet weather, excess flow will spill over the diversion channel to reduce the washout of trapped oil at the separator.

Conventional diversion weirs cannot limit the diverted flow rate into the oil/water separator. Thus, the trapped oil at the separator may be flushed out during a storm event. Thus, a new diversion structure that can limit the divert flow is needed.

A sloping triangular drop channel is designed to divert baseflow into the separator and limit excess flow during wet weather.

An API separator was chosen to be the oil spill treatment facility at Humber Creek. However, the size of the conventional API separator is too big for storm water treatment facility because of limited space in retrofitting situations. Thus, a smaller tilted plate separator which can achieve similar performance as API separator is proposed.

CHAPTER 4

PHYSICAL MODEL STUDY OF THE OIL SPILL CONTROL SYSTEM

4.1 INTRODUCTION

Although the preliminary design of the oil spills control system is based on well-known theories, it is necessary to observe how the control system may operate in real life. By conducting a physical model investigation, the behaviour of the control system under various flow conditions, such as the flow capacity of the diversion channel, the sedimentation problem in the diversion channel, and the back water effect in the separator can be observed. The problems they cause may not be fully foreseeable at the design stage. For instance, the physical model can provide measurements to confirm the theoretical design capacity of the diversion channel. As a result, a physical model investigation of the oil spills control system is essential.

4.2 DESIGN OF THE PHYSICAL MODEL

Since the design of the oil spills control system is based on gravity force, a Froudian model is chosen for the design of the physical model. The length scale of the physical model is 1:5. Thus, the discharge scale of the model is 1:55.6 according to the scaling equations in Table 6.

Table 6 Scales for basic hydraulic quantities[3]

Length Scale	λ_l
Velocity Scale	$\lambda_v = \lambda_l^{0.5}$
Time (duration) Scale	$\lambda_t = \lambda_l^{0.5}$
Discharge Scale	$\lambda_Q = \lambda_l^{2.5}$

4.2.1 DESIGN OF FLOW DIVERSION CHANNEL EXPERIMENTS

The primary objective of the experiments is to measure the flow capacity and water profile in the diversion channel. The measured flow capacity of the diversion channel can be compared with the theoretical design values and confirm the diversion channel design. By measuring the water depths at the diversion channel, a water profile at the diversion channel can be created. The water profile can improve the understanding of local hydraulics and provide data for future hydraulic models. Also, qualitatively testing of floatables on the model was also conducted. If all floating objects are trapped inside the diversion channel, it will decrease its flow capacity and create maintenance problems.

[3] Larkin, G.A. and J. Marsalek 1998 *Laboratory testing of modification to the OCPA oil/grit separator* National Water Research Institute, Technical Note No. AEP-TN98-001

4.2.1.2 Rectangular Diversion Channel

The experiments of the rectangular diversion channel were arranged in four aspects: the rectangular diversion channel, diversion weir flow rate, and floatables and sediments.

- Diversion Channel

In order to find a reasonable size for the rectangular diversion channel, the model was tested in three different widths: 30 cm, 40 cm, and 60 cm.

- Diversion Weir

Since the effect of a typical diversion weir on the oil spill control system is uncertain, the rectangular diversion channel was modified at the downstream ramp to test two different sizes of diversion weirs, as well as a test without the diversion weir (Figure 20).

- Flow Rate

In order to simulate different storm event scenarios, the model was tested at six different flow rates. Table 7 shows different experiments of the diversion channel model at each flow rate.

- Floatables and Sediments

Styrofoam bits and fine sands were added to the flow in order to allow visual observations of their behaviours at the diversion channel.

Table 7 Different combinations of the model in single flow rate

COMBINATION	CHANNEL WIDTH (CM)	WEIR HEIGHT (CM)
1	60	None
2	60	2
3	60	6
4	45	None
5	45	2
6	45	6
7	30	None
8	30	2
9	30	6

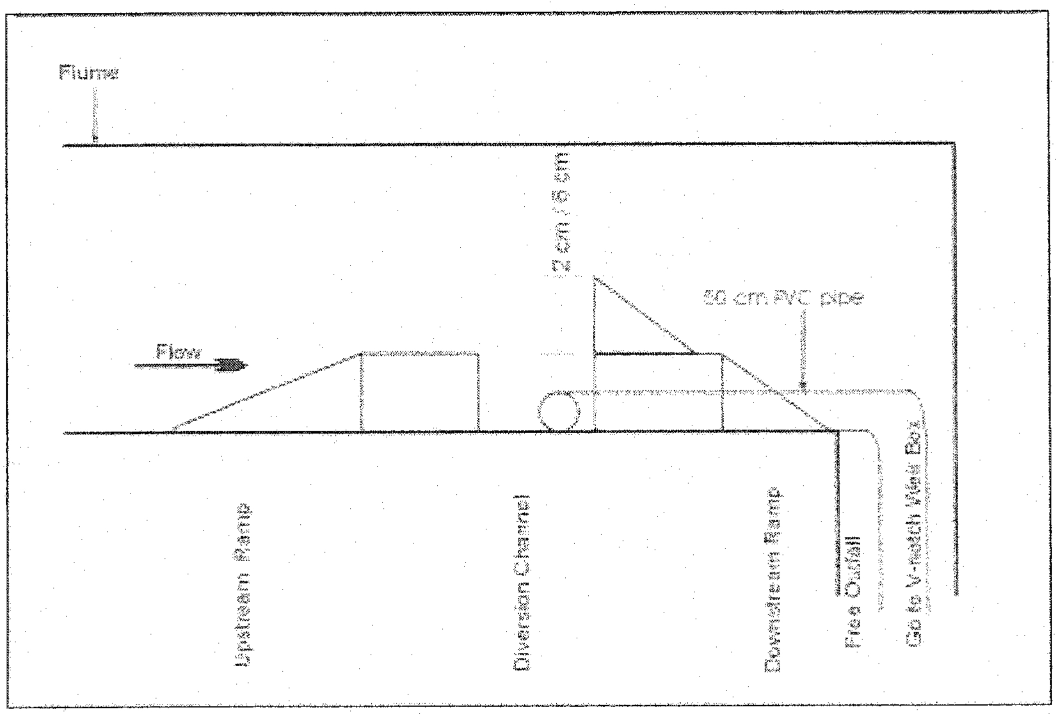

Figure 20 The diversion weir in relation to the diversion channel

For the lowest flow rate, the diversion weir will not be tested because the diversion channel captures all flows without any overflows. Therefore, the size of the diversion weir will not be obstructive to the flow. As a result, there were 48 experiments conducted on the model.

In each experiment, the total flow that enters the flume was adjusted by a valve and measured by the volumetric head tank. Then, the water levels at 26 different locations were measured by a point gauge (Figure 21). For each location, the water level was measured twice. Only the water levels along the inlet of the pipe were measured three times. The finest measure from the scale of the point gauge is 0.1 mm. Thus, the reading error for the water profile is about $\pm$ 0.2 mm. After all water levels were measured, a three-dimensional water profile across the diversion channel could be plotted out. Finally, the discharge of the pipe is measured by a 90^0 V-notch weir box (Figures 22 and 23).

Since the Humber Creek was observed to contain suspended and bed load sediment especially during first flush of storm event, there is a major concern over sedimentation at the diversion channel. Therefore, after the first 48 experiments, the diversion channel model was raised 3 cm to simulate an underflow system for the movement of bed sediments. When the diversion channel was raised up, the bed sediments can pass through the structure without enter the diversion channel while floatables and spilled oil can enter the oil spills control system.

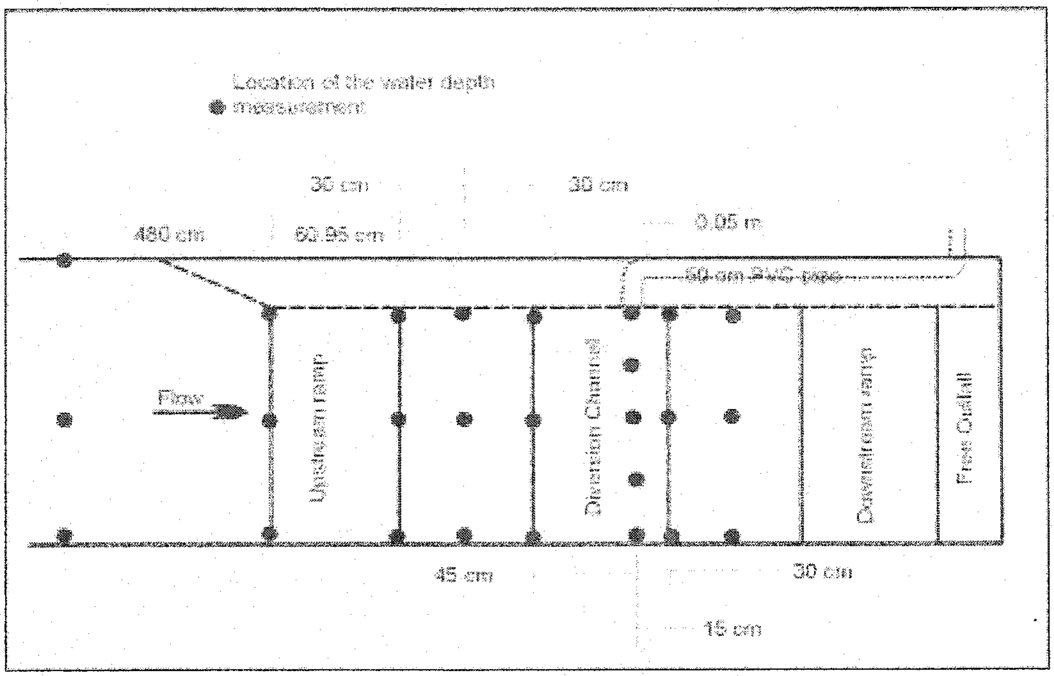

Figure 21 Locations of the water depth measurements at the rectangular channel

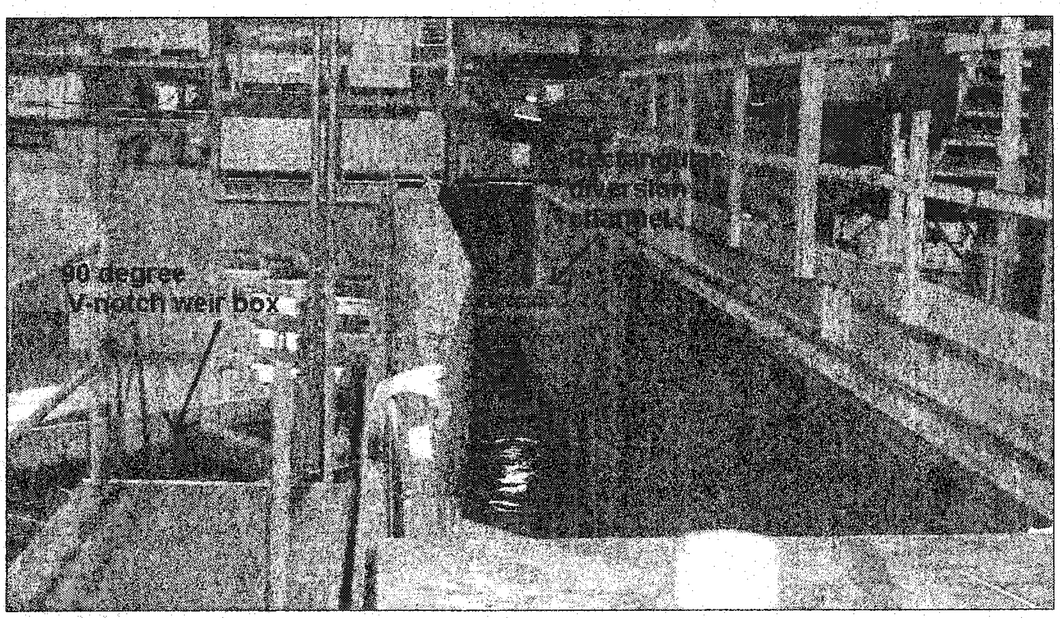

Figure 22 The experiment setup of the rectangular channel

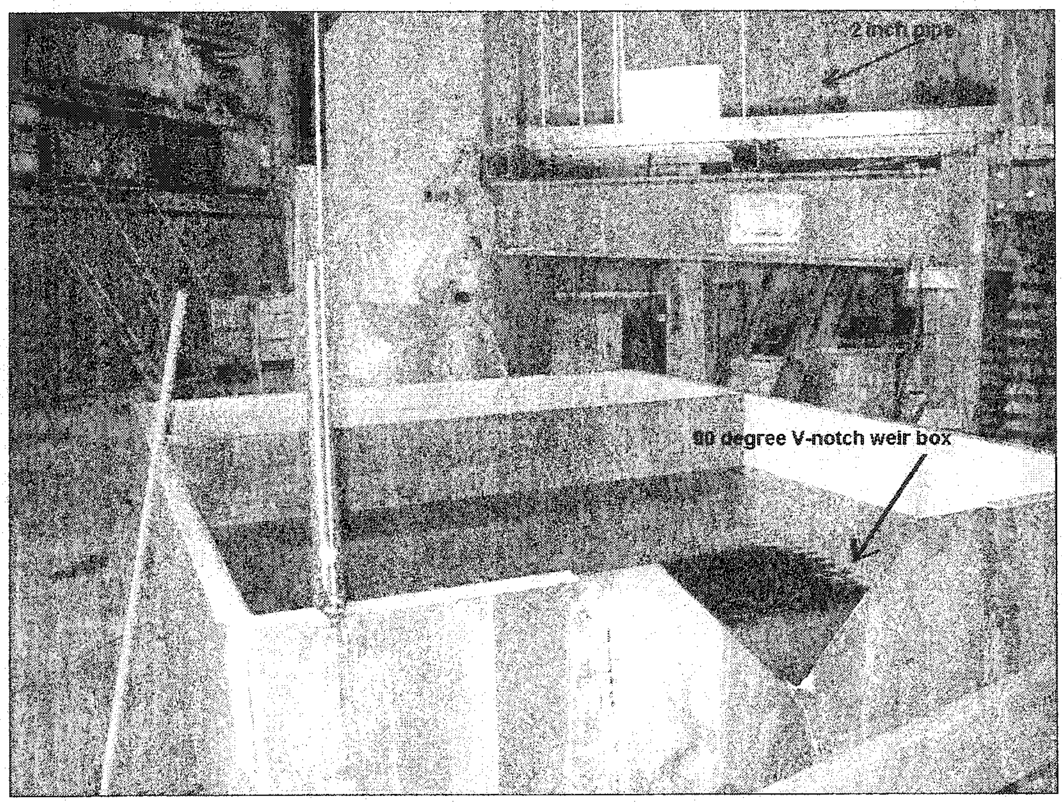

Figure 23 The experiment setup of downstream weir measurement box

4.2.1.2 TRIANGULAR DIVERSION CHANNEL AND TILTED PLATE SEPARATOR

The experiments on the triangular diversion channel were designed to study: the flow rate in diversion channel, the backwater effect at the separator and the height of the first partition of the separator.

- Flow Rate

In order to simulate different storm event situations, the model was tested at five different flow rates.

- Backwater Effect

In order to investigate the significance of backwater effect on the flow through the separator, the experiment wwas repeated two times for each flow rate, one with the outlet pipe connected to the main channel while the other with the outlet pipe connected to an independent measurement box. The water depths at different compartments of the separator under these two conditions were then compared.

- Height of the first partition in the separator

In order to increase the storage capacity of oil and floatables in the separator, the height of first partition was set at the lowest point of the inlet. However, this was thought to have the potential to create turbulent flow in the second partition and decrease the performance of the separator. Thus, the experiments were repeated for different heights of the first partition.

- Floatables and Sediments

Styrofoam bits and fine sands were added to the flow in order to allow visual observations of their behaviours at the diversion channel.

These three aspects, results in twenty experiments. In each experiment, the total flow that enters the channel was adjusted by a valve and measured by the volumetric head tank. Then, water levels at 28 different locations were measured by the point gauge (Figure 24). The water level at each location was measured twice except those along the inlet of the pipe where water levels were measured three times. The finest measurement from the scale of the point gauge is 0.1 mm. Thus, the reading error for the water profile is about $\pm$ 0.2mm. The water profile across the diversion channel was plotted out. The outlet of the separator was connected to a Y-pipe section where outflow (Qs) from the separator could be directed to either a weir measurement box or back to the box culvert. When the outflow (Qs) of the separator directed back to the box culvert, an OTT C-1 current meter initially measured the outflow rate. Due to hydraulic turbulence, the velocity measurements were not possible. In order to estimate this outflow (Qs), the weir formula was used.

$Qo = C\ L\ (dH)^{3/2}$ which Qo = Overflow of the diversion channel = $Q_{total} - Qs$
C = Weir coefficient
L = Length of diversion channel
dH = The overflow depth of the diversion channel

But there are two unknowns in the weir formula; one is outflow (Qs) from the separator, the other is the weir coefficient. In order to calibrate the weir coefficient, the outlet (Qs) of the separator will direct to the weir measurement and the overflow depths of the diversion channel were then measured by a point gauge. Figures 25 and 26 show the regression analysis of the weir coefficent. It is noted that the weir formula works well within the flow range. Therefore, the outflow of the separator that directed back to the box culvert could be calculated from the weir formula.

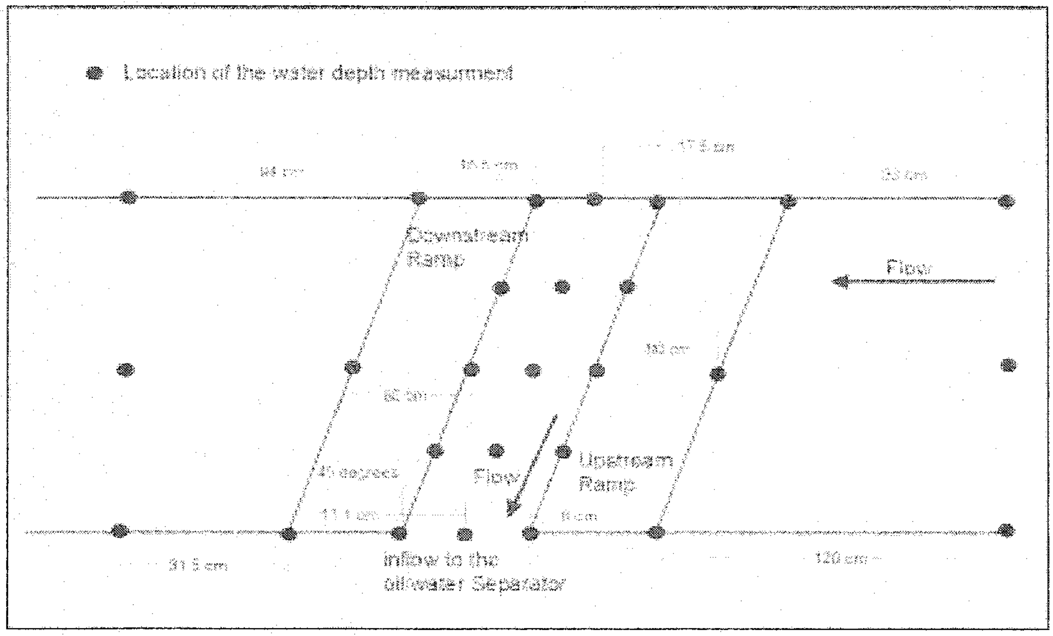

Figure 24 Locations of Water Depth Measurement at the 45 degree channel

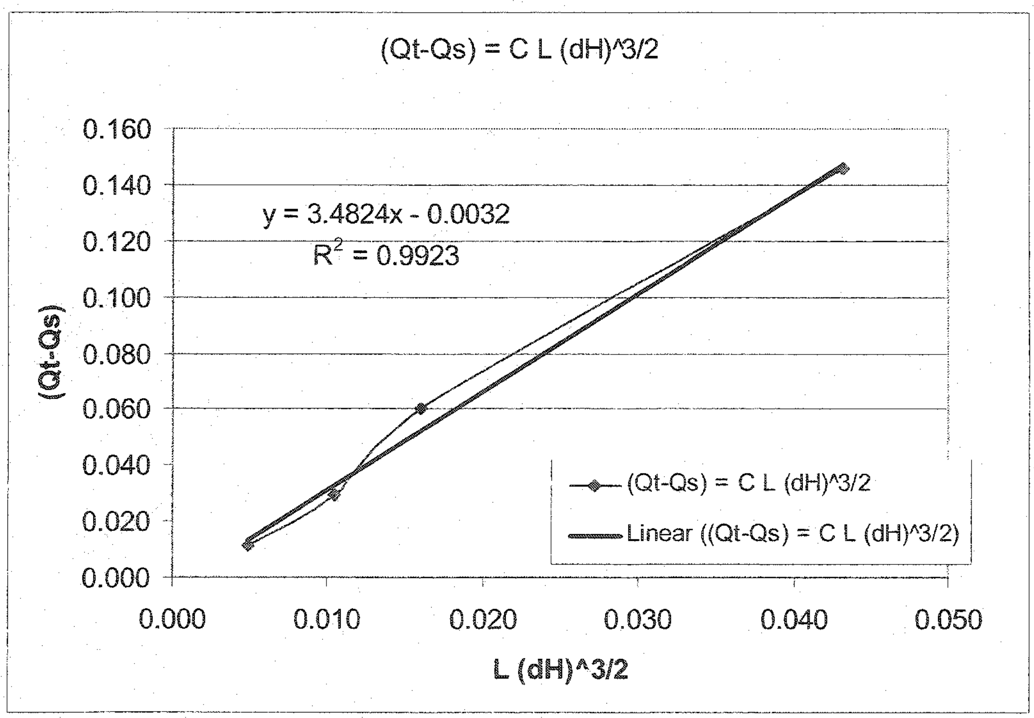

Figure 25 Calibration cure for the overflow rate at the diverion channel (Low parition)

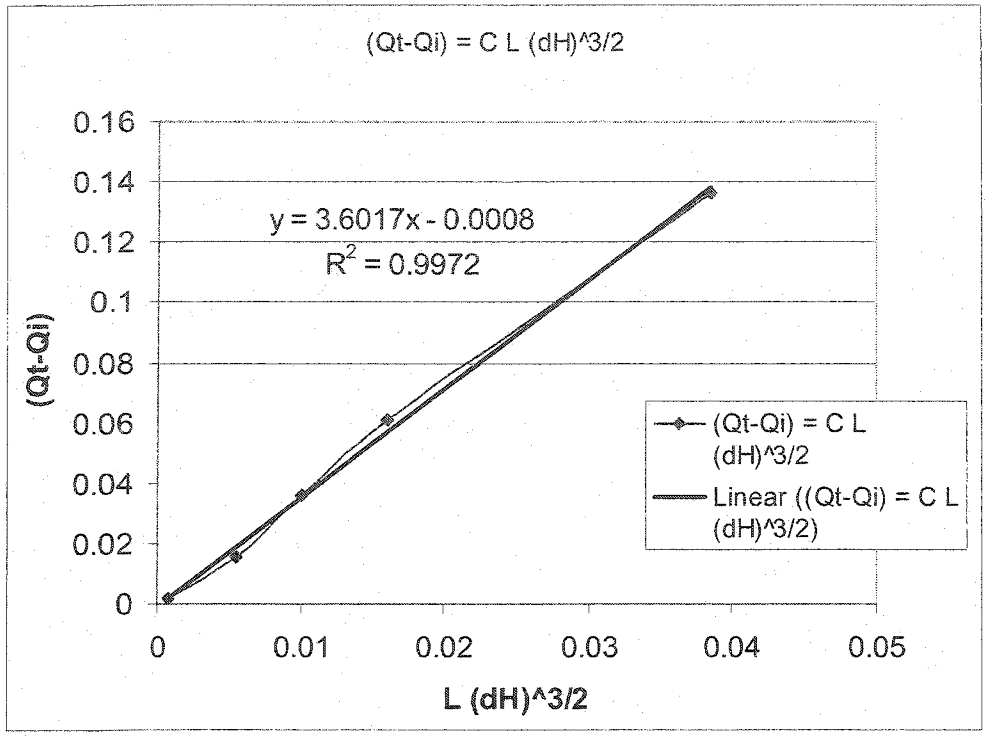

Figure 26 Calibration curve for the overflow rate at the diversion channel (High parition)

4.3 Experimental Results

4.3.1 Rectangular Diversion Channel

4.3.1.1 Inflow to the separator

The experimental results demonstrated that the diversion channel did limit the inflow to the separator during high flows (storm event conditions). Once the total flow exceeds the base flow of the diversion channel, the discharge through the connecting pipe starts to level off (Figures 27 to 29). For example, when the total flow exceeded the base flow, the discharge through the pipe varied from 5.3 L/s to 5.7 L/s for the combination of a channel width of 60 cm without the weir. In addition, the diversion channel did limit the large quantity of water entering the separator. When the total flow equals 362.2 L/s, the inflow to the separator was only 5.7 L/s.

The experimental results also highlighted the fact that the diversion weir did obstruct the total flow in the flume. When the level of the diversion weir became higher, the discharges through the pipe were larger (Figures 27 to 29). For example, the discharge through the pipe increased from 5.7 L/s to 6.14 L/s when the height of the diversion weir changed from 0 cm to 6 cm. The water level also increased when the height of the diversion weir increased. The water level increased by 5 cm when the height of the weir increased from 0 cm to 6 cm (Figures 30 to 32). Although the increment of water level was small, the weir might obstruct water flow and cause water to back up in the upstream area.

In addition, the experimental results indicated that the channel width did not have any effect on the flow through the pipe. When the width of the channel increased, the discharge through the pipe did not increase (Figures 33 to 35).

However, the diversion channel could capture more base flow as the width of the channel increased.

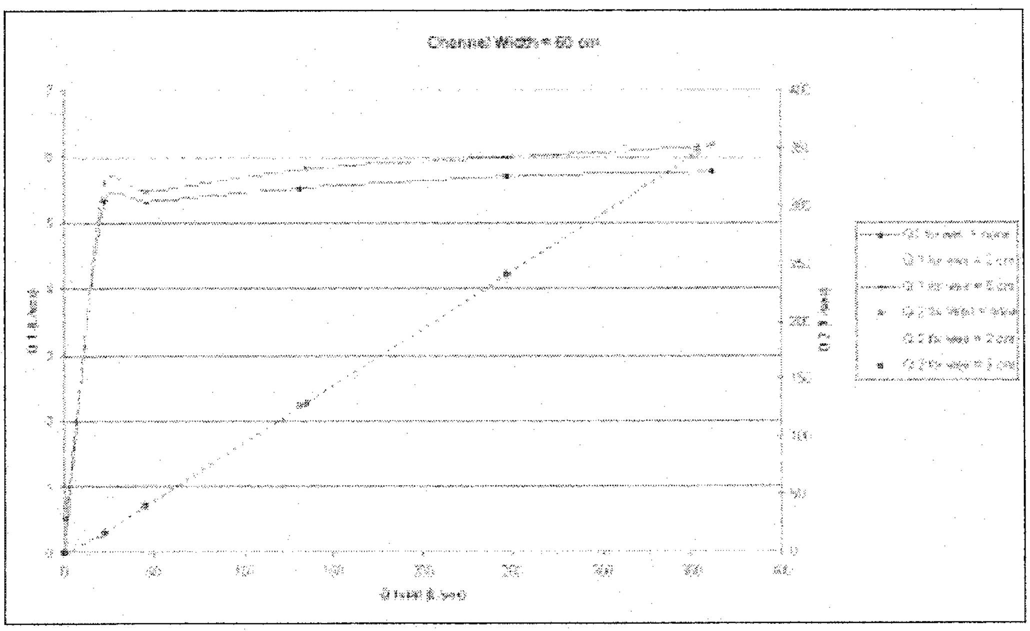

Figure 27 Total Flow (Qt) Vs Pipe Discharge (Q1), Channel Width = 60 cm

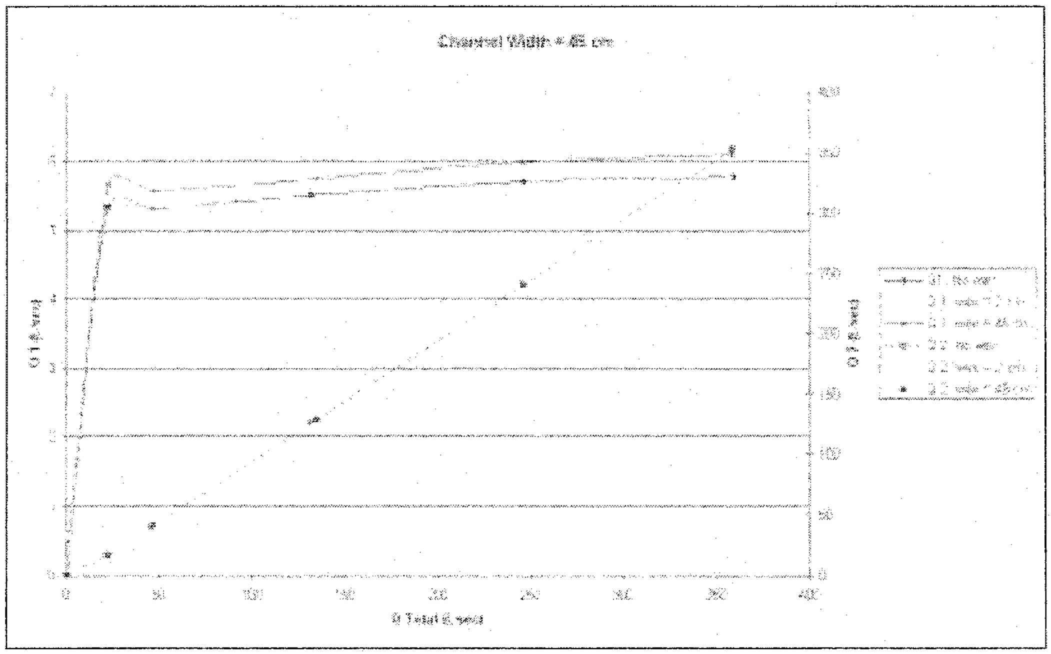

Figure 28 Total Flow (Qt) Vs Pipe Discharge (Q1), Channel Width = 45 cm

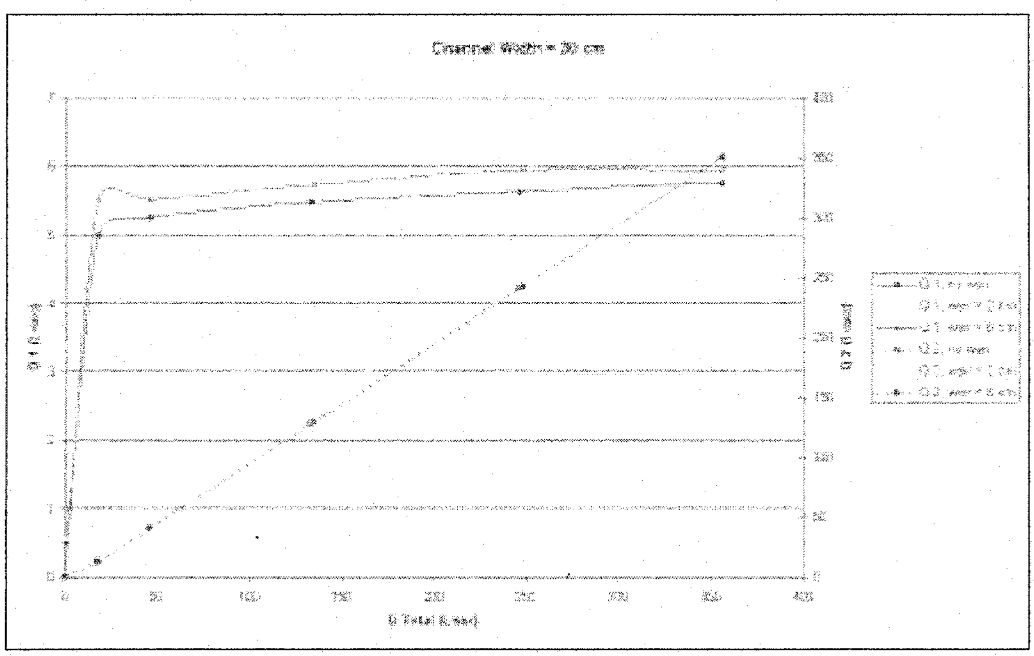

Figure 29 Total Flow (Qt) Vs Pipe Discharge (Q1), Channel Width = 30 cm

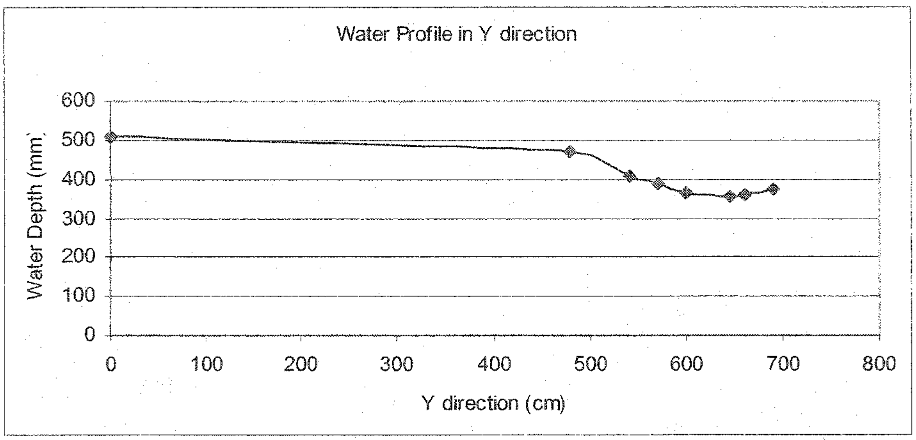

Figure 30 Water Profile for a Channel width of 60 cm and no diversion weir installed

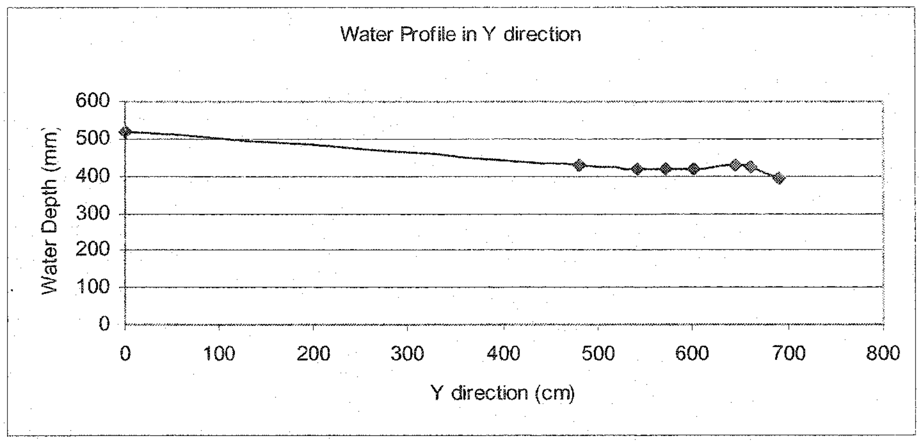

Figure 31 Water Profile for a Channel width of 60 cm and 2 cm height diversion weir installed

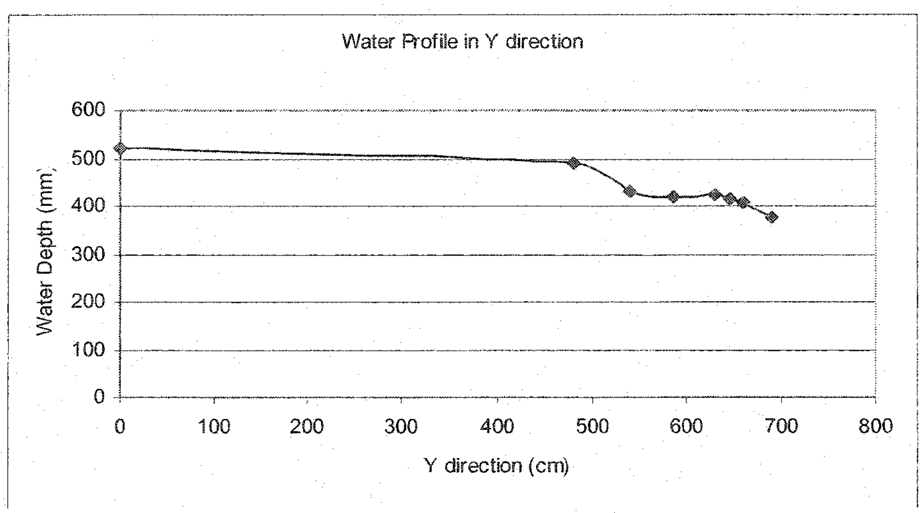

Figure 32 Water Profile for a Channel width of 60 cm and 6 cm height diversion weir installed

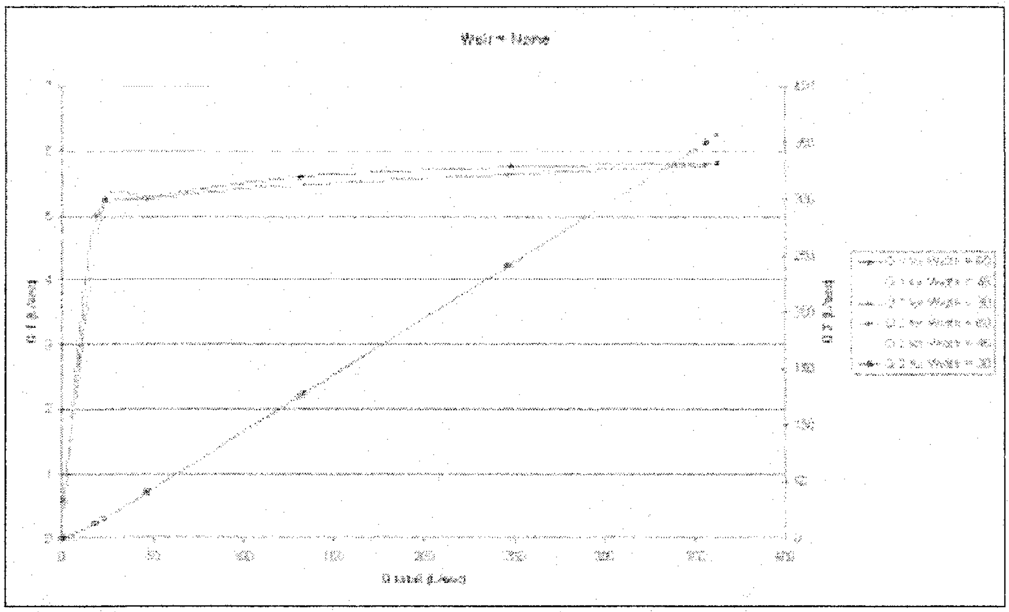

Figure 33 Total Flow (Qt) Vs Pipe Discharge (Q1), No diversion weir installed

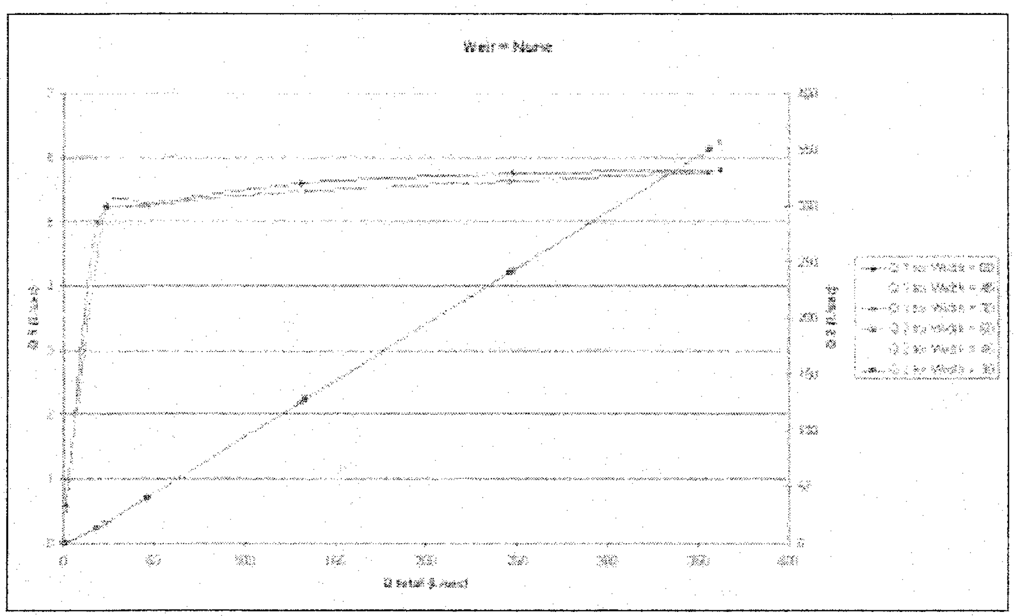

Figure 34 Total Flow (Qt) Vs Pipe Discharge (Q1), Diversion weir height = 2 cm

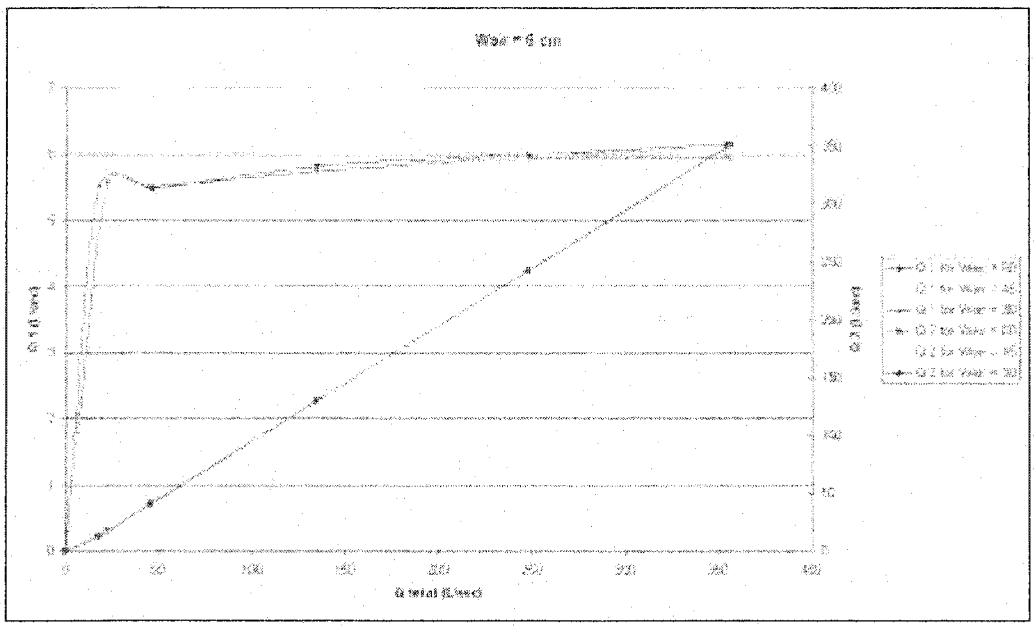

Figure 35 Total Flow (Qt) Vs Pipe Discharge (Q1), Diversion weir height = 6 cm

4.3.1.2 Water Profile

The experimental results essentially demonstrated that the size of the diversion weir did affect the water profile significantly. Without the diversion weir, the water profile at the diversion channel varied along the channel as shown in Figure 36. As the flow reached the inlet of the pipe, the water elevation decreased to the lowest level. However, the water profile was almost uniform when the height of the diversion weir became high. (Figure 37) When a 6 cm weir was installed, the water profile was nearly uniform. (Figure 38) The weir caused a back up of flow, resulting in a uniform water profile at the diversion channel.

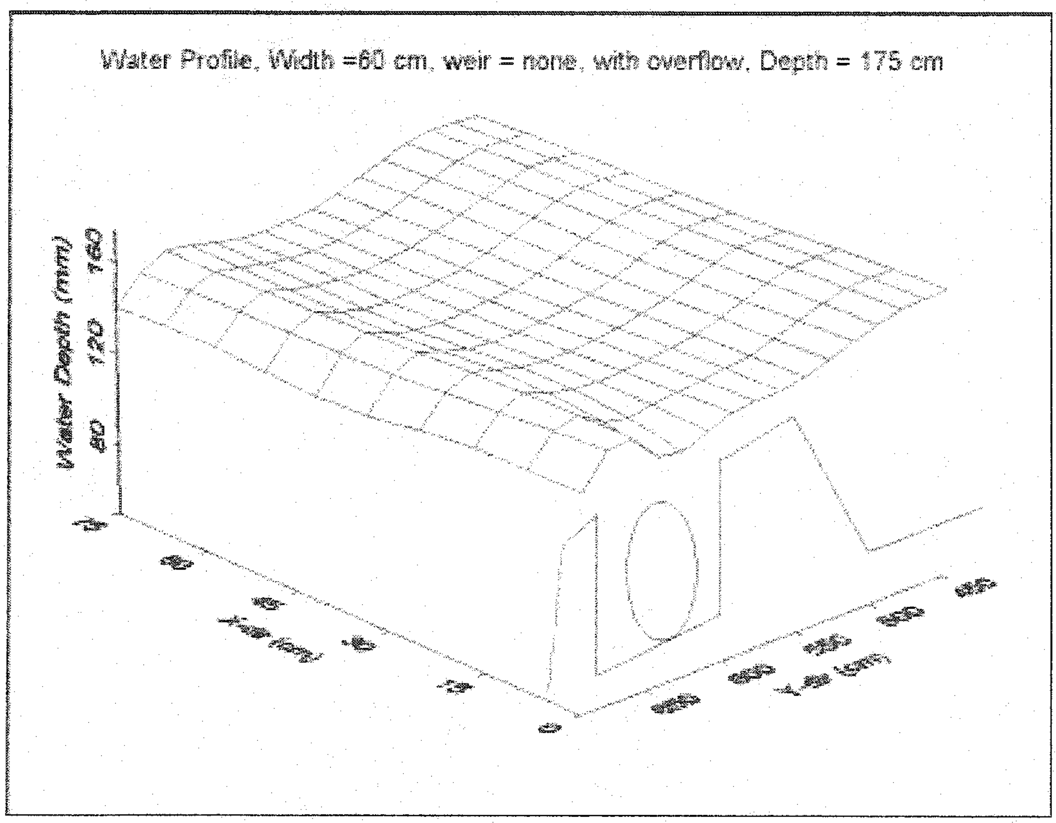

Figure 36 Water Profile for a Channel width of 60 cm, and no Diversion weir

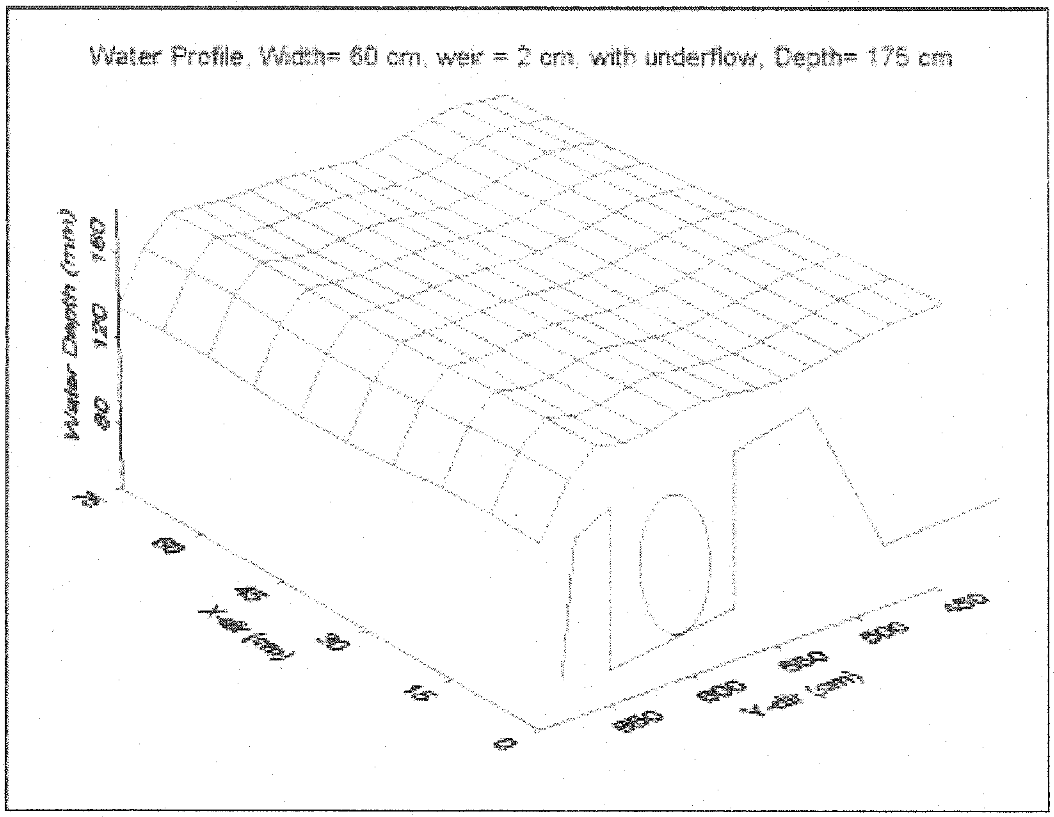

Figure 37 Water Profile for a Channel width of 60 cm, and a 2 cm Diversion weir

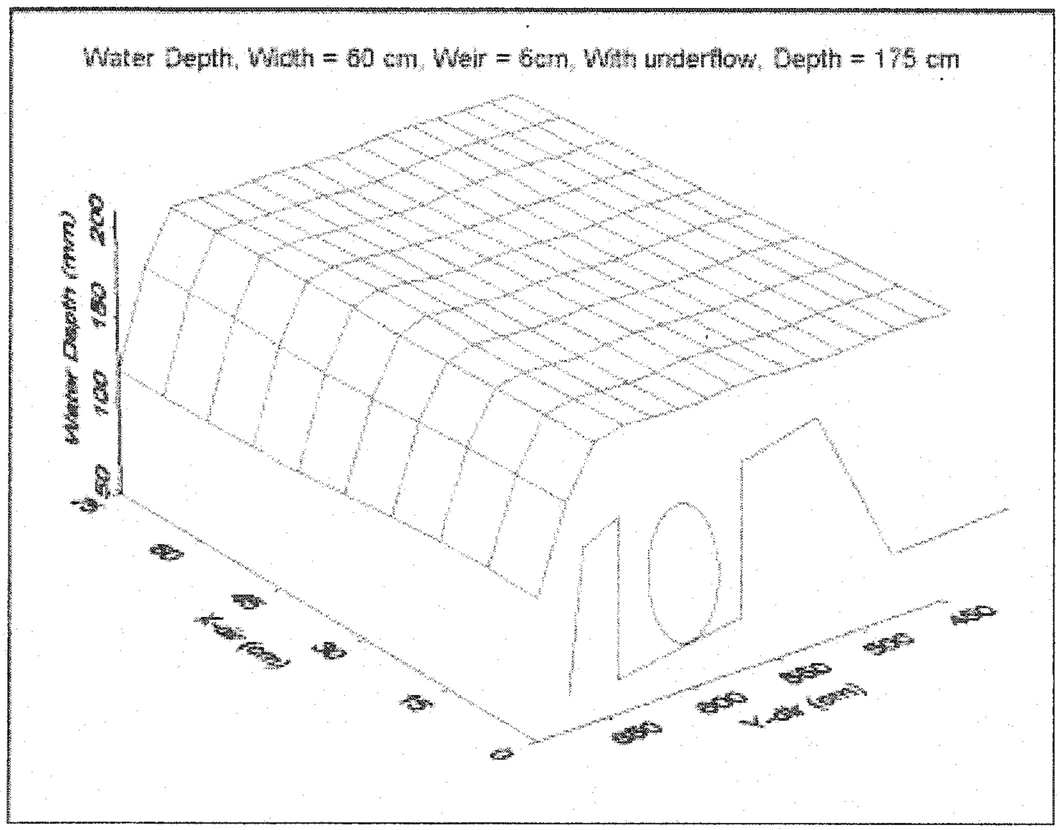

Figure 38 Water Profile for a Channel Width of 60 cm, and a 6 cm Diversion weir

4.3.2 Triangular Diversion Channel and Title Plate Separator

4.3.2.1 Inflow to the separator

When the height of first partition was set at the lowest point of the inlet, the maximum flow conveyed by the diversion channel without any overflow (i.e. baseflow) was 2.43 L/s. Using the discharge scale in Table 6, the projected flow is about 131 L/s which is close to the design baseflow of Humber Creek. As the total flow (Qt) increased, the flow through the separator (Qs) also increased until Qt reached about 70 L/s (Figure 39). Beyond a total flow (Qt) of 70 L/s, the flow through the separator (Qs) began to decrease. Thus, the maximum flow through the separator was about 21 L/s at the model or 1170 L/s using the discharge scale.

When the height of first partition is set at the highest point of the inlet, a baseflow of 0.17 L/s was observed (Figure 40). Using the discharge scale, the projected flow is about 9.5 L/s which is much smaller than the design baseflow of Humber Creek. When the height of first partition was set at the highest point of the inlet, the diversion channel overflowed before the first partition fulfill with water. As a result, the observed baseflow was very small. In the original API design of tilted plate separators, a pressurized pipe was used to direct the inflow into the separator. However, the pressurized pipe was replaced by a triangular diversion channel in the proposed oil spill control system. Therefore, the diversion channel overflowed before the first partition was filled with water.

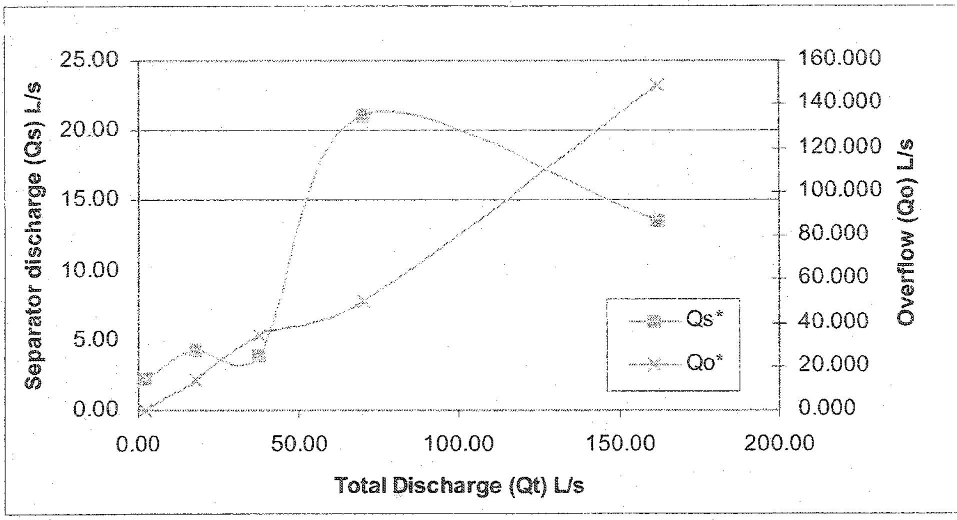

Figure 39 Flow distributions through the spill control system (Low partition)

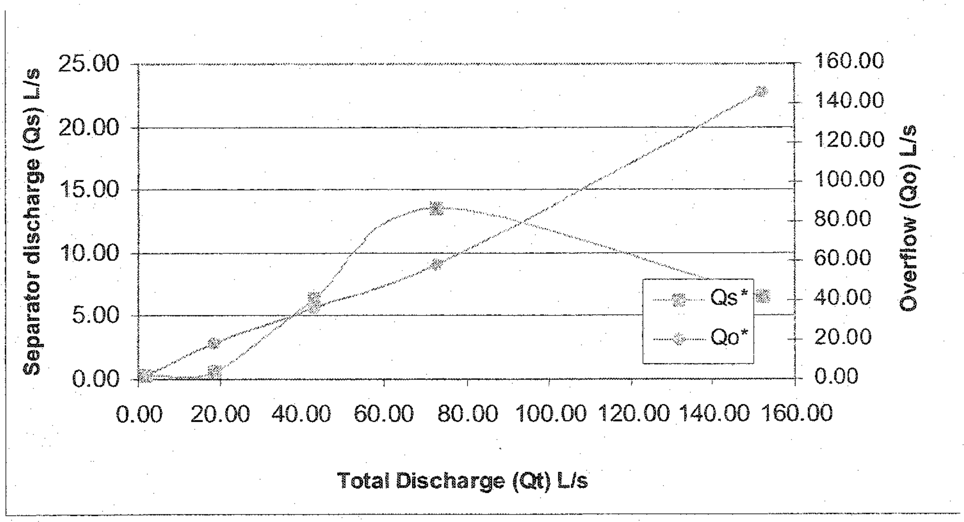

Figure 40 Flow distribution through the spill control system (High partition)

4.3.2.2 WATER PROFILE

The experimental results show consistent water profiles at the triangular diversion channel under all flow conditions (Figures 41 to 43). However, the water profile of the triangular diversion channel also affects the water level at the box culvert. The water level at the upstream of the box culvert was quite high. Once the water passed the triangular diversion channel, the water level dropped significantly. The triangular diversion channel may obstruct the flow at the box culvert and cause a backup at the upstream part of the box culvert.

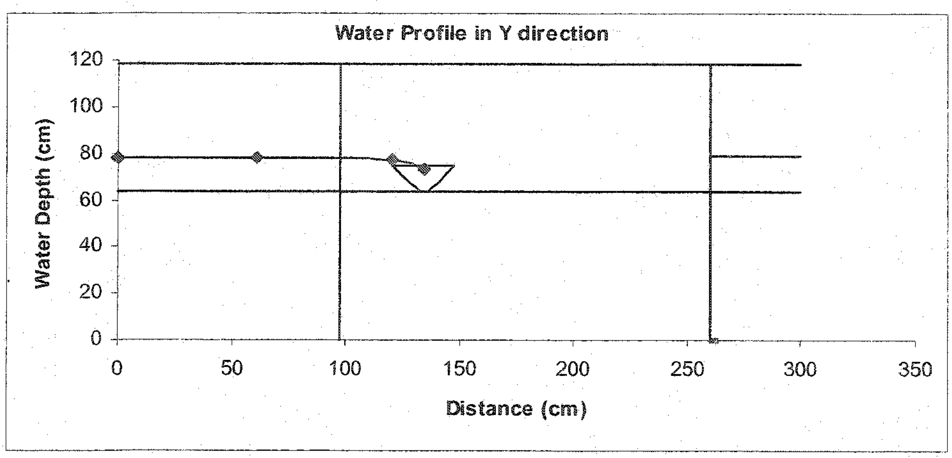

Figure 41 Water Profile for total flow equal 18 L/s

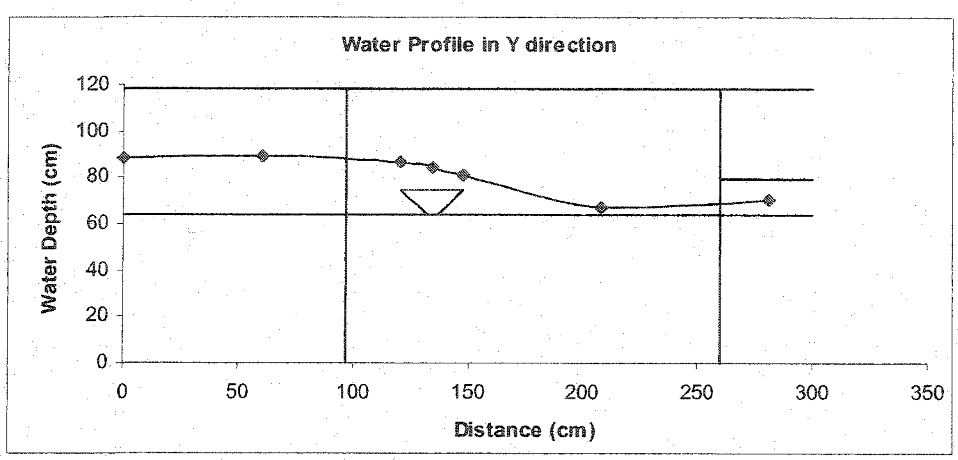

Figure 42 Water Profile for total flow equal 38 L/s

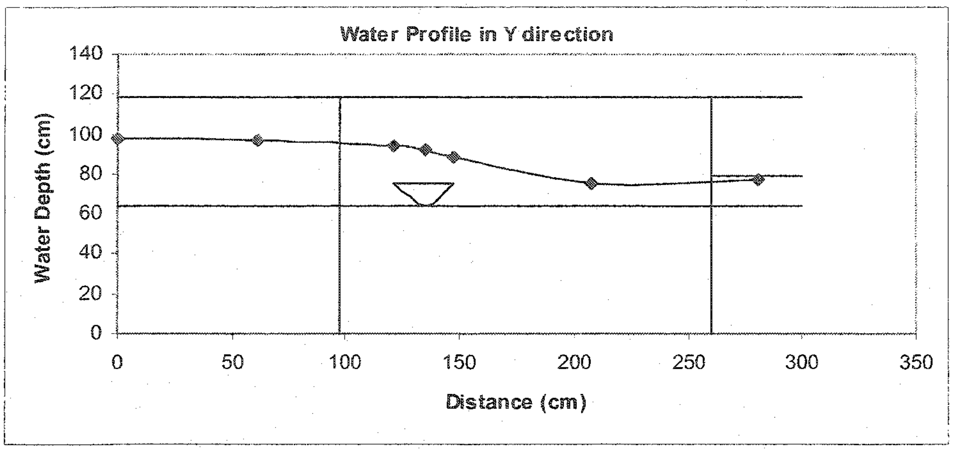

Figure 43 Water Profile for total flow equal 162 L/s

4.4 DISSCUSSION AND OBSERVATION

During the experiments, some interesting phenomena such as hydraulic jumps, sedimentation and backwaters were observed. Listed below are the observations.

4.4.1 HYDRAULIC JUMP

When the total flow reached the diversion channel, large quantity of water was accumulated at the diversion channel. Then, the large quantity of water as backed up and the water level rose quickly. This phenomenon could be interpreted as a hydraulic jump. (Figure 44)

Hydraulic jump is a phenomenon that occurs under the following condition. "When a rapidlly flowing stream of liquid in an open channel suddenly changes to a slowly flowing stream with a larger cross-section area and sudden rise in elevation of liquid surface." (Streeter and Wylie 1985) This description matches the phenomenon observed in these experiments. The main concern of this hydraulic jump is that the sudden rise in water level may create flooding in the upstream area.

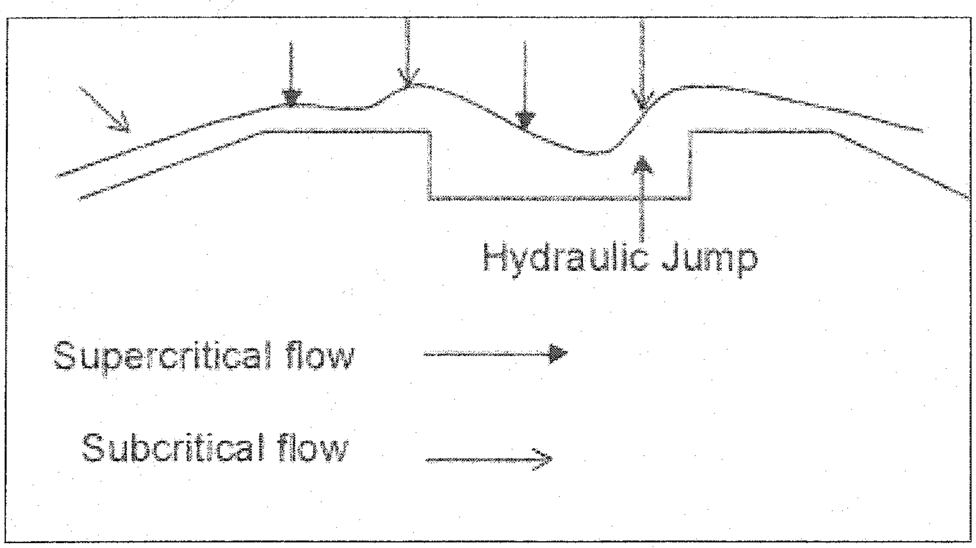

Figure 44 A Hydraulic Jump occur at the Diversion Channel

4.4.2 Visual Observation of Floatables and Sediments

Another interesting phenomenon was the behavious of floatables and sediments at the diversion channel. During the first set of experiments, all the styrofoam bits and sand in the water were accumulated at the edge of the diversion channel. Although all the Styrofoam bits and coarse sand did not enter the diversion channel after the diversion structure was raised by 3 cm, there were still some fine sand settling in the diversion channel. For applications in the field, these fine particles may create a maintenance problem. Since the sedimentation problem at the rectangular channel cannot be avoided, an alternative design of the diversion channel is needed. The sedimentation at the rectangular channel may be caused by two vortices in the channel (Figure 45). In order to avoid the creation of two vortices and reduce dead zones, a triangular shape is chosen for the diversion channel. The triangular shape channel only has one angle in contact with water. As a result, one vortex is created in the channel and this vortex pushes sediments into the separator.

For the triangular diversion channel, light objects such as Styrofoam were pushed into the separator and trapped inside the first and second chambers. Heavy materials such as fishing tank solids settled at the first and third chamber of the separator. However, the 45 degree diversion channel also allowed water to enter the separator at an angle. As a result, a vortex was observed inside the separator (Figure 46). Both the Styrofoam and the fishing tank solids were trapped inside the separator at higher flows without any sign of being flushed out.

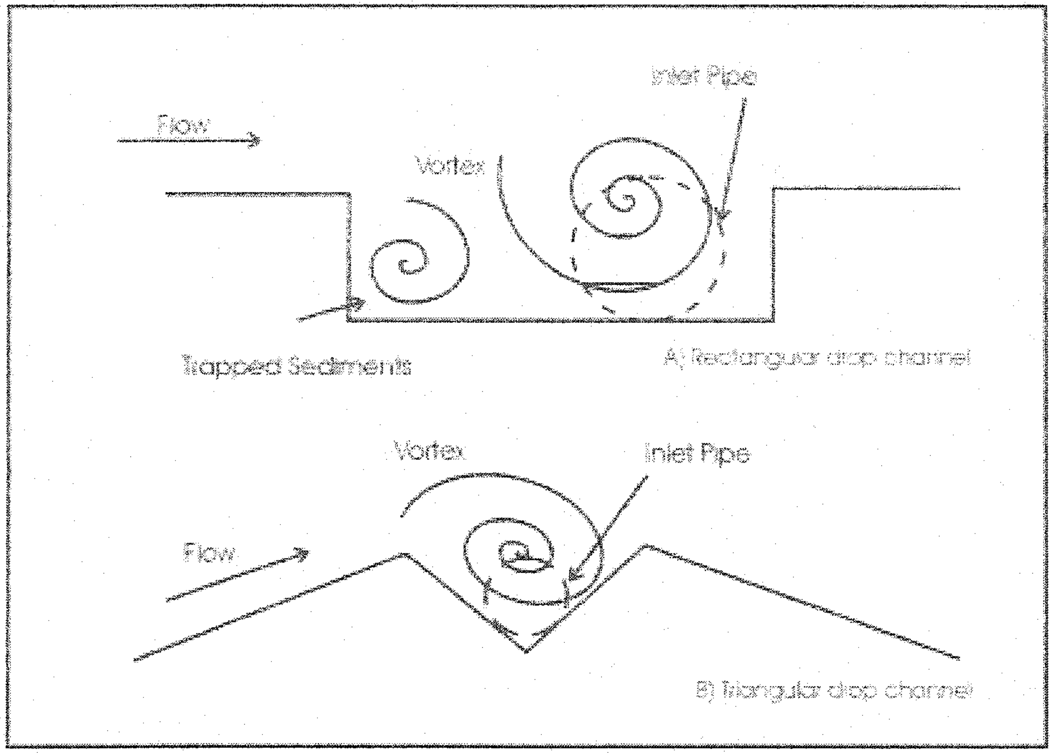

Figure 45 Reasons for Sedimentation in the Diversion Channel

Figure 46 Vortex action inside the separator

4.4.3 BACKUP EFFECT

It was observed that the overflow (Qo) from the diversion channel might have some impact on the flow through the separator (Qs). When the total flow of the box culvert (Qt) was low, (i.e. Qt is equal to baseflow, 18 L/s and 38 L/s) the outflow from the separator (Qs) was not backup by the overflow (Qo) from the diversion channel (Figure 47 to 49). At higher total flows, the backup effect of the overflow was prominent (Figure 50). Therefore, the trend of separator flow (Qs) might be attributed to this backup effect.

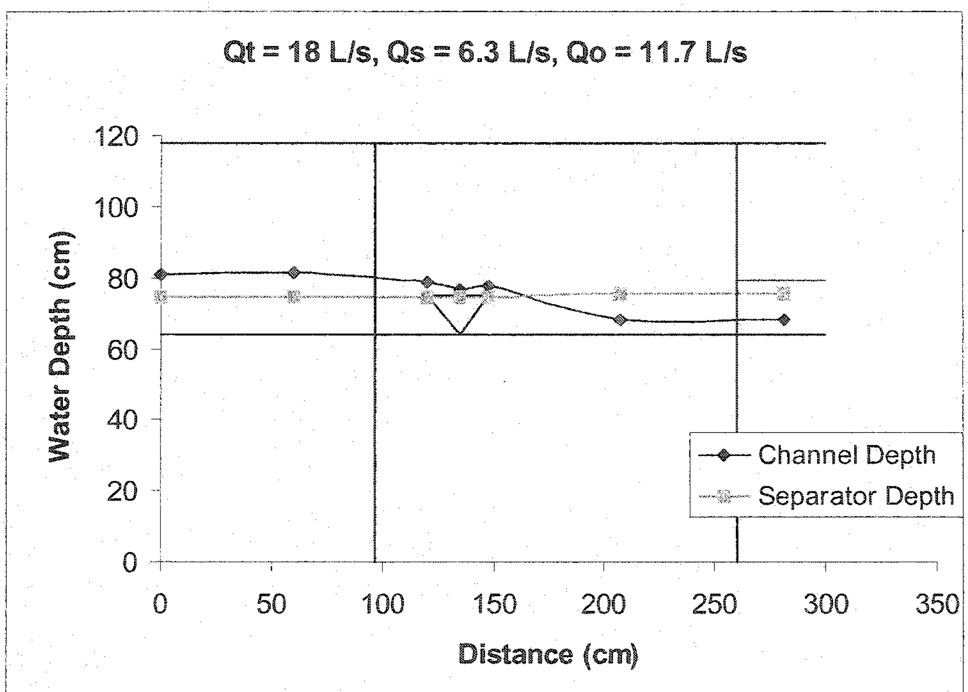

Figure 47 Water profiles along the culvert and the separator at Qt equal to 18 L/s

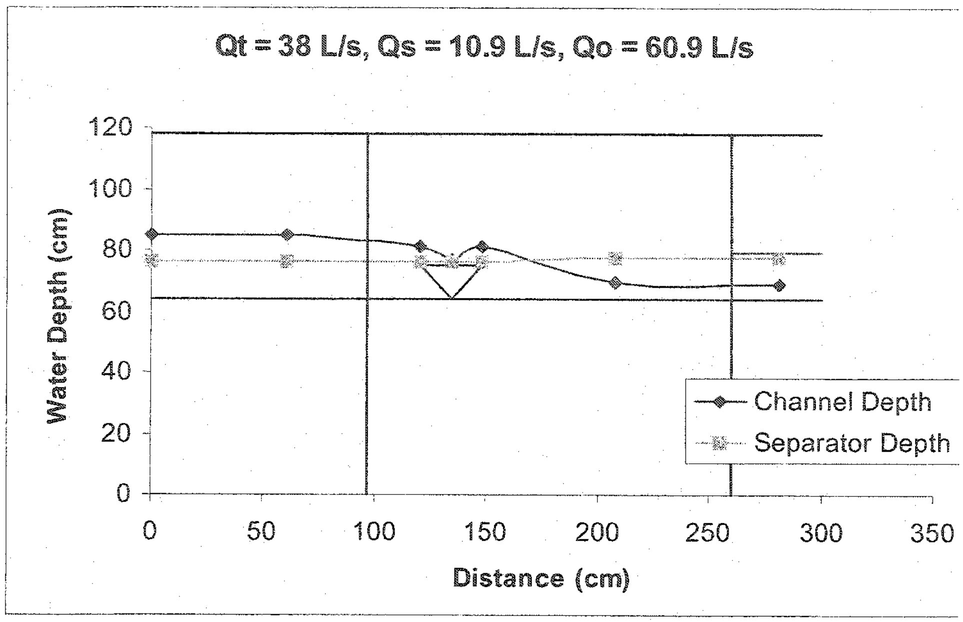

Figure 48 Water profiles along the culvert and the separator at Qt equal to 38 L/s

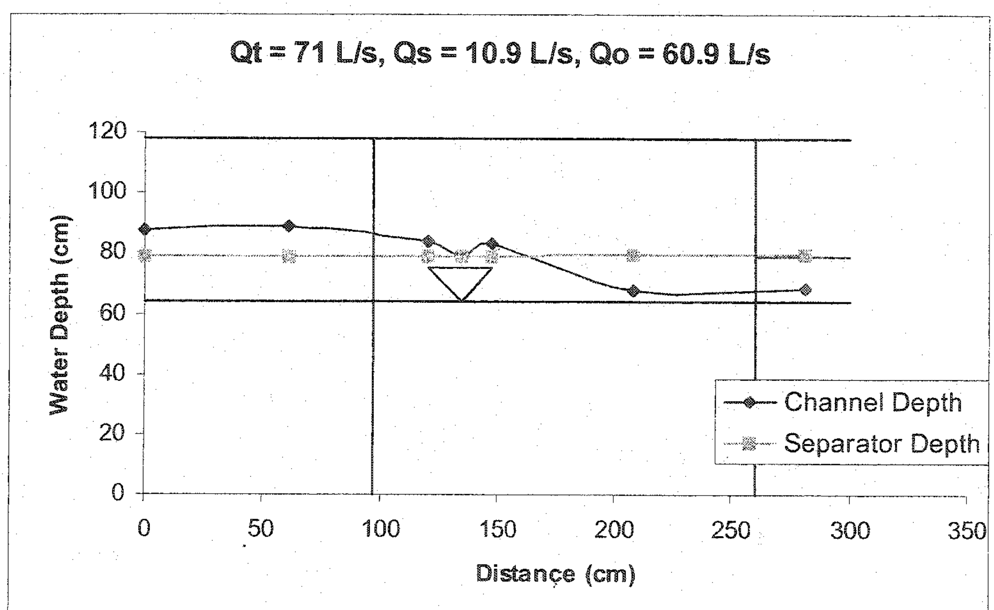

Figure 49 Water profiles along the culvert and the separator at Qt equal to 71 L/s

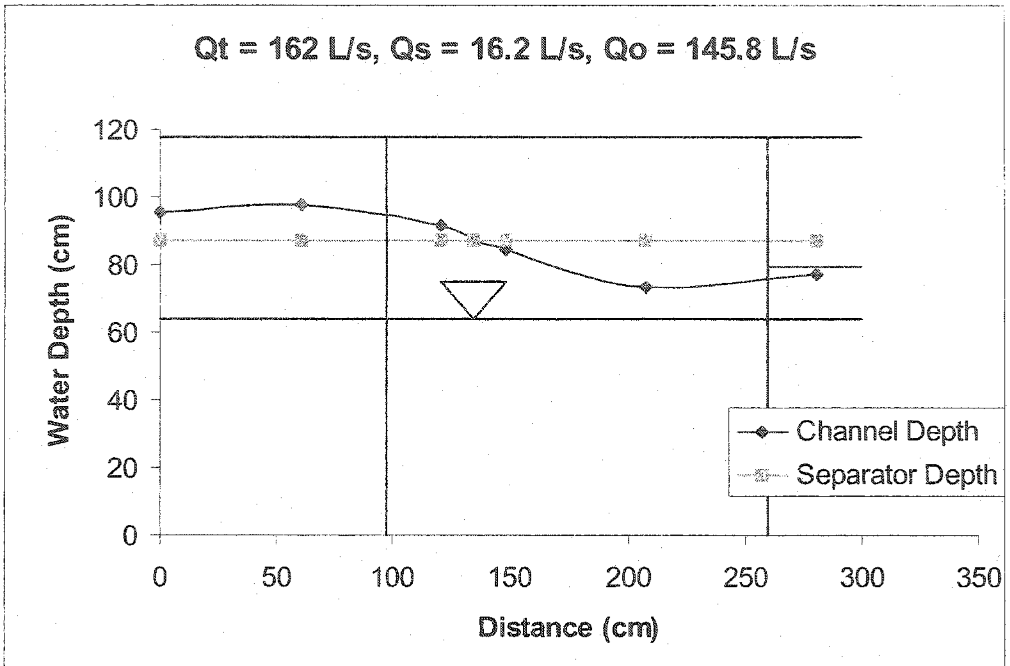

Figure 50 Water profiles along the culvert and the separator at Qt equal to 162 L/s

4.5 SUMMARY

A physical model investigation is essential to the design of an oil spills control system. First, the experimental results can be used to confirm the hydraulic design of the system. Second, the behaviour of the control system under various flow conditions can be observed and unexpected observations such as sedimentation, hydraulic jump and backwater effect can be recorded. These problems were not foreseen at the time of design.

The experimental results showed that the rectangular diversion channel did limit the inflow to the separator during high flows. Once the total flow exceeded the base flow of the diversion channel, the discharge in the pipe started to level off. The results also highlighted the fact that the diversion weir did obstruct the total flow in the flume. When the levels of the diversion weir become higher, the discharge in the pipe was larger. However, the width of the diversion channel did not have any effect on the flow capacity of the diversion channel.

The experiment results showed that the maximum flow that could be conveyed by the triangular diversion channel without any overflow (i.e. baseflow) was similar to the design baseflow of Humber Creek. The triangular diversion channel also limited the separator flow during high total flows due to the backup effect. The experiment results also showed that the baseflow of the triangular diversion channel could be affected by the height of the first partition. When the height of the first partition was higher than that of the separator inlet, the maximum flow that could be conveyed by the triangular diversion channel without any overflow was decreased.

The hydraulic jump phenomenon is quite prominent in the experiments. When the total flow became bigger, more water was backed up and the water level became higher. If a bigger storm event occur, the flow rate in the sewer would become higher and might contribute to flooding in the upstream area.

Sedimentation in the rectangular diversion would be expected to create maintenance problems in field applications. During the experiments, all styrofoam bits and sand from the water accumulated on the edge of the diversion channel. The problem was not solved by raising the system.

The separator flow was affected by the backup effect as shown Fig. . When the total flow (Qt) become higher, the separator flow (Qs) decreased.

CHAPTER 5

SPATIAL ANALYSIS OF OIL SPILLS IN THE GREATER TORONTO AREA

5.1 INTRODUCTION

The use of the term *Geographic Information Systems* (GIS) dates back to the mid-1960s (Goodchild, 1993). It has been utilized in many industries, such as city planning, transportation modeling and forestry.

On the other hand, the use of GIS to analysis the oil spill characterises was rarely found. In year 1999, Ryerson University and City of Toronto conducted stormwater management study on Mimico Creek Watershed by using GIS (Li and Battening 1999) In this study, GIS was used for the site investigations of different retrofit stormwater management practices in Mimico Creek Watershed, such as downspout disconnection, oil/grit separators, stormwater exfiltration systems, and water quality ponds. For the oil/grit separators site investigations, the storm sewer outfalls that received oil spill were identified and the commercial and industrial drainage areas that suitable for oil/grit separators were also identified.

As a result, the spatial analysis of oil spills in GTA area would extend methodology of the oil/girt separator site investigation that have been done in Mimico Creek Watershed.

5.2 Data Preparation

5.2.1 Oil Spill Locations

The Spills Action Centre supplied the oil spill database of Southern Ontario, covering a period from August 1, 1988to December 31, 2000. In this database, each record contains the following information: date, company name, municipality, address, sector, sources, description of a spill, spill event volume, cleanup percentage, reason and cause, oil type, and natural impact. By using the addresses in the spill records, GIS can map out oil spills locations on a street map by a process call "geo-referencing" or "geocoding". "Geo-referencing" links the longitude and latitude of the spill's address to the oil spill database and allows plotting of the spill locations. Unfortunately, this process is limited by the fact that the percentage of geo-coded oil spill locations is low for some municipalities. Almost half of the spill records do not contain proper street addresses, such as valid street number and street name. Moreover, the street names in the records lack consistency such as short form and long form. For example, among 168 oil spill records in Richmond Hill between 1988 and 2000, 89 oil spills records had street addresses and only 63 oil spill records were successfully geo-referenced. Thus, only 38 per cent of the records were geo-coded. Due to the low percentage of geo-coded records, the results shown in this case study could possibly under-represent the full story of the oil spills for the Richmond Hill area.

5.2.2 Digital Data Layers

In this study, the oil spill locations were overlaid with the following:

- Roads and Watercourse

Spill locations were compared with major roads and watercourses to identify which roads or watercourses received the most frequent spills.

- Environmentally Sensitive Areas

Spill locations were compared with the Environmentally Significant Areas (ESA), classified wetland and Areas of Natural and Scientific Interest (ANSI), to identify any spills that might impact on these areas.

- Land use and drainage system

Spill locations were compared with land uses, sewer outfall locations, and storm water management pond locations to identify the potential control options

All feature data are in a digital map format provided by the Toronto and Region Conversation Area (TRCA). Some concern should be considered before overlaying two different digital maps. First, the projection of two maps should be the same or two sets of data should show the same locations when the two maps are overlaid. Thus, before comparing the oil spill locations with the feature data, the projection of the oil spill locations was changed from a polar coordinate system (Name: GCS_North American_1297 [4267], Units: Degree [9102]) into a Projected coordinate system (Name: NAD_1927_UTM_Zone_17N [26717], Units: Meter [9001]) to allow for consistency in the X and Y coordinates.

The other concern is the data quality of digital maps, such as precision, accuracy, reliability and validity of the data (Banting 1992). Precision refers to the degree of detail in the reporting of a measurement or in the manipulation of a measurement in arithmetic calculations. Accuracy refers to the relationship between a measurement and the reality it purports to represent (Goodchild, 1993). Validity refers to the logic of representing reality in a particular measurement. Reliability refers to the consistency of measurements from several replications. Computers are very precise machines soerrors are still encountered due to human inprecesions. For example, errors might occur when the map was digitized. Thus, analysts should be cautious with digital data.

When the oil spills locations were compared with storm water outfalls, the map shows the sewer networks but not the sewershed. A digital elevation model May be useful in identification of spills intercepted by a storm sewer systems.

5.3 GIS ANALYSIS PROCEDURE

There were four steps in the GIS analysis. The first step was to overlay the oil spill locations with features such as watercourses, roads and municipality boundaries. In order to understand the spatial distribution of oil spills in more detail, oil spills were divided into five categories. (i.e. types of impact upon nature, type of spill location, type of road, type of oil and the event volume before they were overlaid with vairous environmental and municpial features)

- Types of Impact

The natural environment (e.g.air, water, and land) that might be impacted by the oil spills were recorded in the oil spills database. By showing these natural impacts with the oil spills locations, the nature environment that might be impacted the most could be identified. However, there are shortcomings to this approach. For instance, the impacts may involve all these nature media.

- Types of Location

The locations of spills refers to the place that spills haves taken place, such as airports, parking lots, transformers, bulk plants, service stations, or catch basins.

- Types of Road

Roads are generally classified into three types: arterial, collector, and local. By matching the street addresses in the spill database with the road designations in the study area, the types of road in relation to the oil spills were identified.

- Types of oil

Oil spills were grouped according to the type of spilled oil, such as gasoline diesel fuel, motor and transmission oil, etc.

- Volume of spills

The oil spills were grouped according to the size of the spills. For examples, five categories of spill event volumes (e.g. 1 - 75 L/s, 76 L/s – 321 L/s, 322 L/s – 900 L/s and 901 L/s – 5500 L/s) were used to identify the significance of spills.

The second step of the analysis was to overlay the oil spill locations with environmental features, such as the wetland, MNR's Areas of Natural and Scientific Interest, and the TRCA Environmentally Significant Areas. By overlaying these data sets together, oil spill locations that were within or in the vicinity (e.g. 750 m) of the environmental features were identified. Typically, government agencies identify buffer zones around environmental areas to protect natural wildlife. In order to make this analysis more realistic, these buffer zones were considered in the analysis. According to the Wetland Policy Statement in the Planning Act, all classified wetlands must have a minimum 120 metre buffer zone. Under "A Biological Inventory and Evaluation of the Credit Folks Area of Natural and Scientific Interest" (MNR Park and Recreational Area Section), all Areas of Natural and Scientific Interest and areas defined by the Niagara Escarpment Plan must have a minimum 10 metre set back. If an ANSI is regionally significant, it must have a minimum 20 metre setback. If an ANSI is provincially significant, it must have a minimum 30 metre setback. Unfortunately, the TRCA data did not provide the classification of ANSIs. As a result, all ANSIs in this analysis were assumed to processes a ten metre set back. Buffer zones for the Environmental Significant Areas are typically defined by an Environmental Impact Study and may have different sizes. In this research, it was assumed that the buffer zone for the ESA be set at 120 m, which is similar to the buffer zone for wetlands.

The third step was to identify the spills which would be potentially intercepted by ponds or sewer outfalls. First, oil spill locations were overlaid with sewer system networks in each municipality. Sewer systems that might intercept spills were identified to be spill prone. If a spill prone sewer system was identified to discharge directly into the watercourse, the associated oil spills were assumed to be uncontrollable. If a spill- prone sewer system was identified to discharge to a stormwater pond, the associated oil spills were assumed to be controlled by pond.

The last step of the analysis was to investigate the control options for each spill-prone sewer system. For spill-prone sewer systems which were identified to discharge to stormwater ponds, these ponds were identified to be spill-prone and additional investigations should be conducted to identify retrofit potential. For spill-prone sewer systems which were identified to discharge directly to watercourses, potential locations for retrofitting outfall control devices (e.g. oil/water separator) were identified by overlaying sewer outfall locations with public land.

5.4 A Case study of Richmond Hill

The spatial analysis of oil spills was demonstrated in southern York Region (i.e. Richmond Hill, Markham and Vaughan). This region contains industrial, commercial, and residential areas and sewershed information is available. The following sections are the analysis results for Richmond Hill. Spatial analysis of oil spills for Markham and Vaughan can be found in other published reports (Li 2002a, 2002b).

5.4.1 Types of impact

In order to simplify the impact analysis, groundwater pollution, surface water pollution, watercourses and lakes were grouped into one class, namely, watercourse pollution. Twenty-one oil spills impacted on soil and seventeen oil spills impacted on water. Figure 51 shows the distribution of these oil spills. The spills that impacted on soil are located between Major Mackenzie Drive and Elgin Mills Road. However, the spills that impacted on watercourses concentrate in the East Don River and German Mills Creek. Most of the spills are located in the Don watershed, which is at the southern urban area of the municipality.

5.4.2 Locations of spills

The analysis results show that the top four most frequent spill locations were sewers, watercourses, roads, and parking lots (Figure 52). This may be attributed to the fact that most of the commercial and industrial areas are located at the southern part of the municipality. However, there are no clear trends for other locations of spills.

5.4.3 Types of Roads

Interestingly, the analysis results show that local roads had the highest frequency of oil spills (Figure 53). Although the arterial roads have more traffic than local roads, there are only three oil spills that occurred on arterial roads. Moreover, half of the local roads (with oil spills) are located in industrial areas where spills were frequent while the other half of the local roads are located in residential area where heating oil is still being used

5.4.4 Types of Oil

According to the oil spill database, the most frequent oil spill type in Richmond Hill is diesel fuel. Figure 54 shows the distribution of these spills. On the other hand, there are other types of oil spills particularly in industrial areas, including motor oil, gasoline, transmission oil, and hydraulic oil.

5.4.5 Volume of Oil Spills

The largest volume of spills was located on Yonge Street (5500 L of hydraulic oil) near the German Mills Creek (Figure 55). Fortunately, other spill event volumes were quite small (i.e. 1L to 75L).

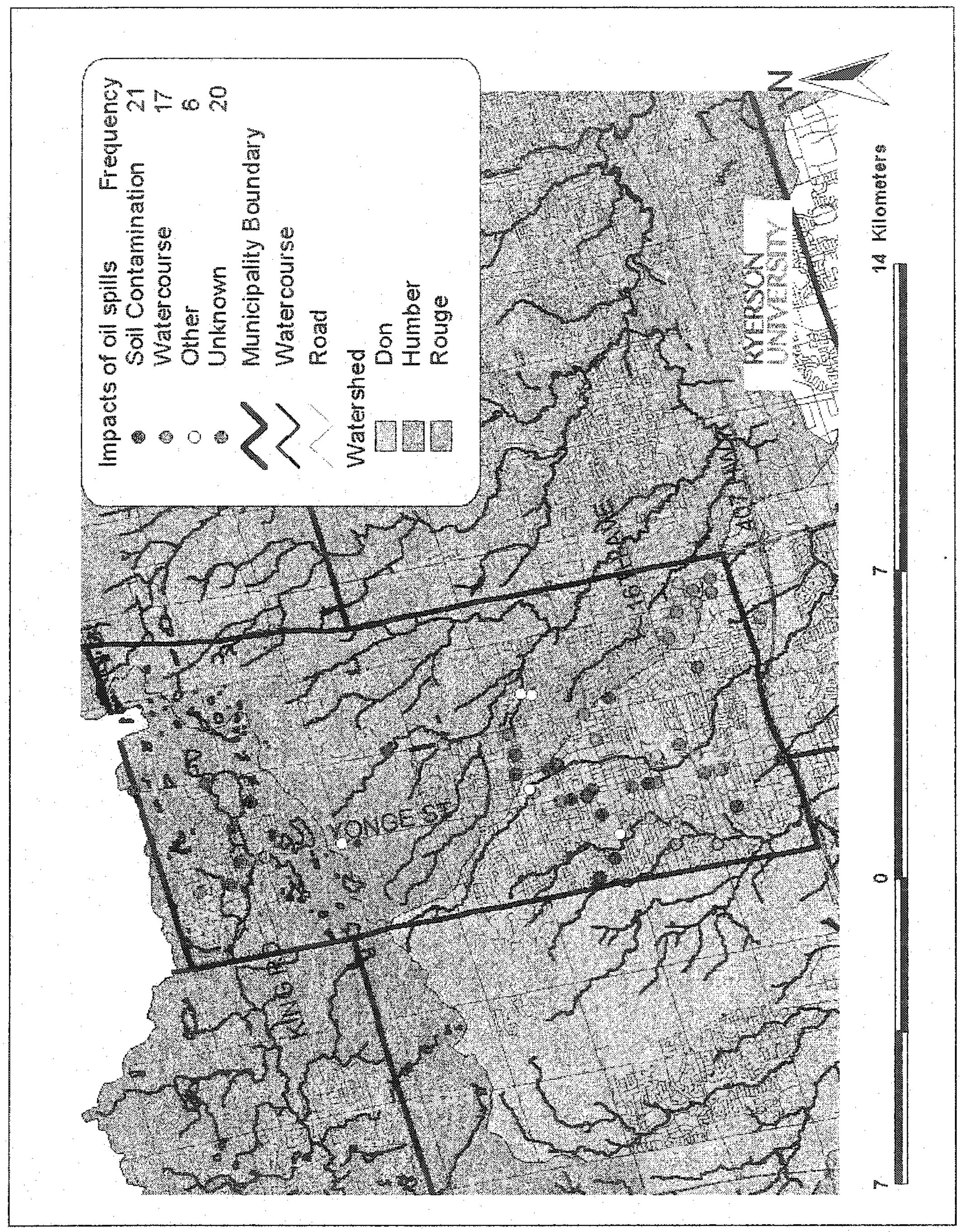

Figure 51 Impacts of oil spills in Richmond Hill

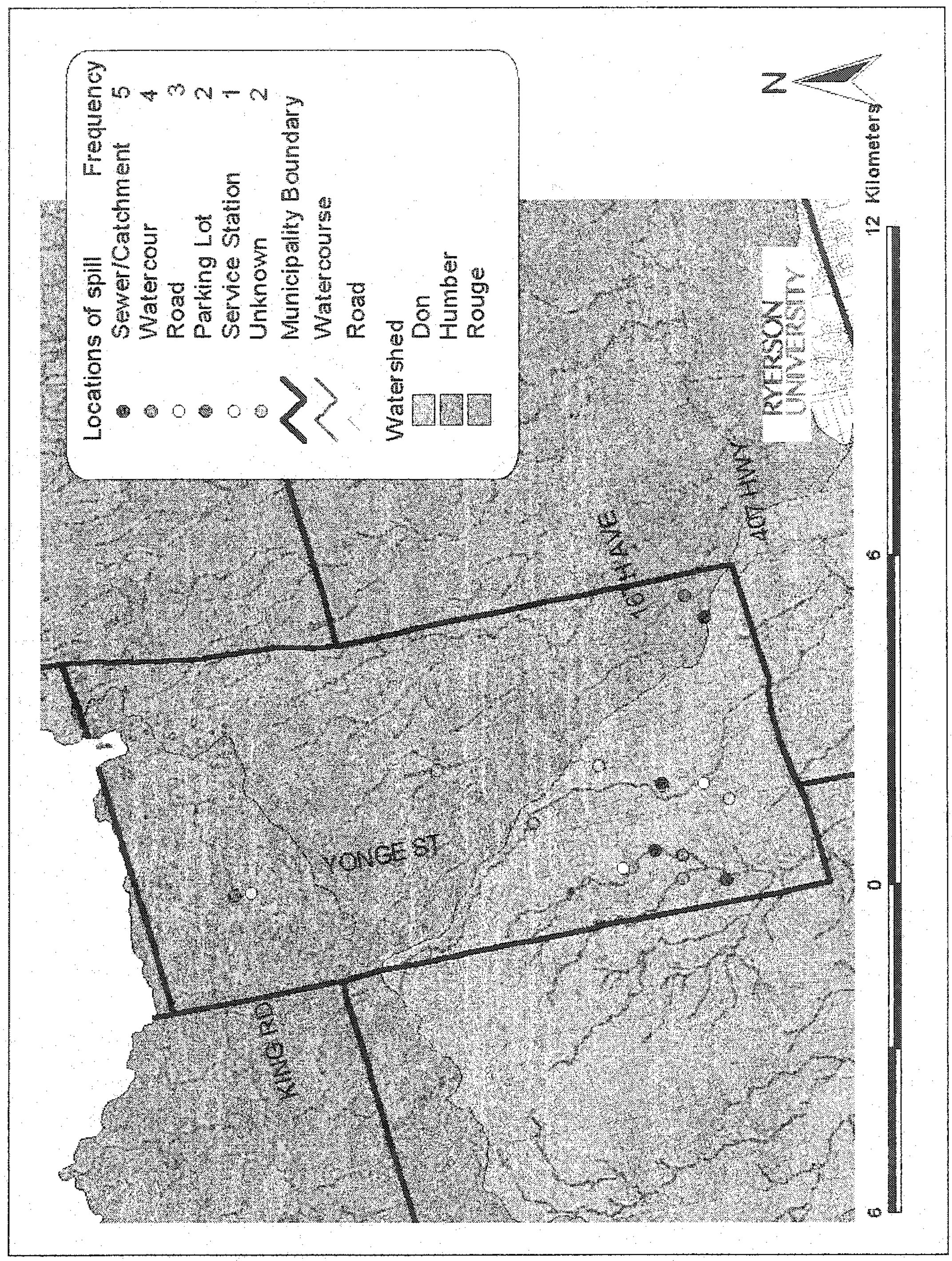

Figure 52 Locations of spills in Richmond Hill

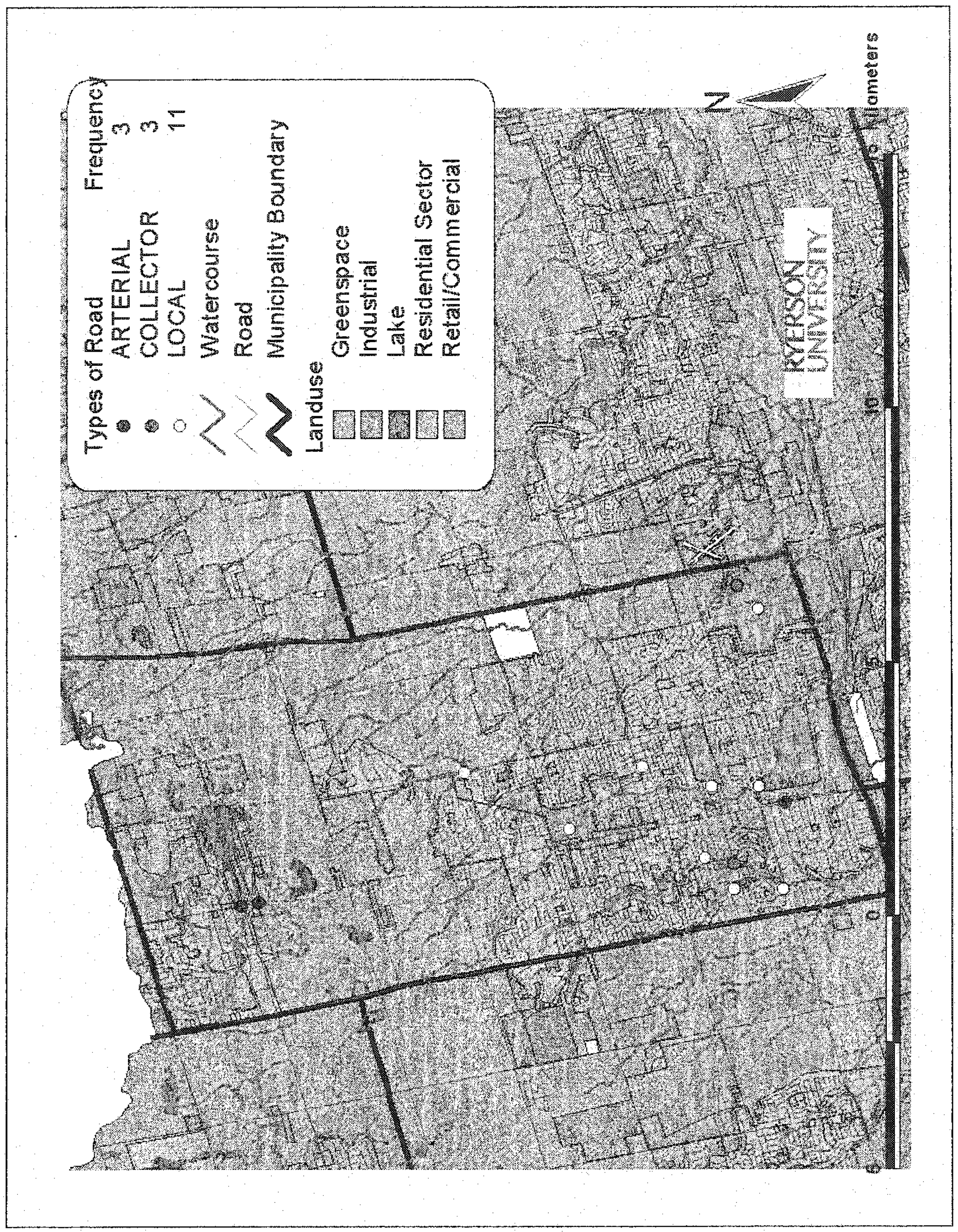

Figure 53 Types of road for oil spills in Richmond Hill

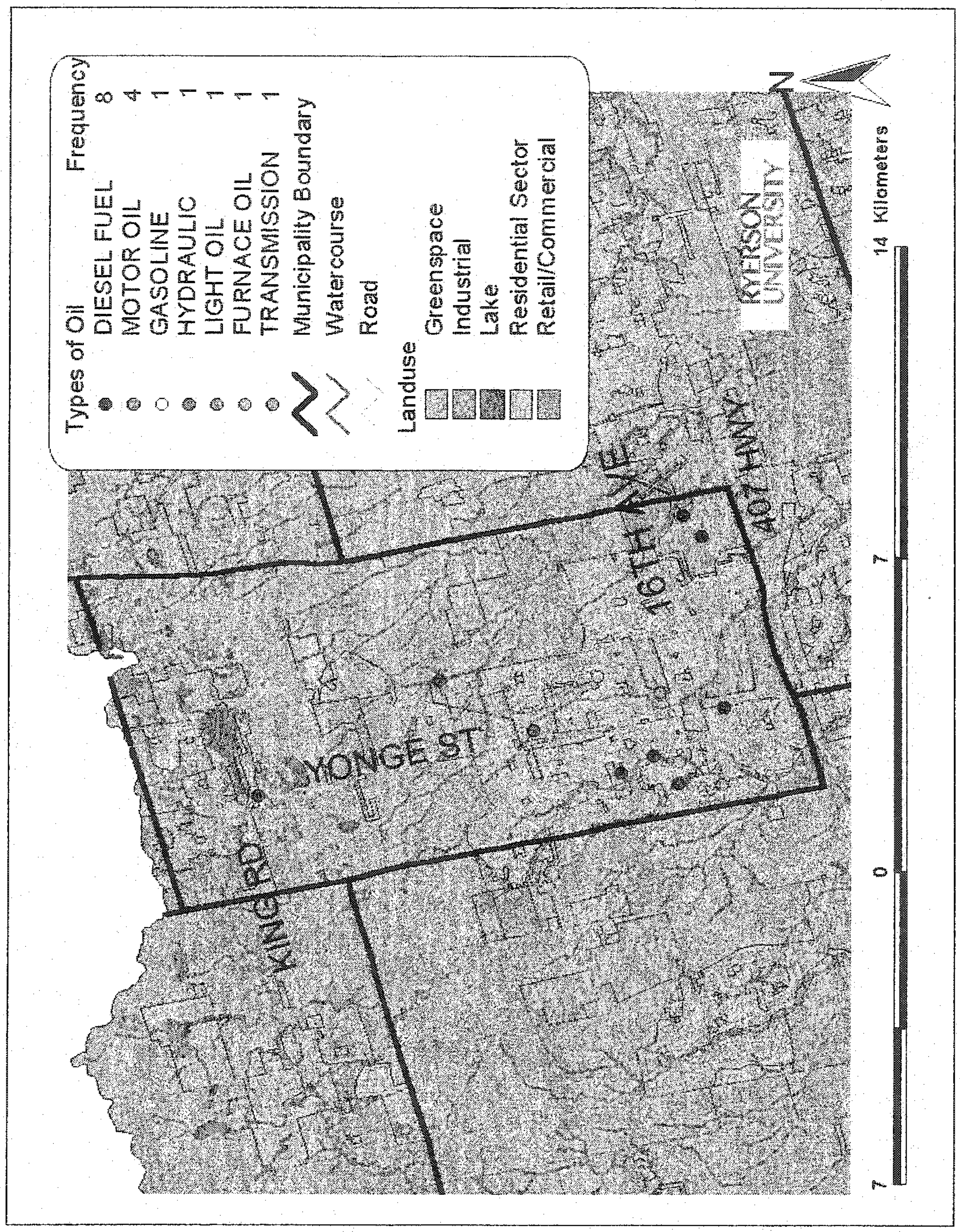

Figure 54 Types of Oil Spills in Richmond Hill

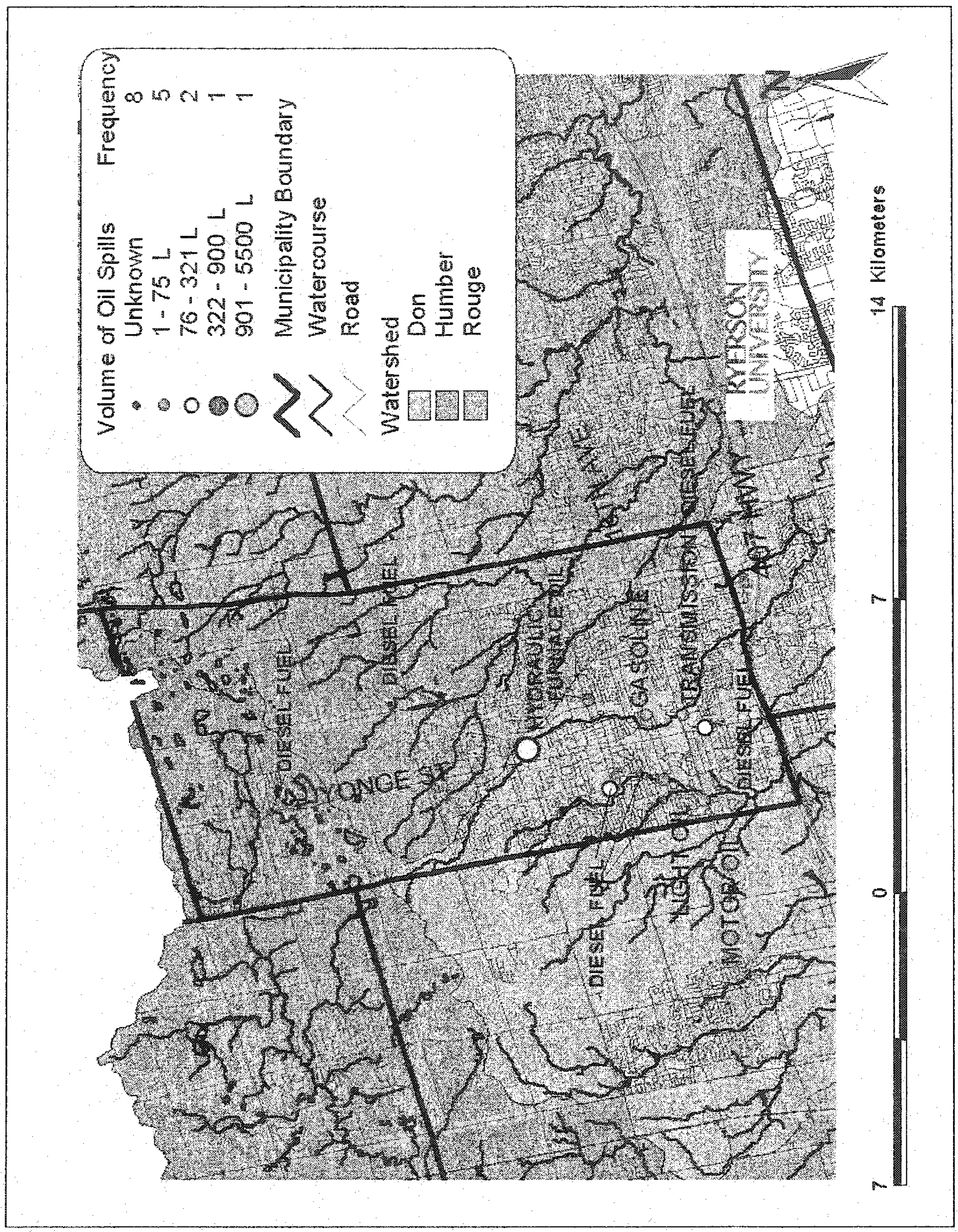

Figure 55 Volumes of Oil Spills in Richmond Hill

5.4.6 Environmentally Significant Area

The analysis result (Figure 56) shows that there was only one spill that was close to the environmental features (Motor oil, unknown volume). This spill was within the 120 metre wetland buffer zone and is located between Yonge Street and King Road. .

5.4.7 Downstream Outfall Controls

In the Don Watershed, there are two spill prone stormwater ponds (Figure 57). One pond, which intercepted one of oil spills is located in the northern part of East Don River (pond no. 24-2); the other pond, which intercepted six of oil spills, is located in the southern part of German Mills Creek (pond no. 26-2). On the other hand, there are many potential locations for retrofitting oil/water separators. In the southern part of East Don River, there are five spill prone sewer outfalls which discharge directly to the river. Thus, if there is enough space to install oil/water separators, some of the future oil spills may be controlled.

In the Rouge Watershed, there are one spill prone stormwater pond and one potential location to install an oil/water separator in Beaver Creek (Figure 58).

In the Humber River watershed, there is one potential location to install an oil/water separator (Figure 59). It is located in the upstream of East Humber Creek, just beside Lake Wilcox.

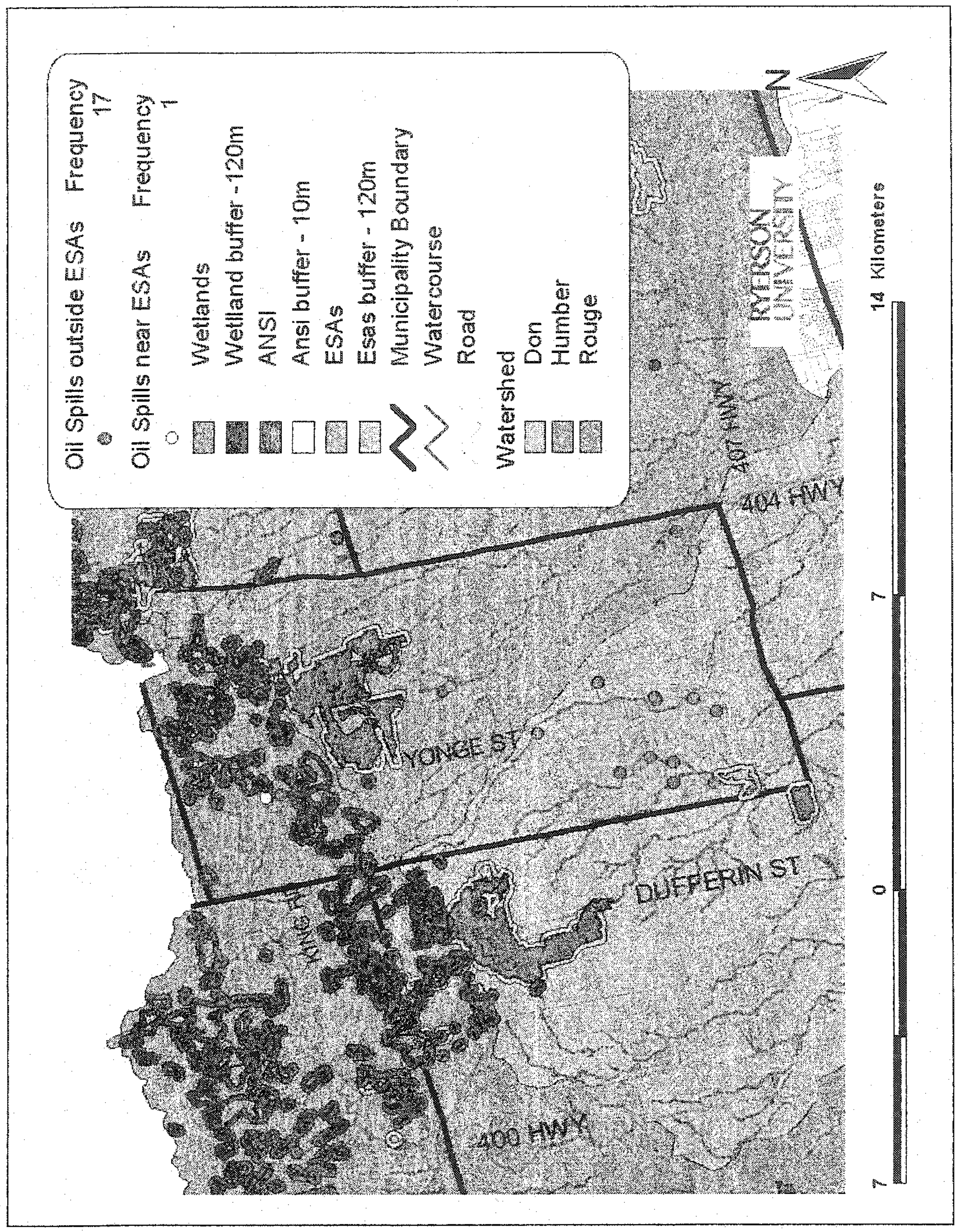

Figure 56 Oil Spills Near Environmental Significant Areas in Richmond Hill

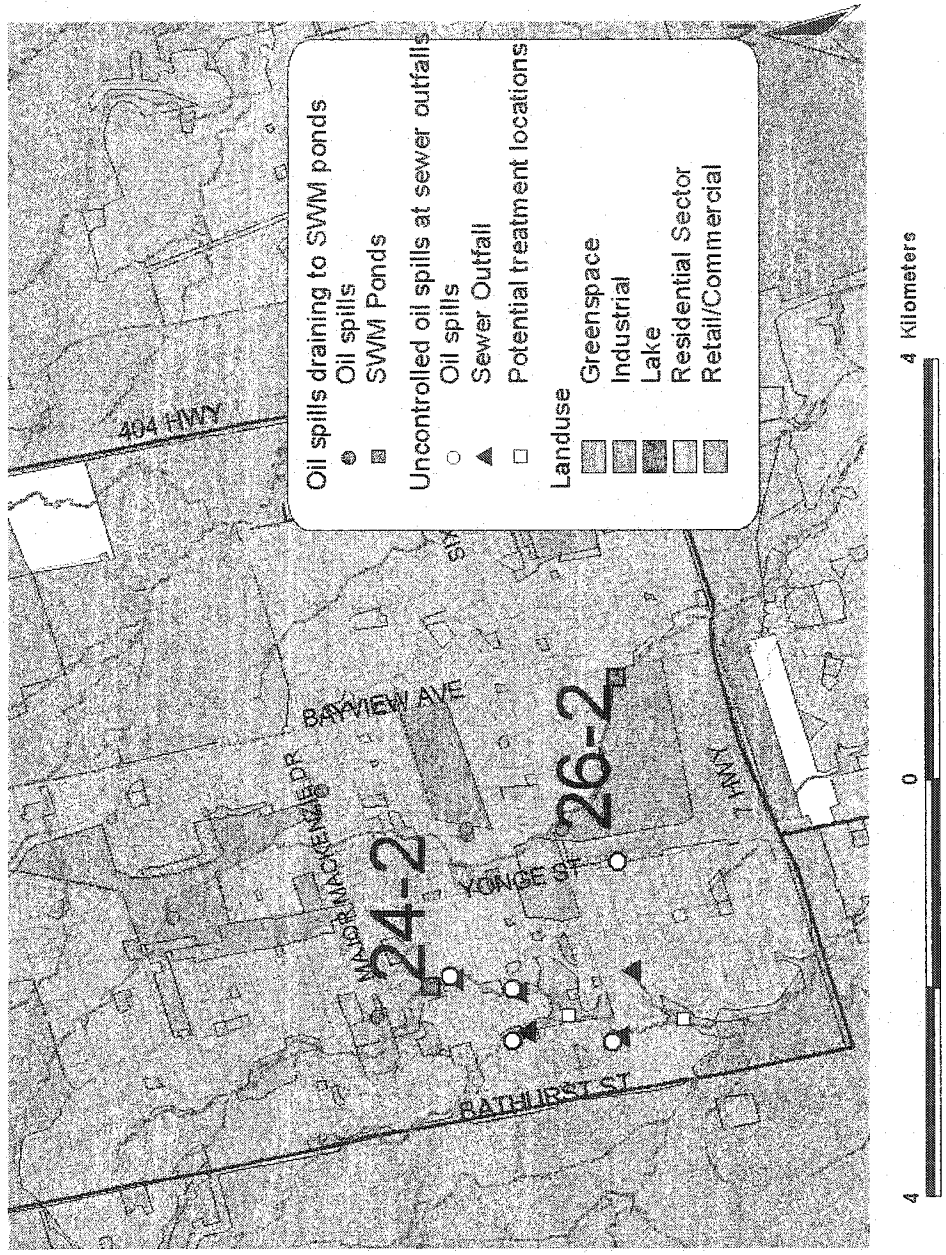

Figure 57 Potential retrofit ponds 24-2 and 26-2 for oil spill control in the Don Watershed

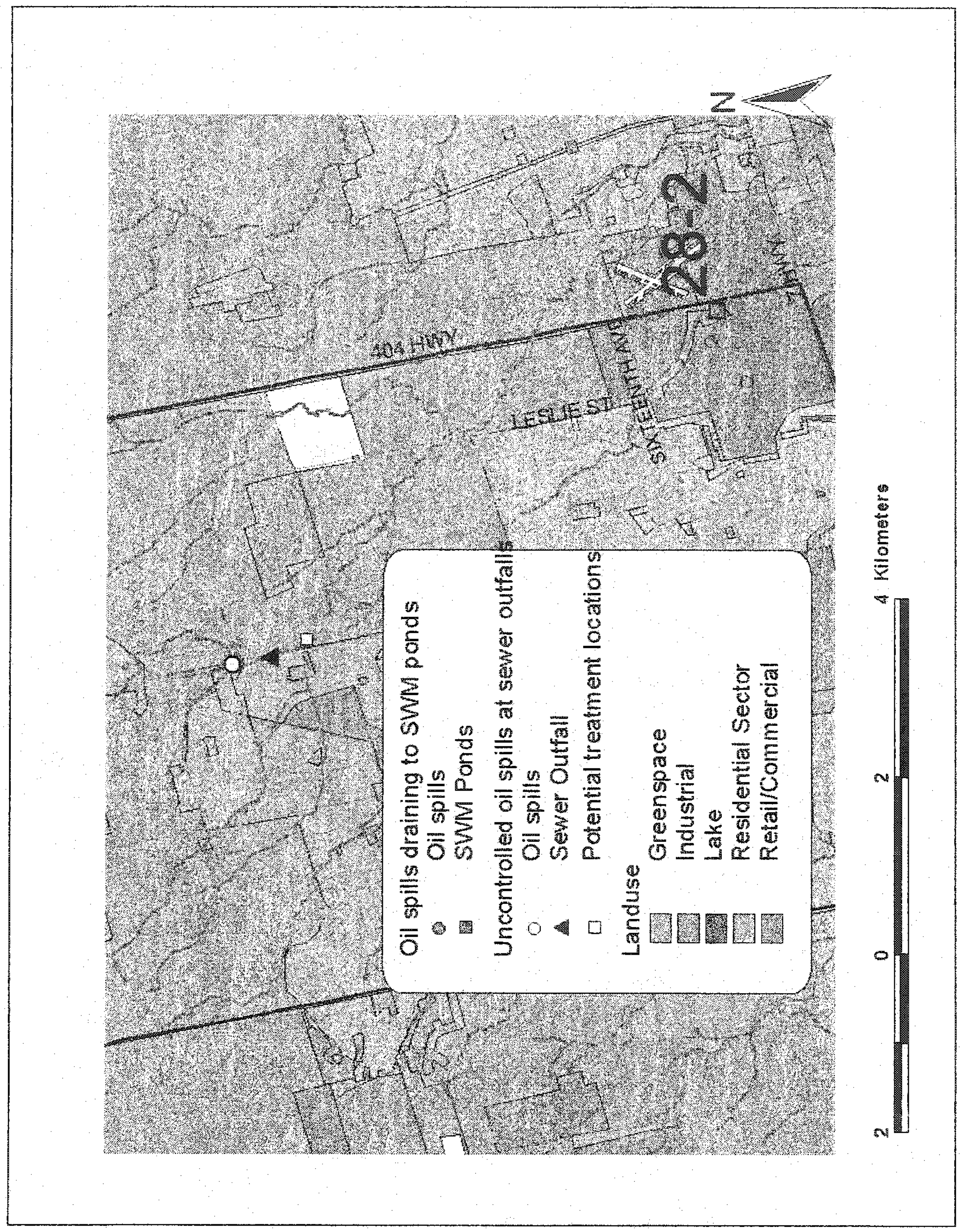

Figure 58 Potential Retrofit Pond 28-2 for Oil Spill Control in the Rouge Watershed

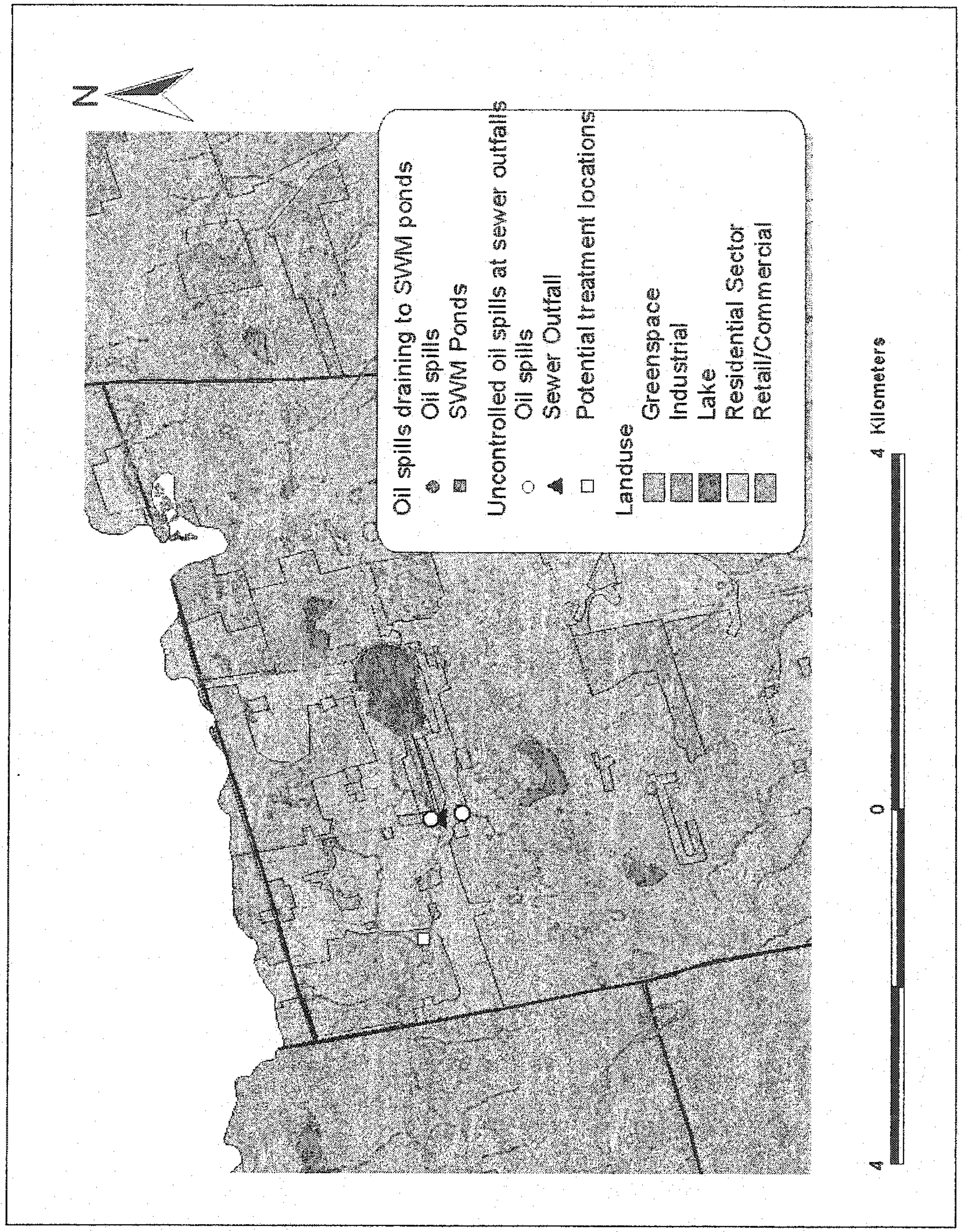

Figure 59 Potential Downstream Control Location in Humber Water

5.5 SUMMARY

GIS allows spatial analysis of oil spills. By overlaying oil spill locations with sewer system networks and SWM ponds, spills that are potentially intercepted by ponds or sewer outfalls can be identified. For spill-prone stormwater ponds, further investigation on retrofit potential is needed. For spill prone sewer outfalls, potential locations for retrofitting outfall control (e.g. oil/water separators) can be identified.

In the Town of Richmond Hill, the Don River watershed has many spill-prone areas, especially at the downstream end of the East Don River (Figure 56). Most of the oil spills in this area were discharged to the watercourse directly without any treatment. There are not many opportunities to refits stormwater ponds for spill control. In order to solve this problem, off-line oil/water separators may be installed at the downstream area of the East Don River.

However, the low percentage of geo-coded oil spills and the missing sewershed boundary did affect the result of this study. If a municipality wants to implement a system for controlling oil spills, these two limitations must be resolved before the analysis.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

In order to rehabilitate the channel in Humber Creek, the water quality in the channel must be improved. The City of Toronto desires to install an oil spill control structure in the Humber Creek sewer outfall to capture oil spills and improve the water quality in the stream (Aquafor Beech 1999). However, the challenge is to design an oil spill control system that can handle both dry and wet spills.

Since most of the oil spills in the City of Toronto are found to occur during dry weather, the treatment capacity of the oil spill control system should be designed for dry weather flow. This customized oil spill control system has two components: a flow diversion channel and an oil/water separator. When the spilled oil enters a sewer, the mixture of spilled oil and baseflow should be diverted into the separator by a flow diversion channel. After the spilled oil is separated from the baseflow at the oil/water separator, the baseflow re-enters the sewer.

During wet weather, the flow diversion channel should prevent high flows from entering the oil/water separator. The conventional diversion weir may not be able to prevent high flow from entering the oil/water interceptor because the high overflow depth above the weir crest may cause more water to enter the oil/water separator. Based upon the physical model study, a triangular lateral diversion channel provides the capacity to convey baseflow and offers better control of inflow to the oil/water separator. Additionally, the angled triangular channel provides the momentum to push sediments and floatables into the separator where regular maintenance can remove oil, sediments, and floatables.

For the Humber Creek's outfall conventional API oil/water separators are found to be too large for oil treatment. A smaller tilted plate separator may achieve the same result as an API separator. Although this research study does not compare the oil trapping efficiency of these separators, the designs of both separators are based upon well established API design manual.

When oil/water separators are designed for stormwater applications, it is important to recognize the maintenance requirements of sediments, oil, and floatables. In order to address these requirements, the configuration of different chambers within the separator should be designed to facilitate the removal of floatables, oil and fine and coarse sediments. Also, the storm water may re-enter the oil/water separator from the outlet of the separator under high flow conditions. If the backup is large, backflow restrictor may be required at the outlet of the separator.

GIS provide a powerful tool to analyze the spatial distribution of oil spills. Nevertheless, adequate resources must be available to collect digital information. For example, in order to analysis the oil spill characterises in a watershed, the oil spill locations, the sewershed network and the geological information about the watershed should be obtained. The quality of the data also important, for example, due to the inconsistence of street address in the oil spill database, the percentage of geo-coded records for Richmond Hill area is very low. As a result, the case study could possibly under-represent the full story of the oil spills for the Richmond Hill area.

6.2 RECOMMENDATIONS

Based on the findings of this thesis, the following recommendations are made.

1. The physical model study focused on the flow capacity of spill control system. Future model studies are needed to address the oil/water separation process at the oil/water separator. For example, the vortex problem that created by the angled diversion channel maybe solved by installing baffles at the 2nd chamber.
2. A monitoring program should be designed to assess the performance and maintenance requirements of the spill control system, such as frequency of maintenance of trapped oil and sediments.
3. The spill reporting and recording system can be further improved by compiling detailed and consistent reports. For instance, spill event volumes should be reported in consistent units and detailed description of cause and reason should be given. Additionally, spill characteristics such as locations, road types, and occurrence of rainfall should be reported as this information will allow the development of sizing criteria for spill control devices. To facilitate spatial analysis of spill characteristics, addresses of spills should be geo-coded by inspectors using Global Position System.
4. Other spill prone sewer outfalls should be identified across the city.
5. Stormwater ponds which have been identified to be spill prone should be investigated further for retrofit potential.

Appendix A

Design Calculations for API separator and Tilted plate separator

DESIGN CALCULATIONS FOR API SEPARATOR[1]

1) **Find out the rise rate for the oil globules. (V_t)**

$V_t = 0.0241*(S_w - S_0)/\mu$ (This is design for 150μm diameter globules capture)

Which S_w = specific gravity of fresh clean water at the 10 ^{0}C
S_0 = specific gravity of gasoline
μ = absolute viscosity of fresh clean water at the 10 ^{0}C, in poise

$V_t = 0.0241*(0.99 - 0.72)/0.013 = 0.5$ cm/s

2) **Find out the maximum allowable mean horizontal velocity (V_H)**

$V_H = 15* V_t \leq 3$

$V_H = 15* 0.5 = 7.5 > 3$, therefore $V_H = 3$ ft/min

3) **Find out the Cross-section area, A_c**

$A_c = Q_m / V_H$ $Q_m = 0.12 m^3/s = 4.24 ft^3/s = 254.3 ft^3/min$
$A_c = 254.3 ft^3/min / 3 ft/min = 84.77 ft^2$

4) **Assume channel width (B), then find out water depth (d)**

Assume B = 13 ft (3.9 m), $d = A_c/B = 84.77 ft^2 / 13 ft = 6.52$ ft = 1.956 m

Depth to width ratio = 6.52 ft/13 ft = 0.5,
Since the ratio is between 0.3 to 0.5, therefore, it is ok

5) **Find out the channel length, L**

$L = F * (V_H/V_t) * d$
Where F = turbulence and short-circuiting factor (dimensionless)
Give $V_H/V_t = 6$, F = 1.37

L = 1.37 * 6 * 6.52 = 53.6 ft = 16 m

---

[1] American Petroleum Institute 1990 *Monographs on Refinery Environmental Control – Management of Water Discharges, Design and Operation of oil/water separators*

DESIGN CALCULATIONS FOR TILTED PLATE SEPARATOR[2]

1) Find out the rise rate for the oil globules. (V_s)

$V_s = 0.00386 * [(S_w - S_0) / \mu]$ (This is design for 60µm diameter globules capture)

Which S_w = specific gravity of fresh clean water at the 10 ^{0}C
S_0 = specific gravity of gasoline
μ = absolute viscosity of fresh clean water at the 10 ^{0}C, in poise

$V_s = 0.00386 * [(0.99 - 0.72) / 0.013] = 0.08$ ft/min

2) Total Surface Area Required

$A = Q / V_s = (254.3\ ft^3/min)/(0.08\ ft/min) = 3178.75\ ft^2 = 295.3 m^2$

3) Total No. of pack Required

Total no. of pack required

= total surface area require/ effective surface area of the pack = $295.3 m^2 / 43.5\ m^2 = 6.7$

Total no. of pack require = 7 packs

[2] Iggleden, G. J. 1978 "The Design and Application of Tilted Plate Separator Oil Interceptors" *Chemistry and Industry*, Nov 4, 1978, pp.826-831

REFERENCE

American Petroleum Institute 1990 *Monographs on Refinery Environmental Control - Management of Water Discharges: Design and Operation of Oil Water Separators.* Refining Department, API Publication 421

Aquafor Beech Limited 1999 *Humber Creek Subwatershed Restoration Plan*

Armold, K. and Stewart, M 1985 Designing oil and gas production systems *World Oil*, March 1985, pp. 69-78

Canadian Petroleum Product Institute. 1994. Draft Code of Practice for Oil Separators.

City of Toronto 2000 *Sewer Use By-law 457-2000*
http://w3.city.toronto.on.ca/involved/wpc/nbylaw.htm

Chow, V. T. 1959 *Open-Channel Hydraulics.* McGraw-Hill, Toronto.

Cochram, R. A. 1973 *An Oil Recovery System Utilizing Polymethane Foam – Feasibility Study*. EPA-670/2-73-084, U.S. Environmental Protection

Delta Controls Corporation 1999
http://www.deltacnt.com/99-00036.pdf

DiSalvo, L. H., and H. E. Guard. 1975 *Hydrocarbons Associated with Suspended Particular Matter in San Francisco Bay Water* Proceedings of the 1975 Conference on Prevention and Control of oil Pollution, American Petroleum Institute, p 163-173

Diniz, E. V. 1980 *Porous Pavement Phase 1 – Desgin and Operational Criteria.* EPA-600/2-80-135 U.S. Environment Proctection Agency, Cincinnati, OH Augst

Environmental Conservation Directorate 1976 *Selection Criteria and Laboratory Evaluation of Oil Spill Sorbents* Environmental Canada, Technology Development Report, EPS-4-EC-76-5

Environmental Emergency Branch 1973 *Guidelines on the Use and Acceptability of Oil Spill Dispersants* Environmental Canada, Report EPS 1-EE-73-1

Environmental Conservation Directorate 1976 *Selection Criteria and Laboratory Evaluation of Oil Spill Sorbents* Environmental Canada, Technology Development Report, EPS-4-EC-76-5

Fedra, K., GIS and Environmental Modeling In Maguire, Goodchild, M., B. Parks, L. Steyaert, 1993, *Environmental Modeling with GIS,* Oxford University Press, New York

French, R. H. 1994 *Open-Channel Hydraulics* McGraw-Hill, Toronto

Goodchild, M., The State of GIS for Environmental Problem-Solving In Maguire, Goodchild, M., B. Parks, L. Steyaert, 1993, *Environmental Modeling with GIS,* Oxford University Press, New York

Harayama, S., H. Kishira, Y. Kasai and K. Shutsubo 1999 Petroleum Biodegradation in Marine Environments *J. Mol. Microbiol. Biotechnology*, Vol 1, No. 1, pp.63-70

Head, I. and R. Swannell. 1999 Bioremediation of petroleum hydrocarbon contaminants in marine habitats *Current Opinion in Biotechnology*, Vol. 10, pp.234-239

Iggleden, G. 1978 The design and application of tilted plate separator oil interceptors *Chemistry and Industry*, Nov 4, pp. 826-831

Larkin, G. and Marsalek, J. 1998 *Laboratory Testing of Modification to the OCPA oil/grit separator (Phase II), Technical Note No. AEP-TN98-001* National Water Research Institute, Burlington, Ontario

Li, J. 1997. Statistical Analaysis of Oil Spill Data in the City of Toronto. Proc. 5th Environmental Engineering Specialty Conference, Halifax, Nova Scotia. 2:43-52.

Li, J. 2000. Sizing Criteria for Oil/Water Separator. Proc. 6th Environmental Engineering Specialty Conference of the CSCE, London, Ontario. 496-503.

Li, J. and P. McAteer 2000 Urban Oil Spills as Non-Point Pollution Source in the Golden Horseshoe of Southern Ontario *Canadian Water Resources Journal*, Vol 35, No.3, pp.331-340

Lin, H. 2001. Geographic Information System Models for Oil Spill Management. BSc Thesis, Dept. of Civil Engineering, Ryerson Polytechnic University, Toronto, Ontario, Canada.

Mohr, S. 1992 A New Type of High Efficiency Oil-Water Separator for Better Water Quality Management Annual Meeting, Pacific Northwest Pollution Control Association, Idaho

Rich, L.G. 1980 *Low Maintenance, Mechanically Simple Wastewater Treatment Systems*. McGraw-Hill, N. Y.

Romano, F. 1990 *Oil and Water Don't Mix: The Application of Oil-Water Separation Technologies in Stormwater Quality Management* Office of Water Quality, Seattle

Shales S, Thake BA, Frankland B, Khan DH, Hutchinson JD, Mason CF: 1989. Biological and ecological effects of oils, p. 81-172. In Green J, Trett MW (ed.), *The fate and effects of oil in freshwater*. Elsevier Science Publishers Ltd., New York

Silverman, S., Stenstrom, M. and Fam, S. 1986 Best Management Practices for Controlling Oil and Grease in Urban Stormwater Runoff The Environmental Professional, Vol 8, pp.351-362

Spill Action Centre 1997 *Summary Report of 1995 Spills* Ministry of Environment and Energy

Stenstrom, M.K., G.S. Silverman, and T.A. Burszynsky. 1984 Oil and Grease in Urban Stormwaters. Journal of the Environmental Engineering Division, ASCE 110(1), pp.58-72

Streeter, V. L. and Wylie, E. B. 1985 *Fluid Mechanics* McGraw-Hill, Toronto

United States of America 1998 *Nondomestic Wastewater Control and Pretreatment Design Cirteria* Department of defense, MIL-HDBK-1005/17

Warren Bell, A Catalog of Stormwater Quality Best Management Practices for Heavily
Urbanized Watersheds. National Conference on Urban Runoff Management: Enhancing Urban WatershedManagement at the Local, County, and State Levels, March 30 to April 2,1993. http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/water/volumes/sodivstructure.pdf.

Zhen, E. 1998. Evaluation of Oil/Water Separators in Removing Hydrocarbon Contaminants in Stormwater. BSc Thesis, Dept. of Civil Engineering, Ryerson Polytechnic University, Toronto, Ontario, Canada.