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A Web-Based GIS Planning Framework For Urban Oil Spill Management

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A WEB-BASED GIS PLANNING FRAMEWORK FOR URBAN OIL SPILL MANAGEMENT

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DECLARATION

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DEDICATION

This piece is dedicated to my beloved mom.

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Chapter 1 Introduction

1.1 Spill Problems – The Need for Spill Management Strategies

Oil is extensively used in industrial societies as a major sustainer of people's daily life. For example, every day, about 260,000 tons of oil and petroleum products are consumed in Canada and about 10 million tons worldwide (Fingas, 2000). Considering the amount of oil handled each year and the number of transfers that oil may be involved in from oil fields to end users, the potential for an oil spill is high (Fingas, 2000). Any accidents, equipment failures or human errors could cause minor or severe spills to the natural environment anytime and anywhere during oil delivery, storage and other oil-related operations. In Canada, most spills take place on land and account for a high volume of oil spilled; about 12 spills of more than 4000L are reported each day (Fingas, 2000). Numerous small oil spills occur daily in major cities across Canada and the total quantity of spillage entering into urban environment is significant. Figure 1-1 shows a chart of typical annual Canadian spills by percentage of volume, numbers and causes.

In Ontario, statistics indicate that the overall probability of a spill can be expressed as one spill per year for every two thousand people (Ontario Ministry of Environment (MOE), Spills Action Centre (SAC), 2000). During the period 2003 to 2006, there was an overall trend upwards in the number of reported spills province-wide: more than a 5% increase in the total number of spills every year (Ontario MOE, 2003, 2004, 2005, 2006). Spills from industrial sources increased by almost 24% between 2003 and 2004 (Ontario MOE, 2005). Oils and fuels represent 57% of spilled materials (SAC Summary Report, 2006). In Toronto, between 1988 and 2000, the number of spills was 300 to 500 per year (Li, 2002a). Roads have the largest frequency of spill occurrences especially highways, arterial and collector roads (Li, 2002a; Ontario MOE 2005, 2006, 2007). Other major spill locations such as service stations, industrial parking lots, storage depots are identified as problem areas (Li, 2002a). Municipalities with large populations and high concentrations of industries also have a large number of reported spills. Generally, accidental releases and intentional discharges to the environment from various sources will continue to occur as long as chemical substances, human errors, and equipment failures still exist in daily spill operation activities.

The fate and behaviour of spilled oil in urbanized areas are very much influenced by the infrastructure of cities. In urbanized areas, if spills happen on roads, parking lots, storage yards, or other impervious surfaces, most likely the spillage will follow the ground slope, stranding and pooling in a pit or flowing to the nearest drain. If it is not properly cleaned up, when rain comes, the residuals also could be transported to the city's storm sewer system then passing to local creeks and lakes. Spilled oil can cause algal blooms in rivers and lakes, destroy fish and wildlife habitats, and jeopardize drinking water quality. One major concern of spilled oil is the interruption of a water treatment operation. It could severely affect water quality by causing turbidity, objectionable tastes, odour and other physical or biological effects. Fox example, in the City of Toronto, when a spill occurs upstream, the downstream water treatment plant has to shut down its operation until the spilled material bypasses the plant, and become discharged directly to Lake Ontario. Consequently, spillage discharges from storm and combined sewers, or from sewage treatment plants are one of the reasons causing the increased bacteria and nutrient, heavy metal and organic chemical inputs in receiving waters (Li, 2002a). Municipalities need to undertake initiatives to manage spill issues in a comprehensive manner.

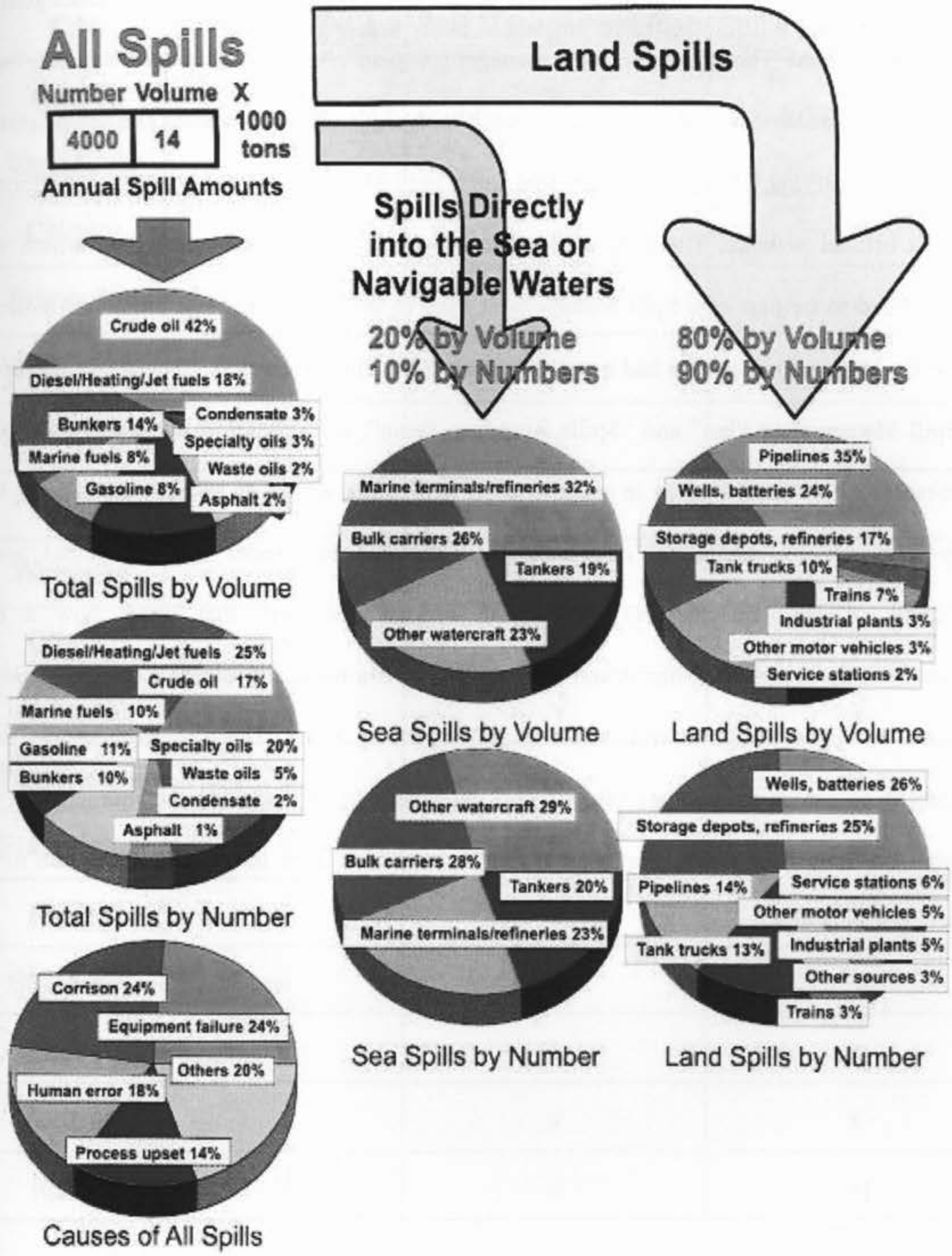

Figure 1-1 National spill quantities (Fingas, 2000)

In order to understand the current oil spill management status in 17 major Canadian cities, a survey was conducted in 2006 to investigate what kind of spill management programs existed. Three phrases, "spill management plan", "spill pollution prevention", "spill response" were used as query criteria to search each city's official website. The search results were not satisfying. There was no city that had a Spill Management Plan posted or mentioned on its official website. The City of Toronto only had a Spills Response Plan which was considered to be part of a Spill Management Plan in this research. Most cities had a Sewer Use By-law, and some cities had a spill response crew. Three measures, "Sewer Use By-law", "Spill Management Plan" and "Spills Response Team", were therefore identified as critical measures a city should adopt in order to cope with spills within its boundary. A Sewer Use By-law prohibits intentional discharge of deleterious substances into municipal sewer systems. A spill management plan is an official document that states how a city systematically manages spills. A spill response team is a team of professionals that responds on-site to spills, mitigates spill impacts, and cleans up spills. These three measures were selected as catena to evaluate current spill management strategies at the municipal level. Table 1-1 shows the results and a cross mark means that there is no such a measure in the surveyed municipality.

City	Sewer Use By-law	Spill Management Plan	Spills Response Team
Victoria	×	×	×
Vancouver	√	×	√
Calgary	√	×	√
Edmonton	√	×	×
Whitehorse	√	×	×
Yellowknife	√	×	×
Regina	√	×	×
Winnipeg	×	×	√
Ottawa	√	×	×
Toronto	√	√	√
Charlottetown	√	×	×
Fredericton	√	×	×
Halifax	√	×	√
St. John's	×	×	×
Quebec	×	×	×
Montreal	√	×	×
Iqaluit	√	×	×

Table 1-1 Survey results of municipal spill management in major Canadian cities

As indicated in Table 1-1, spill management programs in major Canadian municipalities are addressed to varying degrees. Spill management at the municipal level mainly focuses on reactive response rather than preventive management. Some cities do not have a Sewer Use By-law which could empower a city to regulate wastes being discharged into its sewer system and stimulate industries, the business sectors and individuals to improve spill preventive measures. Furthermore, Pollution Prevention (P2) planning as a mandatory requirement is incorporated into the City of Toronto's Sewer Use By-law which could largely motivate businesses with spill problems to identify ways to avoid, reduce or eliminate the creation of pollutants at source (The City of Toronto Water and Wastewater Network, 2001). However, the survey shows that there is no spill management plan for a city to deal with urban spill issues in a comprehensive way. Even the one which the City of Toronto has is a Spills Response Plan which does not address spills prevention and is not the same management plan discussed in this research. Therefore, it can be concluded that spill management strategy is generally lacking at the municipal level.

The motivation of this study is to set up a comprehensive oil spill management planning framework to assist local municipalities to identify the needs for information, methodologies, and a strategic approach to improve the process of producing a spill management plan. A generic planning framework is developed with four consecutive steps: establishment of an oil spill inventory, development of oil spill pollution prevention methods; deployment of spill control countermeasures, and emergency response plans and cleanup techniques. The framework acts as an integrated information system providing for systematic data storage, access, analysis, extraction, methodology and technology to assist in addressing all of these components in a comprehensive way. However, it is not a "cookbook" and is not going to replace municipal spill management practices. It just outlines what a spill management plan needs to be. Some municipalities may already have certain components in their daily practice and they may consider adopting some of the oil spill management options, strategies and recommendations into their current spill management system. Or a municipality may reconsider its management strategies, start to look at the problem area and set up a more comprehensive spill management plan according to the framework.

1.2 Methodology for Analysis

The analysis methods are critical and the output from the analysis could directly affect municipal spill management decision-making. Two main questions guided the overall analysis procedures of each step in the planning framework:

- What kinds of data are needed for each step to perform the analysis?
- What kind of analysis could be applied to each step in order to extract the information to facilitate municipalities to implement spill management measures?

Three major methods are identified as fundamental analysis approaches; these are statistical analysis, GIS spatial analysis and Web-based GIS analysis. Statistical analysis describes one dimensional characteristics of recorded spills within a defined boundary in a certain period of time, such as how many spills occurred during that time frame; the frequency, volume, causes and impacts, etc.

Geographic Information Systems (GIS) have been applied to display spill locations, analysis spill patterns and deploy spill control measures (Li, 2005). In this study, GIS based planning tool provides a systematic analysis methodology can be that integrated into every step of the spill management planning framework in a higher degree and a more dimensional way. The first step of the planning framework for spill management is to establish an oil spill inventory. The integration of GIS as a database management tool could bring benefits to standardize data compilation, maintain data consistency and control data quality. A generic

GIS Data Model is also developed for a municipality to understand the GIS database structure and enable fundamental spatial analysis to support strategic decision-making. In the Spill Prevention step, GIS is applied to screen the most frequently spilled areas and dissociate spill-related information such as spill causes and types of land-use from the map. In the Spill Control step, streamline of map analysis for spill control opportunities is recognised and specific "layers" of data are isolated for further data processing by the analyst. In Spill Response and Cleanup step, the information identified in all four steps is integrated into a unified GIS and web-based GIS system, called an information platform to support spill response information requirements, pre-spill preparation and spill emergency response.

Integration of a web-based GIS technology into urban spill management is a new approach to assist a municipality with the distribution of spill-related spatial information, sharing GIS resources, and manage spill issues in a cost-effective way. Spill data are managed in a remote database centre; only services are delivered to end-users via the Internet. In this manner, web-based GIS make access easy for a wide range of potential uses. The on-line mapping tools provide municipal spill management staff search, query and reporting capabilities for historical spill datasets, rivers, sewer outfalls, roads and other environment-related information. No in-depth GIS experience is required to explore GIS software functions and interactively browsing of spill related geographic layers makes information easily to be obtained by city-wide staff. At the same time, web-based GIS could maximize the usage of GIS resources for a municipality

1.3 Objective

The objective of this research was to develop a generic oil spill management planning framework for municipalities. The framework was recommended to consist of four interdependent components: (1) oil spill inventory analysis; (2) oil spill prevention; (3) oil spill control strategy; and (4) oil spill response and cleanup. The key components are the proactive and preventive measures of the planning framework as a long-term strategy to reduce the number of spills and improve the overall environmental performance within a municipality. Roles of GIS and its distributed form and Web-based GIS play an important part of the proposed framework. A case study of the Etobicoke district (a selected area in the west of the City of Toronto) demonstrates the detailed procedure of municipal oil spill management plan and the effectiveness and efficiency of Web-based GIS technology.

1.4 Scope

Although spill management involves three levels of government in Canada, the research case study focused on:

- municipal land oil spills in southern Ontario especially in GTA (Great Toronto Area)
- oil spills impacts on water
- demonstration of a Web-based GIS spill management plan using a case study in Toronto

1.5 Study Area

The District of Etobicoke, located at the west side of the City of Toronto, adjacent to Ontario Lake (Figure 1-1), experiences a large number of spills every year and it is also a good example for spill management planning, when compared with other Canadian cities. It covers parts of the Etobicoke Creek Watershed, Mimico Creek Watershed and Humber River Watershed. Etobicoke is highly-urbanized and parts of the upper Humber remain rural (Figure 1-2). The watersheds have been highly developed and degraded as a result of years of urbanization and spills are one serious component of the environmental pollution in this area as well. Therefore, the health of the Etobicoke Creek and Mimico Creek watersheds in particular has been identified as a significant environmental indicator for the Greater Toronto Area (GTA) by Toronto and Region Conservation Authority (TRCA, 2006). Therefore, the District of Ectobicoke was chosen as the study area to demonstrate how an oil spill management planning framework can be implemented at the municipal level.

1.6 Organization

The thesis is comprised of five chapters. Chapter 1 presents an introduction and identifies the spill issues and strategy gaps at the municipal level. The objectives and scope of this study are indicated in this chapter. Chapter 2 is the literature review of oil spill research and the role of GIS and its distributed form, Web-based GIS. In this chapter, focus is directed at the review of land-based oil spills and their characteristics, spill prevention measures, control technology, and response and cleanup. It also elaborates on spill related law and enforcement within the Canadian legal system. The applications of GIS and Web-based GIS in spill-related fields are reviewed in this chapter. Chapter 3 focuses on the information needs for the establishment of an oil spill planning framework. How GIS and Web-based GIS could facilitate planning processes. Chapter 4 discusses Web-based GIS architecture as refined for municipal spill management. Chapter 5 presents the case study which examines the planning framework based on a Web-based GIS architecture, and Chapter 6 highlights the conclusions of the study, suggestions and recommendations for urban oil spill management based on the research findings.

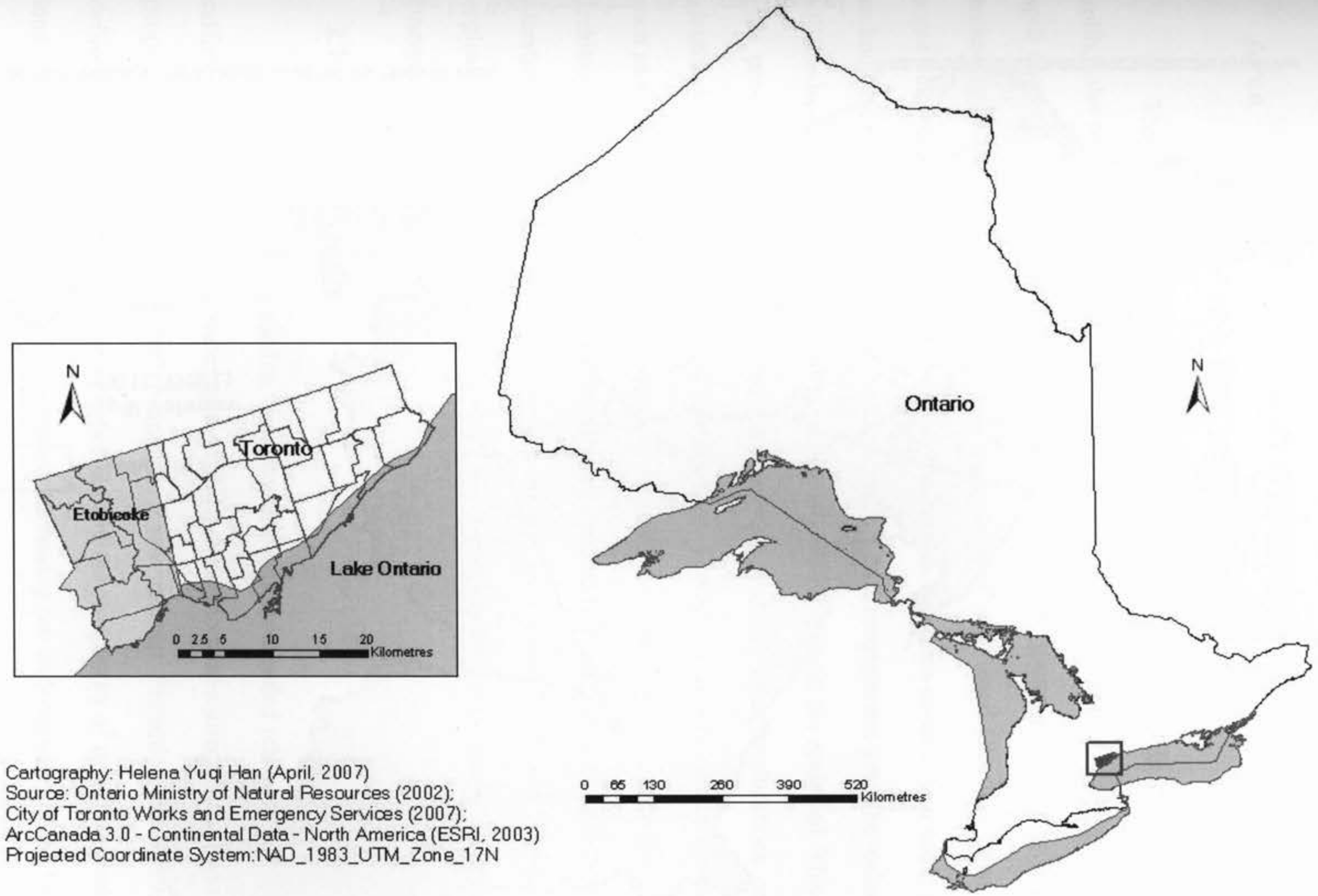

Figure 1-2 Etobicoke, Ontario: geographic location

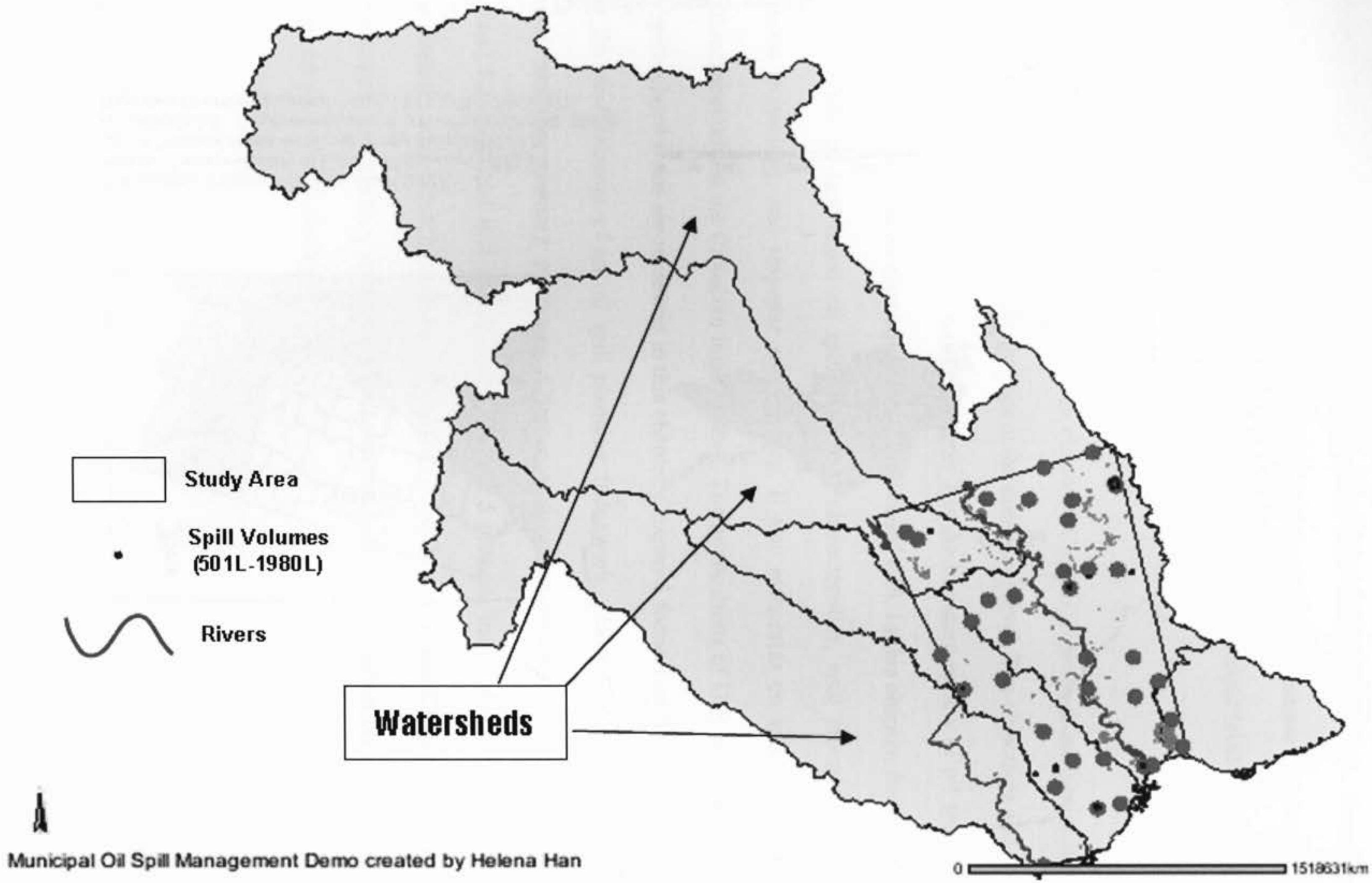

Figure 1-3 Watershed where study area is located

Chapter 2 Literature Review of Inland Oil Spills in Urban Area

The objectives of this Chapter are to review the published literature on land oil spills, roles of GIS in oil spill management, and web-based GIS applications. Topics cover oil spill characteristics, prevention, control, and response and cleanup technologies. Advanced technologies and GIS are reviewed. The applications of web-based GIS have been used in some fields to demonstrate the advantages of using GIS functions on-line. As a relatively new technology, it has not been applied to municipal oil spill management yet. The technologies of Web-based GIS, architecture and functions of each component are reviewed. This review may provide insights of Web-based GIS and the potential roles, applications could be identified and applied to urban spill management. The review covers current technologies, such as software, hardware, the physical environment for establishment of a Web-based GIS architecture and some other Internet technologies related to Web-based GIS applications. The literature is divided into three parts: review oil spill management; GIS and Web-based GIS applied to oil spill management; and the role of municipality in pollution prevention and emergency management.

2.1 Land Oil Spills

An oil spill is "…a sudden, unexpected, or unapprehended release of a pollutant in sufficient quantities to the air, water, groundwater, or land to pose a direct or indirect threat to people, environment or property" (Canadian Environmental Protection Act, 1999). The definition indicates that a spill is unpredictable and the complexity of its nature could cause long term impacts on the natural environment. Increasing our understanding of the behaviour and fate of spilled oil is necessary for preparedness, response, control and minimization of the impact of an oil spill (Levy and Saint-Georges, 1995). In order to thoroughly understand spill issues, a general review of spilled oil properties is listed below.

Properties of Commonly Used Oil

Generally, oil is classified into the five types listed in Appendix I, including very light refined products such as gasoline, naphtha, solvents, avgas 80/100; diesel-like products and light crude oils such as fuel oil, jet fuels, kerosene and medium oils and heavy crude oils (Michel, Christopherson and Whipple, 1994; Li, 2002). The first observable process of an oil spill is its tendency to spread out and be influenced by the physical forces of gravity and surface tension. The horizontal movement of the oil is actually caused by the downward pull of gravity and oil viscosity properties (U. S. EPA Oil Spills Control Manual for Fire Departments, 1973). Viscous oils such as bunker fuel oil and crude oil often have intermediate adhesion features which often form a tarry mass that moves slowly after spilling, particularly in low temperatures. Non-viscous products, such as gasoline, have similar movement to water on a land surface in both summer and winter. Different types of oil have various chemical and physical properties. Properties which could mostly influence the fate of spilled oil are specific gravity, volatility, flash point, viscosity, pour point, emulsification and the water-soluble fraction. The explanation of the properties and some response strategies are listed in Appendix I. These properties provide fundamental information for spill responders to understand what kind of oil is spilled before making any spill-related decisions.

Fate and Behaviour of Oil Spills

The fate and behaviour of spilled oil in urbanized areas are very much influenced by the infrastructure of a city. Municipal roads are covered with an impervious surface and watercourses within urban areas are often used as part of the stormwater conveyance system. Local creeks and watercourses receive the drainage from urban streets and also waste materials and toxins that are introduced to the storm sewers (MOE, Stormwater Pollution Prevention Handbook, 2001). When a spill happens on a road, storage yard or any impervious surface, it most likely flows on the concrete or asphalt surface where it pools and enters storm water catch basins. Quick responses to a spill and containment are critical in order to prevent it from entering the municipal sewer system. On the other hand quick responses and containment also provide potential opportunities for municipalities to deploy control measures at spill-prone areas.

Review of Spill Legislation and Management

The Canadian federal government, responsible for the protection of federally-owned lands and water, plays a role as an advisor to any parties in need of advice on spill countermeasures and information about spilled chemicals, as well as monitors large spill clean-up efforts and evaluation environmental impacts (CEPA, 1999). There is federal legislation which addresses spills including the *Canadian Environmental Protection Act* (CEPA), the *Canada Oil and Gas Operation Act*, the *Canada Shipping Act*, the *Transportation of Dangerous Goods Act*, the *Fisheries Act,* the *Artic Water Pollution Prevention Act* and the *Emergency Plans Act*. These are the significant pieces of legislation which address the integrity of the natural environment and spill pollution prevention nation-wide. Detailed explanations of the restrictions of unlawful discharge or spills of material can be found in Part five of CEPA, under Controlling Toxic Substances, and are listed in section 95 (1-8) (CEPA, 1999).

In addition to the statutory duties imposed by the Environmental Protection Act on the discharger, the *Act* also extends to municipalities the right to respond to spills and the right and a mechanism to recover their costs (CEPA, 1999). Thus, municipalities can reasonably be expected to assist the discharger's response to inadvertent or accidental releases of pollutants especially where these threaten municipal interests (Ontario MOE, 2007).

Environment Canada supports the development and implementation of pollution prevention (also called P2) initiatives (including spill prevention) which promote sustainable resource use and take social and economic considerations into account (Environment Canada, 2000). For a major spill, the Environmental Emergencies Branch of Environment Canada plays support and surveillance roles by providing scientific advice and expertise to lead agencies (Ontario MOE guidelines, retrieved on 2006). The lead agency is assigned to the provincial Ministry of Environment which has legislated reporting requirements (CEPA, 1999). As a result, most incidents are reported directly to the provincial or territorial governments rather than to Environment Canada. The federal government intervenes when provincial or territorial officials ask for help or when the disaster affects an area under federal jurisdiction, such as fish habitat, or federally regulated substances (Environment Canada, 2005).

At the provincial level, for example in Ontario, discharge of contaminants is prohibited by provincial legislation, such as the *Environmental Protection Act* Part II (General Provisions) s.14 (1) and Part X (Spills), the *Ontario Water Resources Act* s.30 (1), the *Emergency Plans Act* (R.S.O. 1990, c.E.9 s.2). They are the pieces of legislation which enforce pollution prevention within Ontario. The Ontario Ministry of the Environment (MOE) has a lead responsibility to respond to province-wide spills based on provincial regulations and guidelines.

However, Ontario's environmental management framework is largely reactive, not preventive (Ontario MOE, 2004). It defines a three-level field response and the Ministry officers will decide whether or not to escalate spill response level: Level 1, the District Response, provides an initial spill assessment and determines what actions need to be taken during or outside of the regular business hours. Level 2 is the Regional Response which can be activated by SAC if additional resources are needed from the Regional office. Level 3 is the Head Office responds (Ontario MOE, 1998). Since the emergency is considered serious and prolonged, it may require sophisticated officer on-scene monitoring (Ontario MOE, 2007). When a spill happens, an internal review by the Ministry will determine how the Ministry will fulfill its role during the early stage based on provincial guidelines and procedures. If a spill causes widespread damage, injuries or fatalities, MOE resources and personnel will assist local agencies by providing information and advice in accordance with the Ministry's capability and expertise. Additionally, the Ministry operates a 24-hour spill reporting and response coordination centre – the Spills Action Centre (SAC) to meet its responsibilities related to spills and emergencies.

The role of a municipality in spill response varies with the complexity of spill incidents. The fire and police departments are always the first ones on site to protect public safety and isolate the spill site. Then municipal Public Work sends its spill response team to check the situation and report the Ministry. It is the Ministry's responsibility to report spill situations to Environmental Canada. If the situation is serious, the Ministry will be the lead agency to coordinate the whole process. The municipality and spillers have the responsibility to clean up the site and Environmental Canada provides guidance. However, it is not the provincial Ministry nor Environmental Canada's role to be a first responder on scene. Much of the Ministry's involvement in spill incidents occurs during the cleanup and restoration phase (Ontario MOE, 2000). Municipalities provide the first line that routinely handle local emergencies including spills.

Municipalities have an active role in developing and implementing source protection plans in all areas under municipal jurisdiction (Belling, 1993). Therefore, a *Sewer Use By-law* for municipal pollution prevention enforcement is considered as effective and should be established (Li, 2002a). Listed below are some useful features of Toronto's sewer use-by law:

- Whoever causes spills should take all necessary measures to prevent spills from entering the drain or sewer.
- Owners or operators shall install, operate and properly maintain a grease interceptor or oil interceptor in any piping system at its premises that connects directly or indirectly to a sewer.
- Industries discharging subject pollutants are required to have a pollution prevention plan.
- Citizens should report spill incidents to the city.
- There is an obligation that the person or industry causes spills shall provide a detailed report to the Commissioner within certain days.

Spill Pollution Prevention

Spill pollution prevention in this paper addresses initiatives municipalities could take to avoid spills prior to the release of oil, not mitigation of damage once a spill occurs. Incorporation of P2 into municipal spill management is advance planning to anticipate and provide for the avoidance of spills (Ontario, MOE, Industrial Pollution Action Team, 2004). Municipalities also can require industries to enact a Pollution Prevention Plan and specify the limitation of pollutants discharge to municipal sewer use system. The City of Toronto sets up a P2 team to inspect industrial facilities for P2 compliance and provide assistance in completing Sewer Use By-law requirements. Li (2002a, 2002b, 2002c, 2002d, and 2002e) recommended that:

- Municipalities should coordinate with provincial and federal agencies and industrial associations to provide spill education and training programs.

- Employee training and preventive maintenance should be emphasized in training programs of spill prone sectors such as petroleum and transportation.
- Spill prevention should also be promoted to residents in older residential areas and institutions where heating oil is still used.

The Regional Municipality of Waterloo has developed water pollution prevention measures for different business sectors such as storage, warehousing, wholesale metals, food industries, etc. Specific P2 measures are identified such as:

- that rising waters be prevented from discharging to sewers or surface water
- that secondary containment be provided for liquid storage areas
- that underground storage tanks (USTs) are not to be used; and above ground storage tanks(ASTs) should have visual gauges
- that uncovered receiving areas should have a spill sump to catch or store spills
- that loading docks are covered to prevent stormwater from mixing with any spillage
- that employees must have WHMIS training

A detailed summary of P2 measures for different sectors is listed in Appendix C. P2 Fact Sheets, brochures and leaflets are used to promote spill pollution prevention and improve the awareness of spill pollution prevention (The Regional Municipality of Waterloo, 2004).

Oil Spill Control Review

Control technologies are the measures or devices put in place ahead of time to capture spilled oil and residuals when they migrate to catchments or downstream sewer outfalls. These are different from spill response containment technologies which intended to prevent spilled oil from spreading by confining it at the source where it has been discharged (Fingas, 2000).

Spill control is considered as a proactive measure in case spills occur by intercepting spillage before it causes significant damage. It is much less costly compared to spill clean-up. For example, Neff (2002) describes how spill control could save huge amount of money in spill cleanup. In 1985, 7,000 US gallons of fuel oil were spilled during the transfer from a tanker trunk to a storage facility in Essex County, New York. The final cost for clean-up was $589,000. An additional $106,000 was paid in interest and penalties after arguments went through the court system for 14 years. The cost of providing an interceptor and containment system for the NY spill described above, would have been approximately (US) $50,000, saving the owner 92% of the clean-up costs. Comparing the expenditures of the lost product, lost time, regulatory fines and the huge potential for civil damages and liability, the cost for spill protection becomes very economical (Neff, 2002).

It has been suggested by Li (2002) that many different sites could benefit from the application of an interceptor for spill control including commercial sites, industrial sites, high volume intersections, gas stations, and convenience and fast food stores. This determination of suitable spill control locations and sizes were based on spill statistical and spatial analysis. In Li's study (2002), spill control devices were site specific and sizing of these control measures was recommended to be based on spill characteristics in addition to a draft code of practice developed by the Canadian Petroleum Product Association (e.g. the sizing oil interceptors be equal to the largest on-site pumping rate over one minute) (Li, 2002). In urbanized areas, containment structures and oil/water separators are recommended as control measures to reduce the quantity of spilled oil entering a city's drainage system and adjacent watercourses.

One possible mitigation strategy that could be adopted by spill management is to insure that oil has been removed from water before the water is discharged into a river or lake.

Oil-water separators are often used to capture road and non-point source spills and to separate spilled oil and water at stormwater outfalls. Two main objectives of an oil-water separator are deployed in spill control and emergency response (Sit, 1999). The first is to remove non-soluble, non-emulsified oil in stormwater, and the second is to intercept accidental spills, which may occur at the loading or unloading facilities. Containment systems such as underground storage tanks, wells, oil pits are usually built around or near fixed facilities to capture spilled oil in a confined area for easy spill control and recovery. When a spill happens, spillage can be directed into the containment facilities instead of being allowed to enter municipal storm sewers. Stormwater ponds pit or trenches near spill-prone areas can be retrofitted to provide oil containment, however these must identified as spill-prone for their construction to undertake.

Land Oil Spills Response Strategies and Cleanup Technologies

Generally, land oil response strategies focus on containment and control as near to the source as possible to minimize the spread of the spilled material (Owens, 2002). Multi-disciplined, trained workers and an internal response team are the best defense and do more to prevent the escalation of an event in the first few minutes than any outside agency or response service can do when they arrive at the scene (Holland, 2003). Therefore, municipal spill management should assist spill-prone industries to establish their own spill response plans and teams. When appropriate actions are not being taken by the spiller, municipal civilian emergency departments such as fire and police departments will be the first responders to take the initiatives to deal with the spill. Since spill emergencies are different from other emergency situations; they need a specially-trained people to guide the response work. A municipality also should have its own a spill response team to take control, provide on-the-scene monitoring, and recording as well as communication with other agencies. It can be an opportunity for urban spill management to find out how to immediately response spills and control it on-site.

Another important response strategy for land spills is to prevent the spilled material reaching streams and rivers because of the significant difference in rates of oil transport on land and water (Owens, 2002). Therefore, identification of the adjacent catchments, drainage, or any entrances connecting to municipal stormwater outfalls should be protected is very important.

After the initial emergency phase of a response to a spill, response should focus on containment and protection on land. The selection of appropriate techniques is dependent on the amount and type of material spilled, the slope of the terrain, the surface materials, and the available time to deploy and intercept. If possible, spillage should be contained at a certain spot such as a dry pond where recovery can be easier. For example, damming to create a pool of sufficient depth can allow the use of skimmers. Once an oil spill has been contained on land, efforts to remove spilled oil should begin as soon as possible. Mechanical containment, recovery, and cleanup equipment are the primary tools used to respond to oil spills. Such equipment includes a variety of booms, barriers, and skimmers, as well as natural and synthetic sorbent materials.

A key to effectively combating spilled oil is careful selection and proper use of the machines and materials most suited to the type of oil and the conditions at the spill site (US EPA, 1999). Booms are the first equipment mobilized to the site and used to control the spread of oil throughout the operation (Fingas, 2000). They cannot only control the spread of oil but also can concentrate oil in thicker surface layers so that skimmers and other cleanup equipment can be deployed to recover the spilled oil. In addition, booms are also use to divert and channel oil slicks along desired paths, making them easier to remove from the surface of the water.

When a spill occurs and no containment equipment is available, barriers can be improvised from whatever materials are at hand (US EPA, 1999; Fingas, 2000). Berms or dikes are built on land to contain oil spills and prevent oil from spreading horizontally. Shallow trenches dug as a method of containment, are particularly effective if the water table is high and oil can not permeate the soil. After containment of a spillage, Vacuum tracks and septic tank pump-out trucks are those commonly used devices with a vacuum unit and a storage tank mounted on a truck. They are used to remove small contained spills (Fingas, 2000).

Spills on land have the potential to have a great impact on human-use activities and resources. Therefore, planning for land-based spills can be quite site specific and can focus on identifiable potential risks and impacts. In cases where the spill is in a populated area, frequently there is the requirement to clean or treat to a higher level. Sorbents are those products or materials which are oleophilic and hydrophobic, meaning that they have a high capacity for adsorbing or absorbing a petroleum product and tend to repel water. Once sorbents have been used to recover oil, they must be removed from the water and properly disposed of on land or cleaned for re-use. Any oil that is removed from sorbent materials must also be properly disposed of or recycled. Detergent may be applied to oil spilled on floors. The waste water will then need to be collected and sent to a water treatment plant.

2.2 Review of GIS in Oil Spill Studies

GIS have been commonly applied to marine oil spill management while few applications touch upon inland spill management except for Li's studies at the Great Lakes Areas of Concern (Li and Mcateer, 2000; Li, 2002a, 2002b, 2002c, 2002d, 2002e; and Li 2005). In marine oil spills management, GIS are applied in spill data management, resource mapping, response support, contingency planning, and spill trajectory modelling (Sorensen, 1995). The experiences learned and some of the general methodologies applied in marine oil spill management could be extended to inland oil spill management especially in spill data management and spill emergency response planning.

The advantages of GIS lie in handling large and diverse spatially-related spill databases (Douligeris et al., 1995). However, early uses of GIS in marine oil spill investigations encountered some constraints. Martin et al. (2004) pointed out that the complexity of spatial data manipulation could create an obstacle to most users and force them to rely on the services of specialized GIS analysts. It was also found that data entry consumes a large amount of time during the initial stage of a spill. Many practitioners suggested that GIS should be configured for spill response prior to a spill event (Douligeris et al., 1995; Li et al., 2000; Li, 2000; and Guillen et al., 2004). Sorensen (1995) described a pre-spill resource database to map spill data by using GIS. It also recommended that "the resource database should include as much base inventory data as possible, as well as simple layer selection and spatial and tabular query capabilities to illustrate how these data are accessible and useful" (Sorensen, 1995). Douligeris et al (1995) suggested that spill-related data should be formed in a way which can be processed by other modelling or algorithm software to perform statistical and spatial analysis. Results are meaningless to spill management if only observational raw data are displayed without any spatial analysis (Douligeris et al, 1995).

Application paradigms of GIS recognized by Goodchild (1998) form the functionality that spill decision-makers may need to incorporate GIS into their spill management and planning. His applications of GIS are:

- Accurate digital map production
- Inventory and management of spatially distributed facilities

- Integration of data: geographic location as common reference for otherwise unrelated data sets;
- Spatial analysis: manipulation of spatial data to extract information and insight
- Dynamic modelling: using digital representations of data and processes to forecast impacts and evaluate scenarios (Goodchild, 1998)

All of these are also considered central to GIS applications in municipal management of oil spills.

The capabilities of GIS in spill management have been to handle and analyze voluminous spill data sets, integrate and synthesize data, standardize data, collect and store shared data, facilitate records, update, and model, test, and compare alternative management strategies before they are imposed on the real world (Pourvakhshouri and Mansor, 2003). GIS could potentially provide spill managers with a means to integrate spill data with geographic features and municipal infrastructure drawings to identify spill management opportunities and deliver constantly updated information and timely maps.

In the survey prepared by the Public Safety and emergency Preparedness Canada, there is an increased awareness of applying GIS in emergency response planning including oil spills (Spearin, 2003). GIS is identified as an effective tool in managing large amounts of spatial data and other response information collected from various collaborative agencies and allowing first responders to have easy access to this critical information in a timely and efficient manner.

In the pre-spill phase, also known as spill preparedness, basic information such as key contacts, responder capability, resource locations, basic maps and facility sites, floor plans, addresses and phone numbers are listed in a pre-spill plan and incorporated into GIS systems (Spearin, 2003). Knowing the location of specialized equipment before and during an event can reduce response time in identifying where and whom to call to provide supporting services. The types of service provided, time and routes for response vehicles to follow to arrive at the site are the inputs for responders to generate contingency actions. It is fundamental knowledge for spill responders to remember that "only after the potential damage of an event is evaluated, can mitigation and preparedness activities start" (Environment Canada, 2003; Spearin, 2003). Therefore, GIS can play significant roles in spill dispersion assessment (Environment Canada, 2003), evaluation of toxic plume direction in relation to population densities and potential routes of evacuation of residents during a major spill event (Spearin, 2003).In the after-spill phase, GIS are used to analyze information gathered during the spill emergency and pre-plan for mitigation assessment and improve spill response planning (Spearin, 2003). The principal benefits derived from GIS usage are identified as improvements in planning, preparedness, responsiveness, and communications (Spearin, 2003).

However, the overall adoption of GIS in emergency response planning in Canada is relatively new and the applications were regional and limited in nature (Spearin, 2003). Lack of knowledge about GIS is a significant barrier to its application as a tool to assist in the development of emergency response plans. Lack of compatibility between various GIS software has been identified a significant barrier to use (Spearin, 2003). At the municipal level, the majority of GIS applications are used in planning and engineering departments which have the ability to apply GIS technology to emergency response planning. However, due to the lack of awareness among relevant organizations and departments, sharing available GIS technologies and database becomes the major barrier to apply GIS in emergency response planning. The availability of data, the cost of software, expertise in GIS, as well as the accuracy of topographical maps due to the age of data for roads and structures could also limit the development of GIS in emergency management planning (Spearin, 2003).

Communication and sharing of information is critical during a spill emergency. Integration and coordination of GIS data among first responders and other stakeholders such as federal provincial municipal agencies and private companies are significant during spill emergencies because shared information is the common base of an effective contingency plan among response agencies (Spearin, 2003). Collaboration with both federal and provincial agencies would be beneficial to first responders as shared information could be used to identify the roles of participate agencies, regulations and guidelines applied to spillers and what are the mutual aid agreements within response agencies. Collaboration between a company's safety personnel and municipal spill emergency team can greatly improve spill response efficiency (Spearin, 2003). Companies' directors, transportation and logistic personnel who involved in the handling, transporting, or storing of hazardous materials may directly involved in the event of an incident or provide support services to first responders. Contact information should be developed into first responders' contingency plan and GIS systems.

In recent years, the role of GIS in oil spill management is gradually enhanced as IT and commercial GIS become more widely understood and more accessible (Peng and Tsou, 2003). Prior to the introduction of GIS, the demands of a rapidly developing emergency often meant that response decisions were based on an individual manager's work experience and intuition rather than current information on the incident (Krishnan, 1995). However, researchers still strongly recommend that modellers, statistical analysts and GIS software programmers should collaborate closely to produce a more seamless integration of these technologies and approaches for data analysis (Krishnan, 1995, Li et al., 2000). Even with all the advanced technologies available, sound judgement and decision making from scientists and response professionals are still necessary to select appropriate oil spill management techniques (Krishnan, 1995). Despite its applicability, GIS technology remains under-utilized in oil spill management and few first emergency responders are using GIS (Spearin, 2003). GIS applications in emergency response practice are self-supporting software developed for a specific purpose for clients. Fewer of these applications are designed for data sharing among a number of users (Spearin, 2003). A lack of GIS integration and coordination increases the cost of database development and can likely result in inadequate or ineffective emergency response planning. A move towards Web-based data sharing sites were set up to address barriers to establishing collaborative systems among multiple users (Spearin, 2003).

2.3 Web-based GIS Technology and Applications

There are more than a hundred papers and books that talk about the Internet GIS technology and the applications. Papers from the Computer Science and Geography domains mainly focus on the development of Web-based GIS technology and architecture. Other studies address the functionality and apply Web-based GIS applications in a specific research field such as trip planning (Peng and Tsou, 2003), transportation (Ziliaskopoulos and Waller, 2000), health science (Kistemann, et al., 2002; Theseira, 2002), environmental monitoring (Kelly and Tuxen, 2003), river monitor (Halls, 2003), fish species at risk (Liu, 2005), slope-land study (Yu, et al. 2007) etc. The objective of this review is to understand what is Web-based GIS, how GIS could be delivered through the Internet and what kind of functionality can be provided by Web-based GIS.

Peng and Tsou (2003) stated that "Internet GIS is a research and application area that utilizes the Internet and other internetworking systems to facilitate the access, processing, and dissemination of geographic information and spatial analysis". The Internet is an infrastructure that hosts many applications such as the World Wide Web, which potentially ease the publication of information and simplify the access by users of that information (Abel et al, 1998). Moreover, the integration of GIS into the Internet allows virtually anyone with an Internet browser to participate in collaborative spatial analysis projects. The GIS industry explored the technologies and built GIS capabilities in a distributed format via the Internet (Tait, 2005). Since the data structure and operation processes of GIS are complex, it is more difficult to build GIS Web services than the ordinary business transactions in Web-based environment (Tu and Abdelguerfi, 2006). A key challenge for distributed GIS is the publishing of geographic content and providing interactive operation interface.

IT (Information Technology) standards, software, physical computing, and network architecture form the foundation of the Internet. IT standards and network infrastructure enable GIS applications to run on the Internet. The Web is platform-independent and interoperable, supporting a HyperText Transfer Protocol that runs on top of TCP/IP based networks (Su et. al., 2000; Peng and Tsou, 2003). It is used for delivering not just data, but geo-processing functionality that can be wrapped in interoperable software components called web services. The GIS industry exploited these IT technologies and built the capabilities known as distributed GIS or Web-based GIS (Tait, 2005).

Challenges facing distributed GIS, such as in Web applications, are largely related to the ability to access the diverse proprietary data formats (Peng and Tsou, 2003; Kim et al, 2005). Open Technologies such as GIS-related Open Specifications and Open Source Software (OSS) are striving to enable the interoperability of GIS in a Web-based environment XML (Extensible Markup Language), is similar to HTML (Hyper Text Markup Language) that separates data from presentation, and transmits data between applications. It enables computers to communicate universally with other computers and create a new generation of web services designed to interact with other services. SVG (Scalable Vector Graphics) is a vector graphics language written in XML to describe two-dimensional graphics, and GML (Geography Markup Language) is an XML encoding for the transport and storage of geographic information, including both the spatial and non-spatial properties of geographic features. They are both XML schemas and offer all the advantages of XML's openness, transportability, and interoperability. The capabilities of SVG are used to represent geographic data on the web and create on the fly maps as response to web-client queries. GML specification supports geographic data interoperability by providing basic geometry tags, a common data model, and a mechanism for creating and sharing application schemas. Once the geometries and attributes of geographic layers are in GML format, they can be passed to any system, application or geo-processing service that is able to read this Open Specification. Thus, if a layer or pieces of information in GML format it can be passed on to the Internet and SVG can convert GML code to maps for web-clients (Kim et al, 2005).

There are three stages of GIS development and three types of architectures represent as shown in Figure 2-1. There are three types of GIS architectures from the GIServices perspective Centralized GISystem, Client/Server GISysterm, and Distributed GIServices (Tsou and Buttenfield, 2002; Pent and Tsou, 2003) (Figure 2-1).

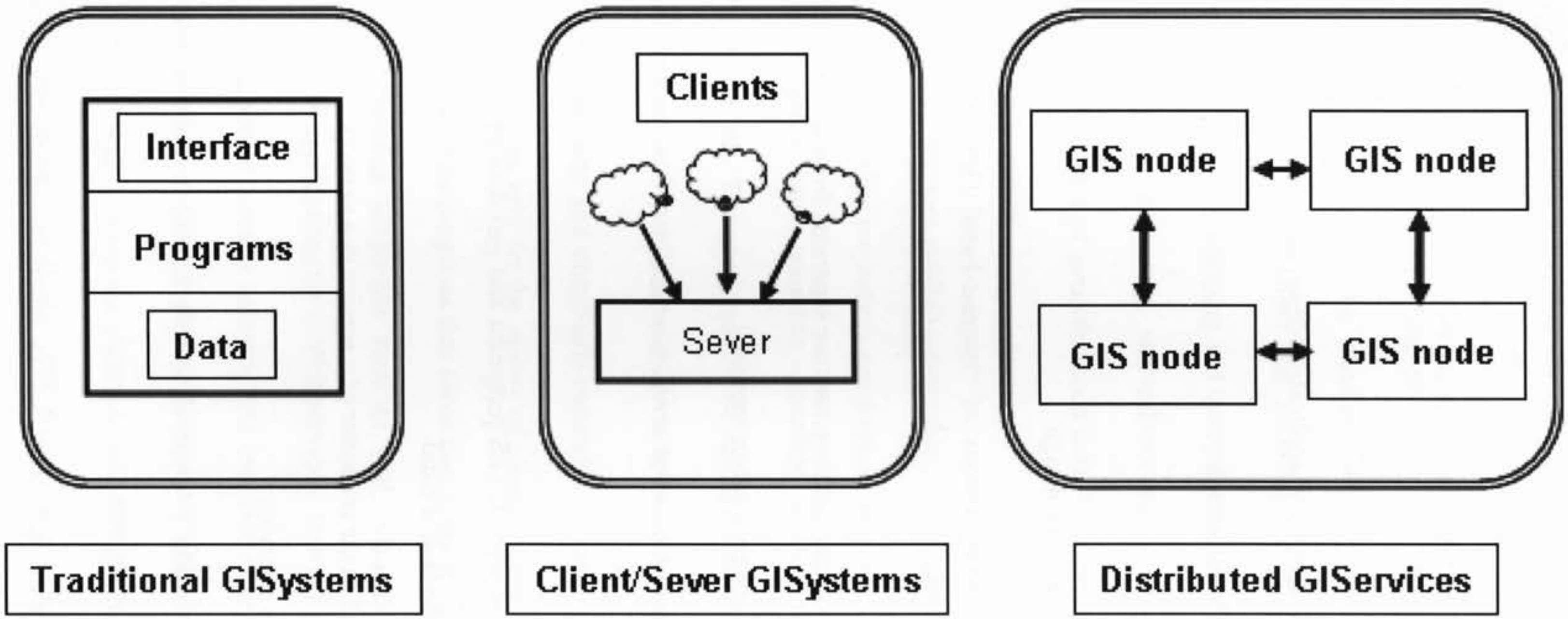

Figure 2-1 Three types of GIS architecture

Traditional architecture:

- Centralized system holding interface, programs, data together
- Each element is embedded in the system and cannot be separated from the remainder of the architecture
- Models remain platform and application dependent
- Most desktop GIS architecture

Client/Server architecture:

- Based on generic network design
- Many current implementations of "internet-based GIS" are built on this type of architecture
- Client-side components and programs are separated from server-side components
- Allows clients to access a server remotely
- Each client can only access one server at a time

Distributed architecture:

- Every GIS module embeds GIS programs and geo-data and can become a client or a server based on the task at hand
- A client is defined as the requester of a service in a network
- A server provides a service
- A truly distributed GIServices model can allow many-to-many communications among computers at the same time

Three components are identified in order to publish GIS contents: a website presents the geographic application or portal; web services publish geographic functionality as a web service; and data management software provides a managed relational environment for both raster and vector geographic content (Tait, 2005). Table 2-1 shows three major components in a distributed GIS architecture, web portal, web services and data management. Each component has elements, supporting programs and its functions (Table 2-1). A geographic web site is developed using standard web development tools, providing a graphical user interface to the web client and allowing access to GIS functions such as geo-coding, gazetteer linkage, and mapping and query functions via geographic web services (Lowe, 2002). Web map service is any network-accessible interface built with Internet technologies that produces maps of georeferenced data. Users type URLs in web browsers and receive graphic maps in return.

Geographic web services publish geographic content and functionality such as map rendering, feature streaming, data projection, geographic- and attribute-based queries, address geo-coding, gazetteer/place name searches, metadata query and management, network analysis, data extraction, etc. The geographic data management component of a distributed GIS supports the active use and maintenance of geographic data.

There are server-side and client-side strategies to improve the performance of the system. Server-side strategies rely on the ability of users to send requests to GIS software through the Internet server. The programs that serve user requests can be written in a number of widely used programming languages such as Perl, VisualBasic, or C++. Computer technology enhances GIS applications tie to Web services. Java is a program embedded into a HTML document, transported across a network, and executed at the machine that downloads it. Since a Web browser alone cannot handle vector graphics data and complex data structures, a Java applet can interact with users at the client (downloading) machine, extract information from the data to answer users' questions, and display vector and raster maps in a way impossible using a Web browser alone (Wang and Jusoh, 1999).

Components	Elements	Environments	Functions
Web Portal	Web Site	HTML,HTTP,XSL,XML, JSP, ASP	Search, Map Viewer, Publish, Administrate
	Web Controls	Java Beans, .NET	Query, Gazetteer, Mapping, Edit, Geocoding,
Web Services	Geographic Web Services	XML, SOAP, WSDL, WMS, WFS, GML	Query, Map render/feature, Transaction, Geocode
Data Management	DBMS Geographic & Tabular Data	SQL	Raster, Vector, Tabular

Table 2-1 Distributed GIS architecture and components design (Tait, 2005)

Java^{TM} Platform technology and the Common Object Request Broker Architecture (CORBA) are utilized to develop better distributed systems (Wang and Jusoh, 1999). CORBA is integrated into various application modules coding in different languages (C, C++, FORTRAN, etc.) and also can run on various Windows or UNIX platforms. The .Net is a newer distributed component technology developed by Microsoft that enables software 'building blocks' to exchange data and services between heterogeneous computing environments. CGI (Common Gateway Interface), Java, ISAPI (Internet Server Application Programming Interface), and NSAPI (Netscape Server Application Programming Interface) are common interface standards which allow the Web server to communicate with needed GIS applications (Wang and Jusoh, 1999).

Client-side improvement strategies attempt to shift some of the work of processing requests to the user-side, called "thick clients" (Peng and Tsou, 2003). Some of the GIS process capabilities are downloaded to the client-side and data analysis is processed by web-clients. The advantages of 'thick client' are: (1) applications take advantage of the processing power of the user's own computer and (2) users can be given greater control of the data analysis process. Once the server has delivered its response, the client can work with the data locally without having to send and receive messages across the Internet. More client-side capabilities can be implemented by Java Applet which uses an HTTP protocol to transfer the required GIS procedure dynamically into a targeted GIS application (Ziliaskopoulos and Waller, 2000). These strategies work well for services used by a smaller set of GIS users within an intranet (Plewe, 1997).

Distributed GIServices bring previous inaccessible GIS data and analysis functions on the Internet and open a door to the general public (Peng and Tsou, 2003). From the management perspective, the great demand for geographic information is driven by government agencies to seek alternative methods to make information available to the public and meet research needs. Governments keep huge and bulky GIS databases that could cause serious data management problems for maintaining, updating, and exchanging geographic information. Web-based GIS system has the potential ability to provide GIS information but at the same time to maintain the data at its source. It has advantages over centralized GIS system in data quality control and increased reliability. If data management failure at one site, it will not mean failure of the entire geographic information service. From the user perspective, demanding location-based information is increased due to the popularity of the Internet and mobile devices. Since GIS data processing requires high-level infrastructure, running large and complex geospatial data sets is limited by local machines. Moreover, the GIS functionality and application features provided by GIS software vendors may not fully utilized by individuals. GIS users hope to utilize distributed GIServices from both their standalone PCs or Workstation and network-based distributed GIS, in an easy and friendly way. Therefore, Web-based GIS could be one of the solutions to provide data management and process functionality in an interoperable environment.

Chapter 3 Urban Oil Spill Management Planning Framework

The development of an urban oil spill planning framework attempts to meet the information needs of local governments to enable them to make informed decisions on oil-spill-related environmental issues. The framework is designed as an integrated information-analysis system with GIS spatial-temporal analysis and information requirements presented in a logic-flow diagram shown in Figure 3-1. It includes four-step analysis procedure and each step comprises key information that a municipality should gather in order to perform the analysis. With recommended analysis tools such as statistical and GIS spatial analysis, information is processed and results are extracted and displayed as maps, tables or other formats to assist management to fulfill the goal of each planning step.

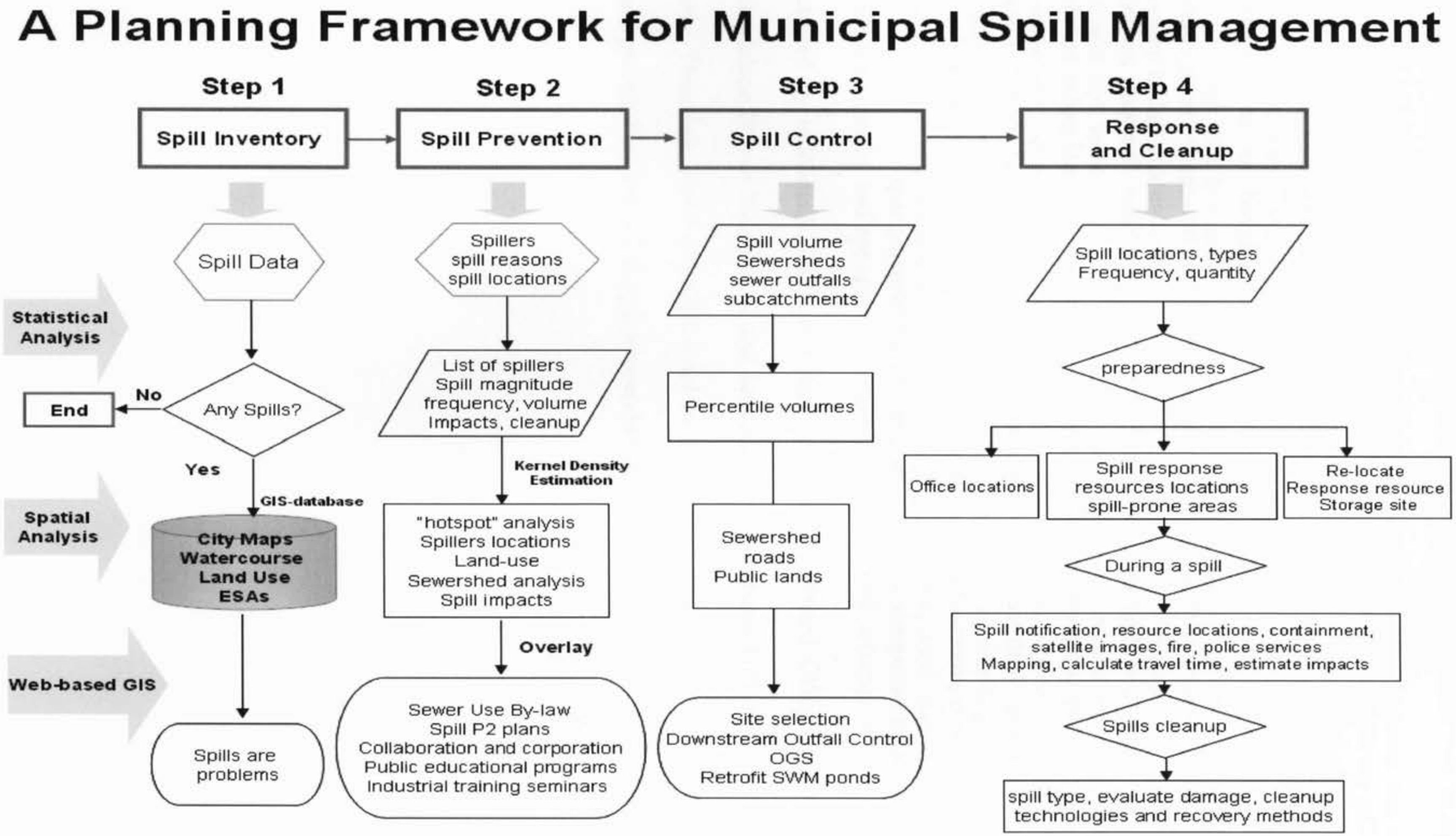

Figure 3-1 Planning framework for municipal oil spill management

The recommended four steps are not isolated but are inter-related with each other. Without any one of the four steps, municipalities may lose oil spill management opportunities. Step 1 is a compilation of a spill inventory which will help a city to identify if spills are problems. At the same time, the database structure and data model will profoundly affect the rest analysis. If spills are identified as problems for a municipality, then the second step is to determine how to prevent the spills. If spills are prevented the next two steps will not be considered. However, spills may still be caused by unpredictable factors such as human errors, traffic collisions, equipment failure, etc. The magnitude of spills could be dramatically decreased because of the implementation of spill pollution prevention which could further reduce the burden of the remaining steps such as spill control. Spilled oil can be intercepted by spill control devices deployed at downstream outfalls before it enters receiving water bodies. Meanwhile the number of a city's responses to emergency spills could be reduced. Consequently, the cost of mitigation and cleanup spills would be reduced.

Currently, urban oil spill management at the local level has been found to be limited. Lack of knowledge, expertise and approaches are the major factors which suppress municipalities' roles in managing urban spills. The major contribution to the planning framework is not only providing recommendations, but also demonstrating how to implement each step by integrating advanced GIS technologies and spatial analysis methods. GIS as an innovative approach plays a vital role in each planning step. Figure 3-2 shows a general idea of how GIS can be used in each step. More functionality of GIS will be explored and an in-depth analysis for urban spill management will be explained in the rest of this Chapter.

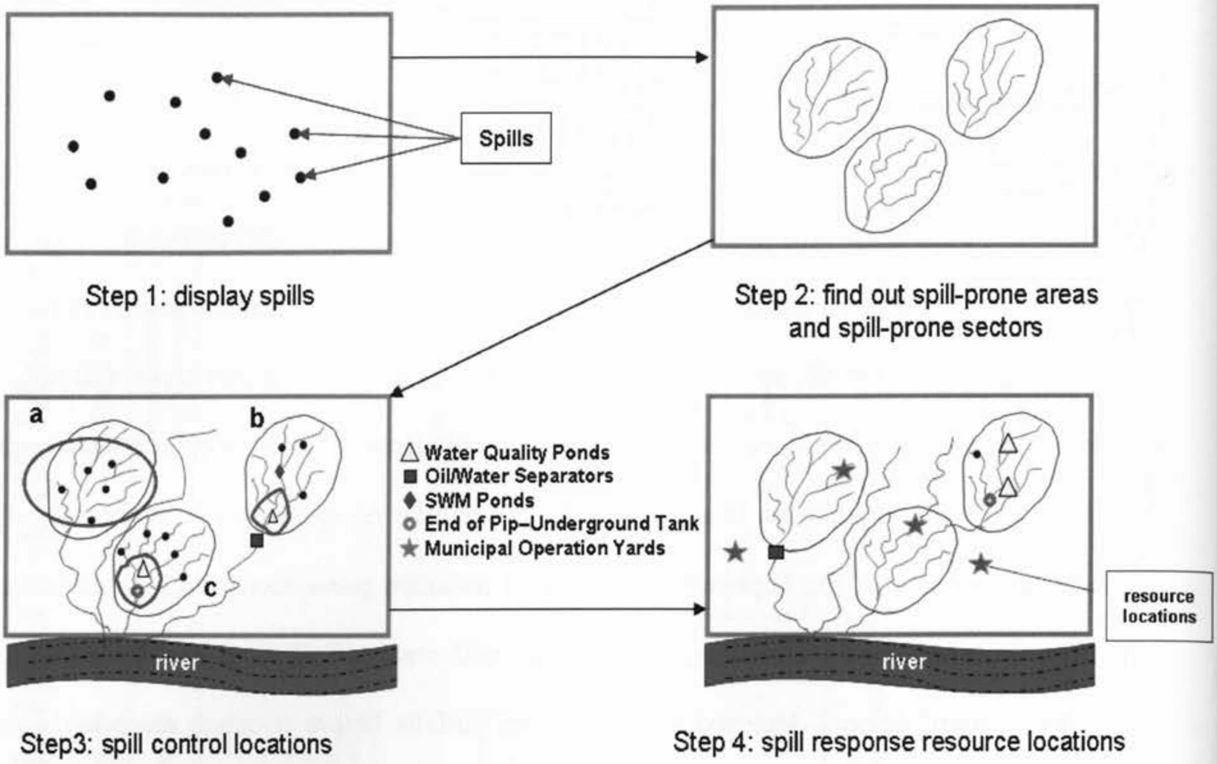

Figure 3-2 GIS functionality applied to urban oil spill management

Step 1. set up a GIS database to visualize if spills are environmental concerns by displaying spill locations on a map.

Step 2. identify spill-prone areas and spill-prone sectors map. So municipalities can target their resources to these sectors areas by providing them with spill-related information, pollution prevention knowledge, environmental regulations, by-laws, training seminars and education programs.

Step 3. identify spill control locations

Picture a. shows that if there are no spill-control devices, spills will follow the gradientss flowing to dwonstream outfalls.

Picture b. shows that if there are retrofit stormwater ponds, quality ponds or end-of-pipe underground tank are on site, some spills can be captured.

Picture c. shows if upstream control devices failed, oil/water separate still can capture the spillage.

Step 4. locate spill response resources at spill-prone areas

3.1 Oil Spill Inventory – Step 1

The components and analysis procedures of step 1 are illustrated in Figure 3-3. Compilation of a spill-data inventory in a consistent format, suitable for data processing and analysis is the preliminary step. If there are no spills that have happened before within municipal boundaries, then the process is at an end. Otherwise, statistical and spatial analysis are applied to obtain descriptive data results such as how many spills occur every year, what is the magnitude of each spill, what are the impacts, etc., providing a municipality with an overall idea of spill situations.

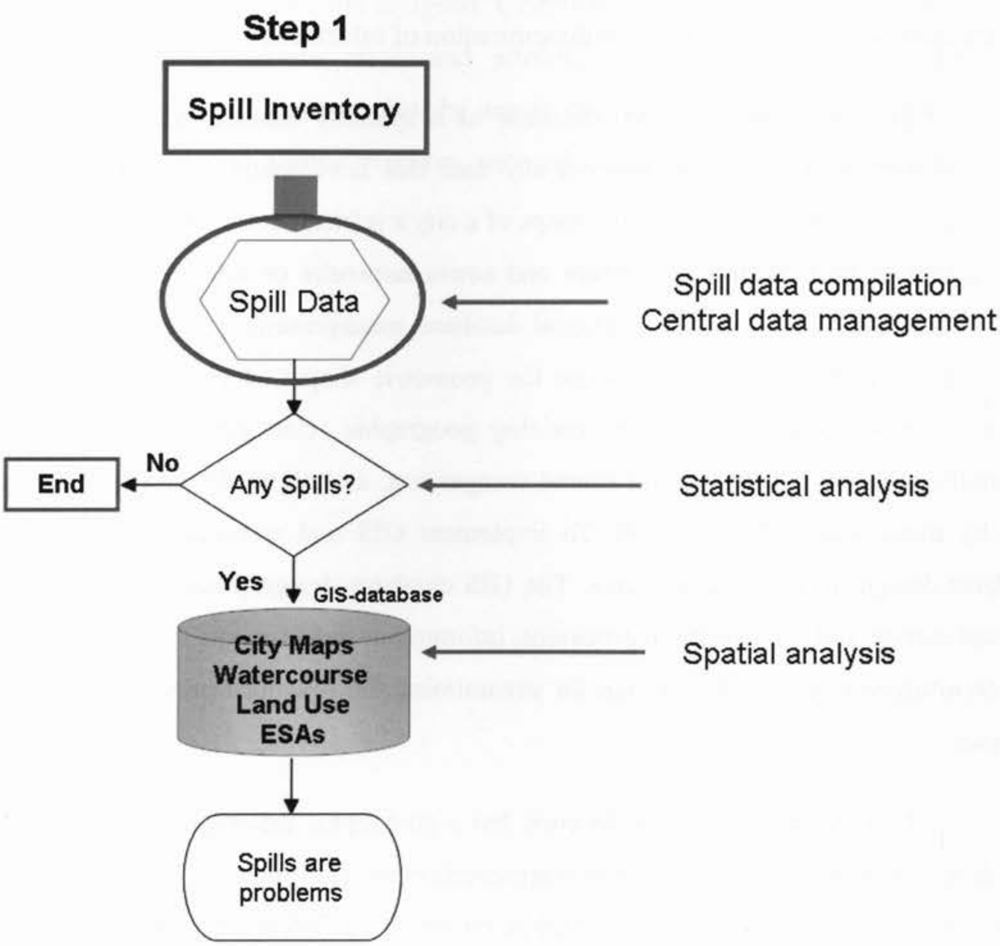

Figure 3-3 Analysis Procedures of Step 1

Based on the literature review, spill data are stored in several ways. The most commonly used software for depository spill data is Microsoft Excel, or similar spreadsheet. Spreadsheets are convenient for statistical analysis and calculation but it is hard to control data quality and users cannot perform bulk queries. Another popular approach is to use a database management program such as Microsoft Access. It is a relational database that has an ability to keep data consistently, control data quality, and query and extract data information. Since spreadsheets and generic databases lack spatial components, data cannot be visualized in its geographical context. The spatial aspects of GIS distinguish them from other kinds of information management systems (Zeiler, 1999). In this research spatial analysis as the fundamental methodology is incorporated into every planning step to assist a municipality in identifying spill management opportunities in their actual locations. Moreover, since web-based GIS can also be built on a spatial database, GIS has been chosen to store and manage spill databases for web-based dissemination of information.

GIS extend the relational database as a spatially enabled database management system (Zeiler, 1999). GIS can process any data that have spatial components. Spill data sources are varied and could be digital maps of a city's infrastructure, land ownership parcels, a collection of terrain contours, stream and sewer networks or satellite imagery. GIS add spatial functions to an ordinary relational database management system. Therefore, a GIS spatial database has the ability to store the geometric shapes, define map layers, support spatial queries, set up rules for determining geographic relationships (topology) such as proximity, adjacency, overlay, and spatial comparison, and allow the editing of geographic data by many users (Zeiler, 1999). To implement GIS and web-based GIS, a solid GIS database design must be put in place. The GIS database design process needs to take into account current spill management processes, information requirements for each planning step, and an ultimate database design plan for streamlining the functions provided by GIS spatial analysis.

The GIS database, at its the core, has a geographic information model to organize GIS data into thematic layers and spatial representations. Designing a proper geographic data model for spill management is the foundation on which all GIS are implemented. Geographic data models are intended to identify and document features with distinctive behaviors, and to allow relationships to be defined among features. Understanding geographic data model concepts is also helpful for knowing how to capture and process spill-related spatial information and to interpret the results derived from the analysis of geographic information. In a GIS data model, geographic objects are represented as features including points, lines and polygons. A database designer builds logical data models and implements physical database designs.

The conceptual and logical design involves modeling the spatial context of spill information, organizing the data sources, determining the data types, and building a simple model to support municipal spill management. A logical data model is constructed to represent the objects of interest to the application and determine the data needed to support spatial analysis functions. The physical design basically involves the actual creation of the GIS database tables from the abstract features defined in the conceptual and logical design (Figure 3-4). In this step, the geometry of discrete features is determined; topological rules are defined, coordinate systems are assigned. Compilation of data for this study requires that every feature dataset, feature class, and attributes will be defined and built into a topologically-structured format, so that the actual data layers can be placed into a uniform GIS spatial database that allows overlays, network connectivity and other spatial-analysis procedures to function.

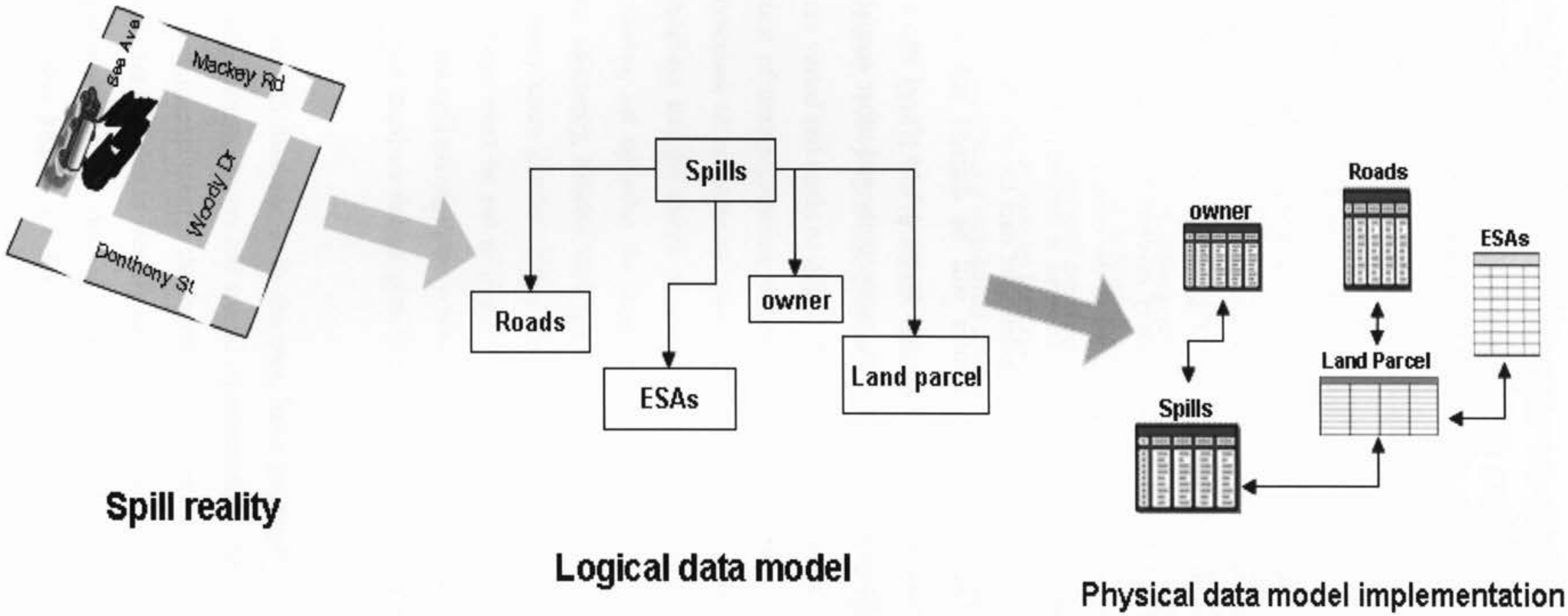

Figure 3-4 Design oil spill data model

The accuracy and integrity of spill data are essential to municipal spill management planning. With GIS, spatial relationships can be expressed through validation rules on feature classifications such as roads with subtypes (local road, arterial road, collector and highway). Attribute domains define a set of valid values that ensure the attribute has one of the expected values such as land use defined by industrial, commercial, residential and institutional. Validation rules control the integrity of spill data features and attributes. By validating oil spill data against the user's requirements, entering, updating, and accessing data can be controlled by cross testing data against the organization's practices and procedures.

Spill data for the case study in this thesis were originally compiled by the Ontario SAC. The usability of the dataset is limited by duplicated records, inconsistent data values, typing errors, information gaps, and missing spatial data for spill locations. Spill data recording also does not follow any classification system thereby resulting in confusing spill locations and spill addresses. These barriers make spill analysis time-consuming and threaten the validity of conclusions. For instance, about 25% of spill records are without proper addresses and these spills cannot be geo-referenced. There are no clear causes and reasons for some spills on roads. This makes it hard for a municipality to prevent road spills because the causes are unknown. It is strongly recommended to include a "Comments" column as a feature class of each recorded spill. It is very helpful for municipal management to extract and verify critical spill information based on the original witnesses' comments. The recommended categories of spills records are listed in Table 3-1. Each category provides crucial information to support subsequent analysis and decision-making.

Column	Description / Examples
Record Number	1,2, 3, ...
Spill Time	Time of the discharge, e.g. 13:10
Spill Data (Year, Month, Day)	2000, 6, 12
Region	Peel Region, York Region
Municipality	Toronto, Brampton
Road Type	Local, Arterial, Highway
Volume	Litre
Spill Address	875 Queensway
Chemical Type	Gasoline, diesel fuel and any associated hazards
Company	Shell Service Station
Source	Transport Truck
Sector	Transportation, government, petroleum
Cause	Tank leak, pipe leak
Reason	Equipment failure
Latitude	43.704058
Longitude	-79.565939
Location	Fuel storage tank, roads, parking, gas stations
Impact	Groundwater pollution
Action	Corrective actions being taken to control spilled material
% Cleanup	Percentage of cleanup spilled material
Comments	Spill reporter's description of spill situations

Table 3-1 Recommended fields for compilation of oil spill datasets

Additional information such as meteorological and hydrological data should also be compiled as they may affect the behaviour and transportation of spilled oil. In the spill study of the Toronto AOCs (Li 2002a), Li correlated historical rainfalls with spill data records. Approximately 25% of the spills happened on rainy days (Conversation with Li, 09/2007). Stormwater can flush out already trapped spillage from containment or stormwater outfalls. Other important data such as local rain gauge data, drainage areas and sewer configuration are important for calculations of travel time of spill within a sewer.

The web-based GIS can share spatial information with other collaborating agencies through the Internet. Since data requirements for each step are different, web GIS can provide the flexibility for users to view a spill database on-line whenever they need data. The spill database can be maintained at GIS centres so users do not need to download it to local machines and they can always get up-to-date information. Spill management could reduce the volume of data storage, save costs, avoid data duplication, increase information accuracy, save time and physical data storage capacity and provide many benefits for users, especially for an on-site crew to pre-view data on-line before going to a spill site. The structure of an interactive Web-based GIS database management system is illustrated in Figure 3-5.

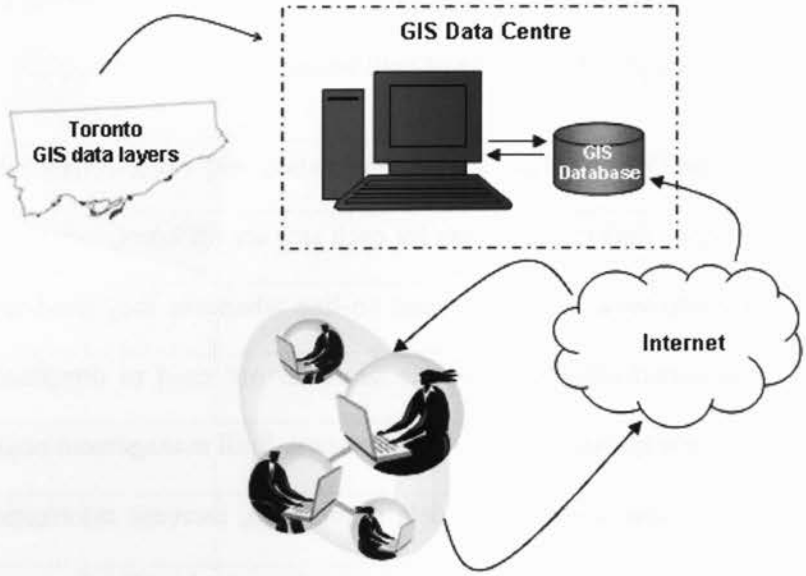

Figure 3-5 Model of central data management

3.2 Oil Spill Prevention – Step 2

Spill pollution prevention is a fundamental component for municipal spill management planning. It is a proactive approach and the most cost-effective way for a municipality to prevent spills as well as to reduce spill frequency. However, the majority of spills occurring on municipal land are not caused by municipalities themselves; it is whoever occupies the land such as industrial, commercial enterprises or temporally uses the municipal facilities such vehicles that caused the spills. Municipalities as government agencies play significant roles in spill pollution prevention management. They can not only enact law and enforcement but can also act as facilitators to assist local industries to implement spill pollution prevention measures.

The responsibility of a municipality to protect the public health and natural environment is through municipal ownership, operation and maintenance of municipal infrastructure to assure their long-term viability (Ontario MOE, SAC, 1995). Enacting a Sewer Use By-law is one method to protect the environment in a municipality from spills damage and regulate the intentional discharge of pollutants into municipal sewer systems (Li, 2002). Every municipality should evaluate its own sewer network and water treatment systems before setting specific contamination discharge limits. GIS analysis could assist a municipality to implement its Sewer Use By-law at spill-prone areas.

Figure 3-6 shows what kind of data and what kind of analysis occurs in step 2. Data information of spillers, spill reasons and spill locations needs to be prepared for statistical analysis. A table of spillers and related spill attributes such as spill magnitude, frequency, volume, impacts, and cleanup is generated. Spill hotspots are identified using the Kernel Density Estimation analysis method and overlay with other spatial data layers such as land-use, municipal and sewer networks. Then a municipality can target resources to spill-prone areas and implement spill measures such as spill pollution prevention and Sewer Use By-law.

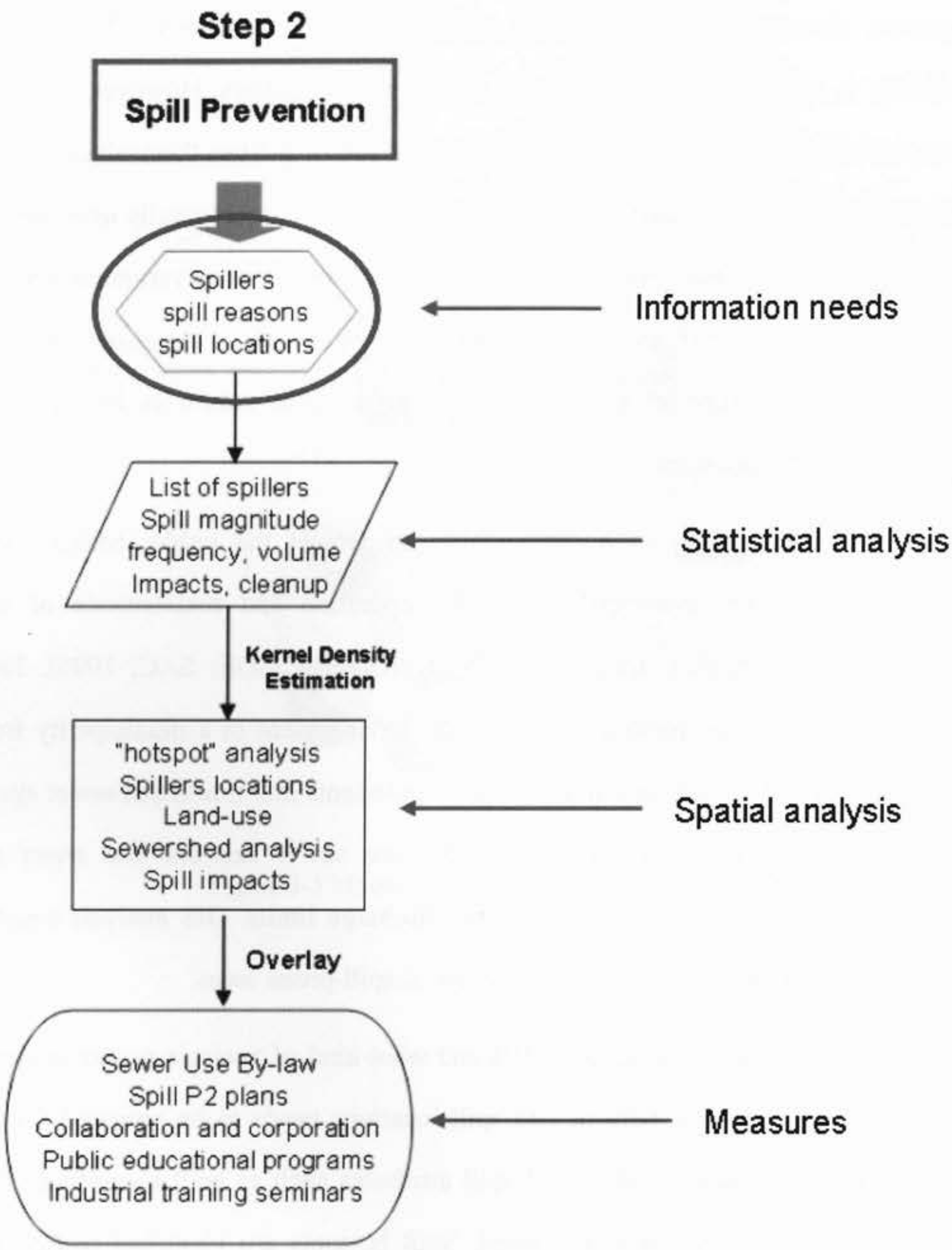

Figure 3-6 Analysis Procedures of Step 2

A spatial analysis method called Quartic Kernel Density Estimation is applied to identify spill-prone areas. It detects frequently happening oil spill locations, called "hotspots" by creating a smooth surface of the variation in the density of point events across an area. It typically requires two parameters to be entered before it can be applied against oil spill data (Chaieny and Ratcliffe, 2005). An application example is demonstrated in Chapter 5. Another spatial analysis procedure is the overlay operation which is used to combine disparate information sources. In step 1, the defined spatial reference system and topologically-structured data format provide the geometric basis to connect two map sources (Chrisman, 1996). When spill-prone areas are identified, the sewer network, private drains connecting to the municipal sewers, land-use, and water-sampling sites can be overlaid on them and composite database items created linking the coinciding features. Thus, city's spill management can isolate land owners from those areas and enforce them to comply with the Sewer Use by Law (Figure 3-6).

As a facilitator, municipalities need to take the initiative and work closely with industrial associations to assist local industries with the integration (P2[1]) measures into their spill management plans. Municipalities need to know who caused spills; where they are located; how spills happened and what the nature of the spills. It is vital for a municipality to target its resource efforts on spill problem areas. GIS can assist municipal staff to find out the locations of spillers. Municipal staff can provide spill prevention seminars, public education and training courses to the sectors with spill problems. If staff members or spillers do not have GIS software installed at their local machine or available data on hand, web-based GIS can help with the display of maps and distribution spill-related information via the Internet. It is convenient for municipal staff to view location-based spill data, manipulate data layers, and extract whatever the information they need to get their work done. Required data layers are shown in Figure 3-6.

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[1] Environmental Canada also calls Pollution Prevention as P2. In this paper, P2 means Pollution Prevention.

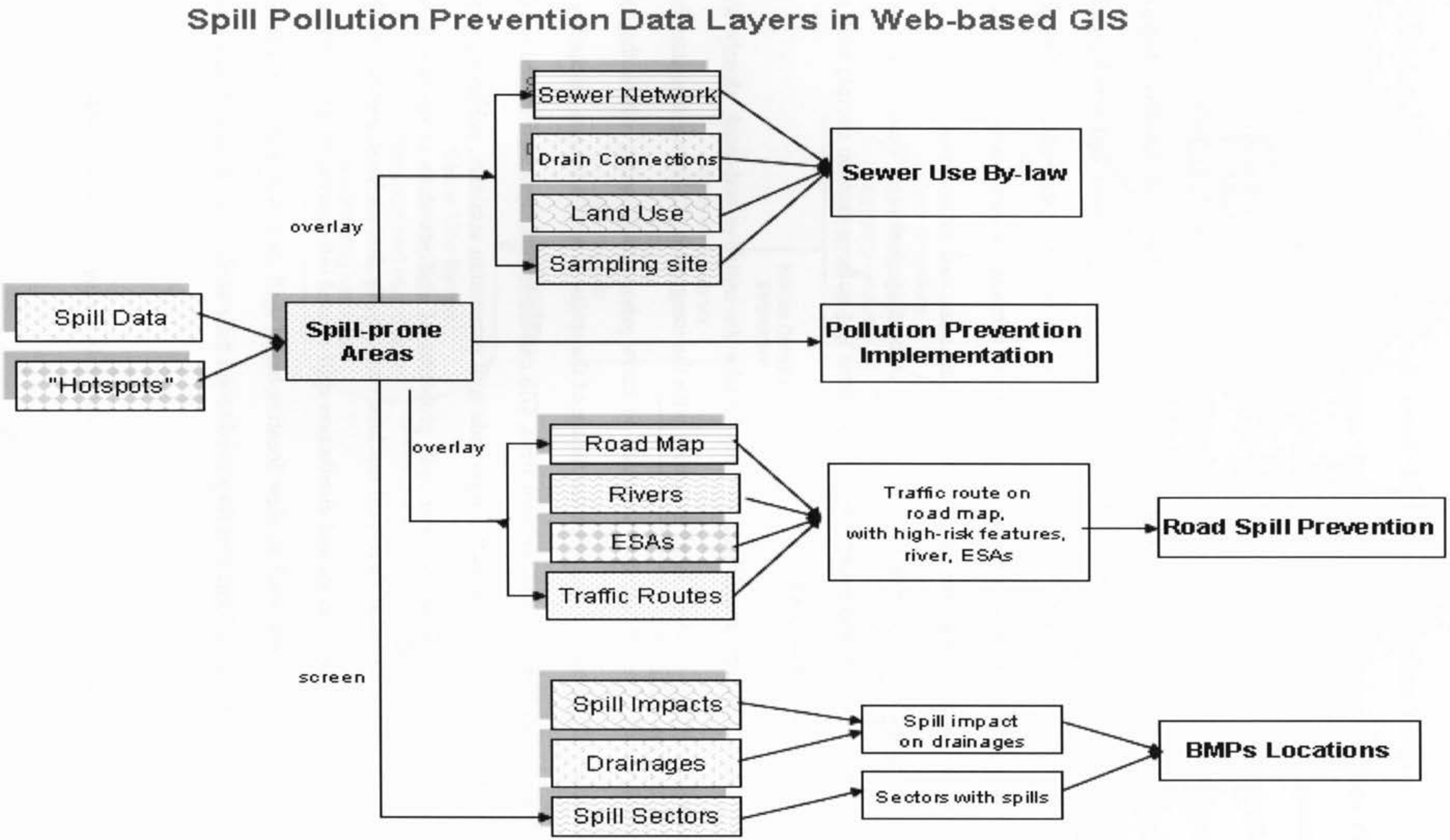

Figure 3-7 A flowchart of data layers for oil spill pollution prevention

Municipal spill management can coordinate local industries participating in federal spill prevention seminars, provide spill-related information, expertise and pollution preventive technologies to spill-prone sectors. For instance, municipalities may need to support small businesses to set up spill preventive measures and promote the awareness of spill prevention in older residential areas where heating oil is still used. Additionally, a municipality can incorporate P2 measures into its *Sewer Use By-law* to enforce industries and business sectors with spill problems to prepare a *Spill Pollution Prevention Plan* (Toronto *Sewer Use By-law*, 2006).

In a *Spill Pollution Prevention Plan*, business owners are required to list the pollutants they are handling on a daily basis, identify potential impacts of a spill, eliminate the usage of hazardous materials or substitute them with comparable products, reduce the chemicals that reach the municipal sewer systems, etc. (The City of Toronto Sewer Use By-law, 2006). It can also require a plant to list actions taken to reduce the potential of a spill (for instance, employee training or routes for redirecting traffic). A municipality may require the spiller to document the methodology and approach it uses in each step in order to review and compare with the regulation requirements and determine if appropriate actions are taken to reduce the risk posed by a spill.

One of the hurdles for industries to implement P2 measures is the lack of spill management information and knowledge (Water Network, Toronto Water, Volume 4, Issue 3, 2005). A municipality cannot replace the roles of industries in spill pollution prevention. Since P2 is site specific it is an industry's own responsibility to develop a comprehensive *Spill Pollution Prevention Plan* for its business-operation purposes. What a municipality can do is to facilitate the planning process by providing spill-related information and provincial guidelines, coordinating resources and expertise. Cities can distribute spill fact sheets or booklets with spill characteristics, adverse effects, and distribution maps to local industries, helping them understand the spill problems, the causes of spills and the likelihood of a spill (re)-occurring at a plant. Appendix A and B show examples of education fact sheets that a municipality may create for industrial and residential education purposes. Municipalities can assist industries with federal and provincial guidelines that document their methodology, provide equivalent standards or specific procedures to determine spill risks and generate appropriate risk management plan. Some of the guidelines listed below:

- "Guideline for Implementing Spill Prevention and Contingency Plans Regulatory Requirements" (O. Reg. 224, 2007)
- "General Guidance on Risk Management Programs for Chemical Accident Prevention (40 CFR Part8)", (CEPA, 2004)
- "Risk Management Guide for Major Industrial Accidents, Intended for Municipalities and Industry", (CRAIM, 2002)

For non-point-source spill pollution such as road spills and transportation corridor spills, municipalities may collaborate with transportation departments to identify spill causes and causes in order to generate practical spill-prevention measures. Spill prevention measures for transportation sectors and truck owners should involve actions consistent with provincial guidelines for transportation of dangerous goods and improvement of tank design, and provide drivers with spill prevention training to avoid accidents especially within environmentally sensitive areas[2] (ESAs). These areas are critical to the maintenance of productive and diverse plant and wildlife populations (British Columbia Ministry of Environment, 2004). Therefore, Therefore, how ESAs are protected from spill pollution and how these areas are limited in terms of access are vital decision for local governments to

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[2] Environmentally Sensitive Areas (ESAs) are places that have special environmental attributes worthy of retention or special care.

make. Data layers such as ESAs along transportation corridors with high-risk features such as wetlands and rivers can be overlaid on spill-prone areas to generate a "dangerous road map layer" containing spill information (Figure 3-6). With "dangerous roads" information municipalities can cooperate with transportation departments, police and fire services to closely monitor these areas, reduce oil truck traffic, modify truck traffic routes, or ban oil-tank trucks from utilizing the "dangerous roads" (US DOT, 2004).

Some business sectors may consider adopting Best Management Practices in their spill prevention plan. Best Management Practices are designed to reduce the impacts of accidental spills and the release of contaminants from industrial manufacturing processes (Ontario MOE, 2001). The essential components of a Best Management Practice plan include: identification and assessment of spill impacts, emergency response plans, preventative maintenance, inspections, and employee training (Environment Canada Pollution Prevention Centre, 2005). A municipality could encourage business sectors to practise good housekeeping which includes periodically inspecting chemicals in storage, identifying deteriorating containers or products, understanding and following waste disposal procedures, having appropriate spill cleanup supplies available. In Toronto, businesses such as automotive facilities, gas stations and car washes (including hand wash and self wash) are required to prepare the Best Management Practices Plan and manage the discharge into municipal sewers. It is important for a municipality to identify what kind of business sectors are qualified to implement a Best Management Practices plan, their locations, spill characteristics, sewer connections, etc. GIS can apply to aid the municipality in identifying the location of spill-prone business sectors by overlaying required spatial data on a map, performing spatial analysis and extracting the information it needs.

Web-based GIS facilitates industrial P2 implementation processes by accessing shared information and improving co-ordination with all levels of governments. Web-based

GIS could provide industrial information to industries with spill problems. This way, the municipality knows who and where they are; what kind of spill problems and what kind of information they need to implement a P2 plan. Web-based GIS allow P2 inspection teams to access information remotely, search industries by locations, select the areas of concern, focus on specific sectors with spill issues, extract location-based information such as types of businesses, spill characteristic, surrounding ESAs features and spill impacts. Therefore, web-based GIS may fill the information gap which current P2 inspection teams encounter in spill-pollution prevention practices. With the information available in a web-based GIS format, municipal staff can go to the website, select a spill-prone area and obtain the information for industries, their sewer connections, the sewer network, and discharge requirements, *etc*.

Moreover, web-based GIS could be used as an education tool as well by offering a channel for the public to participate in spill-pollution prevention management system within a city. With a Web browser, the general public can click a URL link of "Spill Prevention Education", view spill information, learn spill-related laws and participate in training programs. For non-GIS users, the easy interactive mapping interface allows them to zoom in a specific area, explore various data layers where they live to find out spill causes, impacts and information related to spill prevention programs on the city's official website. Spill reports can be posted on the website with summarized spill information such as total spills occurring in a year, volume, causes, impacts etc. By illustrating where a spill occurred, what measures were applied to mitigate the spill impacts in relation to the natural environment and social-economic loss, spill incidents can be much easier for the public to understand. Moreover, the public with well informed spill information can also assist a municipality in preventing spills and reduction of spill damage by installing preventive measures for their own heating-oil tanks at home and report a spill when they detect it.

3.3 Oil Spill Control Strategy – Step 3

Control measures typically target the unknown sources of a spill such as road spills, accidental spills or illegal discharge to drains, ditches, or watercourses. Oil spill control measures are site-specific and spill characteristics and locations need to be identified prior to design of control devices. Downstream outfall control is identified as an effective way to control spillage from entering rivers or lakes, but only as a last defense (Li, 2002a). The preliminary design procedure of an oil spill control system for storm outfall consists of three steps: (1) development of spill control criteria, (2) determination of design flow conditions, and (3) design of flow diversion channel and oil-grit separator. The design flow is the base flow of the creek (Li, 2002a). Most oil spill separators are designed based on the American Petroleum Institute (API) design methodology (American Petroleum Institute, 1990). Spill data information such as volume, need to be collected and analyzed for control design purposes. Municipalities need to work closely with their engineering department to decide the location, type and size of spill control devices.

Figure 3-8 shows the steps of spill control procedures, data needs and analysis methods. Spill volume, sewersheds, sewer outfalls, subcatchments etc. all need to be identified in order to perform spatial analysis. Overlaying with percentile spill volumes locations and size of spill control devices can be decided. Next stage is going to talk individual site spill control.

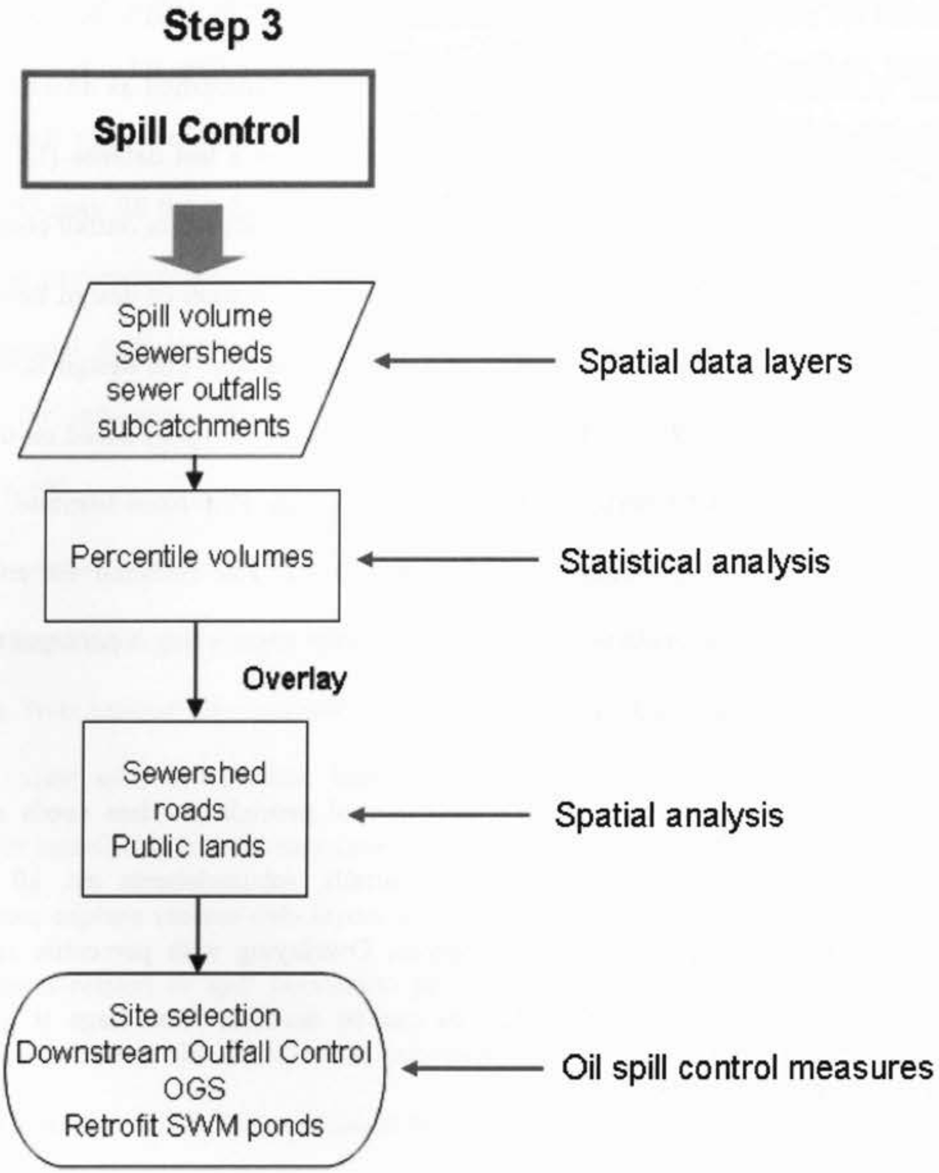


Figure 3-8 Analysis procedures for Step 3

Individual Site Controls

Roads have been identified as the most vulnerable places for oil spills (Li, 2002). Highways, arterial and collector roads are the typical types of roads frequently used by fuel trucks, which make them susceptible to fuel spills. It is necessary to examine different types of local roads and seasons when spills mostly occur. For example, in Toronto, summer is the busiest spill season as the number of running trucks increases on each type of road (Li, 2002). Thus, sewersheds along the roads need to be identified and mapped as "sewered roads" in order to install oil-Grit separators (Li and Banting, 1999); locations of catchments and Stormwater Management ponds need to be mapped in order to be retrofitted as spill control facilities.

Service Stations Many service stations with spill problems are located on arterial roads while others can be found along collector and local roads. A typical gas station has four to six valves allowing gasoline from a fuel tank truck to transfer fuel into an underground storage tank through a pipe. If valves are not properly sealed, fuel may overflow. This could be the major reason for spills. Spill management should identify the locations of gasoline service stations and provide employee-training programs to avoid human-error caused spills. Spill control measures such as underground tanks may need to be considered for installing in catchments which are most prone to spills. Underground storage tank leaking is another type of reason for spills. Double walled design guidelines should be adopted by service stations in order to prevent fuel tank leak.

Parking Lots. Industrial parking lots have the largest number of spill occurrences (MOE, 2006). Most spills flow into sewers. Others may flow to the vicinity causing soil contamination if the surface is not paved. Information such as lot size, sewersheds, open space and soil type need to be collected in order to design an oil-grit separator.

Storage Depots Storage depots are commonly used to store gasoline and diesel fuel. The size may vary from a thousand litres to a million litres depending on the storage depot's purpose and location. Petroleum companies may own several huge fuel tanks at their storage depots which are typically located in less-urbanized areas. Overall, gasoline is the major oil spilled in less-urbanized areas and these spills usually occur in tank fields (Li, 2002). Stomwater-management ponds and water quality pond could be constructed in downstream catchments. Data layers including sewershed, open space, utilities corridors, land-use need to be mapped and overlaid as screen criteria for selecting sites where spill control facilities could be located.

Railway Yards Due to spills, oil leaks, overflows and other human errors, railway yard spills become the fifth largest spill volume recorded by SAC in Toronto (MOE, 2006). Secondary containment systems can be installed surrounding storage tanks such as a berm on the operation area can be sloped inside the berm to a drain. Oil/water separator and retrofit stormwater ponds should be installed on-site in order to catch spilled oil.

Downstream Outfall Controls

A comprehensive spill control strategy should be developed for each spill-prone watershed. Locations in the drainage system at which spillage can be collected by grading the site must be identified. These would coincide with spill-prone commercial and industrial facilities where oil/water separators should be installed. Another control option is to retrofit stormwater ponds which are likely to receive oil spills. This kind of control strategy should be integrated with municipal land-use approval and could therefore be conveniently funded through municipal capital programs. Sometimes a permanent boom is placed at outfalls where spills are frequently detected (Figure 3-7). Installation of large spill-control devices or downstream oil interceptors may be required at spill-prone sewer outfalls to prevent spilled oil from discharging directly to watercourses (Li, 2002).

The procedure to identify outfall control options in a GIS-data environment is itemized in Figure 3-8.

1. overlay oil spills data onto top of municipal sewersheds layer
2. identify spill-prone sewer outfalls where spills are directly discharged to water bodies
3. identify stormwater ponds which are likely to receive oil spills
4. determine which SWM pond is fit for retrofit
5. identify public lands, in the vicinity of these spill prone outfalls, which may provide space for the construction of spill control facilities
6. install oil separators at spill-prone sewer outfalls

Downstream outfalls need to be mapped in order for municipalities to identify a proper spill control location. By analyzing different water samples, storm sewer outfalls with high concentrations of spilled oil as well as their associated sewersheds need to be identified and linked. This overlay of sewershed, and the commercial and industrial drainage areas in a GIS environment could assist the process of determining suitable locations for oil/grit separators.

Based on the results of this study, it is concluded that (1) spill-event characteristics should be analyzed to develop design criteria for oil spill control systems; (2) the preliminary design procedures of oil spill control systems were different from the API's methodology (Chui, 2000); (3) a monitoring program be developed to assess the performance and maintenance requirement of the system; (4) spill-prone sewersheds need to be identified across the entire city.

Figure 3-9 Stormwater Outfall Control (US EPA, 2006)

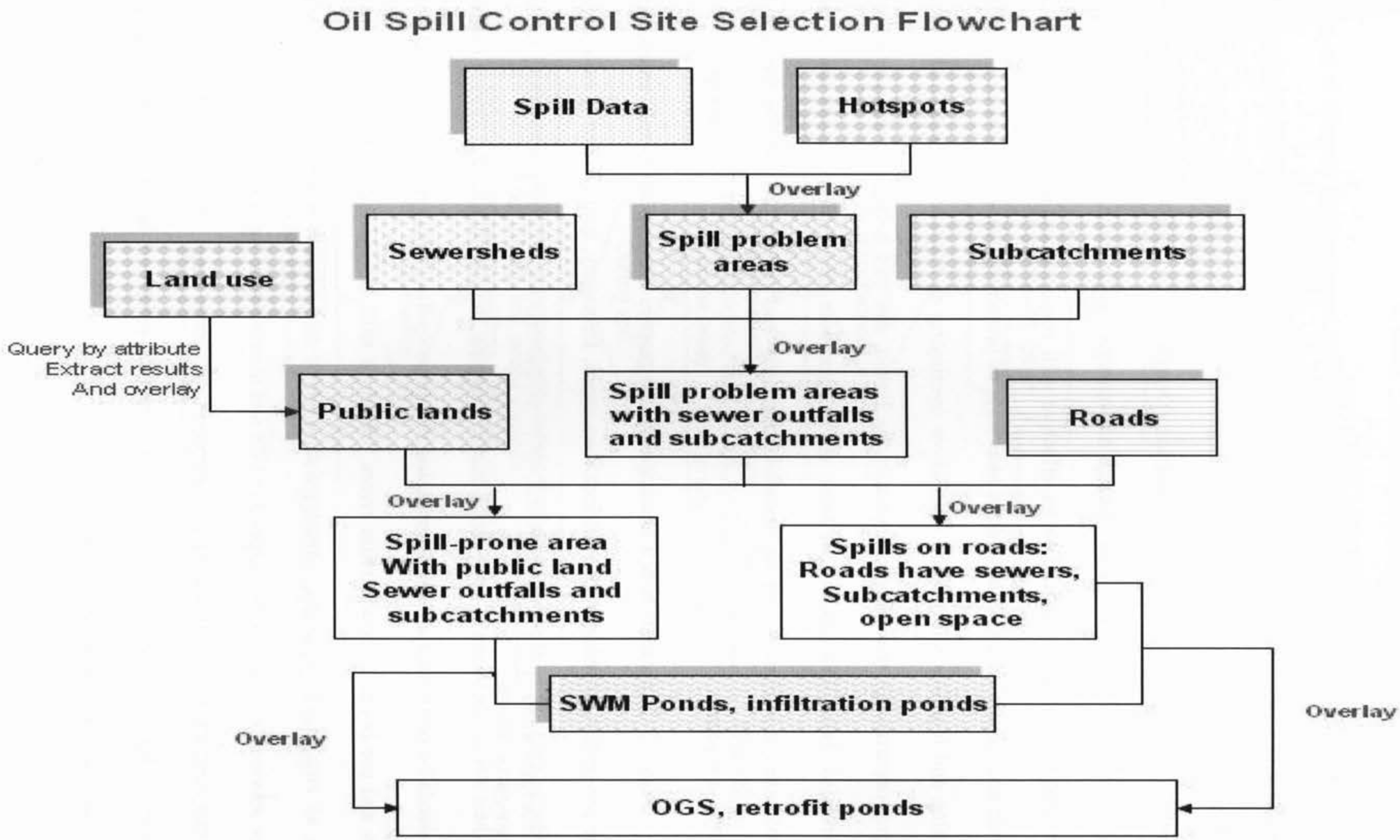


Figure 3-10 A flowchart of spatial analysis for screening oil spill control sites

3.4 Oil Spill Response and Cleanup – Step 4

The primary responsibility for a municipality in responding to spills is to protect the welfare of residents as well as minimize the adverse impacts to the natural environment. Quick actions are dependent upon a high degree of organization and preparation. Response operations need to access critical information (Dougligeris et al, 1996). Better information always leads to better decisions during an emergency situation. Therefore, access to up-to-date information is crucial to an effective spill response and a Web-based GIS may provide such a platform. GIS has added new ways of presenting for spill resource allocation, planning and logistics information. GIS allow overlaying of maps to link information from various departments that may not usually be linked and can help with interpretation of spill-related data. Web-based GIS have advantages over conventional maps since more spatial-based information can be updated frequently and distributed rapidly through the Internet.

Figure 3-11 presents how a municipality can prepare and respond to spill emergencies. In the pre-spill preparation step, spill locations, types, frequency, quality need to be analyzed in order to find out spill-prone areas and spills' characteristics, spill response team locations and their office locations to spill-prone areas. Mapping the distance to the closest highway also needs be performed as well as mapping relocated spill-response resources to spill-prone areas and pre-boom to downstream rivers. During a spill emergency response, data layers such as equipment locations, containment, satellite images, environmental impacts, fire, police services, etc. need to be mapped in GIS and distributed to on-site crew. Moreover, GIS also can conduct spatial calculations to determine spill travel time. In the spill cleanup stage, cleanup technologies and recovery methods can be estimated based on historical spills statistical analysis and stored n GIS format.

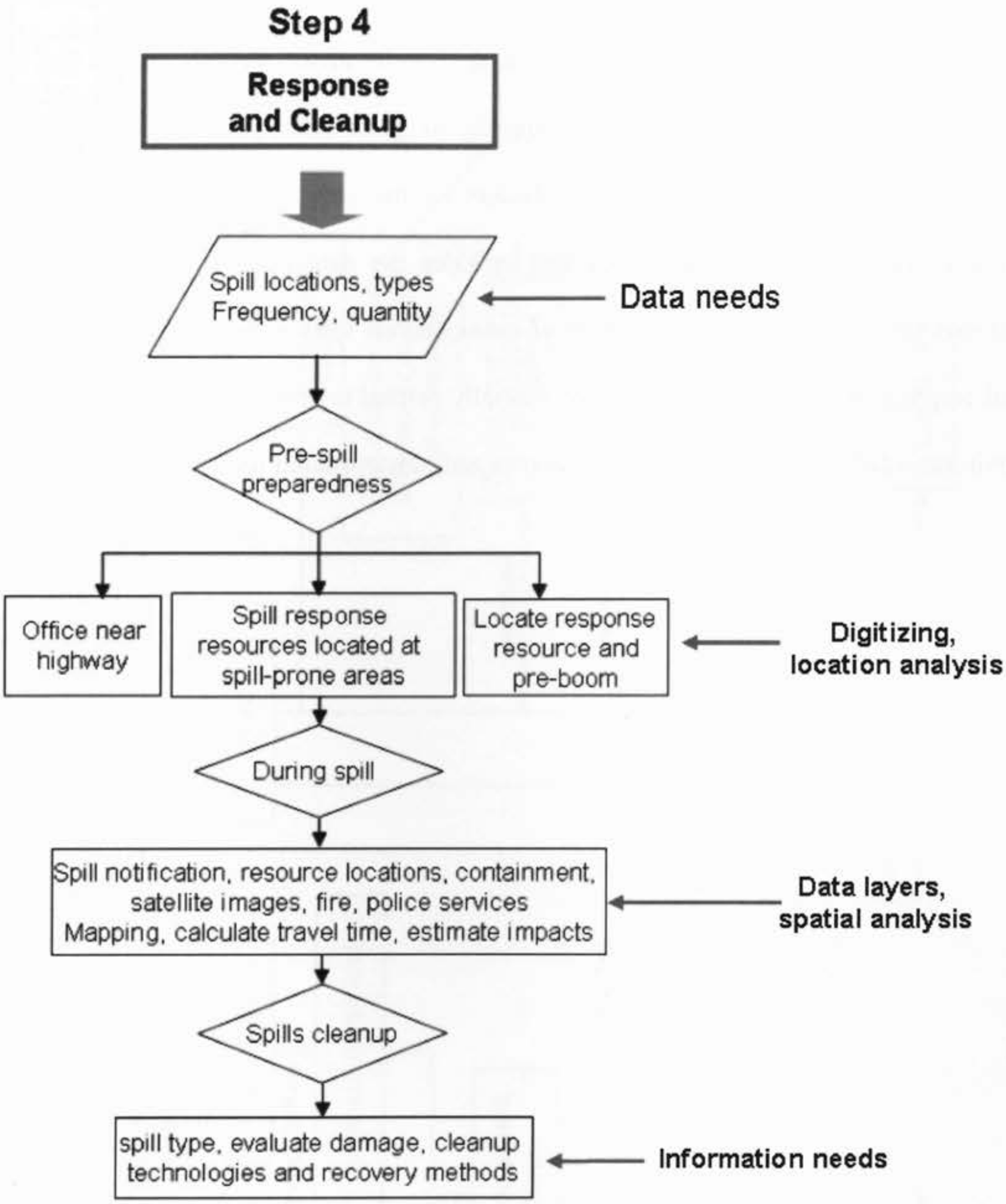


Figure 3-11 Analysis procedures for Step 4

Oil Spill Emergency Response Preparedness

Preparedness is a state of readiness for municipalities to respond to oil spill incidents (Perry and Lindell, 2003). It results from a process in which municipalities examine historical spill-patterns, spill magnitude and spill-prone areas; identify human and material resources available to cope with spills. Having adequate and accurate spill knowledge and response equipment on site are the key factors for the early response and intervention at a spill. Figure 3-9 shows a flowchart that includes the data information needs and spatial analysis procedures for the preparation of municipal oil spill emergency response. Resource and response team locations should be spatially related to spill-prone areas and to adjacent environmentally sensitive areas, watercourses and transportation routes.

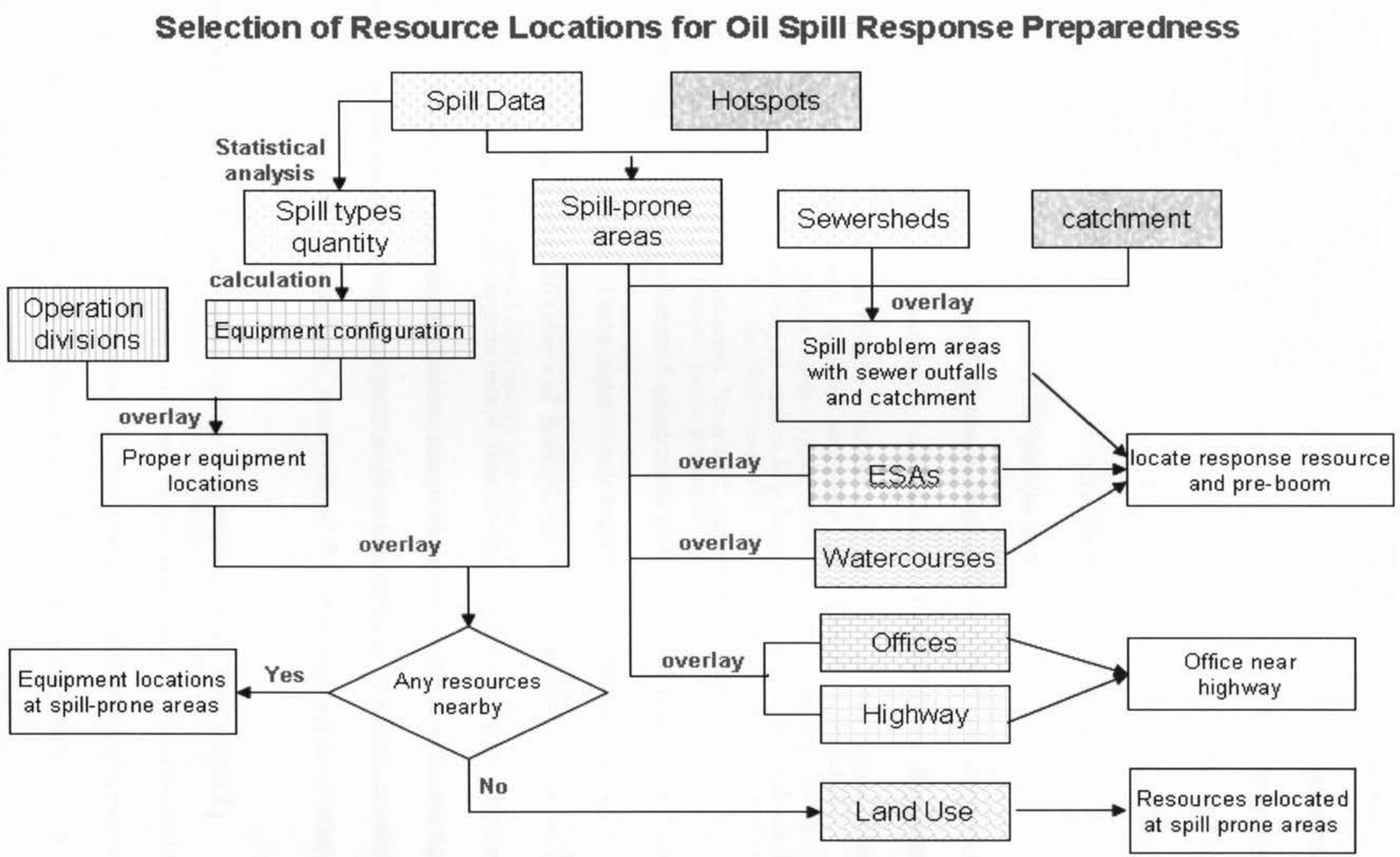


Figure 3-12 Data requirements and spatial analysis for oil spill emergency response

A municipality needs to develop and maintain a computerized directory of scientists and experts as well as industrial in-house personnel who may be contacted in an emergency to provide technical supports. Their office buildings can be geo-referenced and stored as a GIS data layer along with their contact information and specialized fields. Industrial sites need to consider having trained workers and an internal response team for site-specific spills and releases. During an event, in-house personnel know the plant layout, danger, access points, etc., better than any responder coming to the site. Personnel at the site have first-hand knowledge of the chemical solutions and a vested interest in identifying potential spills within the plant.

Equipment pre-staged on spill-prone locations and the quantity of equipment available should be related to historical spill studies. In previous planning steps, spill-related information such as spill characteristics, "hotspots", impacts, etc. could assist municipalities to find proper storage locations within municipality boundaries (Figure 3-9). Sometimes the availability of equipment can be changed since it might need to be moved to another area and materials such as Sorbents can become depleted. In a web GIS system, this information can be updated in time and tracked by on-site staff. Spatial analysis can help to decide if there are enough absorbent materials to cope with spill incidents. Spatial and temporal analysis may also help to analyze if supplies need to be refilled, or a new storage should be built near spill-prone areas (Figure 3-9).

Keeping spill control equipment at spill-prone locations or protected areas would be of little value if spill response personnel were not properly trained to deploy the equipment. The achievement of emergency preparedness takes place through a process of planning, training and exercising, accompanied by the acquisition of equipment and apparatus to support emergency actions (Perry and Lindell, 2003). Every municipal department or agency should conduct "awareness" training for all personnel and more in-depth training for personnel who will respond to citywide spill emergency operations. A response team should therefore need to be established at the municipal level. During a spill emergency response, the municipal spill response team would be sent out to mitigate and clean up a spill. Proper training (e.g. use of supporting vehicles, communication equipment, response strategy, means of tracking time, equipment, personnel, and costs) ensures that emergency responders know what, when, and how to respond to oil spills.

In the event of an oil spill, the map, database, and photographs will provide the basis for formulating informed and timely on-the-scene command decisions. These kinds of data need to be prepared ahead of time. Potential spill sources, facilities' names, addresses, storage facilities, outfalls, nearest storage yards, travel and proximity time to the facility should be mapped and stored in the Web-based GIS. It is important that municipal staff be aware of special areas which require special protection against spills. GIS can be used to map the following important areas:

- Environmentally sensitive areas, publicly managed natural resource areas and other areas of environmental significance in a municipality (Figure 3-9)
- Surface water intakes need to be identified because the operation has both human health and economic implications. Additional information should be compiled such as the reserve storage time, seasonality of the water use, and alternative water sources.
- Stormwater drainage system with flow directions throughout the city

This preparedness and response capability will place the municipality in a very advantageous position during an oil spill, in addition to the support from provincial and federal agencies.

Oil Spill Emergency Response, Containment and Cleanup

A municipal spill emergency has two phases of response, the "emergency response" phase when immediate actions are taken to secure the site to assure the preservation of safety of the response personnel as well as the citizens located in the immediate area (Conkin, 2003). Fire, police departments and health services are always the first responders of an incident at the breaking moments of a spill event. The "spill response" phase follows, in which the spill response teams start to clean up spillage and protect vital services, municipal interests or properties (Conkin, 2003). Spill responders are often the first representatives of a municipality to investigate and initiate actions for dealing with the spills. It is a municipality's responsibility to work with different departments and make them act as a joint action to cope with spill issues. During a spill emergency, effective organization and coordination of resources are critical for cities to cope with spill emergencies. Effective coordination of resources during both the emergency response and spill response phases of a cleanup can significantly reduce both the immediate and potential long-term environmental impacts resulting from a spill.

A timely response not only allows good decisions to be made promptly but also reduces the stress associated with uncertain environmental damages, especially protection of human health and water resources. A significant challenge in emergency management is delivering the appropriate information to the proper party at the appropriate place and time in a useful form. "Useful form" in this context refers to the scale, accuracy, and detail of the delivered information (ESRI, 2000). Having fast access to reliable, meaningful information can mean the difference when spill emergency happens. For instance, spill samples and analytical results should be received by municipal spill responders within hours. Important information must be presented clearly and cohesively to enable decision making under crisis conditions. Location information needs to be shared among all levels of governments. There is a special need under these circumstances for maps to be easily available and interpreted in the field.

Through web GIS, the understanding of spill situation is increased and it also helped to raise the level of preparedness among all partner agencies through training and conducting drills together. A Web-based GIS can generate real-time spill-related maps. . The image provides a realistic backdrop for displaying the vector layers in GIS. When response staffs look at the Web GIS and zoom in on map layers, they can determine what areas and facilities they are looking for. As a result, the spill response teams would dispatch the response resources via the safest and the shortest route. Effective coordination of resources during and after a spill can significantly reduce both the immediate and potential long-term environmental impacts (Spearin, 2003). Figure 3-9 shows some of the information needs to be mapped and ready for first responders on-site

- Infrastructure database and inventory of infrastructure locations
- Vehicle routing maps and interactive interface that allows users to compare different routings; retrieve infrastructure types, and property sites.
- Capacity for allowing different parties to create multi-layered maps through a specific Web site and sharing information during a spill emergency
- Access to locations of residential and industrial sites in the spill-risk zone
- Capability for first responders can search information for assistance from other resources

When a trans-boundary spill happens, the municipality should report it to the province and inform downstream cities at the same time. Areas of mutual cooperation should include the sharing of information such as the inventory of local experts, community cleanup equipment, valuable local resources and their sensitivity to oil, potential oily waste disposal sites, and transportation facilities. The use of computer-generated maps and related data will be important as it is expected that a high demand for efficient information capture, analysis and retrieval during a spill event. When a spill flows into sewer system, spill responders need to notify downstream municipalities (Figure 3-9). By using GIS, spill transportation time can be calculated and spill responders can estimate spill location and time of traveling. The real-time information can be presented in Web-based GIS and overlay with the municipal sewer networks. Therefore, spill responders will know when and where to contain spillage before it causes a major impact.

Containment of an oil spill refers to the process of confining the oil, either to prevent it from spreading to a particular area, to divert it to another area where it can be recovered or treated, or to concentrate the oil so it can be recovered, burned, or otherwise treated (Fingas, 2000). Containment booms, berms or dikes can be deployed to contain spilled oil and prevent it from spreading horizontally. Berms can be built with soil from the area, sand bags, or construction materials. Berms need to be removed after cleanup in order to restore the area's natural drainage patterns.

Protecting human health and safety is the top priority when cleaning up oil spills on land. Cleanup operations should be chosen for specific environments based on the ecological impact and the type of spilled oil. The cleanup methods for spilled oil are typically based on common principles as recommended by the Canadian Petroleum Product Association. Depending on the site specifications, oil water separators, mechanical containments, booms, skimmer, sorbents and alternative countermeasures for inland oil spills are the common cleanup equipment and materials. A variety of other mechanical or manual methods (e.g., vegetation removal, mechanical oil/debris removal, and cold and hot water flushing) are used in cleaning up spills (Fingas, 2000). Any excess oil that can be recovered without causing physical damage to the environment is always removed from a spill site, using techniques that do not disturb the surface. Some equipment and techniques include suction hoses, pumps, vacuum trucks, and certain skimmers and sorbent. Sorbents are best used to remove the final traces of oil from a water surface since they must be disposed of appropriately.

GIS can contain information on where equipment and cleanup materials are located to assist municipal spill responders to mobilize resources. A GIS map showing the location of critical resources with other spatial data layers (e.g., roads, streams, boat ramps, etc.) can be generated on a variety of base-map layers. Municipal spill response teams are able to use this GIS application in the field to efficiently and effectively stabilize accidental or intentional releases as soon as possible and avoid the initial confusion associated with spills.

Chapter 4 The Design of Web-based GIS Architecture of Urban Oil Spill Management

Web-based GIS technologies and the applications were reviewed in Chapter two. In Chapter three, information requirements for each step are identified, data model and database structure are designed to meet GIS spatial analysis. This Chapter is going to design a Web-based architecture to support municipal oil spill planning management and explore the functionality that could meet the information needs and spatial data distribution requirements.

4.1 A Web-based GIS Architectures for Urban Oil Spill Management

The Web-based GIS for urban oil spill management is chosen a three-tired architecture with a client component, a web server and geo-spatial servers (Figure 4-1). The tier 1 describes client-side components which is typical a web browser sending clients' spatial requests to a web server. There are two kinds of viewers, an HTML viewer and a Java Viewer. Images and maps are sent as HTML via HTTP to end-users. When customers request Java viewers, the web server sends a Java Applet program and it runs on client-side to enable clients to view images. The tier 2 comprises a standard web server managing the incoming requests and replies with the proper map data back to the client-side browser or application window. The tier 3 includes an application server, one or many geo-spatial servers, geo-database servers and software. A geo-spatial server is a data processing engine that runs on the server side and renders spatial data onto maps as services (ESRI, 2006).

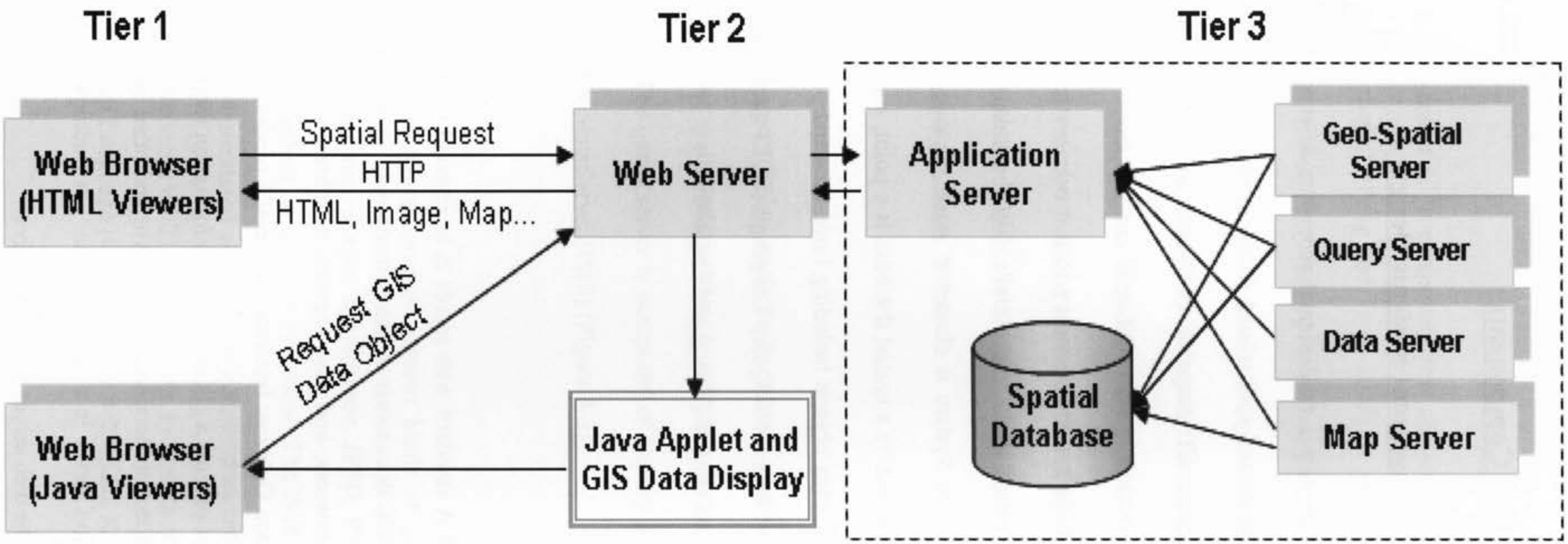


Figure 4-1 A three-tier Web-GIS architecture

4.2 Design Web-based GIS Components

4.2.1 Data and Database Management Systems Design

The GIS data model design is a fundamental procedure to support municipal oil spill management planning processes and spill-related decision-making. To do so, it should meet the data processing requirements, GIS mapping, query, analysis and online manipulation through a web-based GIS information system. Oil spill analysis needs a wide range of spill-related geographic data including a city boundary map, roads, water ways, watershed, ESAs, land-use, sewersheds, sewer networks and outfalls, SWM ponds, city infrastructure, *etc.* A Spatial Database Management System is chosen to store, manage, and maintain the spatial data. The simplest object stored by a spatial database is a point, and spatial databases combine points to make more complex objects including lines, arcs and polygons. A Spatial Database also should also support Structured Query Language (SQL) query and filtering to enable isolating specific spatial data records (Huang and Lin, 1999).

4.2.2 Servers Design

Web Server

The major function of A standard web server is to respond to client requests via HTTP. It can send existing HTML documents or ready-made map images to the client; or send Java applets to the web-browsers; and pass requests to other servers, invoking other programs such as a CGI (Common Gateway Interface) that could process queries (Peng and Tsou, 2003). A web server cannot process a client's spatial information request. It needs to be passed to other servers. The connection between a web server and other servers is called an application server. The application server is a "glue program" or middleware that acts as a translator or connector between the web server and a map server.

Database Server

A data server is "a component that contains and delivers data across a common interface to any clients" (Peng and Tsou, 2003). It serves spatial and non-spatial data in a relational or non-relational database structure. Data services typically are tightly coupled with specific data sets and offer access to customized portions of that data. When the user makes a request, that request is transferred to the server; the server then searches the database and returns the query results as data services to the user. Data services allow clients to retrieve spatial data and information from the Internet to local machines. Using the Internet, the latest version of the dataset is accessible to all users immediately when the datasets are updated on the central web server (Theseira, 2002).

Query Server

Spatial query helps analysts to access properties of spatial features, to filter information, to test spatial relationship, to calculate distances and direction or to derive new spatial features. The query server is composed of a query processor, Spatial Database Engine (SDE) and Internet Map Server (IMS) (Figure 4-2).

Geo-spatial Servers

Geo-spatial servers provide various kinds of geo-spatial services such as map services that generate map images, for instance, JPEG, PNG; graphic element maps, SVG (Scalable Vector Graphic); or vector-typed maps. The Web Coverage Service (WCS), which provides access to unrendered geospatial information as needed for client-side rendering; and the Web Feature Service (WFS), which allows a client to retrieve geospatial data encoded in Geography Markup Language (GML) (Figure 4-2) (Kim, Kim, Lee and Joo, 2005).

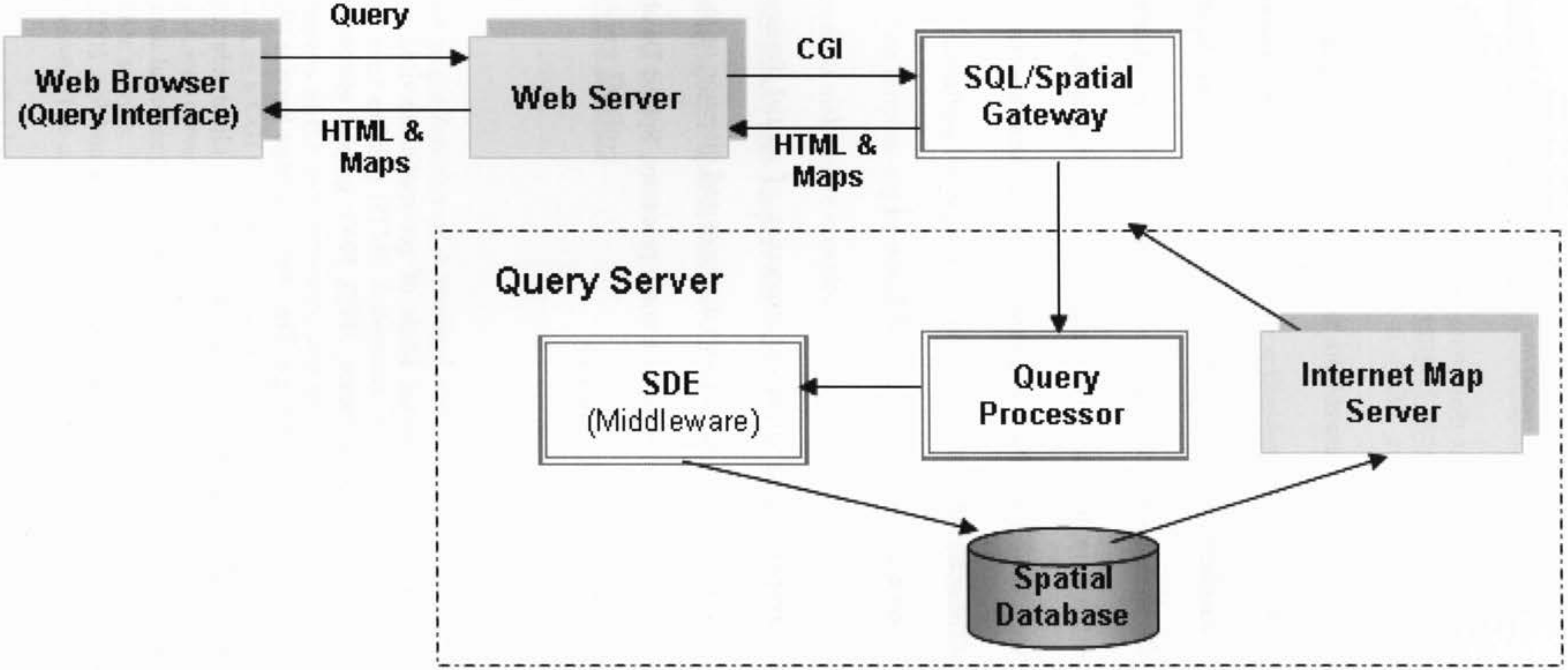


Figure 4-2 Architecture of SQL/Spatial Server (Huang and Lin, 1999)

A Map Server has some basic functions (OpenGIS WMT specifications, 2006):

1. to produce a symbolized map based on user's requests;

2. to perform spatial analysis such as buffering, feature overlay, spatial search, and network analysis

3. to communicate with other programs about the availability of services and data, such as what maps it can produce and which of those can be queried further

4. to provide an interface for associating default symbology with a data set for use by clients with data publishing capabilities

5. to invoke other map servers to perform other analyses, which is some times referred to as a cascading map server in OGC's WMT specifications.

Application Servers

The Web Server and the Geo-spatial Server cannot directly communicate because they talk in different languages. The web server uses HTTP and HTML, while each geo-spatial server may require different types of query structure and format. Therefore, the web server and the geo-spatial server have to rely on "middleware" to be the translator between them. These in-between programs are called application servers

4.3 User Interface Design

The user-interface for municipal oil spill management is designed for multiple users with a wide range of management background and technology skills. It should be simple in design and perform quickly. In the same time, it can provide the end-users with an interactive platform on which they can view maps, select features, make queries, process data; present results as a new map and print it out, or download it to a local computer. In an oil spill emergency situation, first responders may need to upload spill-related information as vector maps to collaborative agencies. In order to meet the spill-information requirements, client-side programs such as plug-ins, Java applets or Java beans, and ActiveX controls are needed to be added to improve the web-client functionality. Two types of the interface are designed for urban oil spill management:

HTML Viewers: it is chosen for large audiences and to provide general functionality. Simple map operations such as zoom interactively, pan the map, turn on or off layers, select features, perform spatial analysis and download attribute tables are designed to meet the general information requirement.

Java-based Viewers: it allows users to interact directly with the spatial features on a map. It usually incorporates map-rendering and data processing functions in the Java applet so that the user can render maps, make queries, and do other spatial processing inside the viewer without going back to the map server. Java-based viewers support both feature data and map images.

A dynamic HTML (DHTML) client is an interactive interface that displays maps, queries spatial data, and outputs analysis results. There are no add-on programs for a web browser and all of the client demands are processed at the server-side (Figure 4-3). Viewers in the forms of Java applets are executable Java codes that are downloadable from the web server and executed on the web browser at runtime (Figure 4-3). Since a Java applet can also establish a connection channel to the database server, feature data can be streamed to the Java viewers and temporarily cached on the client machine. End-users then interact with the feature data, vector maps and images. They can also add their own data to the map viewer to obtain a more comprehensive understanding of spatial relationships and data distribution patterns. When the Java viewer is closed the temporary cache is removed. So the Java viewer does not take any permanent disk space in the client's computer. Java applets have the advantage of being platform neutral and more secure (Peng and Tsou, 2003).

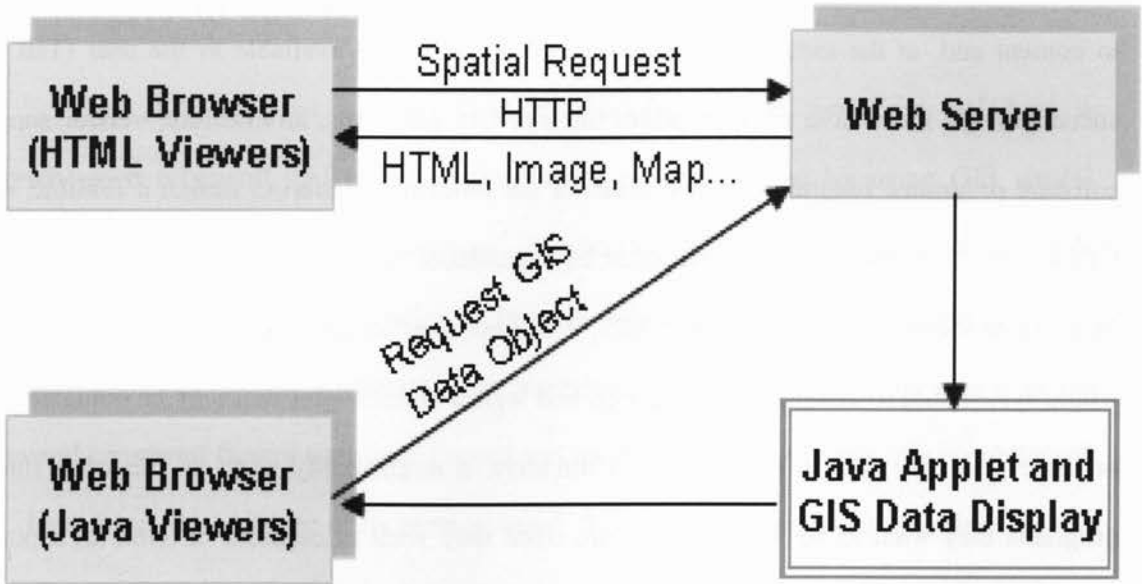


Figure 4-3 Client-side viewer designs

A municipality should decide whether a server-side or client-side approach is appropriate when choosing the Internet GIS programs for oil spill management. The following questions should be considered:

- Is the system designed for a "thin" client or a "GIS-expert" client?
- Which server platform can carry the user needs and tasks?
- Which client platform will be used by the user?
- Is Hypertext Markup Language (HTML) or Java Script used by the user?
- Is ActiveX control available on the user's system?
- Is a distributed-component model useful to the user?
- How does the user communicate with the server?

Web-based GIS performance can be enhanced by building web pages that are easy to download; expand bandwidth, a portal can be designed to minimize the number of user "clicks" to get to content and, at the same time, maximize the functionality available to the user (Tait, 2005). A successful site must have an appropriate Internet GIS platforms, architecture, vendor supports, and software programs. Identification the needs is the fundamental step to design a feasible Web-based GIS architecture. The server systems must be dependable, reliable, scalable, secure, and long lasting. In order to identify the right Internet GIS, it is important to develop a comprehensive plan for the whole system and to avoid ad hoc solutions and legacy technologies that may be outdated within two or three years (Peng and Tsou, 2003). Ultimately, a municipality must decide what Internet GIS programs they want to buy and what future trend they want to consider in terms of a portable and expandable system that can accommodate the future changes in hardware, software and networking (Jere, 2000).

Chapter 5 Case Study: The District of Etobicoke Oil Spill Management and Web-based GIS Architecture

This chapter uses a case study to demonstrate the procedures of how a comprehensive urban oil spill planning framework is implemented by using GIS spatial analysis and Web-based GIS architecture. Application of Web-based GIS in oil spill management is a new initiative. It relies on Internet infrastructure and a geo-database format to display maps and perform spatial analysis procedures. The selection of study area is based on several constraint factors such as the speed and bandwidth of the Internet, the capability of a PC hard drive, the capacity of its memory card, the limited resources and the time for the research. As the case study is only a demonstration, the selected area and the spill database are small enough to efficiently run into the Internet environment without loading waiting time and bad images. After several trials on a notebook computer, it was decided that the City of Toronto was too large to implement into our Web-based GIS architecture. It was then that the Etobicoke, a district of the City of Toronto was selected as the demonstration area.

5.1 Location of the Study Area

The geographic features of the District of Etobicoke include the Etobicoke and Mimico Creek watersheds, and the Humber River Watershed. The watersheds, a part of the Great Lakes Basin, are located within the Greater Toronto Area and drain to Lake Ontario (Figure5-1). As a highly urbanized area, Etobicoke district encloses dense industrial lands and transportation corridors where deliberate discharges and accidental spills are especially prone to occur (Figure 5-2). Spills directly affect the region's receiving water quality and have become a high priority for the city in its efforts to improve the overall receiving water quality.

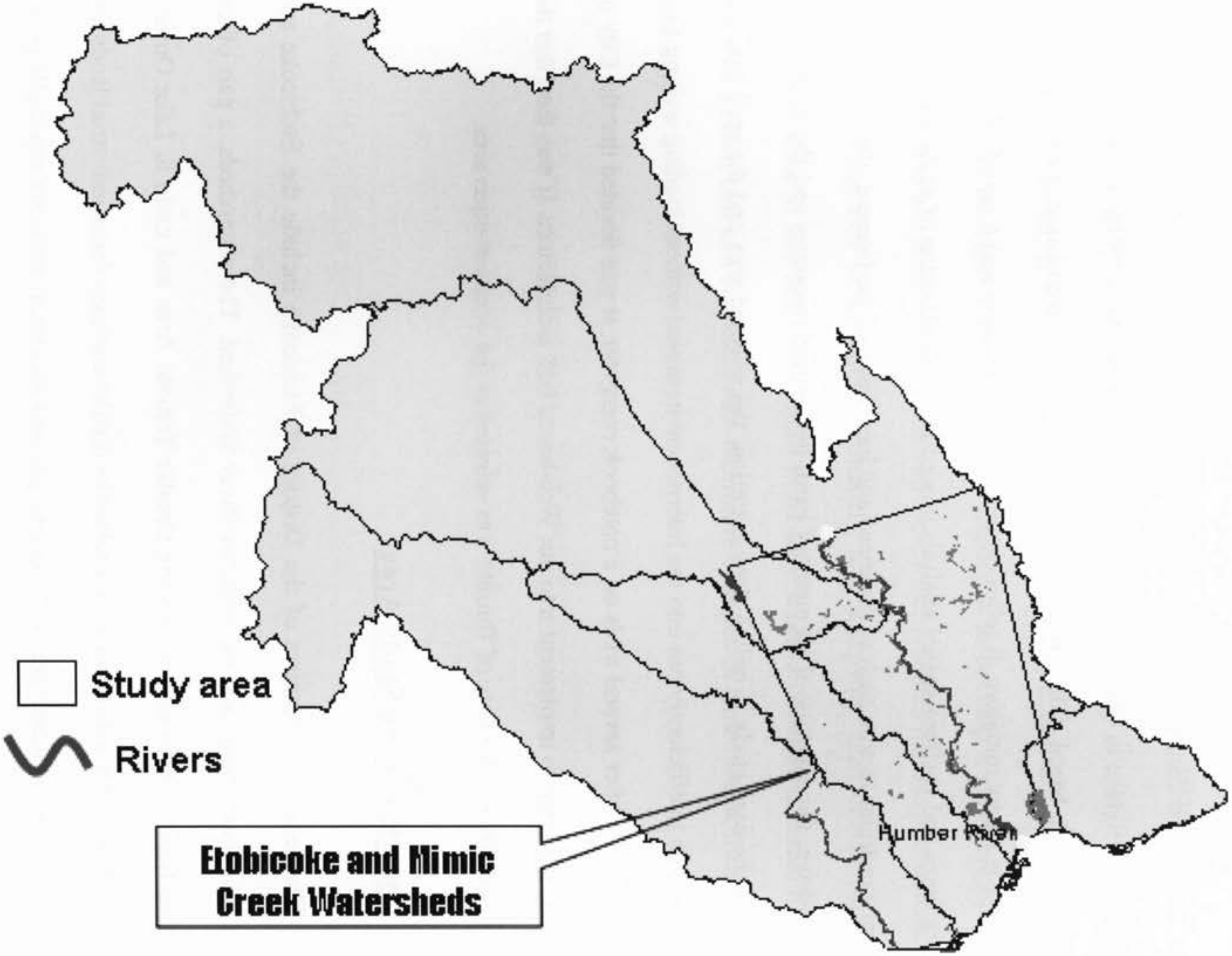


Figure 5-1 Geographic Features of Selected Study Area

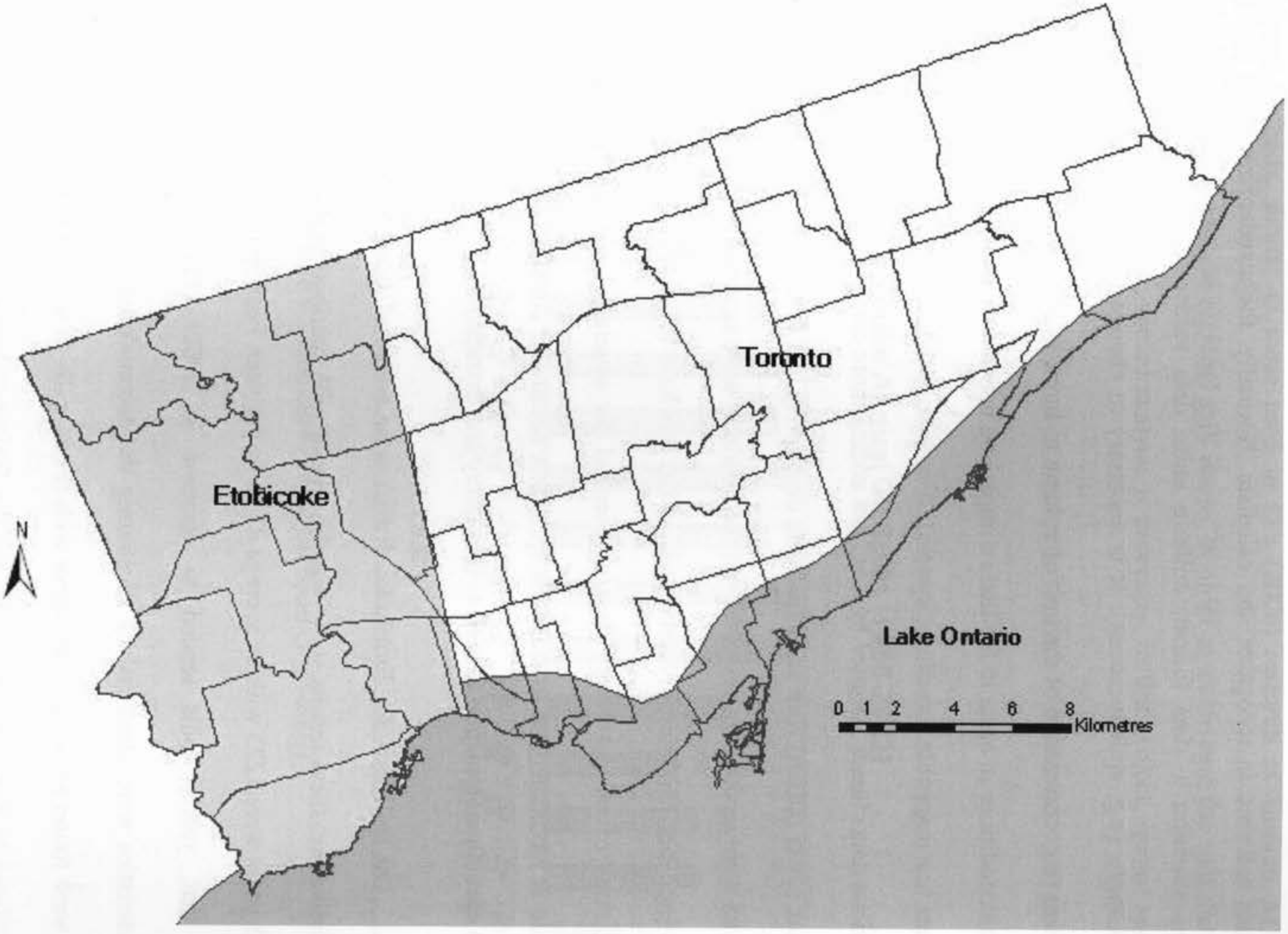


Figure 5-2 Demonstration Area of the District Etobicoke

5.2 Oil Spill Characteristics of Etobicoke

Data standardization is considered a significant step in compiling the data for computer software to recognize and calculate. Normally, the standardization of raw data includes attention to data format, uniform units, data values (e.g. oil types), oil types, specifications (e.g. spill locations). It is necessary to change the format to make the data consistent (e.g. conversion of the unit of volume to litres, standardization of temperature and pressure conditions in order to facilitate comparison between chemicals, identification of spill locations in a mappable coordinate system). A reorganized data file is completed by decoding the various data classes assigned by SAC and adding more categories (e.g. location, road type, land use, sewer outfall) with accompanying descriptive text (Sit, 1999). For example the SAC spill data were recorded in text files and the incidents were summarized in coded fields. This data compilation will simplify data retrieval but it is hard to analyze. Some adjustments and verifications of the SAC spill data are needed for municipal spill analysis. GIS spatial database is recommended to store the spill data because it contains geometric features and allows spatial manipulation as well as data query and extraction.

Oil spill data for Etobicoke district were collected from 1988 to 2002 by SAC. Descriptive statistical results show that the annual spill distribution shows the total spills in past 15 years were 1225 with an average 82 spills per year. Peak spill years were in the 1990s. After that, yearly spills tended to decrease in 2000s (Figure 5-3). Seasonal spill characteristics were identified by illustrating the accumulated spills by months. The most spills were found to occur in summers with fewer spills in winter (Figure 5-4). The overall spill volume in Etobicoke was small but the frequency was high. Most spill volumes were less than 100L, which was approximately 54% of total spills. Volumes over 1000L were rare (Figure 5-5). Despite the unknown type of many spills, gasoline is the most spilled material found in Etobicoke and next is diesel (Figure 5-6). Based on the statistics, parking lots are where most spills happened, and local roads are the second (Figure 5-7). The statistical analyses methods, similar to those used in Li's (2000) research of Toronto AOC's are generally applied to analyse regional spill issues. In order to understand the spill distribution and find out problem areas, spatial analysis is necessary. In this project, spatial analysis is performed in Web-based GIS.

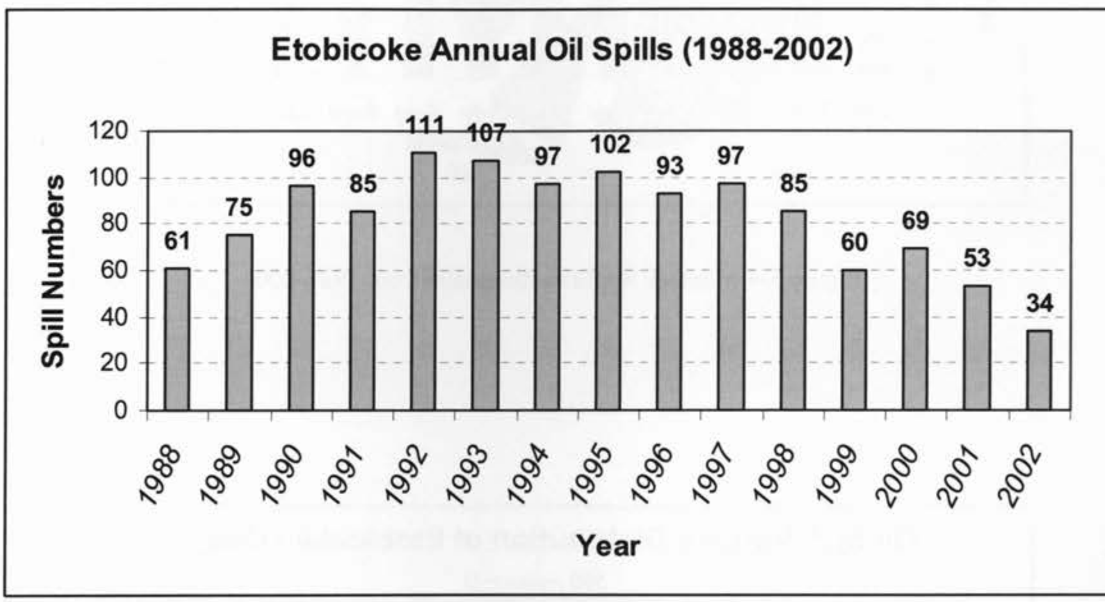


Figure 5-3 Etobicoke Annual Oil Spills (1988-2002)

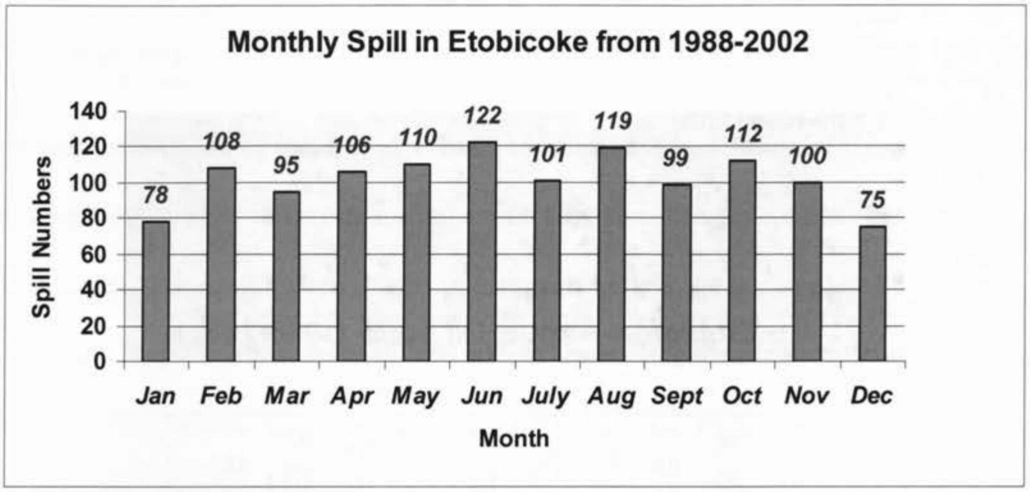


Figure 5-4 Monthly Spills in Etobicoke from 1988-2002

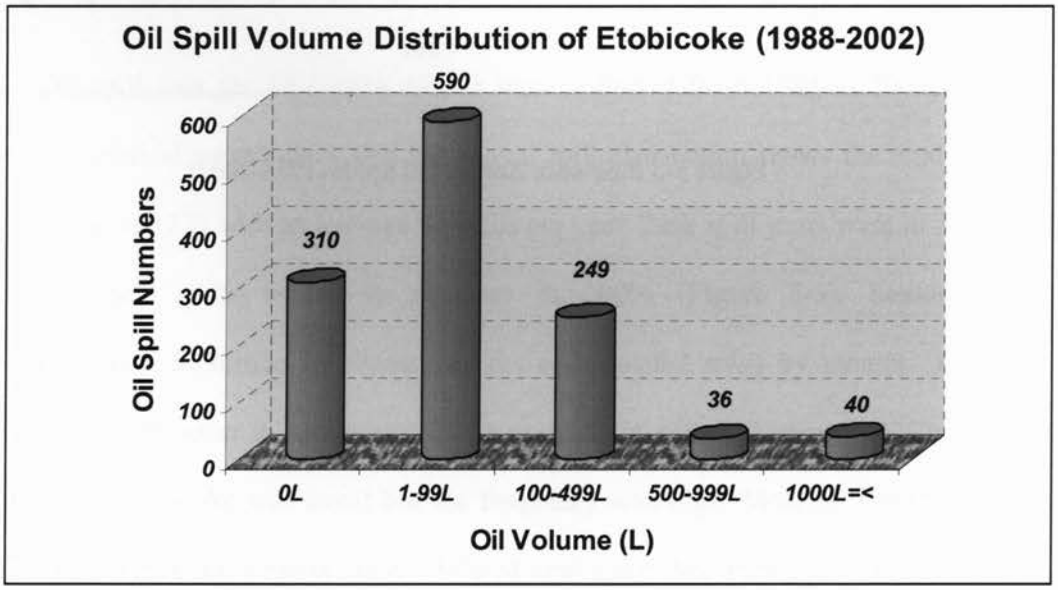


Figure 5-5 Oil Spill Volume Distribution of Etobicoke (1988-2002)

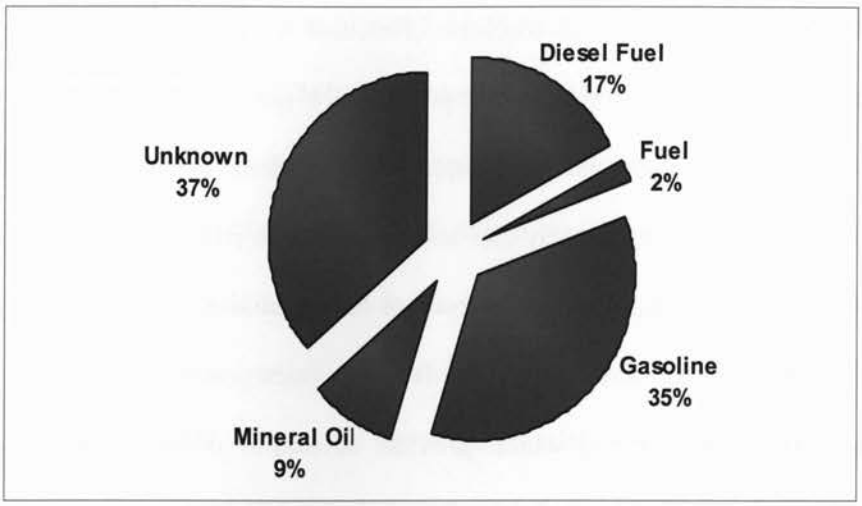


Figure 5-6 Oil Spill Types

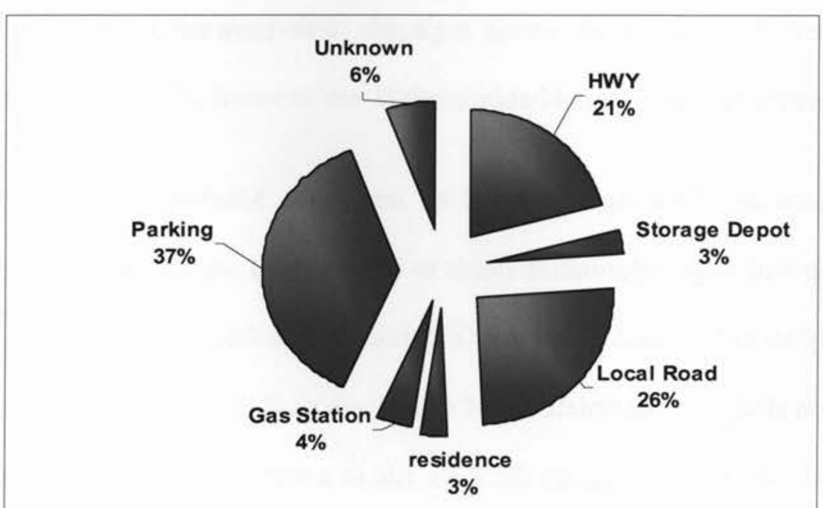


Figure 5-7 Spill Locations

5.3 Implement a Web-based GIS System

A Web-based GIS system built on ESRI's ArcIMS v. 9.0, and was run on a 1400 MHz 768Mb Ram computer with Windows Server 2003. The three components of ArcIMS were all installed on the same machine. The user interface was structured in Microsoft Internet Explorer 5.0. The system components are shown in Figure 5-10. The Web GIS operates on the server-side, performs basic GIS operations, and interprets the spatial data in its specific format. A user-friendly and low-maintenance strategy was adopted to design the system. The ArcIMS mapping service resides on a spatial mapping server with HTML and JavaScript for system communication. It adds management applications with Author, Designer and Administrator, which provide access to components for creating maps, administration and designing websites. A geospatial data processing engine, Spatial Server, runs on the server side for creating cartographic map image files (e.g. in JPEG or PNG format); streaming map features; searching to query the database; geocoding for address matching operations; and extracting data to create a subset that can be sent back in a shapefile format (Mathiyalagan et al., 2005 and ArcIMS ESRI, 2006). This arrangement allows a user with the Internet connection to access a graphic Web browser interactively and remotely explore interrelationship of spatial data.

There are three steps to build an interactive MapService in ArcIMS. Firstly, a thematic map with layer information needs to be generated and the ArcIMS Manager system automatically saves it as an AXL format (Figure 5-9). "EtoEducation. axl" was created for the demonstration study. The complete list of data layers used for this study is presented in Table 5-1. The next step was to integrate the AXL file to a web site as a MapService. There is a group of virtual severs running on the server-side that define the type of incoming request and send it to the Spatial Server. "FeatureServer1"was used to render Java Viewer and needed the client-side program to support the viewing. An "ImageSever1" was chosen for this study's purpose and to provide Image Services (Figure 5-10). Thus, a map-based AXL file is ready for the Spatial Server to render MapServices to Web clients (Figure 5-11).

The default viewer is shown in Figure 5-12. It can be customized by changing some features in the website folder and HTML files, when ArcIMS creates an HTML viewer (by default located in C:\ArcIMS\Website\<website name>). The "images" folder contains all the images used for designing the HTML viewer, including button icons and frame backgrounds. Customized images or logos could be added in this folder. The JavaScript folder contains the HTML Viewer JavaScript Library, which is a series of javaScript files used to create ArcXML requests and process ArcXML responses from the Spatial Sever. ArcIMSparam.js is a JavaScript parameter file, where the simplest customization takes place. It manages basic map parameters as well as other variables which affect the website's look and behaviour. The ".htm" files are used to define the contents of each frame within the viewer. The "Viewer.htm" defines the frame layout for the HTML Viewer which can also be customized. The Toolbar.htm produces a different look for the viewer's toolbar. The jsForm.htm is used to send information though the Internet to the Web Server. Figure 5-13 is an example of a customized HTML page. The frame colour is changed to blue and some features are added.

ArcIMS Components

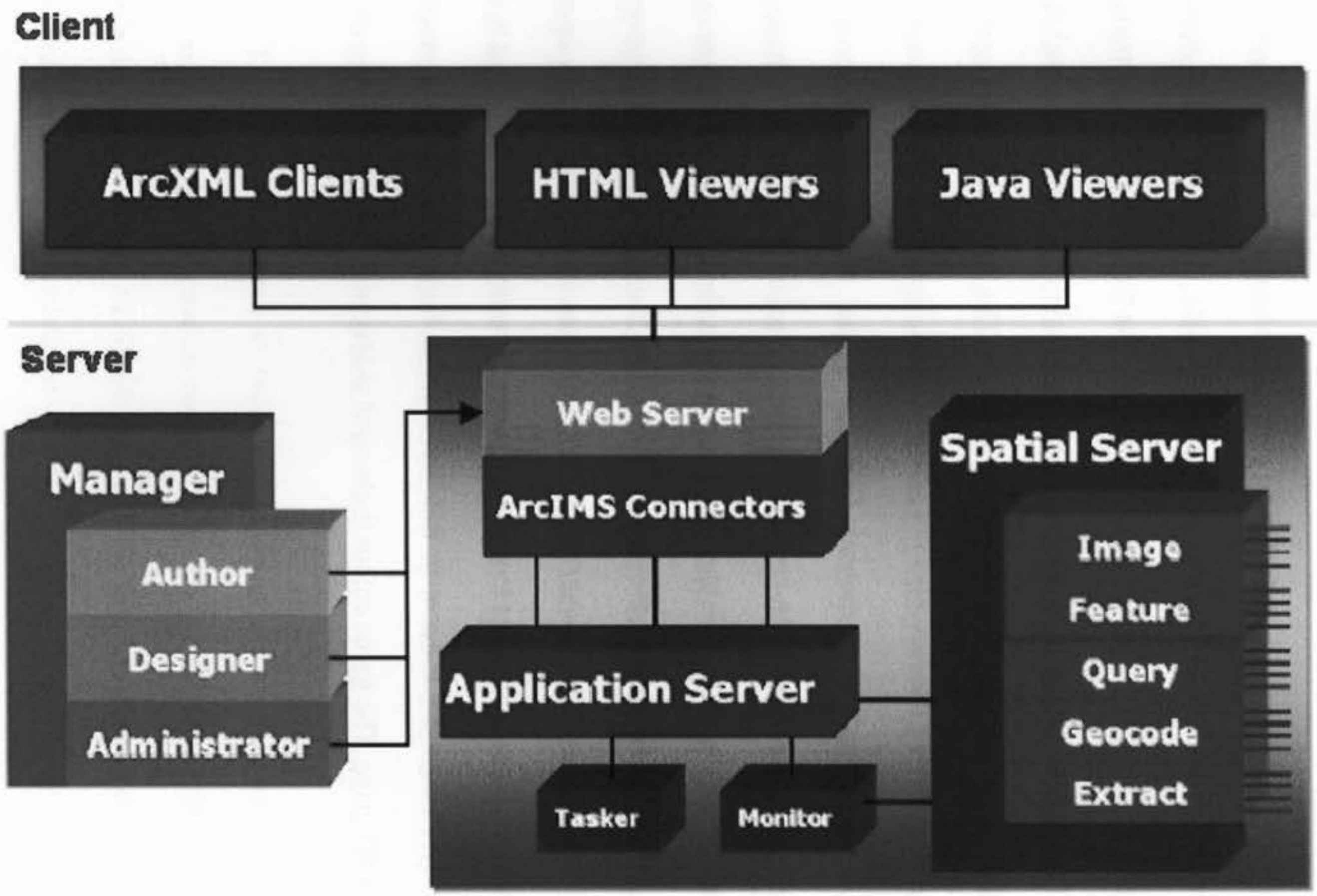


Figure 5-8 ArcIMS components for Web-based GIS

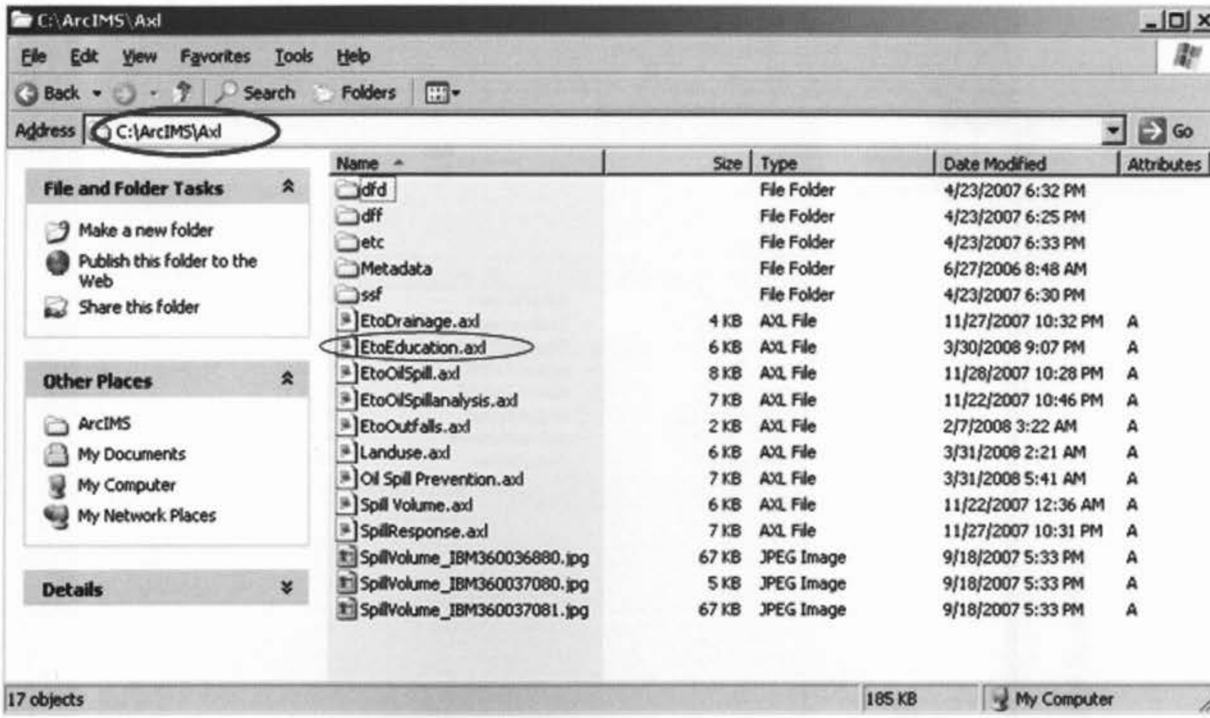


Figure 5-9 A thematic map generated as AXL format

Layers	Source
1. EtoSpills	SAC – Spill Action Centre (MOE)
2. Roads	The City of Toronto/DMTI Spatial Inc
3. Waterways	The City of Toronto/MNR (Ontario Ministry of Natural Resource)
4. Land use	The City of Toronto/ DMTI Spatial Inc
5. Satellite Image	The City of Toronto
6. ESAs	TRCA (Toronto Region Conservation Authority)
7. Study Area	The City of Toronto/ DMTI Spatial Inc
8. Watershed	DMTI Spatial Inc (Ontario Watershed)

Table 5-1 Specific data sources

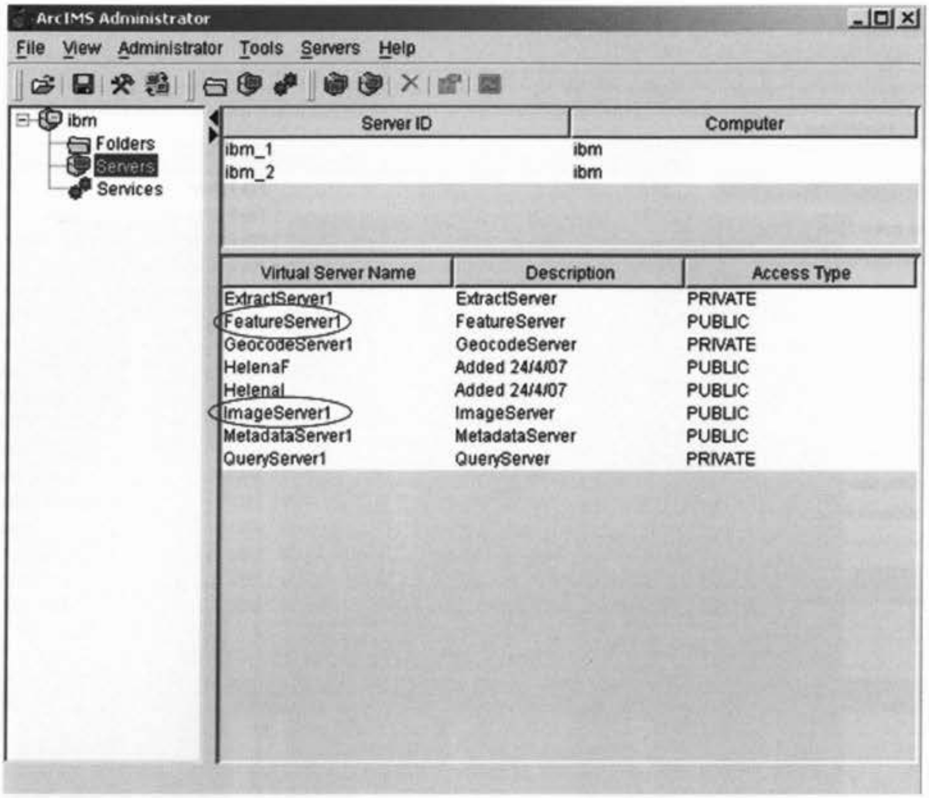


Figure 5-10 Virtual servers

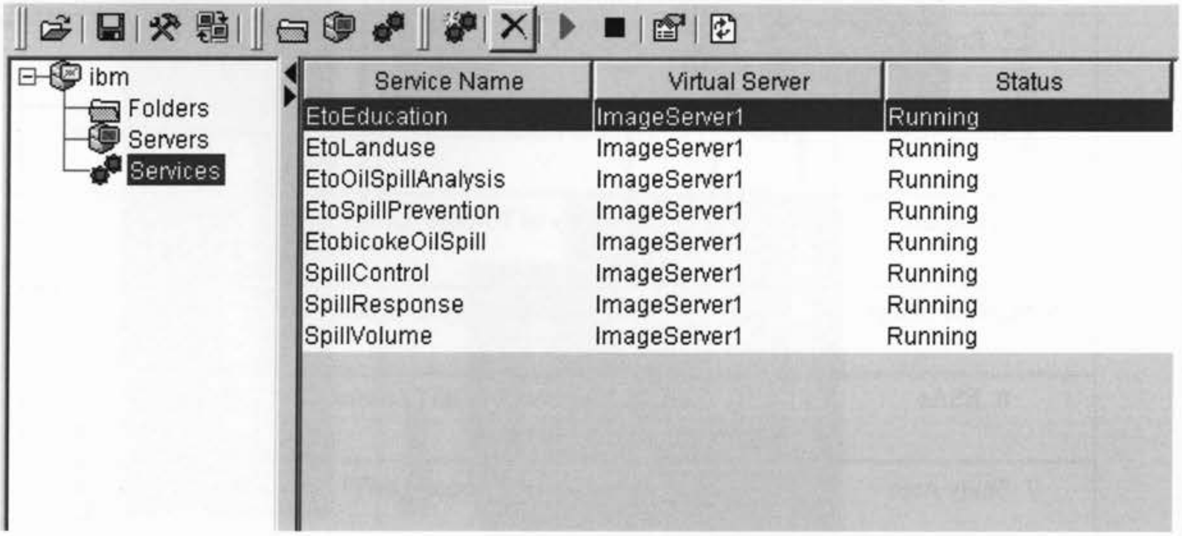


Figure 5-11 ImageServer1 and Demo MapService

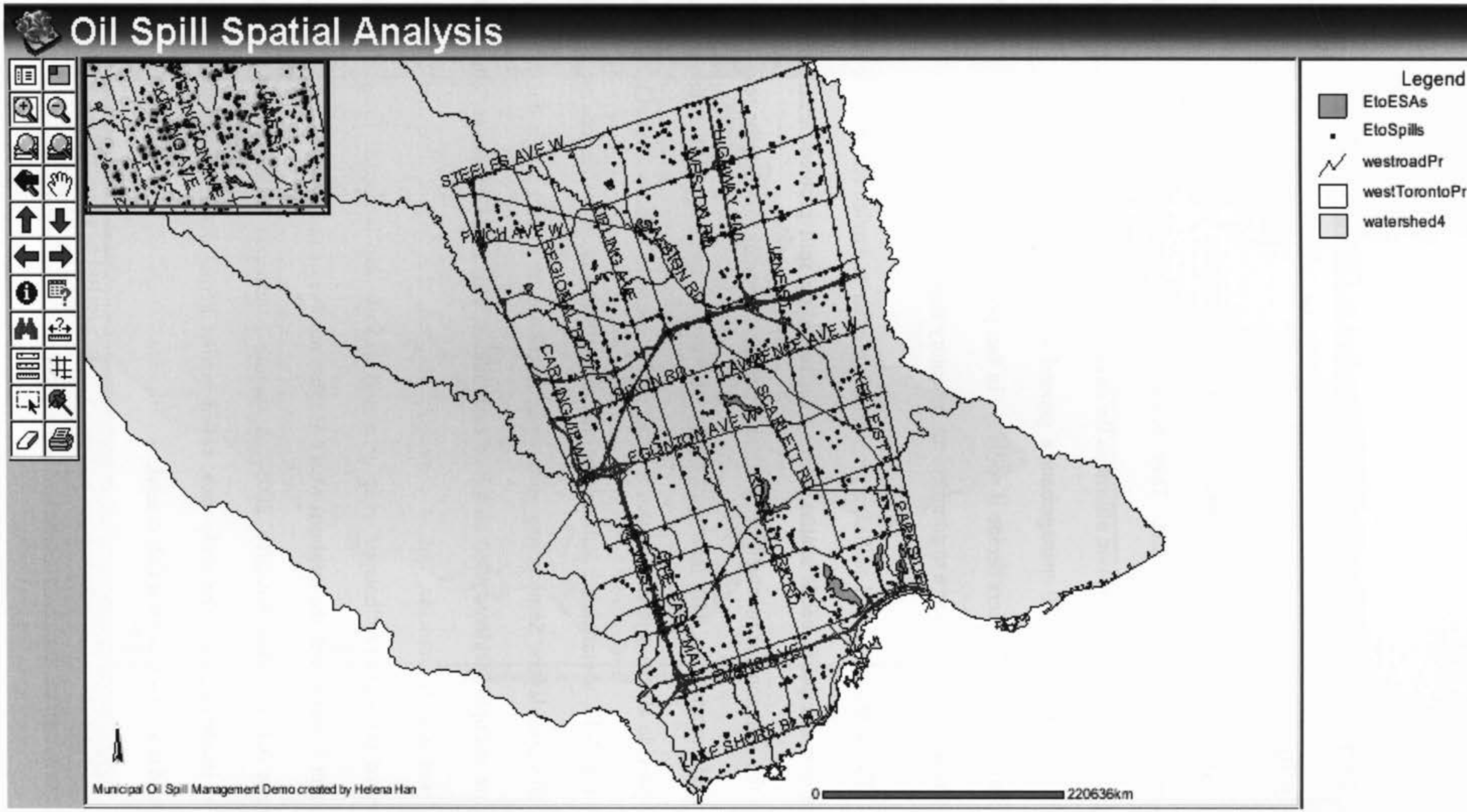


Figure 5-12 The default HTML Viewer generated by ArcIMS®

5.4 Demonstration Web-based GIS Applied to Oil Spill Pollution Prevention

Spill locations are important information especially combined with other spill-related geographic information. They could provide municipal spill-management information to focus spill prevention efforts on the environments affected. A spill distribution map will give municipal spill management a general view of a spill situation within the municipality to help responders decide if spills are in fact posing an environmental or social threat. Mapping could well serve to complete the inventory step in the planning framework.

The next step is spill pollution prevention. In order to implement spill prevention measures, a municipality needs spatial information regarding spill problem areas and the nature of the spill sources involved. It can then focus the resources to assist the responsible and affected communities with their spill issues. However, a spills distribution map alone may not provide all the information that a municipality needs to identify the spill problem areas. In Fig. 5-13, accumulated spill data spread across Etobicoke's watersheds are shown Toronto GIS Data-layers. Some points on the map might appear to be a single dot but they actually are multiple incidents piled on top of each other. This could appear as "clutter" if they did not exactly coincide, but as commonly mapped, the symbol does not tell the frequency of the spills. A "hotspot" map or a spill density map is needed to assist spill management to distinguish the locations where a higher number of spills happed than average occurrences (Chainey and Ratcliffe, 2005). A smooth continuous surface represents the density of incidents across the study area, called quartic kernel density estimation is one solution and is available when a GIS is used.

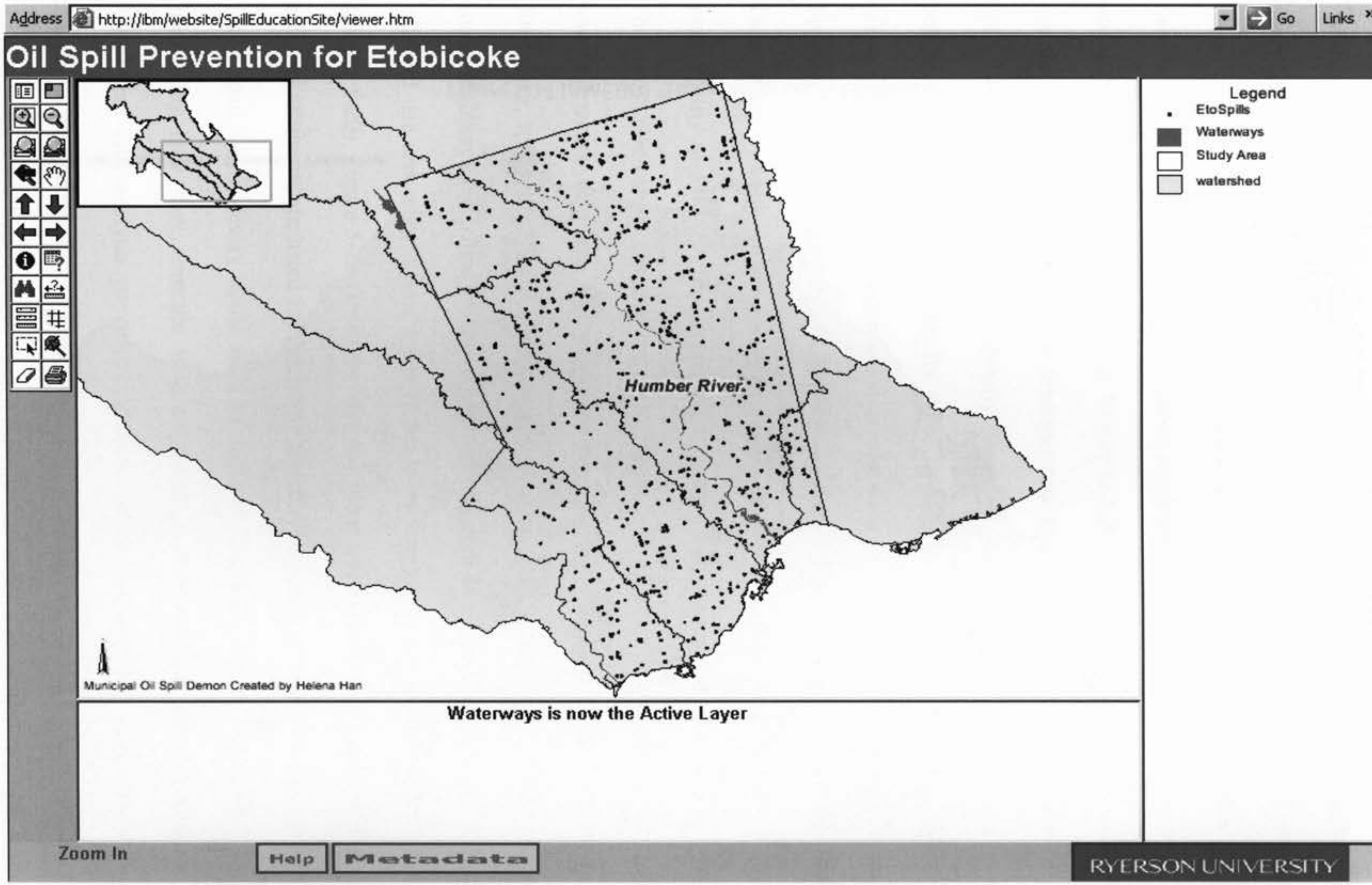


Figure 5-13 Customized HTML viewer for the study are

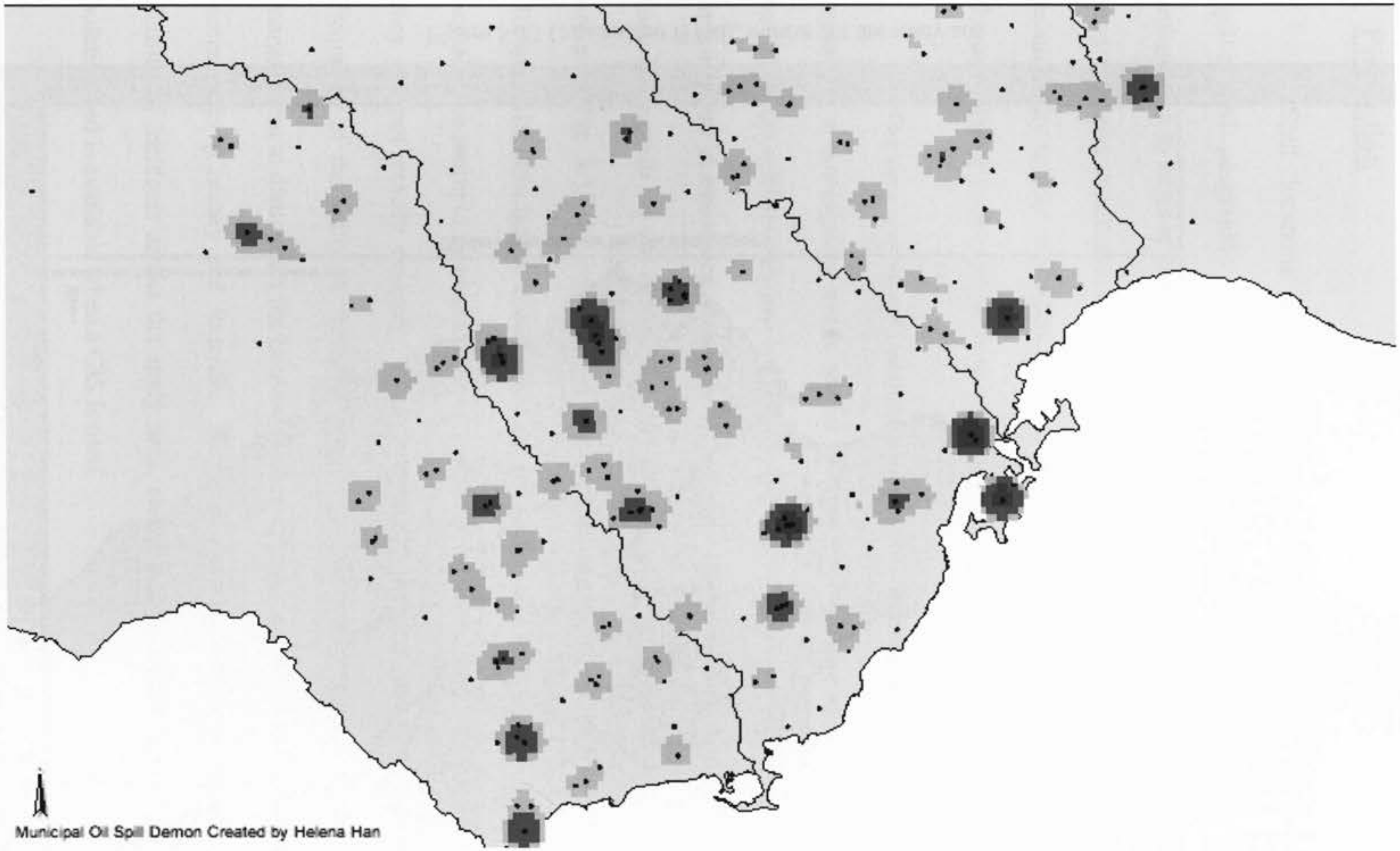


Figure 5-14 Identified "Hotspots" areas in Etobicoke

The technique requires two parameters the grid cell size and the bandwidth (search radius) which can strongly affect the output. Thus, it needs to be selected carefully. In this study the method of choosing a bandwidth is created by Williamson et al. (1999), which is based on the mean nearest neighbour distance between each point and either its closest nearest neighbour, its second closest nearest neighbour, or its *n*th closest nearest neighbour. A scenario in which the grid cell size is 40 metres and a bandwidth is used 300 metres. A layer created "hotspots" is added to the thematic map and shows in Figure 5-14. The graduated colour of symbols represent the density degree of spills in a particular area, the darker the colour, the higher the spill density After overlaying the "Hotspots" layer onto land-use (Figure 5-15), land-owner information around each "hotspots" was identified (Figure 5-16). From tool bar, a drawing polygon function is selected and drew a polygon around "hotspots". Information of land owners are generated in an attribute table which is very useful for a municipality to find out the identify and contact information for spillers. The symbol of "hotspots" also can be changed shown in Figure 5-18 to give a better view of the "hotspots" and underneath land use. Some spill patterns can be identified from the map. In south Etobicoke, spills often occur at industrial and commercial areas; while in the northern part, roads, highways and ramps are the most frequently spill locations (Figure 5-19). After turning off land use and other layers, spills at roads and highways are identified and highlighted (Figure 5-20). Figure 5-21 shows the selected roads and highways with spill problems and a table of attributes are listed in Table 5-2. Some other analysis tools can also be applied to study road and highway spills such as incidents within a buffer distance of roads and identifying how they coincide with surrounding environmental features (Figure 5-22). Web-based GIS analysis provides a flexible interactive mapping environment in which municipal staff can easily combine data layers, explore analysis methods, extract information and get better knowledge of spill related information within a municipality's jurisdiction.

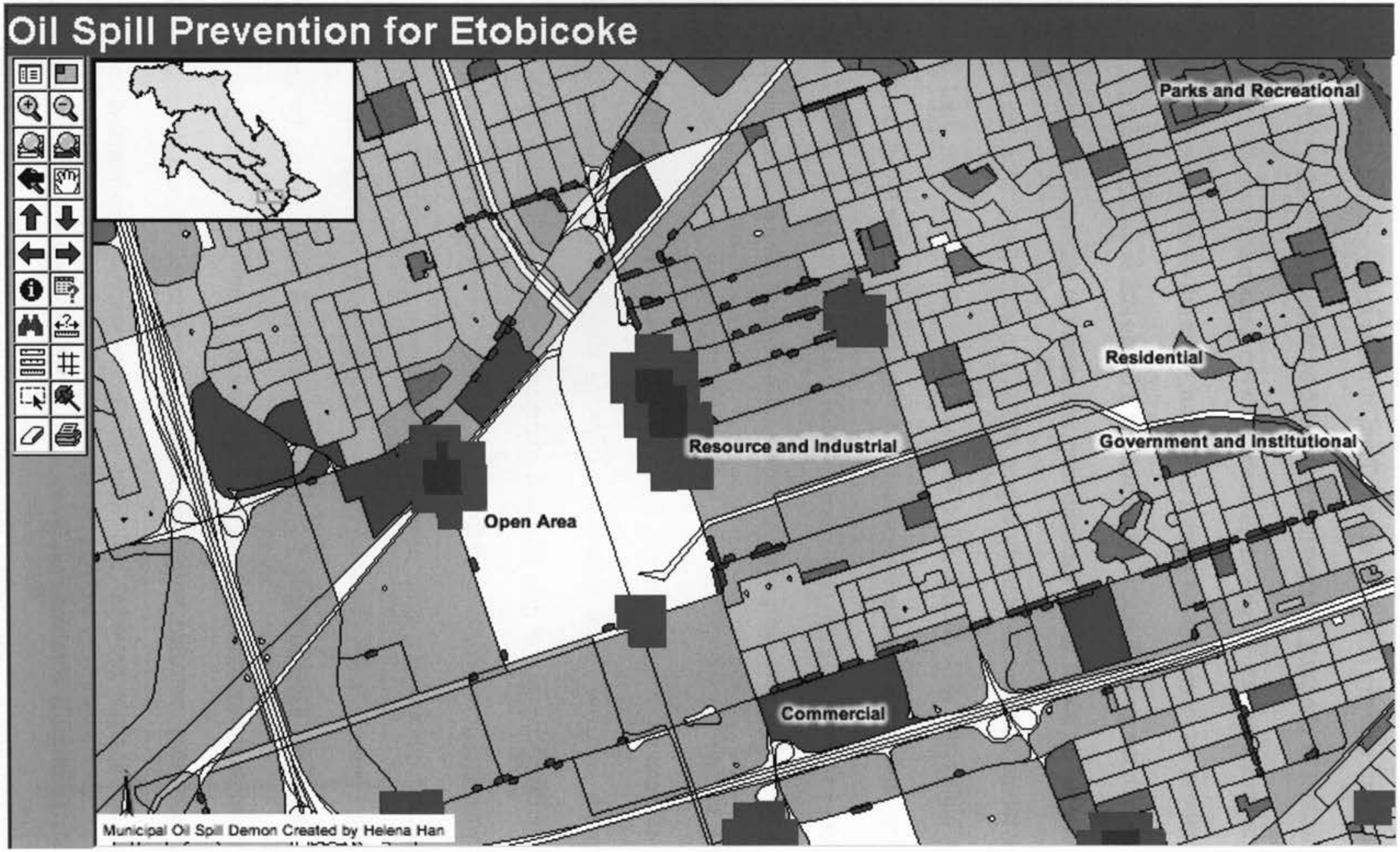


Figure 5-15 Overlaid "hotspots" areas with land use layer

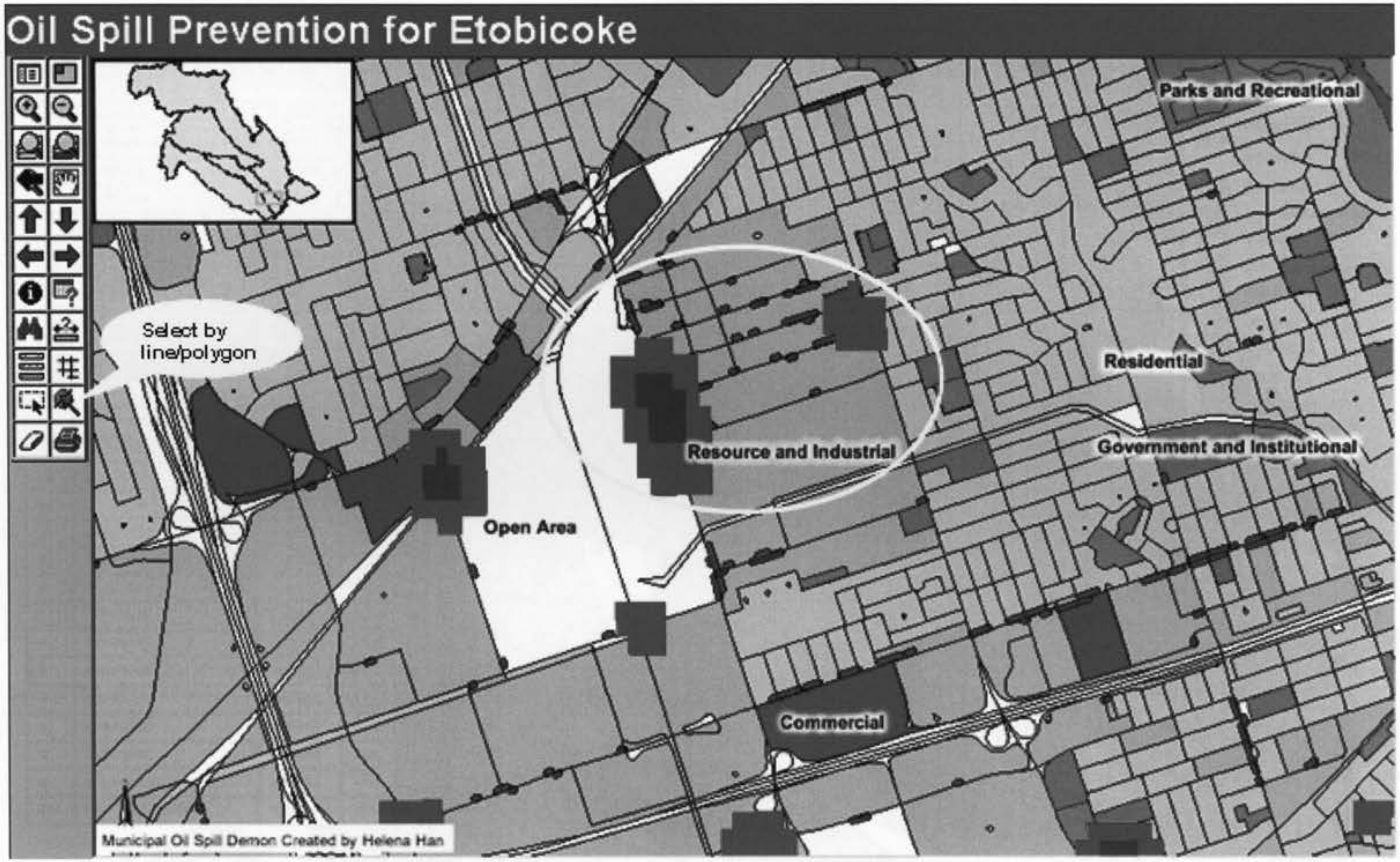
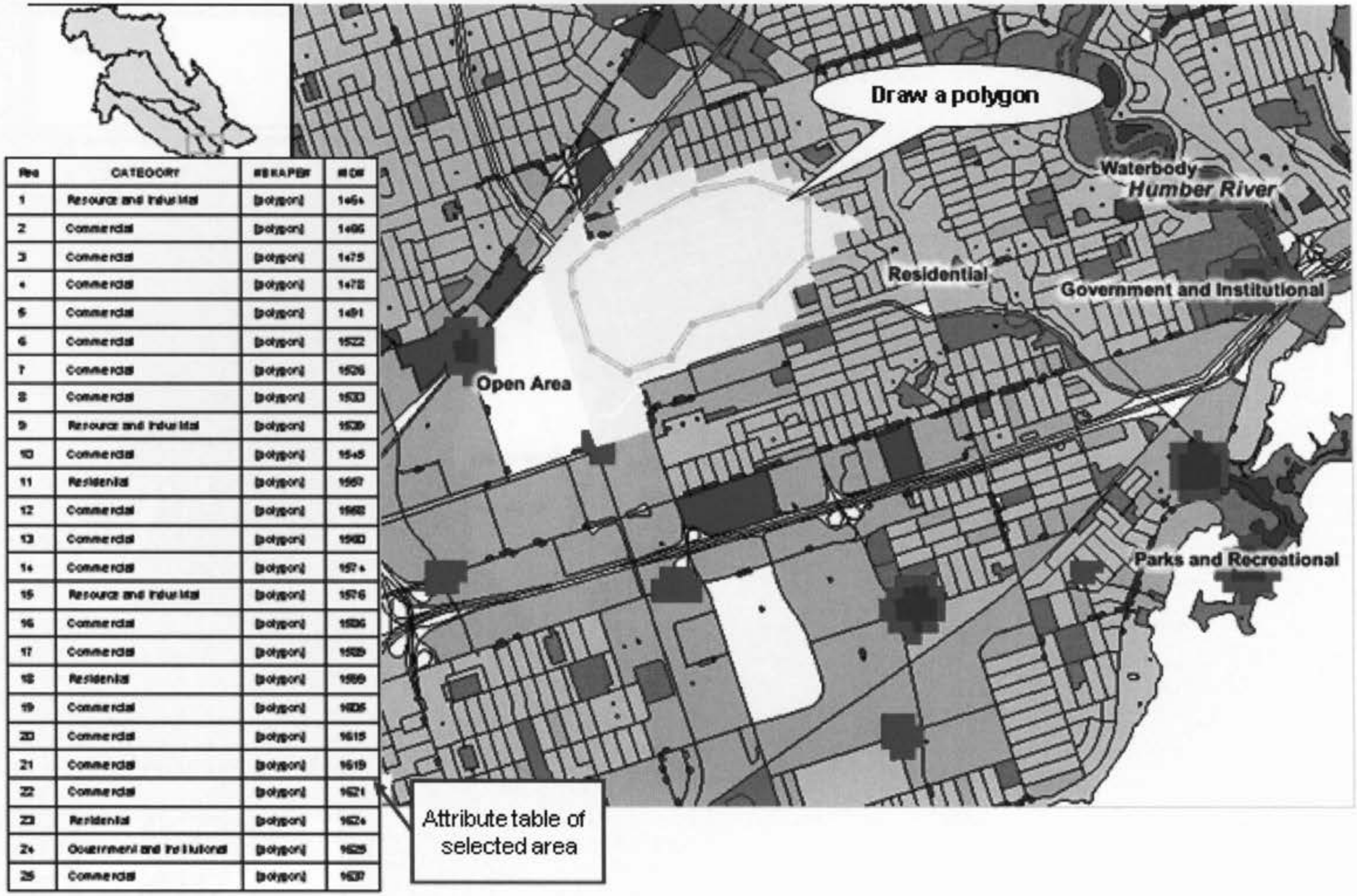


Figure 5-16 Identification of spill-prone sectors



Rec	CATEGORY	#SHAPE#	#ID#
1	Resource and Industrial	[polygon]	1464
2	Commercial	[polygon]	1466
3	Commercial	[polygon]	1475
4	Commercial	[polygon]	1472
5	Commercial	[polygon]	1491
6	Commercial	[polygon]	1522
7	Commercial	[polygon]	1526
8	Commercial	[polygon]	1530
9	Resource and Industrial	[polygon]	1539
10	Commercial	[polygon]	1545
11	Residential	[polygon]	1567
12	Commercial	[polygon]	1568
13	Commercial	[polygon]	1560
14	Commercial	[polygon]	1574
15	Resource and Industrial	[polygon]	1576
16	Commercial	[polygon]	1586
17	Commercial	[polygon]	1589
18	Residential	[polygon]	1599
19	Commercial	[polygon]	1606
20	Commercial	[polygon]	1615
21	Commercial	[polygon]	1619
22	Commercial	[polygon]	1621
23	Residential	[polygon]	1624
24	Government and Institutional	[polygon]	1625
25	Commercial	[polygon]	1637

Figure 5-17 Extracted information of property owners at spill-prone areas

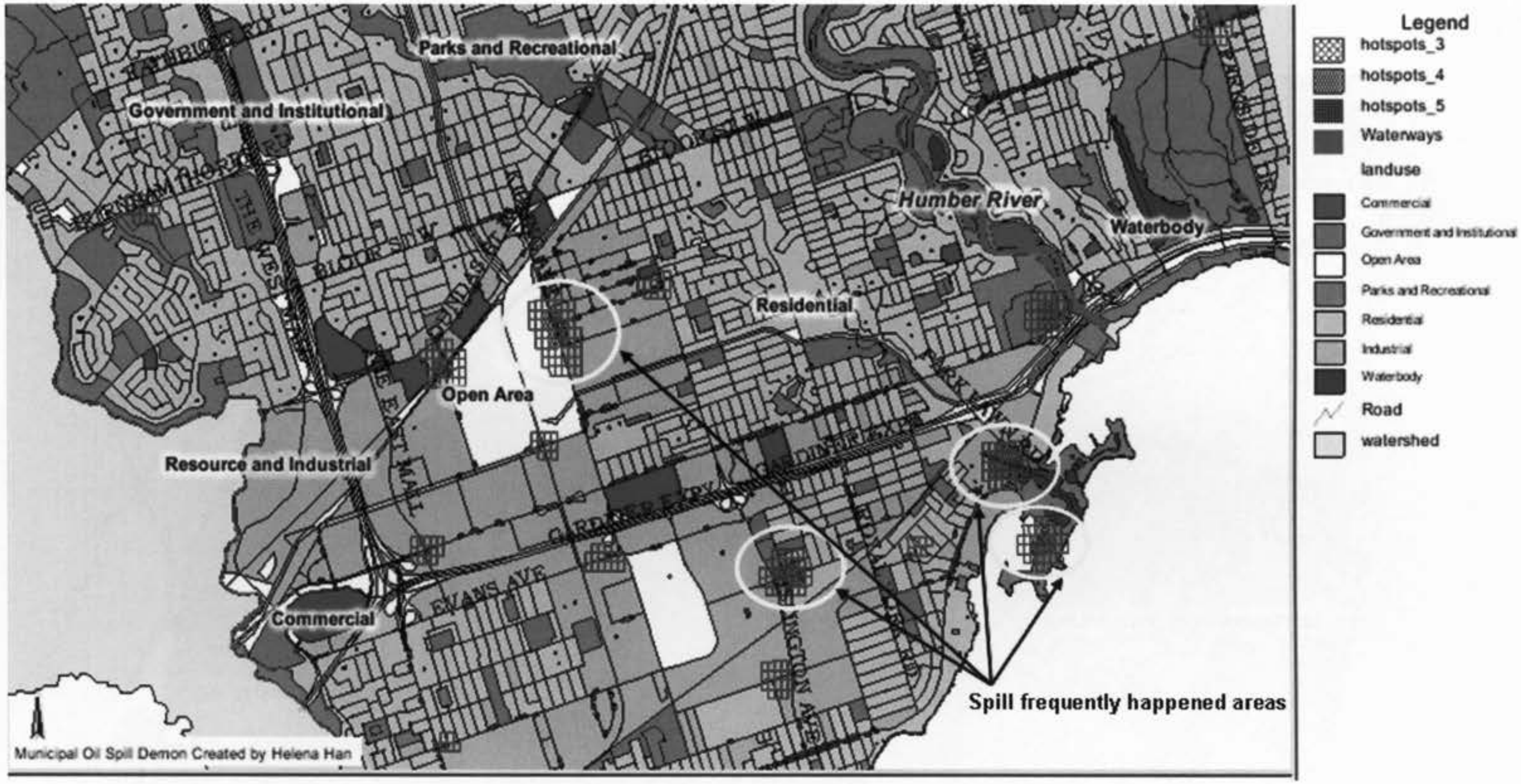


Figure 5-18 Change symbology of "hotspots" as grids to visualize the land use

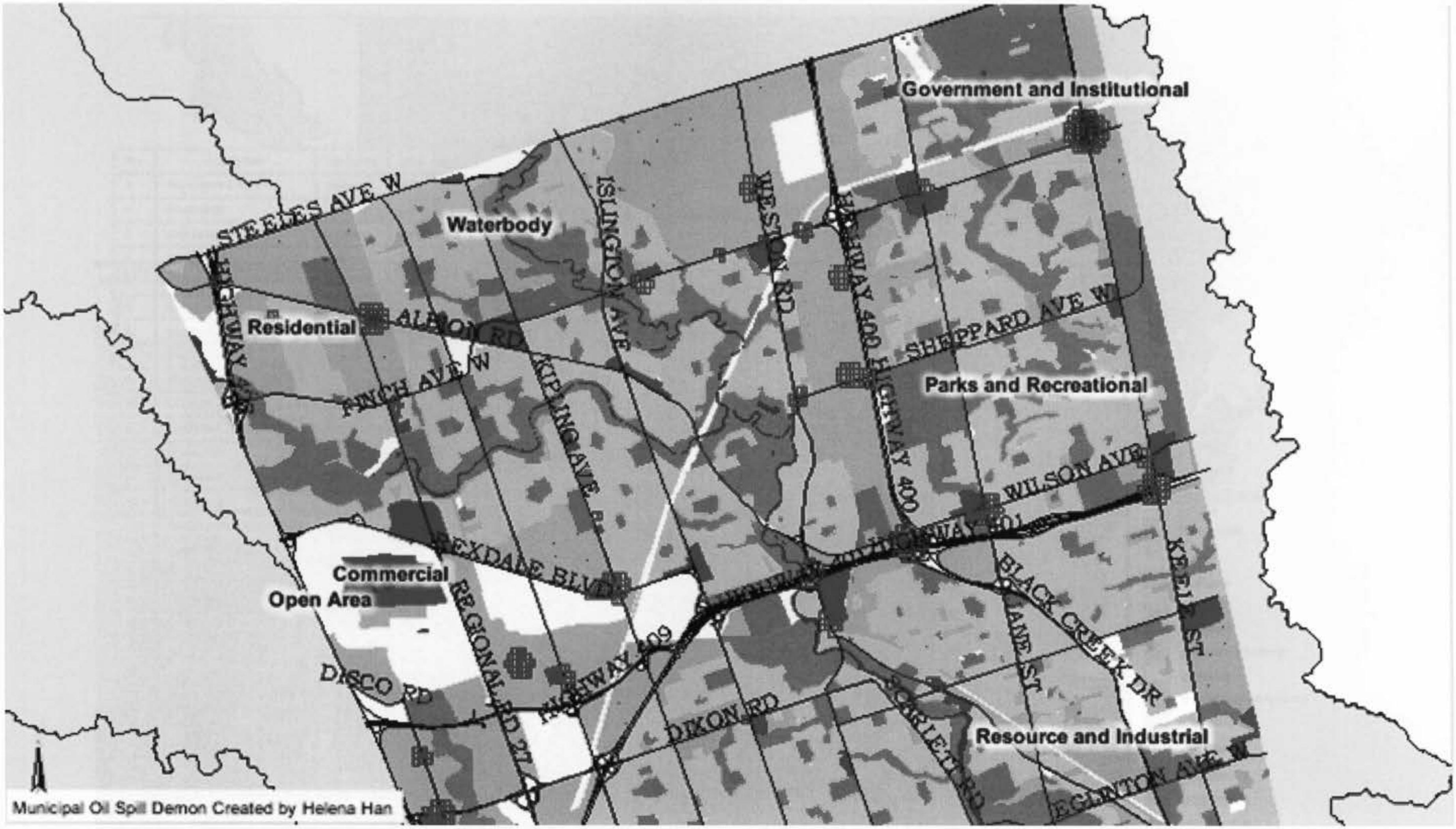


Figure 5-19, most roads and highways spills happened in the north of Etobicoke

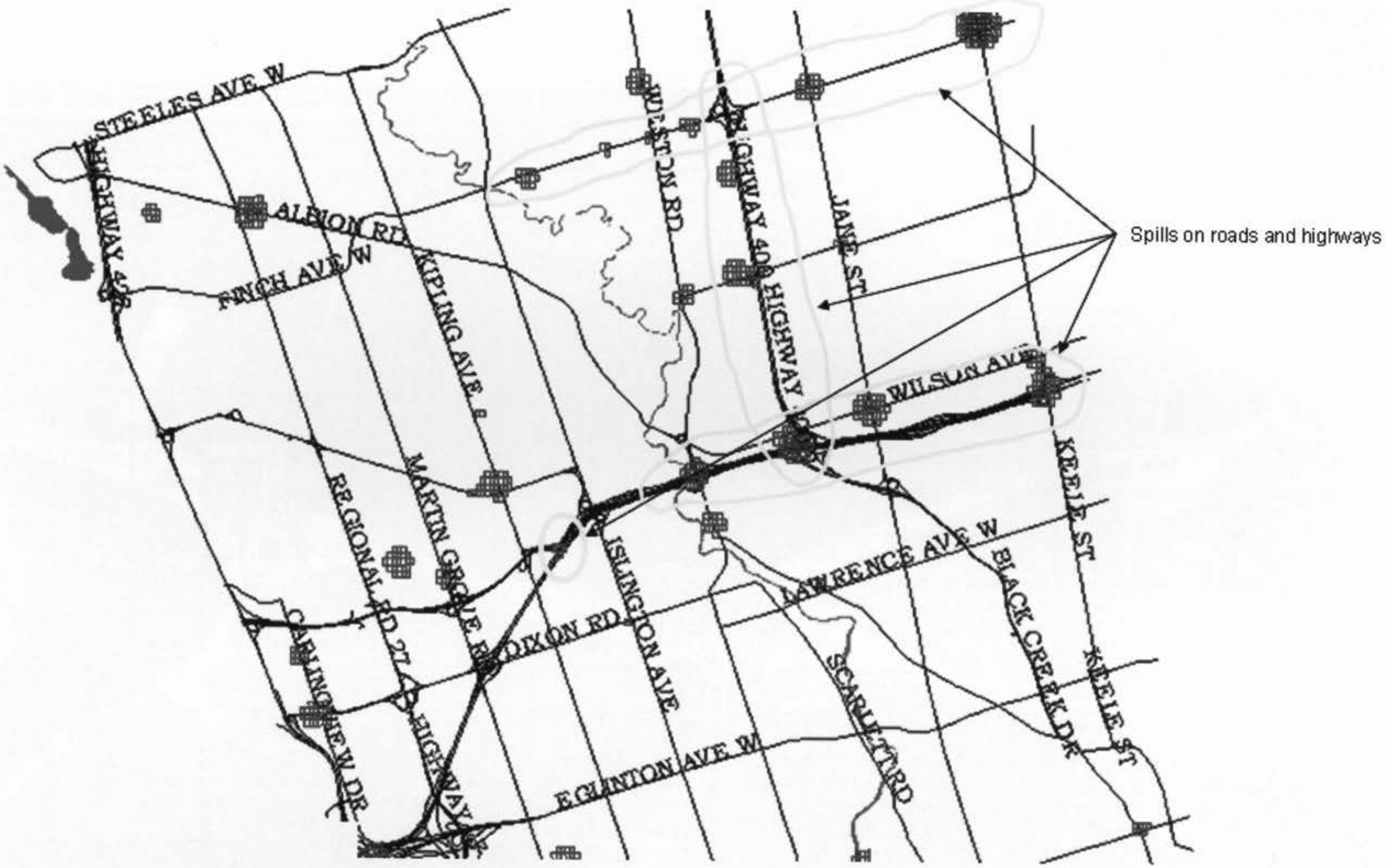


Figure 5-20 Switch on road and highway data layers to analyze spills on roads

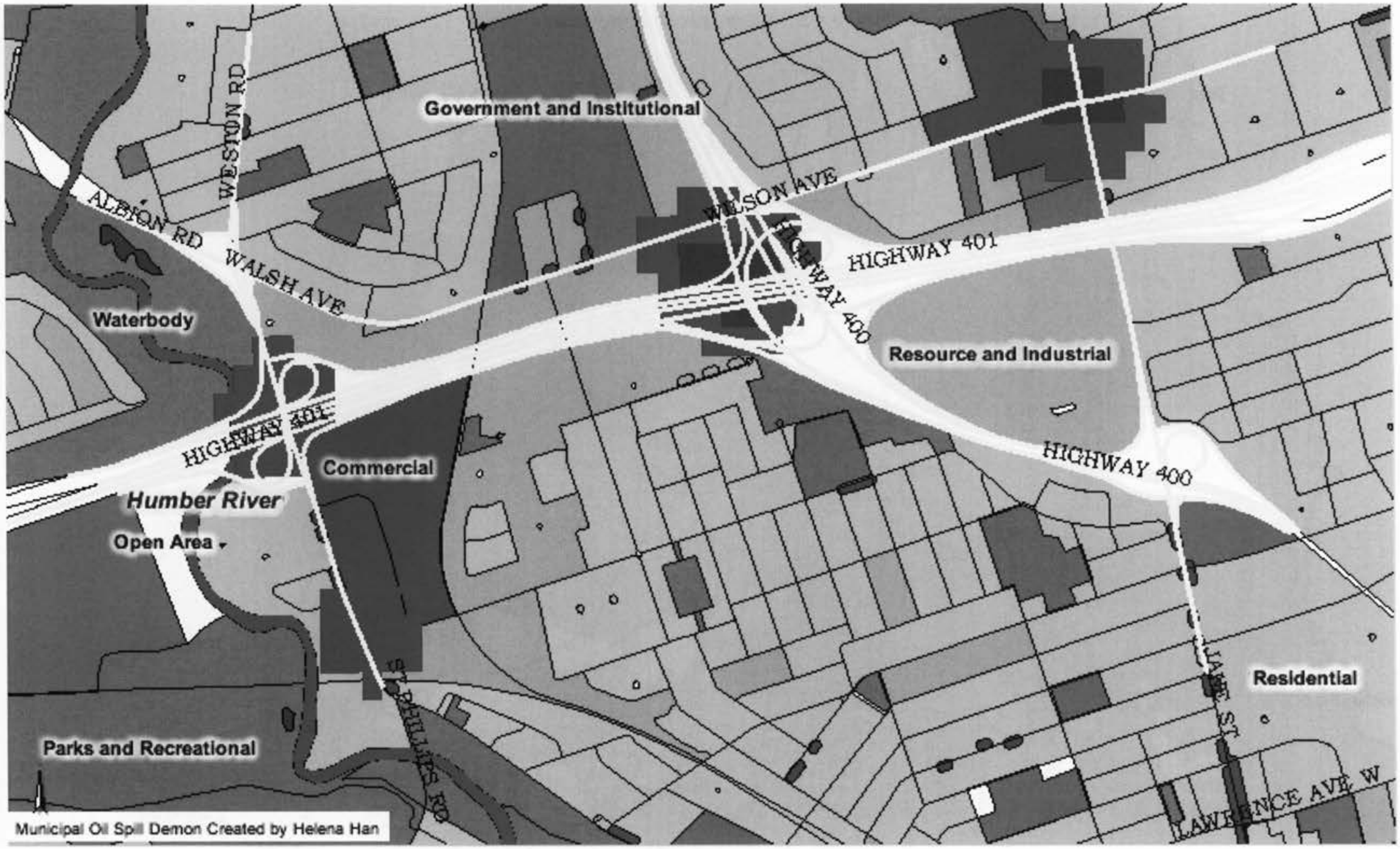


Figure 5-21 Highlighted spills on roads and highways

STREET	CARTO	LEFT_MUN	RIGHT_MUN	LEFT_MAF	RIGHT_MAF	LEFT_PRV	RIGHT_PRV	SHAPE_LENG
HIGHWAY 27	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00036917742
HIGHWAY 27	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00033252176
HIGHWAY 400	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00018293715
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00460969319
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00642728619
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00548485367
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.0015647064
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00101841357
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00259936398
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.01031711737
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.01390827209
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00601814043
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.01018044435
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00704984995
HIGHWAY 401	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00584922127
HIGHWAY 409	1	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00046949188
KIPLING AVE	4	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00184220148
WESTON RD	4	TORONTO	TORONTO	TORONTO	TORONTO	ON	ON	0.00021339184

Table 5-2 Extracted roads and highways spill data information

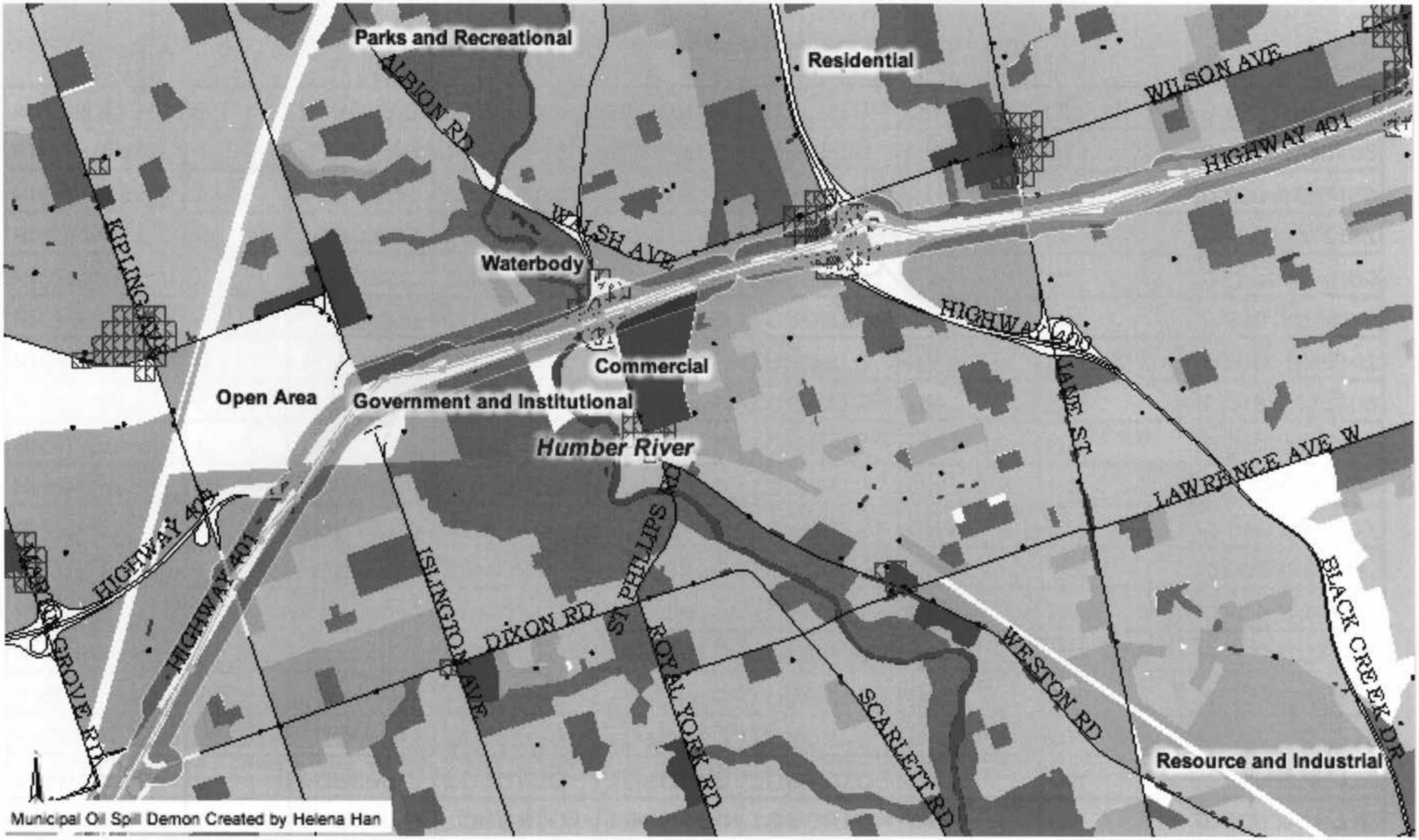


Figure 5-22 Buffer a highway with 100m distance

Figure5-23 illustrates examples in which spills within a selected area of interest are analyzed. In order to study spill impacts on rivers, a 100m distance is selected and spill information within the buffer zone is shown in a table. Figure 5-24 shows wetland ESAs in the study area and how spills distributed along wetland ESAs. Understanding urban environmentally-sensitive areas can assist a municipality to identify the protection priorities, prevent spills in those areas and prepare spill response resources when spills do happen. The effects of an oil spill and its behavior also can vary in different locations. Thus, the ability to review historical data and distribution maps will help decision makers to make more informed management choices. In Figure 5-25, a buffer zone is specified around the wetland ESA. Spills within this buffer zone are then selected and analyzed. The spill characteristics are extracted to Excel or Access for further analysis (Figure 5-26). In the buffer area, the most-frequent spilled oil is petroleum and spill volumes are small but the impact could still be significant. Therefore, specific spill prevention measures need to be implemented at ESAs.

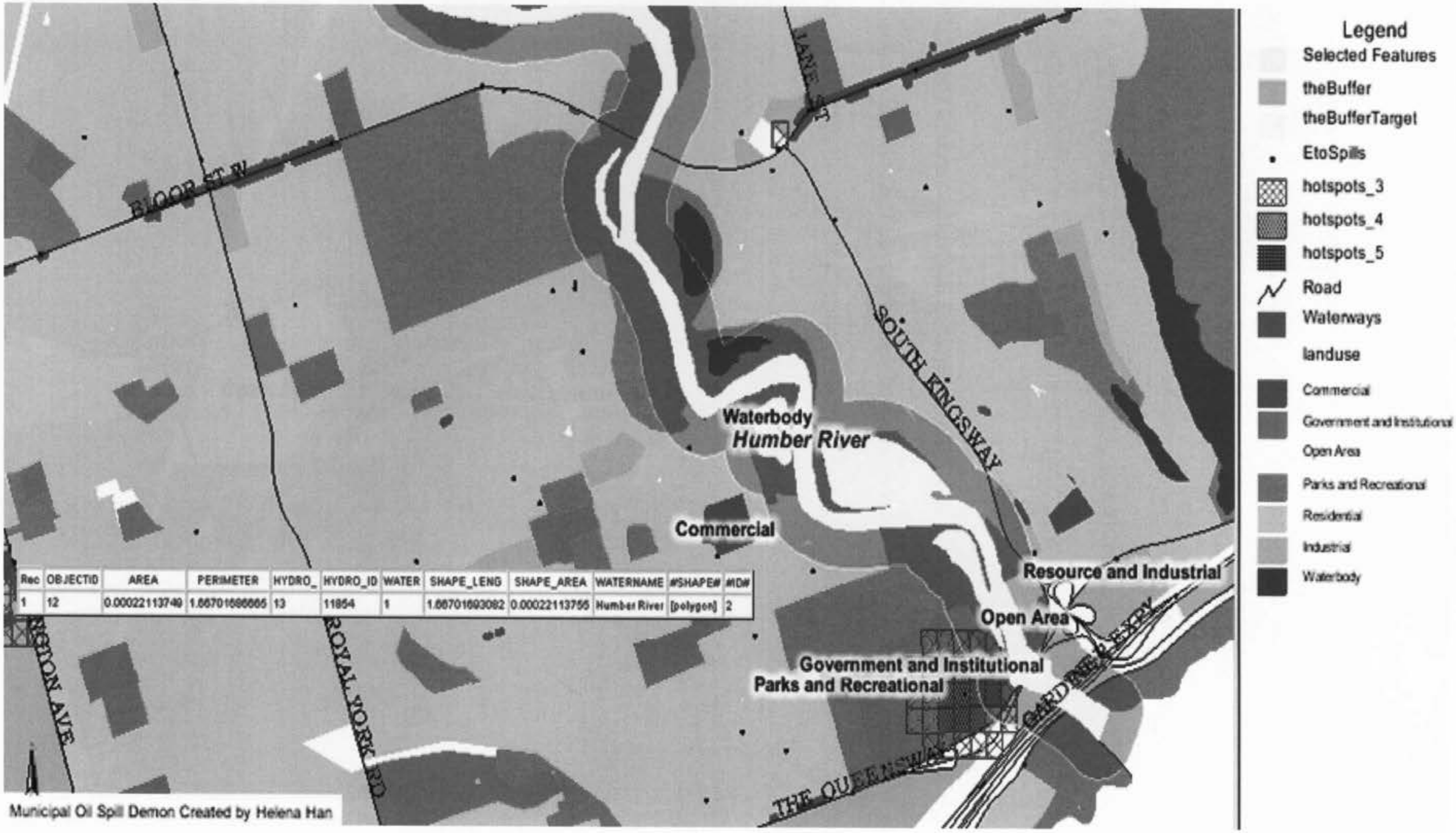


Figure 5-23 Analysis oil spill impacts on rivers

Figure 5-24 Overview of spills and ESAs

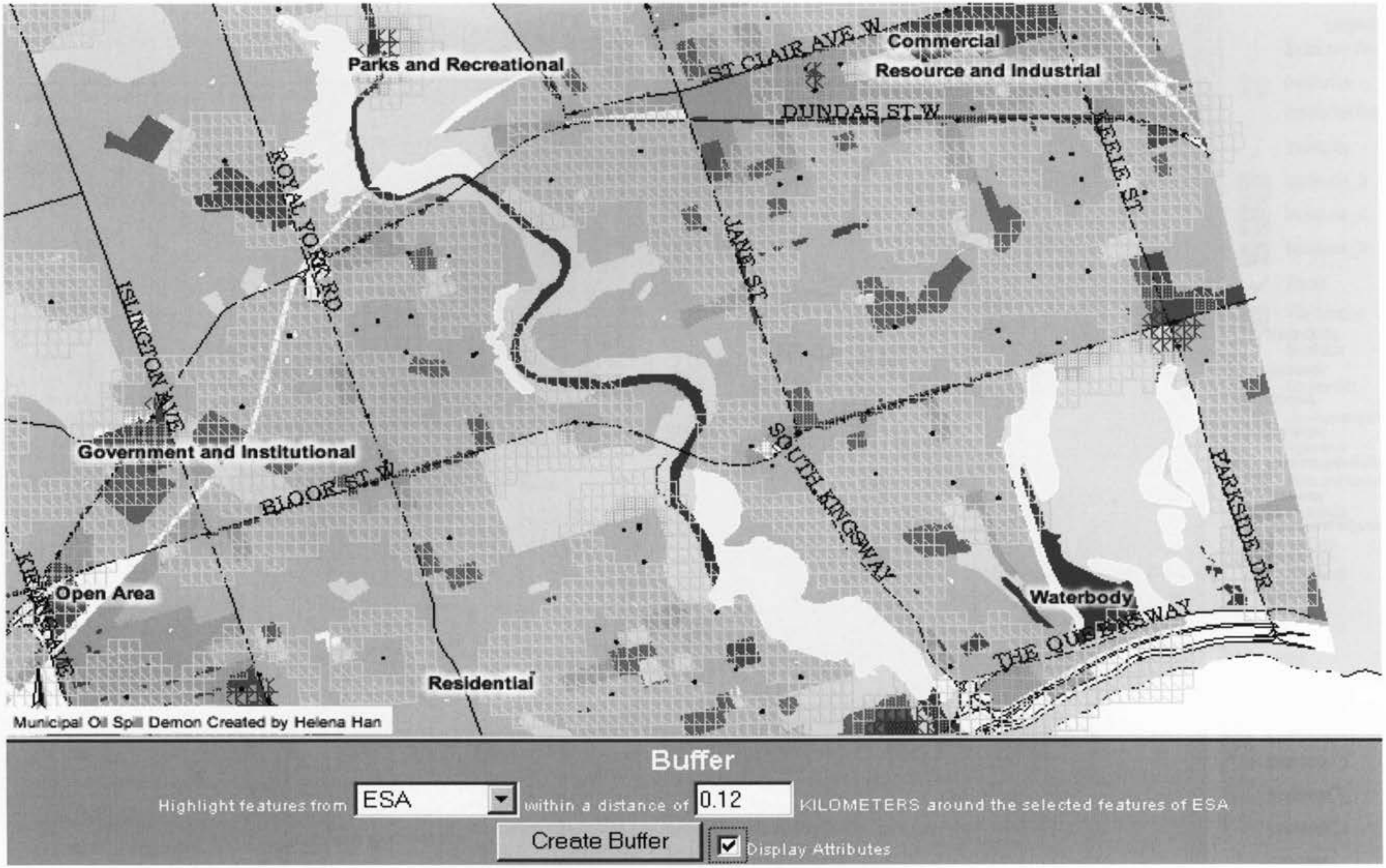
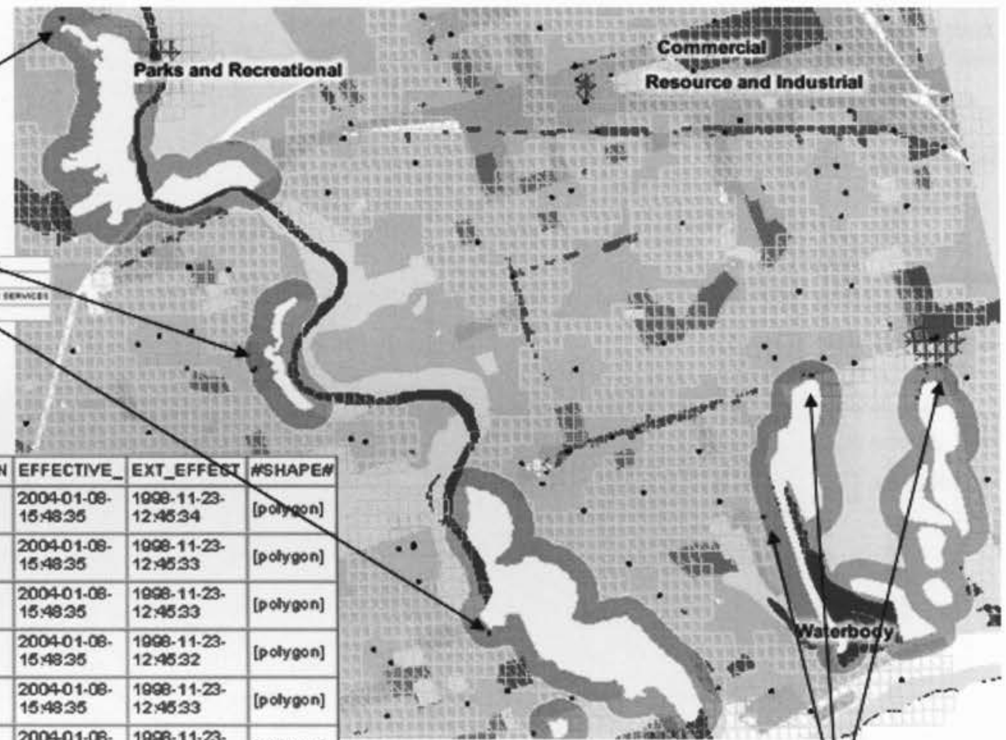


Figure 5-25 Set up a buffer distance of ESAs



Rec	YEAR_	MONTH_	DAY_	REGION	OIL_TYPE	VOLUME	ROAD_TYPE	LOCATION	SECTOR
1	1990	5	11	Etobicoke	diesel	0	N/A	#VALUE!	N/A
2	1990	9	10	Etobicoke	PETROLEUM OIL (N.O.S.)	0	N/A	PARKING	TRANSPORTATION SERVICES
3	1998	10	26	Etobicoke	N/A	0	1210 FINCH AVE W	HWY	CITY

Rec	DESCR	ID	FMF_OBJECT	OFFICIAL_N	EFFECTIVE_	EXT_EFFECT	#SHAPE#
1	Environmentally Sensitive Area	202	1200808797	Yes	2004-01-08-15:48:35	1998-11-23-12:46:34	[polygon]
2	Environmentally Sensitive Area	200	1200808795	Yes	2004-01-08-15:48:35	1998-11-23-12:46:33	[polygon]
3	Environmentally Sensitive Area	201	1200808796	Yes	2004-01-08-15:48:35	1998-11-23-12:46:33	[polygon]
4	Environmentally Sensitive Area	198	1200808793	Yes	2004-01-08-15:48:35	1998-11-23-12:46:32	[polygon]
5	Environmentally Sensitive Area	199	1200808794	Yes	2004-01-08-15:48:35	1998-11-23-12:46:33	[polygon]
6	Environmentally Sensitive Area	197	1200808792	Yes	2004-01-08-15:48:35	1998-11-23-12:46:32	[polygon]
7	Environmentally Sensitive Area	196	1200808791	Yes	2004-01-08-15:48:35	1998-11-23-12:46:32	[polygon]
8	Environmentally Sensitive Area	195	1200808790	Yes	2004-01-08-15:48:35	1998-11-23-12:46:31	[polygon]
9	Environmentally Sensitive Area	194	1200808789	Yes	2004-01-08-15:48:35	1998-11-23-12:46:31	[polygon]
10	Environmentally Sensitive Area	193	1200808788	Yes	2004-01-08-15:48:35	1998-11-23-12:46:30	[polygon]
11	Environmentally Sensitive Area	296	1200808891	Yes	2004-01-08-15:48:35	1998-11-23-12:48:12	[polygon]
12	Environmentally Sensitive Area	192	1200808787	Yes	2004-01-08-15:48:35	1998-11-23-12:46:30	[polygon]

4	1990	3	24	Etobicoke	N/A	1000	16731 KINGSTON RD	GOVERNMENT - PROVINCIAL	PRIVATE OWNER
5	1991	6	13	Etobicoke	PETROLEUM OIL (N.O.S.)	4	16731 KINGSTON RD	GOVERNMENT - PROVINCIAL	FOOD PROCESSING
6	1992	3	4	Etobicoke	N/A	126	16731 KINGSTON RD	#VALUE!	Hydro Co

Figure 5-26 Selected ESAs and spills within the buffer areas

Orthophotographs or the satellite images are very useful in spill-location visualization. Due to the network bandwidth limitation of this demonstration, the demo can only show few orthophotos in Figure 5-27. Land use, land parcels, buildings, roads, ESAs and rivers are displayed as real objects on the map. Spill locations are specifically marked and surrounding objects are identified. Particularly, these orthophotographs can be very helpful especially in spill emergency response.

Several common analysis capabilities available via Web GIS are useful for spill analysis. These include: (1) measurements – spatial extent and volumes of mapped features; (2) attribute reclassification – combining information from different data layers (e.g. determine soil types and land parcels owned by different people); (3) topological overlay to determine common boundaries or subdivide existing map into other layers; (4) connectivity operation to determine the shortest route along a network; (5) coordinate transformations to bring different data sets into a common spatial coordinate system so they can be overlain for surface analysis. These Web GIS analysis functions offer considerable promise for oilspill research and municipal spill-management practice

Figure 5-27 Orthophoto of a spill location

Chapter 6 Conclusion and Recommendations

6.1 Conclusions

Web-based GIS have never been applied for spill management in municipalities. The case study presented in this research effort is the first application to incorporate Web-based GIS and spatial analysis for urban oil spill management. The case study shows how Web-based GIS architecture has been successfully implemented as a tool for urban oil spill management by establishing GIS spatial database, installing ESRI ArcIMS software in a standard web server and running on the Internet.

End users can actually use this Web-based GIS architecture tool to view the live maps, zoom in and out, turn on or off layers; perform spatial analysis such as select areas, draw polygons; extract information from selected areas as spreadsheets and do further statistical analysis and generate reports. The selected areas can be highlighted and stand out with colourful symbols. It is helpful for engineers, planners and field crew to identify objects and get updated information.

Accurate information on occurrences of spills is the core component for municipality to analyze spill problems. Spill records used for the case study in this thesis were originally compiled by the Ontario SAC. Some of the spill records were found incomplete, redundant, inconsistent, and incorrect. These problematic records required a significant amount of time to verify and correct and some of them might even deemed not useable. Spill types, locations, time, road types are some of the important fields required for emergency spill response. Spill sources, causes, owners, and impacts provide important information for spill prevention planning. For instance, most spills occur on roads, however, there are no clear causes and reasons for those spills making it difficult for a municipality to prevent road spills because the causes are unknown. It could be caused by a vehicle collision, over speed truck, driver fatigue or the inherited design problem of the road such as sharp turn, shallow width, etc. Without knowing causes of spills, it is hard for a municipality to prevent similar spills from happening in the future.

Other land information data layers such as roads, sewer networks, land-use, property parcels, etc. are needed to be constructed by municipalities. Most of the data layers used on the case study were obtained from the City of Toronto. With the broadened access to spill records provided by a Web GIS, I could be expected that data deficiencies would be overcome, since interest in completeness would grow.

6.2 Recommendations

Although oil spills as major environmental pollution have been extensively studied, urban oil spills management especially at the municipal level has not yet been touched, except Li's study for Toronto, Richmond Hill, Markham and Vaughan, (Li, 2002a, 2002b,2002c,2002d and 2002e). Repeated spills in the urban environment from industrial, commercial and institutional sectors are profoundly impacting on urban environment. Numerous oil spills are related to the loss of fuels and cargo in transportation accidents. The data for 2005, 2006 and 2007 show that, when aggregated, transportation-related spills (motor vehicles, transport trucks and tank trucks) are the single largest group of spills reported to SAC. The number of oil spills with between 10 to 100 litres was the single largest grouping of spillage. However, due to lack of a spill management strategy, technology and information, most Canadian cities do not have a comprehensive spill management system to deal with spill problems. At the provincial level, such as Ontario Ministry of Environment, it is found that the majority of their resources are focused on spill response. For those small-scale and high-frequency land-based spills the strategies are focused on spill response and not for urban oil spill management. To protect the public and the natural environment, municipalities should have such an innovative approach to prevent spills. Moreover, lack of provincial guidelines and communications from the three levels of governments are the other reasons that municipalities do not incorporate oil spill pollution prevention measures into their management. Therefore, it is recognized that a comprehensive spill management strategy is lacking at the local municipal level.

There is no simple solution for spill prevention and management at the municipal level. A long-term solution will require a multi-pronged approach. Spill pollution prevention should be integrated into spill management planning as a long-term strategy. Municipal spill prevention should focus primarily on development of Sewer Use By-laws, public education and industrial training as demonstrated by the Humber Creek subwatershed study (Li and Mcateer, 2000). From the spill-control literature review conducted on the GTA, it was learned that municipalities incorporate spill control either by retrofitting stormwater ponds for spills or by installing oil/water interceptors at sewer outfalls. Unless a response and cleanup strategy is developed ahead of time, it is very difficult to coordinate response and cleanup activities at the time of an emergency.

The proposed generic spill management planning framework will provide a comprehensive planning tool for municipal spill management using an interactive Web-based GIS platform. Accessing spill records and performing standardized impact assessment of each spill occurrence can be determined rapidly. In general, the network-based Web GIS framework will be able to provide an effective approach for scientific data management in oil spill analysis and enable organizations to use geographic information to make more informed decisions. The power of distributed GIS services, as decision-making tools and query engines, will allow spill information to be released from the GIS professionals to the public. With the progress of computer networking technologies, distributed GIServices can provide broader capabilities and functions compared to traditional GIS systems. The Web-based GIS will broaden the access of geographic information from a wide range of on-line geospatial applications and services; providing a variety of information to different end-users.

Selecting the optimal technology for distributed spatial analysis functions in the design and implementation of Web-based GIS architecture could be very difficult when a municipality adopts a Web-based GIS for oil spill management. The selected technology must provide robust, secure, and efficient communication via the Internet/Intranet. Security and stability must be addressed in the application of distributed GIS services. Network vulnerability could cause serious problems for GIS services, due to viruses, unauthorized users, and network traffic jams. Municipal staff should consider to utilize distributed GIS services from their stand-alone PCs, Workstations or wireless devices

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Appendices

Appendix A   Oil Classifications

Group 1 *Very light refined products (e.g. gasoline, naphtha, solvents, avgas 80/100)*	• Very volatile and highly flammable (flash point near 100^{0}F/40^{0}C) • High evaporation rates; complete removal by evaporation is likely • Low viscosity; spread rapidly to a thin sheen • Specific gravity less than 0.80; float on water • High acute toxicity to biota; can cause localized, severe impacts to water-column and intertidal resources • Will penetrate substrate, causing subsurface contamination • Recovery usually not attempted because of fire hazards • Exclusion booming of sensitive areas must be completed rapidly
Group 2 *Diesel-like products and light crude oils (e.g. no. 2 fuel oil, jet fuels, kerosene, marine diesel, West Texas crude, Alberta crude)*	• Moderately volatile (flash point varies from 100 to 1500F /40-650C) • Light fractions (up to two-thirds of the spill volume) will evaporate • Low to moderate viscosity; spread rapidly into thin slicks • Specific gravity of 0.8 – 0.85; API gravity of 35 – 45, so slicks will float on the water surface, except under turbulent mixing conditions • Moderate to high acute toxicity to biota; product-specific toxicity related to type and concentration of aromatic compounds in the water-soluble fraction • Will coat and penetrate substrate; some subsurface contamination • Stranded oil tends to smother organisms

	• Containment/recovery from the water is most effective early in the response
Group 3 *Medium Oils and Intermediate Products (e.g., North Slope crude, South Louisiana crude, intermediate fuel oils, lube oil)*	• Moderately volatile (flash point higher than 1250F/≈520C) • Up to one-third will evaporate • Moderate to high viscosity • Specific gravity of 0.85 – 0.95; API gravity of 17.7 – 35 • Variable acute toxicity, depending on amount of light fraction • Can form stable emulsions • Will coat and penetrate substrate; heavy subsurface contamination likely • Stranded oil tends to smother organisms • Recovery from the water and shoreline cleanup is most effective early in the response
Group 4 *Heavy crude oils and residual products (e.g., Venezuela crude, San Joaquin Valley crude, Bunker C, no. 6 fuel oil)*	• Slightly volatile (flash point greater than 1500F/650C) • Little product loss by evaporation (usually less than 10-15 percent) • Very viscous to semi-solid; may become less viscous when warmed in sunlight • Specific gravity of 0.95-1.00; API gravity of 10 – 17.5; so slicks will float initially and sink only after weathering or incorporating sediment • Low acute toxicity relative to other oil types

	• Form stable emulsions • Little penetration of substrate likely • Stranded oil tends to smother organisms • Recovery from the water and shoreline cleanup difficult during all stages of response
Group 5 *Very heavy residual products*	• Very similar to all properties of group 4 oils, except that the specific gravity of the oil is greater than 1.0 (API gravity less than 10). Thus, the oil has a greater potential to sink when spilled.

Appendix B

Regional Municipality of Waterloo Spill Pollution Prevention Fact Sheet	
Sectors	**Pollution Prevention Measures**
Warehousing and Storage; wholesale Metals, Hardware, Heating, Plumbing, Building Materials; Wholesale Motor Vehicle, Parts and Accessories	•Prevent rise waters discharge to sewers or surface water •Inventory of materials stored on site •Secondary containment container •Annual testing of unprotected steel tanks and piping systems •Underground storage tanks (USTs) should not be used; (ASTs) should have visual gauges •Uncovered receiving areas should have a spill sump to catch or store spills •Find out the water drains •Employees must have WHMIS training
Food and Beverage Service Industries	•A system to collect all grease, fat and meet scraps and contract a facility to pick up them •A preventative maintenance program for all kitchen appliances and equipment •Fast food outlets should have a centrally located receptacle for pre-consumer food scraps •Use physical rather then chemical cleaning methods wherever possible
Retail Food, Beverage and Drug	•Set up waste collection stations with labelled containers for each kind of waste available through out workplace for spent chemicals, soiled rags, etc.
Food and Beverage Manufacturing	•Locate composting and biosolids storage facilities on high ground to prevent contamination of run-off after a heavy rain. •Help to collect leachate and prevent the contamination of groundwater by placing a gently sloped, impermeable liner •Place trays under conveyor belts to catch particles of breading which is a concentrated source of BOD5 •Minimize spills of ingredients, raw materials and finished product on floors; always clean up the spills before washing •Install a blood collection system and remove blood from floors before they are washed down
Business Service Industries	•Set up a staff waste reduction and pollution prevention committee •Keep staff informed about pollution prevention programs, policies and objectives •Provide clearly labelled waste containers for training cleaning staff to source separate materials
Accommodation Service Industries	•Use physical rather than chemical cleaning methods wherever possible •Use automated systems for laundry chemical dispensers •Reduce pesticide applications by using non-chemical pest control measures

Health and Social Service Industries	•No floor drains in x-ray processing rooms, labs, or where regulated medical wastes are stored •Use amalgam traps in dental offices to prevent silver and mercury bearing amalgams from entering subsurface disposal system or sanitary sewer •Reduce solvent use by minimizing sizes of cultures or specimens; use calibrated dispensers •Transport chemicals or dispose medical wastes according to regulations •Wastewater from lab operations should discharge to a separate lab drain and lead to a neutralization system before discharging to the sanitary sewer
Building, Developing and General Contracting	•Quickly stabilize disturbed areas by restoring overburden, replacing topsoil, avoiding steep slopes, reproducing natural drainage patterns and replacing vegetation •Topsoil and subsoil should be striped from operation areas and kept for restoration the area
Veterinary Services	•Collect pesticide dip solutions and washdown water in a holding tank and removed by a licensed hauler •Prior to injection into the leachfield, make certain to meet maximum contaminant levels for all parameters •Tank and leachfield design to serve only domestic sewage, bath and kennel facility but not dip solutions •Floor drains in rooms where dips are performed must be connected to the municipal sanitary sewer or to a holding tank in unsewered areas •Do not discharge disinfectant solutions down the drain; •Pump out tanks at least annually •Disinfectant solutions can be removed from surfaces with paper towelling and disposed of according to regulations
Furniture and Fixture Manufacturing	•Substitute water-based paints for solvent based paints •Drippage during the application of stripping agents should be collected and recycled via filtration, distillation or carbon adsoption processes •Paint thinner life may be prolonged if multiple cleaning steps are used. Send waste solvents to a waste exchange for further reuse or recycling
Automotive Vehicles, and Accessories Sales	•Each service bay should be provided with a waste collection station which include labelled containers for each type of waste liquid or labelled sinks which lead to an appropriate waste holding tank •Service pits should have spill containment such as a sump which discharges to a holding tank

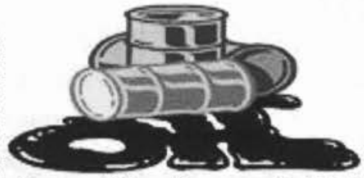
Appendix C

Residential Fuel Oil Tank Spill Prevention and Control

What is s spill incident???

". . .a sudden, unexpected, or unapprehended release of a pollutant in sufficient quantities to the air, water, groundwater, or land to pose a direct or indirect threat to people, environment or property"

1. Tanks are installed by a registered contractor
2. Inspecting regularly
3. Tank installing meet requirements
4. Maintain basement and above-ground tanks
5. Handling spills and leaks
   i. Eliminate all sources of ignition
   ii. Stop the leak
   iii. Contact fuel supplier or a registered contractor for assistance
   iv. Contain spilled oil using whatever materials are available (pails, rags, newspapers, peat moss, kitty litter, absorbent pads, sheets of plastic, etc.
   v. Do not flush spilled oil or contaminated materials down the floor drain or sewer
   vi. Transfer any remaining oil from the leaking tank to a sound tank or other approved container, made of leak-proof material, such as a 45-gallon drum
   vii. Clean up spilled oil and any contaminated soil or materials and place in appropriate containers such as plastic pails and garbage bags. For large spills, you may need the services of a professional cleanup contractor
6. Properly dispose of any recovered oil, contaminated soil and other contaminated materials
7. Notify the Ministry of the Environment's Spills Action Centre (SAC) if the spill causes, or is likely to cause, adverse effects such as ground or surface water contamination, or damage to a neighbor's property.
8. Local municipal works department and the Ministry of the Environment can provide you with information on acceptable waste management practices
9. Contact your insurance agent



For more information on residential oil tanks and Ontario laws governing them, please contact:
Technical Standards and Safety Authority (TSSA)
Fuels Safety Division
3300 Bloor St. W.
4th Floor, West Tower
Toronto, ONM8X 2X4
416-325-1615

To report spills or to obtain more information on spill cleanup procedures, please contact:
Ministry of the Environment
Spill Action Centre
1-800-268-6060 (24-hours)
or 416-325-3000

Dispose of Oil Properly!

Never pour oil on the ground or down storm drains or throw it in the garbage.
One quart of oil will cause an oil slick covering one acre
One gallon of oil will contaminate 250,000 gallons of drinking water.
Improper disposal of waste oil exceeds the Valdez oil spill by 190 million
gallons every year. Don't be a part of this pollution problem.

2007-04-18

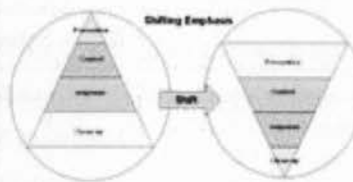
Residential Oil Spill Prevention Fact Sheet

Appendix D

Industrial Spill Pollution Prevention Fact Sheet

What is s spill prevention???

"Spill prevention is a systematic process by which the significance and frequency of pollutant releases to the natural environment, whether these releases are accidental or intentional, are reduced of eliminated"



Spill pollution prevention measures:

- Prevent rise waters discharge to sewers or surface water
- Inventory of materials stored on site
- Secondary containment container
- Annual testing of unprotected steel tanks and piping systems
- Underground storage tanks (USTs) should not be used; (ASTs) should have visual gauges
- Uncovered receiving areas should have a spill sump to catch or store spills
- Find out the water drains
- Employees must have WHMIS training
- Contact your insurance agent

Spill Prevention Benefits:

- Reduced magnitude and prevalence of spills
- Uninterrupted operating time
- Improved efficiency and cost savings
- Avoidance of costly remediation programs
- Reduction in environmental liability
- Exhibiting due diligence
- Reduced impact of pollution on the environment
- Reduction in materials lost
- Streamlined decision making
- Enhanced internal accountability
- Increased employee and public safety
- An increase in staff morale
- Proof of the facility's commitment to environment protection
- Overall improved corporate image

The city has compiled a list of Pollution Prevention Practices for most businesses in the Region. For additional information on pollution prevention, contact the following:

Water Service Division
3300 Bloor St. W.
4th Floor, West Tower
Toronto, ON M8X 2X4
416-325-1615

To report spills or to obtain more information on spill cleanup procedures, please contact:

Ministry of the Environment
Spill Action Centre
1-800-268-6060 (24 hours)
or 416-325-3000

Dispose of Oil Properly!

Never pour oil on the ground or down storm drains or throw it in the garbage.
One quart of oil will cause an oil slick covering one acre
One gallon of oil will contaminate 250,000 gallons of drinking water.
Improper disposal of waste oil exceeds the Valdez oil spill by 190 million
gallons every year. Don't be a part of this pollution problem.

Industrial Spill Pollution Prevention Fact Sheet

Appendix E - Summarize Web-based GIS application design

Applications	Software and Architecture	System design
Oak Mapper Website Public tree disease discover report (Kelly and Tuxen, 2003)	ArcIMS 3.1 Back-end database Microsoft Access 2000 Java, Microsoft Visual Basic, Microsoft Active Server Pages	Creation of GIS database Reports of symptomatic trees Visualizing, querying and analyzing the database
Response to slopeland hazards and decision making (Yu, Chen, Lin, Lin, Wu and Cheung, 2007)	AutoDesk MapGuide Microsoft Windows 2000 server Autodesk MapGuideServer 5.0 Microsoft SQL server 2000	4 databases and 3 major modules build in Web GIS platform
Trip planning (Peng and Huang, 2000)	MapObjects IMS (ESRI) NetEngine library (ESRI, 1998) Microsoft Access relational database	User interface design (thin client side, spatial query and searching functions) Map server functions design Database design Network analysis component
The University of California, Los Angeles (UCLA) (Su, Slottow and Mozes, 2000)	ArcView IMS (ESRI) Unix platform MapCafe	Map server design Client interface design Map tools Data sets for online mapping
Fish species at risk (Liu, 2005)	ArcIMS 9.0 Microsoft Windows 2003 server Microsoft information server 5.0 Tomcat Servlet 5.0	Common GIS mapping tools Design of WebGOS major functions Design query funtions Dynamic reporting Geodatabase design
Florida Wetlands (Mathiyalagan et al, 2005)	ArcIMS (ESRI) Structured Query Language (SQL) Microsoft Visual Basic, Microsoft Active Server Pages and Java	Three-tier client/server architecture An Internet client and Web browser Web/application server Database server
Sharing health data (Theseira, 2002)	ArcIMS 3.0 (ESRI)	User interface design Geocode server
water quality in lower Cape Fear river (Halls, 2003)	Arcview and ArcViewIMS (ESRI) Windows NT Server with IIS Java Java scripts 180k	Interactive mapping Dynamic graphing on the web

Definition

Attribute: the range of possible values of a characteristic; an attribute value is a specific instance of the characteristic associated with a geographic feature.

Arterial Road: a road primarily for through traffic.

Best Management Practices: state of the art methods or techniques used to managte the quanity and improve the quality of wet weather flow. BMPs include source, conveyance and end-of-pipe controls

Catchbasin: box like underground concrete structure with openings in crub and gutter designed to collect runoff from streets and pavement

Collector Road: a road on which traffic movement and access to property have similar importance

Drainage: natural or artificial means of intercepting and removing surface or subsurface water (usually by gravity)

Drainage area: The total surface area upstream of a point on a stream that drains toward that point. Not to be confused with watershed, the drainage area may include one or more watersheds.

Drainage system: a system flow of gully inlets, pipes, overland flow paths, open channels, culverts and detention basins used to convey runoff to its receiving waters.

Local Road: a road primarily for access to property.

Minor Spill: a spill of such magnitude and nature that it does not cause significant adverse effects or public concerns, where the spiller can, utilizing his/her own resources, undertake the necessary measures to control, contain and clean up the material spilled

Moderate Spill: a spill of such magnitude and nature that it causes significant adverse effects in the immediate vicinity of the spill, where the resources under a municipal or co-operative contingency plan may be required to effectively contain and clean up the material spilled

Oil/Grit Separator (OGS): systems designed to remove trash, debris and some amount of sediment, oil and grease from stormwater runoff based on the principles of sedimentation for the grit and phase separation for the oil.

Outfall: the point, location, or structure where wastewater or drainage discharges from a sewer pipe, ditch or other conveyance to a receiving body of water.

Pond: a body of water smaller than a lake, often artificially formed.

Runoff: that potion of the water precipitated onto a catchment area, which flows as surface discharge from the catchment area past a specified point.

Services: refers to component services that is, components with certain functions can be downloaded and reassembled together to build larger, more comprehensive services to perform certain tasks.

Spiller: (a) for purposes of spill reporting responsibilities, the spiller is defined as "every person who has control of a pollutant that is spilled and every person who spills or causes or permits a spill of a pollutant that causes, or is likely to cause, an adverse effect"; or,
(b) for purposes of spill clean-up responsibilities, the spiller is defined as "the owner of a pollutant and the person having control of a pollutant that is spilled and that causes or is likely to cause an adverse effect".

Spill:

A discharge of a pollutant into the natural environment from or out of a structure, vehicle or other container which is abnormal in quality or quantity in light of all the circumstances of the discharge. If a spill causes, or is likely to cause, any of the following adverse effects, it must be reported and cleaned up:

(a) impairment of the quality of the natural environment for any use that can be made of it;
(b) injury or damage to property or to plant or animal life;
(c) harm or material discomfort to any person;
(d) adverse effects on the health of any person;
(e) impairment of the safety of any person;
(f) the rendering of any property or plant or animal life unfit for use by humans;
(g) the loss of enjoyment of normal use of property; or, (h) interference with the normal conduct of business.

Minor Spill:

A spill of such magnitude and nature that it does not cause significant adverse effects or public concerns, where the spiller can, utilizing his/her own resources, undertake the necessary measures to control, contain and clean up the material spilled

Moderate Spill: A spill of such magnitude and nature that it causes significant adverse effects in the immediate vicinity of the spill, where the resources under a municipal or co-operative contingency plan may be required to effectively contain and clean up the material spilled

Major Spill:

A spill of such magnitude and nature that it presents a hazard to human health or causes serious adverse effects over a wide area, and for which the Ministry may be required to assume control of the clean-up and restoration activities

Emergency:

Defined by the *Emergency Plans Act* as: "A situation caused by the forces of nature, an accident, an intentional act or otherwise that constitutes a danger of major proportions to life or property"

Stormwater: surface runoff resulting from rain or snowmelt events.

Watercourse: (a) A natural well-defined produced wholly or in part by a definite flow of water and through which water flows continuously or intermiitently. Also, a ditch, canal, aqueduct, or other artificial channel for the conveyance of water to or away from a given place, as for the draining of a swamp. (b) A stream or current of water. Leagally, a natural stream arising in a given dranage basin but not wholly dependent for its flow on surface drainage in its imeediate area, flowing in a channel with a well-defined bed between visible banks or through a definite depression (as a ravine or swamp) in the surrounding land, having a definite and permanent periodic supply of water (the stream may be intermittent), and usually, but not necessarily having a perceptiable current in a particular direction and discharging at affixed point into another body of water. (c) A legal right permitting the use of a flow of a stream (especially of one flowing through one's land) or the receipt of water discharged upon land belonging to another.

Wetland: a vegetated area such as a bog, fen, marsh, or swamp, where the soil or root zone is saturated for part of the year.

Thin Client: there is little or no logic processing at the client side; most of the processing is performed at the server side.

Thick Client: most logic processing is performed at the client side.

The **Internet** is any network composed of multiple, geographically dispersed networks connected through communication devices and a common set of communication protocols.

The **World Wide Web (WWW, or the Web):** a networking application supporting a HTTP that runs on top of the Internet.

Acronyms

API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
ASP	Active Server Page
CAD	Computer-Aided Design
CGI	Common Gateway Interface
CPU	Central Processing Unit
DBMS	Database Management System
DEG	Display Element Generation
DEM	Digital Elevation Model
DHTML	Dynamic HTML
DWG	AutoCAD Drawing Format
EPA	U.S. Environmental Protection Agency
ESRI	Environmental Systems Research Institute
FTP	File Transfer Protocol
GIF	Graphics Interchange Format
GPS	Global Positioning System
GUI	Graphic User Interface
HTTP	HyperText Transfer Protocol
IIS	Internet Information Server
IP	Internet Protocol
IT	Information Technology
JPEG	Joint Photographic Experts Group

LAN	Local-Area Network
MOE	Ministry of Environment
OGC	OpenGIS Consortium
PDF	Portable Document Format
ROM	Read-Only Memory
RAM	random-Access Memory
SAC	Spill Action Centre
SDE	Spatial Data Engine
SHP	Shape File
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
SVG	Scalable Vector Graphic
TCP/IP	Transmission Control Protocol/Internet Protocol
TIFF	Tagged Image File Format
TIN	triangular Irregular Network
URL	Uniform Resource Locator
WAN	Wide-Area Network
WMS	Web Map Server
WWW	World Wide Web