Development of an Oil Spill Emergency Mapping System Using Internet GIS

by

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

ABSTRACT

Oil spills have serious effects on marine ecosystems and can cost over millions of dollars in cleanup, remediation and monitoring efforts. In British Columbia, Canada, an emergency mapping system in a centralized way of sharing geospatial data within the oil spill management community is not available today. Existing conventional emergency mapping system only focuses on sensitivity mapping. Currently, many other programs and tools used for oil spill planning are now using geographic information systems (GIS) to manage data and display results. These include oil spill detection using RADARSAT images and the Shoreline Cleanup Assessment Technique (SCAT). There have been initiatives to integrate these tools and programs with the conventional emergency mapping system. Internet GIS provides a framework for developing such a system. It also allows rapid dissemination of data to a number of stakeholders for a more effective response to oil spills.

This study attempts to apply the commercially available ArcGIS Server to develop an interactive Web-GIS oil spill emergency mapping system (OSEMS). A framework was proposed to integrate the systems mentioned above. The client application was developed using ArcGIS API for JavaScript. The system was evaluated on its usability through a questionnaire, which incorporates real world oil spill scenarios. The evaluation proves that the OSEMS is very useful for oil spill response and also demonstrates that the system integration is effective. The OSEMS application was developed to make it easy for first responders to use without being GIS experts.

ACKNOWLEDGEMENTS

First I would like to thank my supervisor, Professor Dr. Jonathan Li for all the help and support he has provided me during the course of my research at the University of Waterloo. His valuable insight and input has helped me through this challenging journey. I would also like to give great thanks to my thesis committee member, Dr. Robert Feick, Associate Professor at the School of Planning, his guidance helped me focus my research. I also really appreciate feedback and suggestions from my two thesis readers, Dr. Su-Yin Tan at the Department of Geography & Environmental Management and Dr. Jane Law at the School of Planning.

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Last but not least, I would like to thank my family for their love and support, through this long and difficult undertaking.

DEDICATION

I would like to dedicate this thesis to my mother Sabrina Gomes and grandmother Annette Pinto. Their love and support has been unconditional. They both got me through hard times in my life and provided me with the motivation to make it through this challenging journey. I would like to thank them for believing in me and being there for me through thick and thin.

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LIST OF ABBREVIATIONS

API	Application Programming Interface
CCG	Canadian Coast Guard
CEM	Comprehensive Emergency Management
CGI	Common Gateway Interface
CIS	Canadian Ice Service
DBMS	Database Management System
DGI	Distributed Geographic Information
FISS	Fisheries Information Summary System
GIS	Geographic Information System
GRP	Geographic Response Plan
GUI	Graphical User Interface
HCI	Human–Computer Interaction
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IAP	Incident Action Plan
ICS	Incident Command System
ISTOP	Integrated Satellite Tracking of Pollution
LAN	Local Area Network
MAD	Mapping, Analysis and Design
NASP	National Aerial Surveillance Program

OGC	Open Geospatial Consortium
OSC	On-Scene Commander
OSEMS	Oil Spill Emergency Mapping System
QC	Quality Control
REET	Regional Environmental Emergency Team
RMS	Response Management System
SAR	Synthetic Aperture Radar
SAR	Species at Risk
SCAT	Shoreline Cleanup Assessment Technique
TOC	Table of Contents
UE	Usability Engineering
WAN	Wide Area Network
WMS	Web Map Server

CHAPTER 1

Introduction

1.1 Marine Oil Spill Pollution

The Port of Vancouver is one of the largest ports on the West Coast of North America and is the largest port in Canada. Other major ports in British Columbia include Prince Rupert, Nanaimo and Fraser. Due to the longer coastline and large scale shipping activity, the coastal areas of British Columbia are at high risk for major oil spills. A great deal of oil and petroleum products are shipped through the Vancouver Port, about 4000 metric tones of hydrocarbons are transported through the port on a yearly basis (Port Metro Vancouver, 2008).

Oil spills can cause large-scale environmental damage due to the characteristics of oil. There are a number of ways in which oil is released into the environment. An accidental spill is only one of several ways that oil ends up in the water. Some other ways are from naturally occurring oil seeps, offshore oil and gas production, marine transportation, waste discharges and runoff (Fingas, 2001). Oil spills can cause adverse effects to the environment. If a major oil spill occurred along the coast of British Columbia it would impact the biological, socioeconomic and physical resources of the region. Over the last few years British Columbia has seen increased amounts of vessel traffic along the cost, this is due to the rapid growth of the economy in the region. There has been an increased amount of oil spills along the coast as well. On August 4, 2006 at Squamish dock terminal, just north of Vancouver the *M/V Westwood Anette*, departing under tow from the

Squamish docks during high wind conditions, punctured a fuel tank on a metal piling. This caused approximately 29,000 liters of bunker fuel to be released into the environment and the high winds blew the oil on the shore near the terminal and into the estuary of the Squamish River. The estuary marshes were heavily contaminated. It was estimated that about $5-million was spent on the cleanup and monitoring program (BC Environmental Emergency Management Program, 2007).

1.1.1 Mapping Systems Using Internet GIS

The use of geographic information systems (GIS) in oil spill emergency management has grown rapidly. Knowledge of area resources, priorities and sensitivities for spill response is the most basic requirement. At the time of a spill it is essential to have immediate access to maps and spatial data. GIS provides a framework for acceding the required datasets and information. A GIS can hold information at any scale. In addition, data from different sources can reside together, which include satellite images, air photos and sensitivity data. Web mapping based on Internet GIS is an effective tool for this purpose since it gives responders and stakeholders' rapid access to large amounts of geospatial data. As Internet GIS becomes more widely utilized within the oil spill realm, the possibilities of linking different GIS systems and data are also increasing. In this way it is possible to exchange data between organizations operating different systems. Internet GIS provides an effective way of integrating large amounts of spatial data and also solves the problem of interoperability by the adoption of standards.

1.2 Problem Statement

In managing oil spills an initial concern is to understand the effects of oil in different eco-systems under different circumstances (Krishnan, 1995). Sensitivity mapping plays a key role in identifying this risk in a geographic area. The use of sensitivity mapping for oil spills has a long history. Initially ((Strong & Semple, 1986) were some of the first to identify the use of GIS for oil spill management. Their work outlined the deficiencies of non-computerized environmental databases for oil spill management. They also outlined how a geographical database can be used for oil spill response and contingency planning. The work of (Dicks & Wright, 1989) took this one step further by linking databases to maps. It is also important to mention the work of (J. R. Jensen et al., 1990), which proposed the integration of GIS and remote sensing for sensitivity mapping. These early works supported the advantages of integrating GIS for oil spill risk assessment. The ability to relate different data from many sources to produce new information is key in helping to solve some of the spatial problems present during oil spills (Krishnan, 1995).

Sensitivity mapping applications are spatial information systems that are composed of different types of data. Usually the three main components of data include shoreline segmentation data, biological data and human activities data that includes commercial, recreational and areas of high value. Many efforts have been made to develop sensitivity mapping for oil spill planning around the world (Jensen, Halls, & Michel, 1998). Before the use of GIS, environmental sensitivity mapping was analog. Atlases of different areas were in a paper format for areas that had a high risk of oil spills. With the development of GIS technology, sensitivity mapping began to be available using desktop GIS systems. With the development of new Internet GIS technology, sensitivity mapping can be made available through the World Wide Web (WWW), which increases the ability to distribute such information to a much larger audience (Baker, Spalding, & Moore, 2005). Many other programs and tools used for oil spill planning now use GIS to manage data and display results. They include oil spill detection using RADARSAT images, the Shoreline Cleanup Assessment Technique (SCAT) and Development of Geographic Response Plans (GRP) integration of all these systems into one common interface can be bifacial. These systems are stand alone desktop GIS applications. Around the world many countries are developing Web based emergency mapping systems that are tailored to their data and programs.

In British Colombia, there is a high risk of oil spills. There has been no development of an emergency mapping system to meet the existing need in British Columbia. A common interface that manages this spatial data and integrates data from other programs and tools does not exist in British Colombia. There is an urgent need to integrate these different systems into one common interface. This will provide stakeholders with a common platform to make better decisions during an oil spill. The lack of an emergency mapping system poses a serious problem.

1.3 Thesis Objectives

The overall goal of this study is to develop a prototype oil spill emergency mapping system (OSEMS) using Internet GIS for effective management of marine oil spills in British Columbia. The system should be able to provide stakeholders with the ability to view spatial sensitivity data from multiple agencies and integrate data from other programs such as oil spill detection using RADARSAT images, and Shoreline Cleanup Assessment Technique (SCAT). The focus of this development is to integrate a sensitivity mapping system, an oil spill monitoring system and an emergency response system into one interface. During an oil spill it is critical to know what is at risk in an area of impact. The purpose of the oil spill emergency mapping is to reduce environmental impact of oily waste to the sensitive marine and coastal ecosystems in the region. This can be done through pre-planning and timely responding. The system that has been developed, as part of this thesis will help improve the management and response of large-scale marine oil spills in British Columbia and will also create a network between academia, government and industry, which will facilitate further research within the oil spill community in British Columbia. This system also hopes to achieve participation between various stakeholders by giving them the ability to view sensitivity and view what is at risk. The main objectives of this study are to:

- propose a framework for developing an oil spill emergency mapping system, which combines sensitivity mapping, oil spill detection using RADARSAT images and the Shoreline Cleanup Assessment Technique (SCAT).
- develop a Web-GIS system for oil spill emergency mapping based on the framework proposed and provide the user with background information for using this system.
- evaluate the usability of the application using real world oil spill scenarios.

1.4 Study Area

The Province of British Columbia, Canada, is the western most province in Canada. It is bordered by the Pacific Ocean to the west, to the south by the Unites States U.S. States of Montana, Idaho and Washington, to the east by the Province of Alberta, to the north the Territory of Yukon, and finally to the south west by the U.S. State of Alaska. The total area of landmass in British

Columbia is approximately 944,000 km^2. The coastline of British Columbia stretches for about 27,000 km from the U.S border in the south state of Washington to the U.S. border in the north state of Alaska. The coastline also includes numerous islands and fjords. This large coastline makes British Columbia very susceptible to environmental devastation if an oil spill did occur. Furthermore this region is important is because it borders the U.S., and international spills are challenging to deal with. British Columbia's large coastline and heavy ship traffic makes it very susceptible to oil spills. The Web mapping interface discussed in this thesis will be developed for the coastal areas of British Columbia.

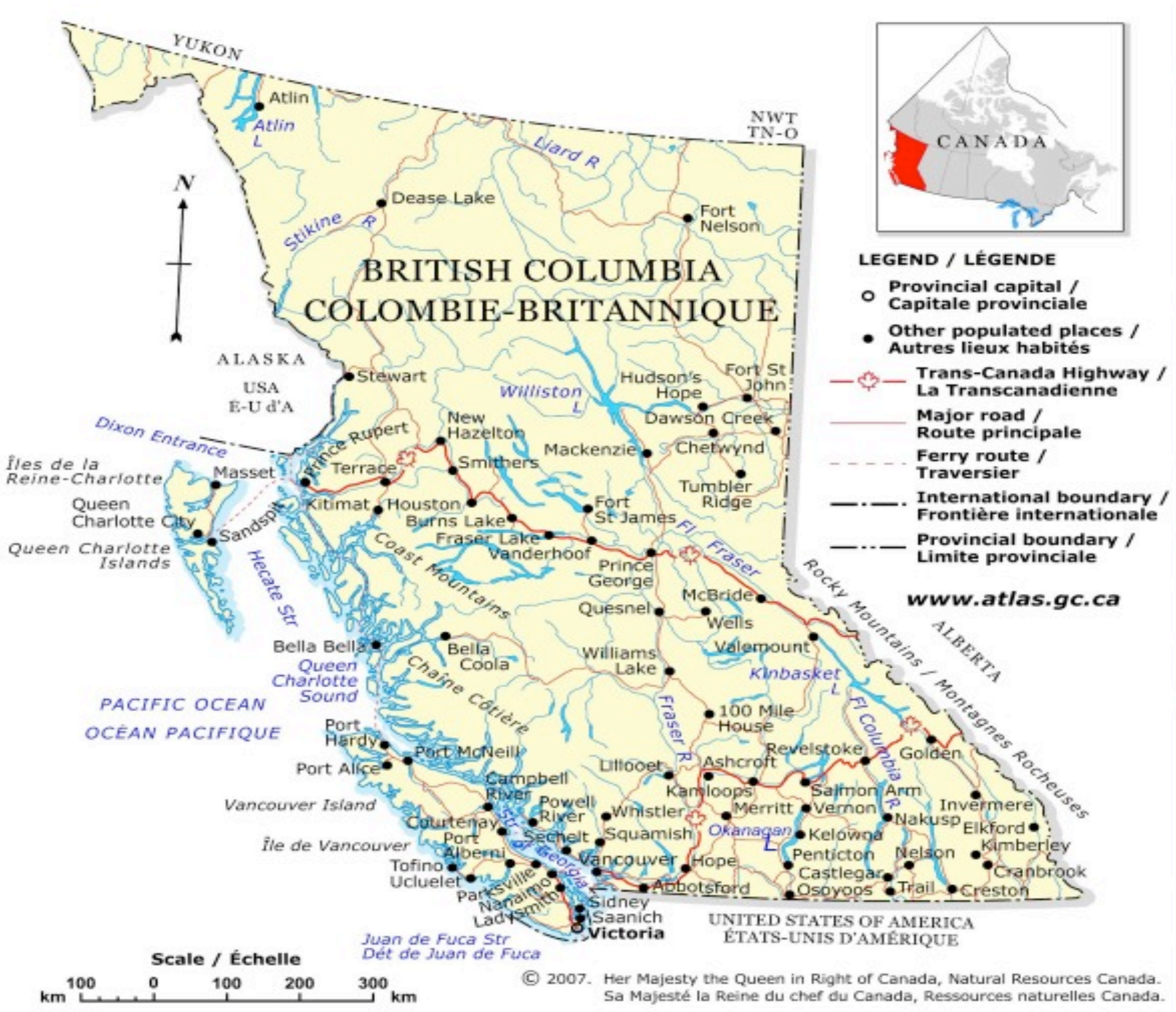


Figure 1-1: Map of British Columbia, Canada

(Source: Natural Resources Canada, 2007)

1.5 Thesis Outline

The remainder of this thesis is organized into four additional chapters.

Chapter 2 reviews literature on current Internet GIS technologies. It provides a brief history of Internet GIS, reviews ArcGIS Server and provides the advantages and limitations of using Internet

GIS. A literature review on the integration of oil spill emergency management with GIS is also provided. The Comprehensive Emergency Management (CEM) structure is introduced and examples of past emergency mapping systems developed in Canada are also provided

Chapter 3 builds from previous chapters. First, the needs to develop an Internet GIS application are identified from a user's perspective. Data sources, data processing and database design are then described. Furthermore, a model to integrate different applications using GIS is outlined. Finally, a conceptual design of the application is discussed followed by the implementation of the system.

Chapter 4 presents and discusses the results based on the development of the Web application for online mapping oil spills. The results of the usability testing are outlined. Some problems and issues encountered during the implementation stage are discussed. The development cycle, database maintenance and updating and performance issues associated with the OSEMS are discussed.

Chapter 5 presents conclusions derived from the results of this study. Suggestions for further improvements and additions to the system are also given.

CHAPTER 2

Internet GIS for Oil Spill Emergency Management

In this chapter, an overview of Internet GIS is provided. It provides a brief history of Internet GIS, reviews ArcGIS Server and provides the advantages and limitations of using Internet GIS. This chapter also reviews GIS for emergency management, provides a framework for handling large-scale emergencies using a comprehensive emergency management structure while integrating GIS in each of its phases. It also introduces a command structure during an oil-spill event and explains how GIS plays an important role within this structure. The last section introduces other emergency mapping systems developed in Canada elsewhere for oil spill emergency mapping.

2.1 Internet GIS

GIS has evolved over the last three decades and the development has followed the progress of computer technology. The evolution has experienced three phases which include: mainframe GIS, desktop GIS and now distributed GIS. It is very important to define the terms since there are many variations related to Internet GIS. Some of the common terms include: Internet GIS (Peng, 1999), GIS on line, and distributed geographic information (Plewe, 1997). These terms refer to GIS data access and processing over the Internet. It is critical to understand that Internet GIS is very different from Web GIS (Plewe, 1997).

For the purposes of this study, Internet GIS will refer to the use of the Internet as a medium to exchange data, perform GIS analysis and present results. Web based GIS will refer to the use of the World Wide Web as a primary means. Both Internet GIS and Web GIS use the client/server model. Web GIS uses the Web as a client, but the Web is not the only client in case of Internet GIS. The Web is a major part of the Internet and sits on top of the Internet. The term Internet GIS is much broader in relation to Web based GIS (Peng, 1999).

2.1.1 History of Internet GIS

The Internet and GIS were created about three decades ago. In the mid 1990s there was the rapid development in Internet technology and it soon became mainstream (Hall, 1994). The development of the Internet was one of the most powerful driving forces for the progress in GIS technology. This led to the development of Internet GIS. Internet GIS has a very short history since it is still a new and emerging technology, it only dates back to a decade and a half.

At first, the Web mainly used text and images; during 1993 the first browser that supported multimedia was introduced. This led to the revolution of Web technology. In 1994, the first Web based map server was created. The Xerox PARC Map Viewer was one of the first Web-mapping systems created. The PARC Map Viewer served up more than 150 million maps (Longley, 2001). It went on to be used with the US Gazetteer Service to provide text based query functions. At the time the system was developed using the Hyper Text Markup Language (HTML), which was made up of a series of hyperlinks for selecting options. It was used for four years and then dismantled in 1997. NAISMap was developed by Natural Resources Canada in 1994. This system was set up to allow the client to select map layers, order map layers and even overlay. Once the client selected the location with the required operations, the client application passed this to the server. The server would compile the data and return back to the client (Peng & Tsou, 2003). GRASSLink was developed in 1995. It was the first and only functional system that connected the GRASSGIS software. The main reason for its development was to facilitate sharing of data between environmental agencies. It could perform many operations like querying, overlay and buffering. It was the first system to display fully functional online GIS services (Plewe, 1997). Recently there has been a rapid growth of Internet GIS. With the new advancements in Internet and Web technology, Internet GIS is also frequently changing and evolving. Xerox PARC Map Viewer and GrassLink Web mapping technologies were the pioneers and led to the development of many Internet software products by different GIS vendors. By 1996 Autodesk, ESRI, Intergraph and MapInfo, all introduced their first Internet GIS products (Longley, 2001; Plewe, 1997).

Peng and Tsou (2003) gave a brief overview of the different types of Web mapping in terms of the evolution of Internet GIS. Four major types were identified, including static map publishing, static Web publishing, Interactive Web mapping and distributed GIServices (Figure 2.1).

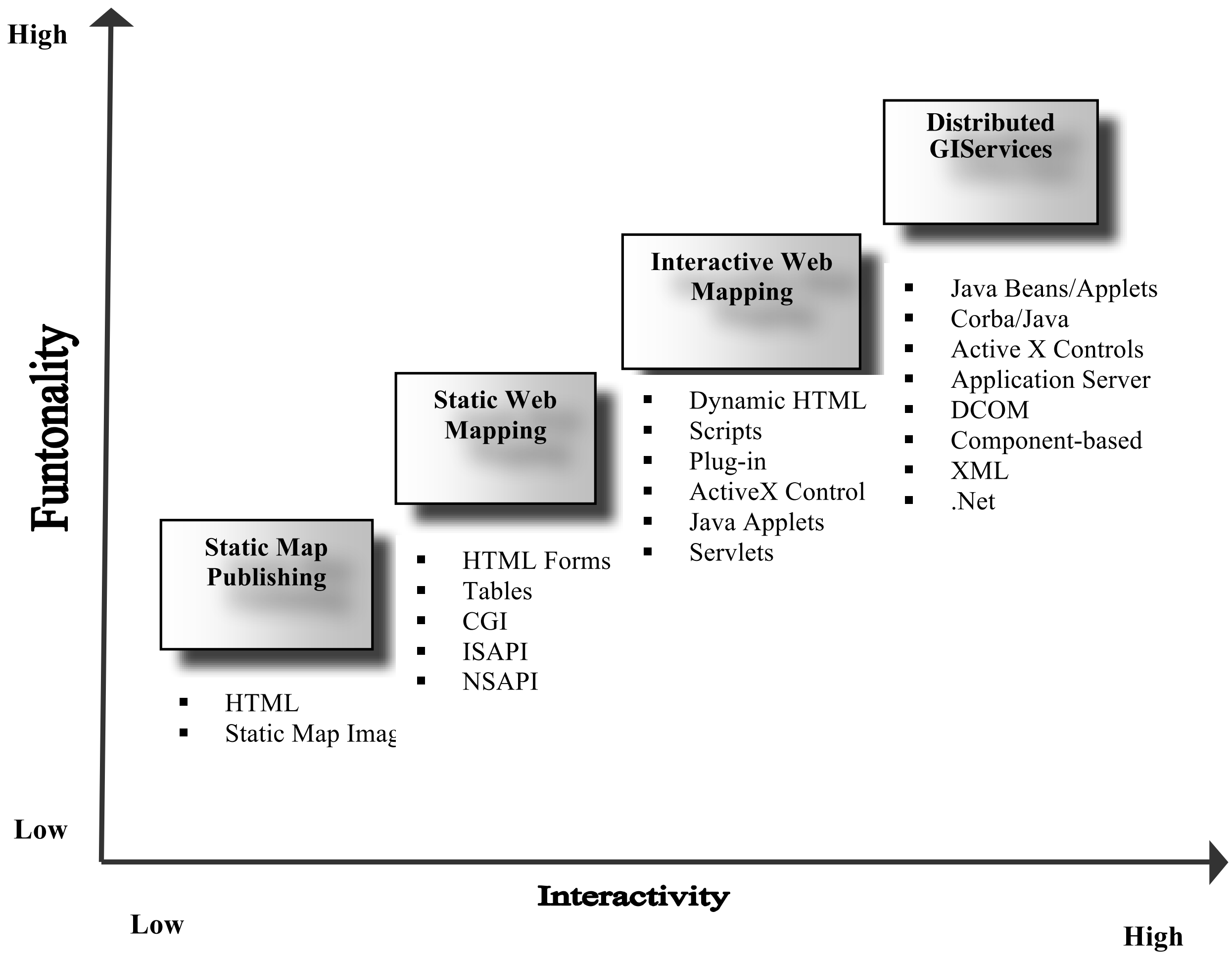


Figure 2-1: The evolution of distributed GIS

(Source: Peng, 1999)

Static Map Publishing: This type of Internet GIS refers to the process of embedding a static image like a JPEG, PDF or GIF inside a HTML page. In this type of Internet GIS, the map is static and there can be no interaction between the client and the map.

Static Web Mapping: Traditional Web publishing techniques adopted a two-tier client/server model. Static Web mapping adopted a three-tier model, which consisted of the Web client, the

Hypertext Transfer Protocol (HTTP) server and the Common Gateway Interface (CGI) and the last component included application servers, such as map servers and database management systems (DBMS) servers. The client is given the ability to have some interaction like zoom in and out, find locations and run queries. It is important to keep in mind that this three-tier architecture dominated the early stages of Web mapping. All requests that are made on the client side are processed by the server side application. Some examples include Xerox PARC Map and Google map (Peng, 1999).

Interactive Web Mapping: Simple HTML viewer is very limited in functionality and lacks client interactivity in relation to spatial data. For this reason, we need more interactive and dynamic client applications that can handle spatial data. At the client side, more dynamic Active X, java applets, plug-ins and dynamic HTML are used to enhance the client experience. On the server side, to improve the performance of CGI, many CGI extensions are used like ClodFusion, Javasoft serverlets, WemObjects. Today all commercial Internet GIS products are based on this model, which includes a dynamic viewer, integrated with CGI and CGI extensions (Green & Bossomaier, 2002). This model still needs a desktop GIS to build up the data and then it can be broadcasted through the server. The client component is interoperable.

Distributed GIServices: Client applications, which are in use today, are mainly designed for graphic display of maps and cannot really provide GIS operations and analysis to the full capabilities. Functionality is very minimal in these Web mapping applications and cannot carry out complex GIS modeling and processing. The ideal distributed system hopes to achieve a system where the client has direct communication with the GIS server. This would mean the elimination of CGI applications between the client and GIS server. The distributed framework promotes distributed components that can be located on different systems or computers. Currently, there is no distributed GIService available. Distributed GIServices are the next phase in Internet GIS, and may revolutionize the way GIS is carried out in the future (Peng, 1999).

2.1.2 ArcGIS Server

There are two sets of Internet GIS servers that can be used: one is the open source, which is available for free download, and the other is a commercial product, which has to be purchased. Open source products are free and available to everyone. Some of the characteristics of open source products include availability of the source code and the right to modify it, redistribute modifications and improvements and no restrictions on the use (Mitchell, 2005). Some of the most popular Internet GIS open source tools include MapServer and MapGuide Open Source. MapServer is one of the most successful open source Internet GIS products out there (The Map Server Team, 2010). MapGuide Open Source is another Internet GIS platform like MapServer, which enables users to develop interactive Web mapping applications. It stems out of the closed source MapGuide developed by Autodesk (Autodesk, 2008). In today's market, there has been an explosion of commercial Internet GIS tools. They include Autdesk MapGuide, Intergraph GeoMedia WebMap, ESRI ArcIMS and the new ArcGIS Server. Autodesk MapGuide Enterprise is different from the open source product as it has more functionality and a different licensing agreement (Autodesk, 2007). Intergraph GeoMedia WebMap is another Internet GIS tool for publishing maps online. ESRI came out with many tools for Internet GIS, which included ArcView IMS, MapObjects IMS and finally introduced ArcIMS (ESRI, 2002). Now ArcGIS Server has replaced ArcIMS but it is still important to introduce this product since it is still used by many government and private organizations in British Columbia.

ArcGIS Server is the GIS server based software component from ESRI's suite of ArcGIS products, replacing ArcIMS to publish spatial data on the Web. It has also been included with the data management systems ArcSDE and provides software development in the .NET framework and JAVA programming language. Now it also has the ability to be incorporated with Web browsers, mobile devices and existing desktop GIS systems and supports the Open Geospatial Consortium (OGC) standards that include WMS, WFS, WFS-T, WCS and KML. It also provides different APIs for developing client viewers in JavaScript, Java, .NET, Flex and sleverlight (ESRI, 2004).

Architecture: ArcGIS Server is an object server that can manage a set of GIS server objects. A server object is software that serves a GIS resource such as a map or a location. Server objects are ArcObjects, which are a collection of software objects that make up the foundation of ArcGIS. ArcGIS Server is fundamentally an object server that manages a set of GIS server objects (ESRI, 2004). ArcObjects components have multiple developer application programming interfaces. These include COM, .NET, Java, and C++ (ESRI, 2007).. Developers can use these APIs to build applications that make use of ArcObjects functionality. ArcObjects is at the core of all the ArcGIS products: ArcGIS Desktop, ArcGIS Engine, and ArcGIS Server. ArcGIS Server adds the framework for running ArcObjects in a server. ArcGIS Server also provides a framework for developers to build advanced GIS Web services and Web applications using ArcObjects in standard application server frameworks such as .NET and J2EE. As described above, at the core of ArcGIS Server is a rich ArcObjects library that can be exploited in Web applications and Web services to deliver advanced GIS functionality to a wide range of users who interact with the server through Web browsers and other client applications (ESRI, 2007). These Web applications can deliver advanced GIS functionality to the end user through browsers.

ArcGIS Server System: The ArcGIS Server system is a three-tier system, see Figure 2-2.

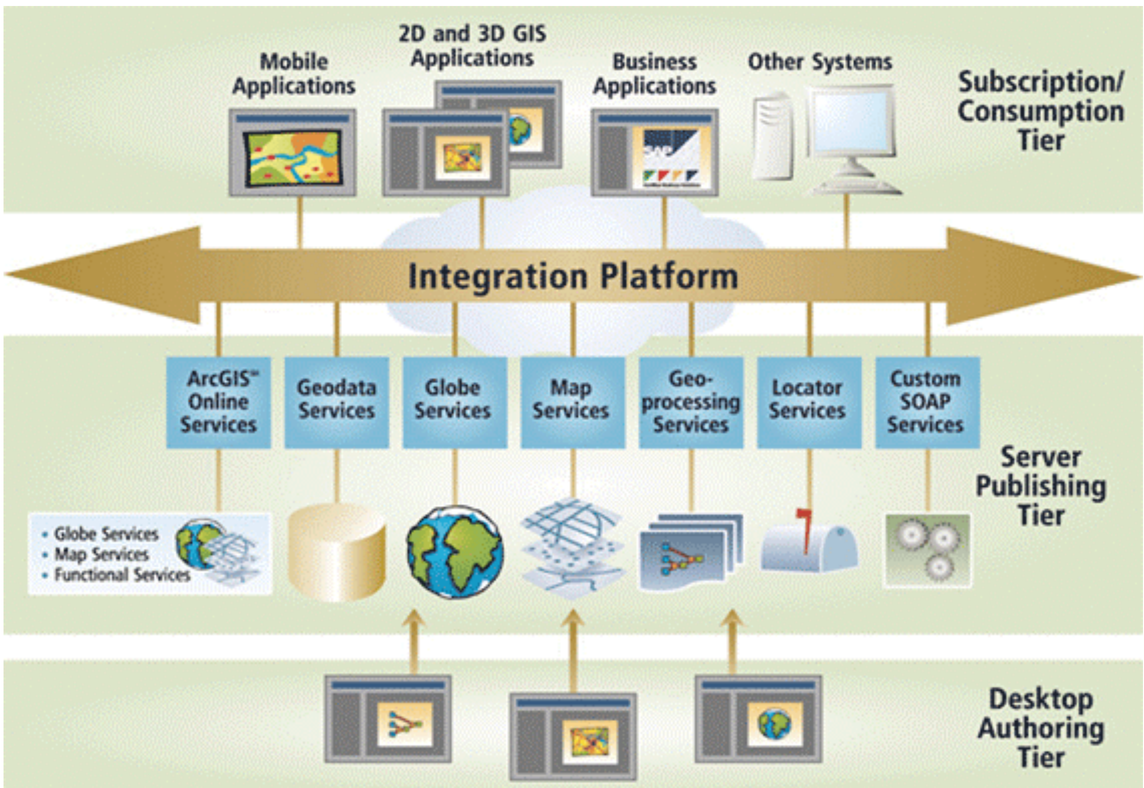


Figure 2-2: ArcGIS Server - a three-tier system

(Source: ESRI, 2007)

The thee-tiers include the desktop authoring tier, server and publishing tier and the client or consumption tier. The client or consumption tier is the interface that users can access, analyze and interact with the maps and data, which include mobile devices, 2D and 3D application and desktop systems. Within the server and publishing tier, the server handles requests from the client and the administrator can manage and publish the services required. At the desktop authoring tier, the data to be published over the Internet is put together using desktop GIS software. Figure 2-3 presents an overview of the entire ArcGIS Server system.

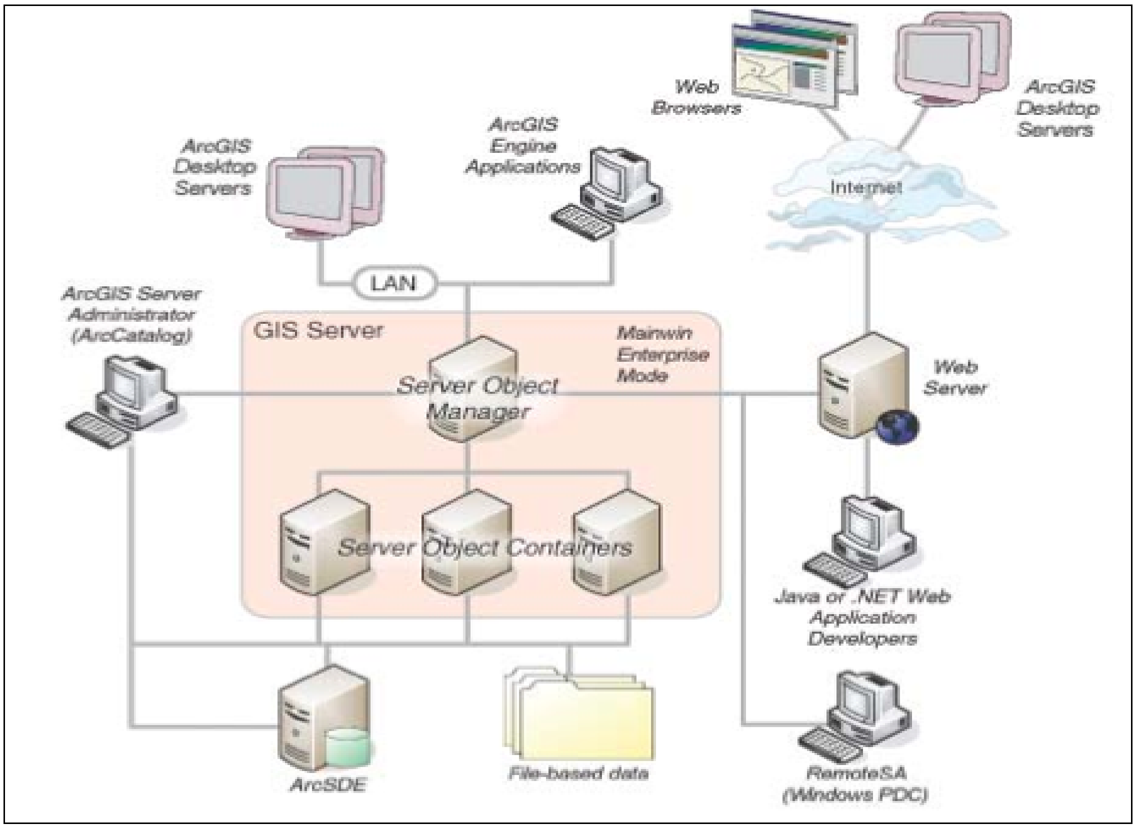


Figure 2-3: Overall structure of ArcGIS Server

(Source: ESRI, 2004)

ArcGIS Server is a disabused system that consists of many different components, which can be implemented over many different computers or just one. Each component in the ArcGIS Server system plays a specific role in the process of managing, activating, deactivating, and load balancing the resources that are allocated to a given server object or set of server objects (ESRI, 2004a). The components of ArcGIS Server can be summarized below and seen in Figure 2-3:

- GIS server—Hosts and runs server objects. The GIS server consists of a server object manager (SOM) and one or more server object containers (SOCs).
- Web server—Hosts Web applications and Web services that use the objects running in the GIS server.
- Web browsers—Used to connect to Web applications running in the Web server.
- Desktop applications—Connect over HyperText Transfer Protocol (HTTP) to ArcGIS Web services running in the Web server or connect directly to GIS servers over a LAN or WAN.

Source: (ESRI, 2004)

Web Application Development: ESRI has introduced different ArcGIS Web mapping application-programming interface APIs with the introduction of ArcGIS Server. ArcGIS Web Mapping APIs and ArcGIS Server can be used to build and deploy Internet applications and mash-ups that include GIS functionality and ArcGIS services. The ArcGIS Web Mapping APIs are a collection of cross-browser and cross-platform client libraries for creating rich Internet and desktop GIS applications (ESRI, 2004). The APIs include ArcGIS API for Flex, ArcGIS API for Microsoft Silverlight and ArcGIS API for JavaScript.

The Flex API is a product for Adobe and it can be used to develop rich and very interactive applications on top of ArcGIS Server. It is based on the free flex framework developed by Adobe. It is a client side technology that is rendered by a flash player or Adobe AIR (ESRI, 2009a).

The Silverlight API is built by Microsoft and can be used to create interactive Web and desktop applications. It can provide all the functionality that ArcGIS Sever and Bing offer, which includes: mapping, geo-coding and geo-processing. It is built on the Silverlight/WPF platform, which integrates with Visual Studio (ESRI, 2009a). To run these applications a plug-in must be installed.

The ArcGIS JavaScript API is easy to use and a lightweight way of embedding maps in a Web application. JavaScript is a language that can be used to make Web pages more interactive. It runs within the browser so it does not cause the page to refresh or blink when an operation is carried out, like zooming in. No program is needed to program in JavaScript and all Web browsers can understand the language. ArcGIS JavaScript API can be used to bring maps and tasks from ArcGIS Server into the Web: a display on an interactive map, execute a GIS model on the server and display the results, search for features or attributes in your GIS data and so on. The ArcGIS JavaScript API can be utilized to access information from several different servers in one application. The ArcGIS JavaScript API provides the following resources for developing Web mapping applications: the API supports display of both dynamic and tiled map from ArcGIS Server, the client can draw graphics and it also provides information boxes and pop-ups when the client clicks or hovers the mouse over a graphics feature on the map. It includes the following tasks: querying, finding addresses, identifying features and geo-processing. It also provides access to Dojo and other libraries. Dojo JavaScript Toolkit provides access to dijits (Dojo widgets) and other JavaScript tools (ESRI, 2009b).

2.1.3 Advantages and Limitations of Internet GIS

GIS started by using mainframe GIS and then desktop GIS. Mainframe GIS refers to GIS programs hosted on a centralized terminal. Desktop GIS refers to a single software package and the data installed on a single computer. This traditional approach is software driven and lacks interoperability. With the growing need for GIS, this model is no longer feasible in situations, which require multi-platform, multi-software and multi-user capabilities. Internet GIS, on the other hand, can provide what is lacking in traditional GIS approaches. Internet GIS provides interoperability and flexibility, which are impossible to achieve in a stand-alone GIS (Green & Bossomaier, 2002). When using Internet GIS, all the processes which include user interface, data and processing, are split up to optimize the system (Buttenfield, 1997). In traditional GIS, software is needed and this can trap the user into using just one type of data format, all operations have to be carried out on the local computer and data needs to be collected, which can cost significant amounts of money. Using Internet GIS, little software is needed; most of the operations can be accessed through the Internet. GIS services can be bought based on the usage, data can be used from other sources or can be shared which reduces the cost of data (Green & Bossomaier, 2002; Plewe, 1997; Tsou & Buttenfield, 1998). Internet GIS has many advantages over traditional GIS approaches. It gives the user the ability to access GIS on any computer system that has Internet access and also provides much faster and easier access to GIS and increases the usage. Furthermore, it eliminates the need for proprietary GIS software, hence reducing the cost for the user to access GIS. It also eliminates the duplication of work, since a common interface is being used and gives users the ability to combine data and resources from different sources. Lastly, it reduces the cost of GIS in general (Green & Bossomaier, 2002; Plewe, 1997; Tsou & Buttenfield, 1998).

One of the main advantages of Internet GIS is that it aids in the transmission of spatial data to a much larger audience. It has helped in dispersing new ideas and information to a worldwide audience, which has provided the general public with the ability for better decision-making and empowerment. This process can now be carried out through the Internet. It has also facilitated large amounts of spatial data being shared over the Internet and data access has become easier and more convenient in the GIS world. Internet GIS has also helped in a shift from the static nature of maps to more dynamic maps on the Web. It has given the client the ability to query, analyze and display the data, which makes it a more interactive experience (Andrej, 1998).

Internet GIS is developing very rapidly; applications are being developed that give the client the ability to perform many more analytical operations. Accessing GIS on the Web gives the user the ability to be independent from operating system platforms, hardware, vendors and applications (Andrej, 1998). It frees GIS users from making big investments in GIS software packages and being restricted to one GIS vendor system.

The development of standards by different organizations like the Open Geospatial Consortium, Inc. (OGC) has also helped with the development of Internet GIS. The main goal of OGC is to develop a set of standards that can be used to develop Internet GIS. This has facilitated interoperability with different systems and vendor software. The OGC Web mapping standards were put forth by (Doyle, 1997) opening up a new era in Internet GIS.

Our society is evolving to adapt to technological advances and many services in government and the public sector are offering most of their services using Web mapping technology. This is leading to the digital divide where people who are not users of this technology are not getting the services they require. Internet GIS has given people the ability to download data, analyze data and make decisions. This new trend of neo-geography is increasingly prevalent today resulting in a world where there is geography with no geographers. Consequently, people with little or no background in the area, have the ability to use GIS technology as long as they have access to Internet. This is shifting the conventional users of GIS in academia, industry and military to mass users of GIS, which includes the general public. Also, the introduction of open source GIS and the OGC standards have offered the general public access to software that has been very expensive to obtain in the past. Internet GIS is reaching people who do not know the basic principles of GIS and the analysis carried out and yet they can still influence decision-making. It is possible there may be a negative impact if the analysis used is not well understood (Li, 1996).

2.2 Oil Spill Emergency Management Using GIS

GIS plays a critical role in emergency management and planning. Emergency management is defined as the discipline and profession of applying science, technology, planning, and management to deal with extreme events that can injure or kill large numbers of people, do extensive damage to property, and disrupt community life (Drabek & Hoetmer, 1991). There are two types of emergencies that can be identified; the first are natural emergencies that include floods, earthquakes, volcanic eruptions etc., and the second are man-made emergencies that include oil spills, chemical spills, transportation accidents etc. Usually, most of the critical problems that arise during these events are spatial problems (Brugnot, 2008). During an oil spill most problems have an inherent spatial component. Some of the spatial problems include, looking for the most environmentally sensitive area, and identifying areas of protection. Consequently, the spatial aspect of emergency management makes GIS an ideal framework for contending the spatial problems. GIS helps in asking questions that have a spatial component and ultimately decisions can be made using GIS. GIS applications are now being integrated with emergency management and there have been many applications developed in recent years (Mondschein, 1994).

There has been a significant amount of emerging research carried out in the field of emergency management, which includes (Bruzewicz, 1994; Johnson, 1992; Mondschein, 1994; Newsom & Mitrani, 1993) environmental hazards, (Emani et al., 1993; Gatrell & Vincent, 1991) GIS and its uses for natural hazard management (Coppock, 1995; Dangermond, 1991; Wadge et al., 1993). There are a few papers published which have examined the use of GIS in oil spill management (Castanedo et al., 2009; Harbaugh, 2005; Martin & Moosavi, 1994). As it is a relatively new research topic and there are very few reference journal articles, it is essential to take into account other sources, such as conference proceedings, technical reports and trade journals, as they will provide relevant context for discussing how GIS is influencing oil spill management.

2.2.1 Emergencies in Context

It is very important to define the different terms since many exist in the emergency management field. Some of the terms like risk and hazard are used interchangeably despite being two different concepts. Risk is a measure of the expected losses due to a hazardous event of a particular magnitude occurring in a given area over a specific period of time (Coppola, 2006). Risk is a function of the probability of a particular occurrence. Risk depends on the nature of the hazard, vulnerability of factors that are affected and economical value of those factors. Vulnerability refers to the extent to which an area is likely to be damaged or disrupted by the impact of a particular hazard (Coppola, 2006). Hazard is defined as the phenomenon that poses a threat to people, economy and the environment. The hazard could be manmade or naturally occurring (Coppola, 2006). An emergency occurs once the hazard has occured and affects people and the environment (National Research Council, 2007).

Disaster management activities strive to reduce the impact of the disaster to the community, economy and environment while simultaneously returning the area of impact to pre-disaster conditions. There are a number of activities carried out before and after the disaster, which are designed to reduce the impact to a point of elimination. Yet, the very nature of disasters makes this unachievable (National Research Council, 2007). The following five main characteristics of disasters that make them hard to overcome have been outlined by (Donahue & Joyce, 2001; Waugh, 2000).

- *Disasters are large, rapid-onset incidents relative to the size and resources of an affected jurisdiction*. Disasters affect a high percent of the jurisdictions property population and damage occurs very quickly relative to the jurisdictions ability to deal with it. They may also impact the resources and personnel that will be responding, for example if oil spills into a dock, it will affect the boats used for response. A jurisdictions human resources, equipment, supplies and funds are dramatically affected. If pre-incident data is available, this can provide important insight into the nature and extent of the spill.
- *Disasters are uncertain with respect to both their occurrences and their outcomes*. The

uncertainty comes about because hazards that cause disasters are hard to identify and the relationship between hazards and disasters is poorly understood. This makes it difficult to estimate risks for the type and severity of damage that can occur.

- *Risks and benefits are difficult to assess and compare*. Although it is important to minimize the exposure of populations and infrastructure to disasters, such as those in high-risk coastal areas, the majority of human populations are found in coastal areas. The development of communities near water sources is natural as water is fundamental for life. Furthermore, ports and fisheries are vital businesses and coastal areas are aesthetically pleasing, which increases real estate value and population density. Consequently, these areas are usually susceptible to oil spills, making it difficult to compare and assess risks and benefits due to the variety of these environments.
- *Disasters are dynamic events*. Emergencies usually evolve as they progress through time. In the case of oil spills, the change is based on the response and natural factors. Since an oil spill is so dynamic, it is extremely important that responders are able to understand and adapt to the changing nature of a spill. Managing emergencies can thus be a highly technical endeavour requiring specialized expertise for both policy development and policy implementation (National Research Council, 2007).
- *Disasters are relatively rare*. Emergencies are experienced very infrequently. Many communities or agencies are unlikely to have experience handling large-scale emergencies and government agencies may lack funding for disaster management. Specialized capabilities, such as geospatial data and tools, are essential from the preparedness aspect of emergencies.

2.2.2 Comprehensive Emergency Management

It is important to segment the emergency management process when examining GIS and its integration. One framework used in oil spill management and other emergency management is the Comprehensive Emergency Management (CEM) system (National Research Council, 2007), see Figure 2-4. In CEM the emergency management process is split into a cycle of four processes, which is based on time. These four phases include mitigation or prevention, preparedness, response and recovery. Mitigation is the action carried out before a spill occurs, for example, regulations that are in place to reduce the frequency and severity of oil spills like building ships with double hulls. Preparedness is the action adopted before an emergency to develop operational capabilities and help in the better response to a spill, for example having stockpiles of equipment in areas most susceptible to oil spills. The response phase is the action carried out right before, during and immediately after an emergency occurs. In the response phase the main goal is to reduce the impact of the oil spill to the environment and make sure that the recovery phase is implemented effectively. The recovery phase is the action taken to return the environment to its initial or normal level (National Research Council, 2007).

GIS plays an important role in each of these phases. In the mitigation phase, GIS is used for risk mapping. In the recovery phase, it can be used for damage assessment and for the environmental impact assessment. Preparedness and response phases can be considered as one phase in relation to GIS because GIS applications developed for the preparedness phase are also used in the recovery phase of the spill. Hence, from a GIS perspective, it is better to combine theses two phases.

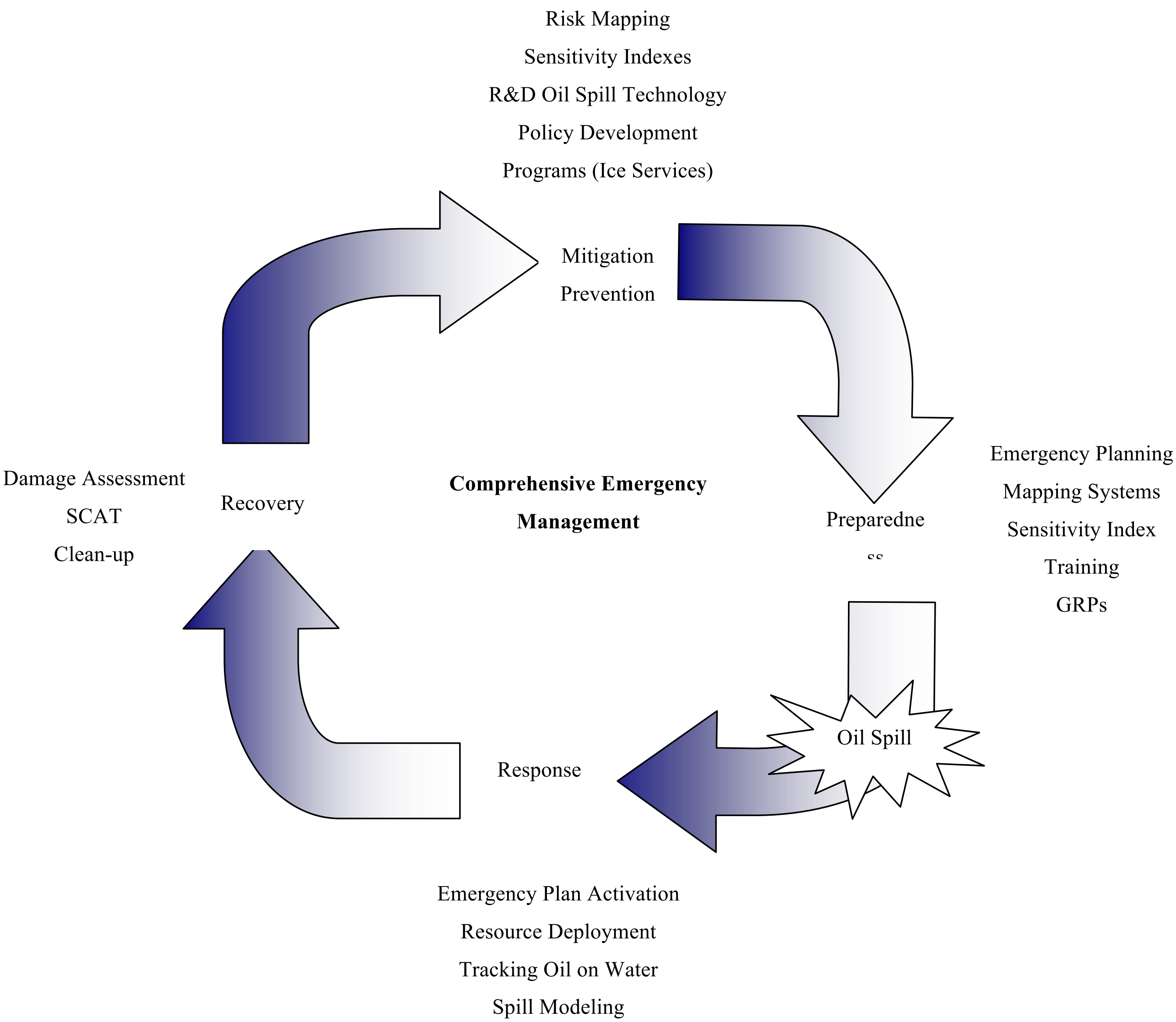


Figure 2-4: Comprehensive Emergency Management Structure and the role of GIS

Adopted: (National Research Council, 2007)

Preparedness involves all the activities undertaken before an emergency occurs. This phase helps improve the delivery of the response by preparing organizations and individuals for an emergency. The goal of the response phase is to help shorten the time required for response, and to expedite the recovery phase. During this phase, planning is carried out to develop better ways for response and recovery. In the case of oil spills, identifying areas of protection, developing new ways to recover oil and developing new technologies to aid the process of protecting the environment are a few ways of being prepared. Another aspect of the preparedness phase is training. Training helps responders be prepared for real events through exercises and drills. These include conceptual discussions, as well as formalized tabletop exercises where real events are mimicked (Haddow, Bullock, & Coppola, 2008). From a GIS perspective, there are a number of activities carried out in this phase. Some of them include identification of data required, development of datasets and development of sharing portals. It also includes activities such as identifying risks, locations of equipment and assets used during an oil spill response, developing universal standards for data, making decisions based on the data sets and also compiling data and metadata in a common repository. The preparedness phase is enhanced when all agencies and responders are working with the same data and interface. Understanding where all the data is originating from is critical. The preparedness phase can further be enhanced if all the data is housed in one location and disseminated to the entire oil spill community using a common interface. Applications like Web servers and services have to be developed in relationship to different response and recovery activities. GIS tools can be used when identifying risks and hazards, developing oil spill models and developing Geographic Response Plans (GRPs) for identifying sensitivities (ESI). GIS helps to integrate information with different sources, scales, formats and accuracy into a single source that can be used for modeling, mapping and decision-making during an oil spill. This common Web mapping application can be used for training, developing plans for response and identifying risk in the preparedness phase. Some of the research that has been done includes real time GIS (Elliot, 1994) and remote sensing for disaster management (Hecker & Bruzewicz, 2009).

Response activities are carried out right after an emergency occurs. The response phase starts with the onset of the emergency, it main goals are first to reduce impact to human life, prevent damage to property and reduce the impact on the environment. During this phase activities include preventing the source of the oil being spilled, recovering oil that is on water, protecting areas that are environmentally sensitive and deploying resources where they are needed. Notably, not all emergencies occur suddenly, for example, when a tanker with large amounts of oil has run a ground and can potentially rupture a tank, the emergency is anticipated. Consequently, the response phase overlaps with the preparedness phase (Haddow et al., 2008). This phase usually lasts for 72 hours for most emergencies but it is still very difficult to define a clear end point for this phase (Hecker & Bruzewicz, 2009). After the 72-hour phase, it is followed by the recovery phase; usually there is an overlap between recovery and response phases. GIS plays a critical role during this phase, in regards to an oil spill emergency. GIS helps within the incident management structure and also supplements decision-making. The incident management structure for an oil spill will be discussed in more detail in a later section. GIS activities include developing maps showing the location of the oil from aerial surveys, developing maps that will help field personnel locate areas to be protected, allocation maps of assets in the area and identifying the most sensitive areas in the vicinity of the spill. During the response phase, time plays a critical role. A timely response can minimize damage to the environment and help save valuable ecosystems in the vicinity of the spill. Hence, it is essential to have access to a mapping system that is easily available, simple to use and is capable of viewing maps that can be used within the incident management structure. The system proposed in this thesis can be used in the response phase to view some of the data required. It can also be integrated with modeling to view the results over the Internet. These results can be disseminated to all individuals and organizations involved in the planning and management of the oil spill. Some of the literature in the recovery phase includes tracking oil on water using GIS (Friel, Leary, Norris, Sargent, & Warford, 1993). It also includes literature in oil spill modeling (Chen et al., 2005; Shyue et al., 2007; Xie & Yapa, 2006).

Recovery is carried out after the response phase of the spill. It includes short and long term activities after the spill has occurred with the main purpose of restoring the areas impacted to their original conditions, or as close as possible. Short-term activities include surveying areas that have been impacted, developing clean-up strategies and disposal of recovered products. The long-term activities include an environmental impact assessment and monitoring of water and soil quality. One of the major tasks that uses GIS in the recovery phase is the shoreline clean-up and assessment techniques (SCAT). Another important task is capturing and archiving data collected as part of the emergency. This data needs to be viewed and disseminated to all the stakeholders involved. Stakeholders can use the Web mapping interface proposed in this thesis to view data captured during the response phase. This can help stakeholders visualize the effect of the oil spill and what has been impacted which in turn will help provide better recovery efforts and reduce the impact to the environment. Some of the literature in this phase includes development of a SCAT database and integration with GIS (Lamarche et al., 1996; Lankford et al., 2008; Reimer et al., 2008).

Mitigation/Prevention includes activities that are carried out after the end of one emergency and before another one arises. The main goal of this phase is to help prevent or reduce the occurrence of an emergency. Activities that are carried out during this phase include assessing risk, developing legislature to reduce risk, assessing and reducing vulnerability to risk and identifying hazards. In short, it is a set of sustained activities designed to reduce the impact of future disasters. Mitigation involves implementing policy changes and new strategies (National Research Council, 2007). Examples of policy-based activities includes regulations which require vessels to have double hulls in order to prevent spills, requiring refineries to have oil spill exercises and so on. Other activities include identification of highly sensitive areas with the development of sensitivity indexes. In Canada, programs have been developed to detect oil spills on water using RADARSAT images. Canadian Ice Service (CIS), a branch of Environment Canada, has been providing such services to detect ships discharging oil into the marine environment. In this study, data from CIS will be integrated into the Web mapping interface. This will help stakeholders view oil spills detected off the coastline and in turn facilitate a response.

2.2.3 Command System during an Oil-Spill Event

An Incident Command System (ICS) is used during large-scale emergencies, including oil spills for managing the incident. It is widely accepted by government and industry for use in emergencies because it is usable, adaptable and a well-tested approach to emergency management. An ICS provides a management system, which organizes the functions, tasks, and staff within the emergency response. Emergencies cause a lot of confusion and the ICS helps transform the chaos into a well-managed system. The ICS promotes better communication and coordination during an emergency (Lutz & Lindell, 2008). In Canada, a similar structure is followed. It is based on the Canadian Coast Guard (CCG)'s Response Management System (RMS) (Department of Fisheries and Oceans, 2006). This system is used when the Coast Guard is the lead agency for an oil spill. In most marine spills for ship sources, CCG is the lead agency, and hence this structure will be introduced here. Figure 2-6 shows the organizational structure of CCG's RMS.

The RMS organization under a CCG led response is managed by the on-scene commander (OSC) and consists of two groups; the advisory staff and response staff. The advisory staff works directly under the OSC and includes the communication officer, health and safety officer, legal, liaison and Regional Environmental Emergency Team (REET). The Communications Officer is responsible for setting up the Information Center where all media sources will be able to access relevant information for information dissemination. The Health and Safety Officer is accountable to the OSC for all aspects of health and safety during response operations. Legal provides legal advice to the OSC. The liaison is responsible for coordinating and maintaining relations and communications with outside agencies, community leaders and other interest groups (Department of Fisheries and Oceans, 2006). The REET is a group set up by Environment Canada. They are responsible for providing environmental advice. The REET includes different stakeholders that have involvement with the area impacted. The REET will provide advice and guidance to the OSC (BC Ministry of Environment, 2007). Particular emphasis will be given to providing advice and guidance during the development of the Incident Action Plan (IAP).

As shown in Figure 2-5, there are four main phases to the RES, namely planning, operations, logistics and finance. Planning is responsible for the collection, coordination and assessment of data, which is used to develop an IAP. The Operations phase is responsible for the direction and conduct of response operations. Logistics is responsible for providing facilities, services and resources for the conduct of response operations. Finance is responsible for the collection and organization of all financial aspects of response operations (Department of Fisheries and Oceans, 2006). This structure is developed in a modular way for marine oil spills. The system is designed to expand or contract based on the size of the emergency.

The use of GIS plays a critical role within this structure. The main uses of GIS are within the planning and REET sections of the REM. Development of an IAP requires many support documents like mps and images. In order to make these plans, it is important to use GIS to outline areas of operations. Within the REET, GIS is also used to identify areas of sensitivity and protection during a spill. Many stakeholders need to identify areas that are of value to them. GIS is an important tool that can be used to achieve some of the spatial problems that are prevalent during an oil-spill event.

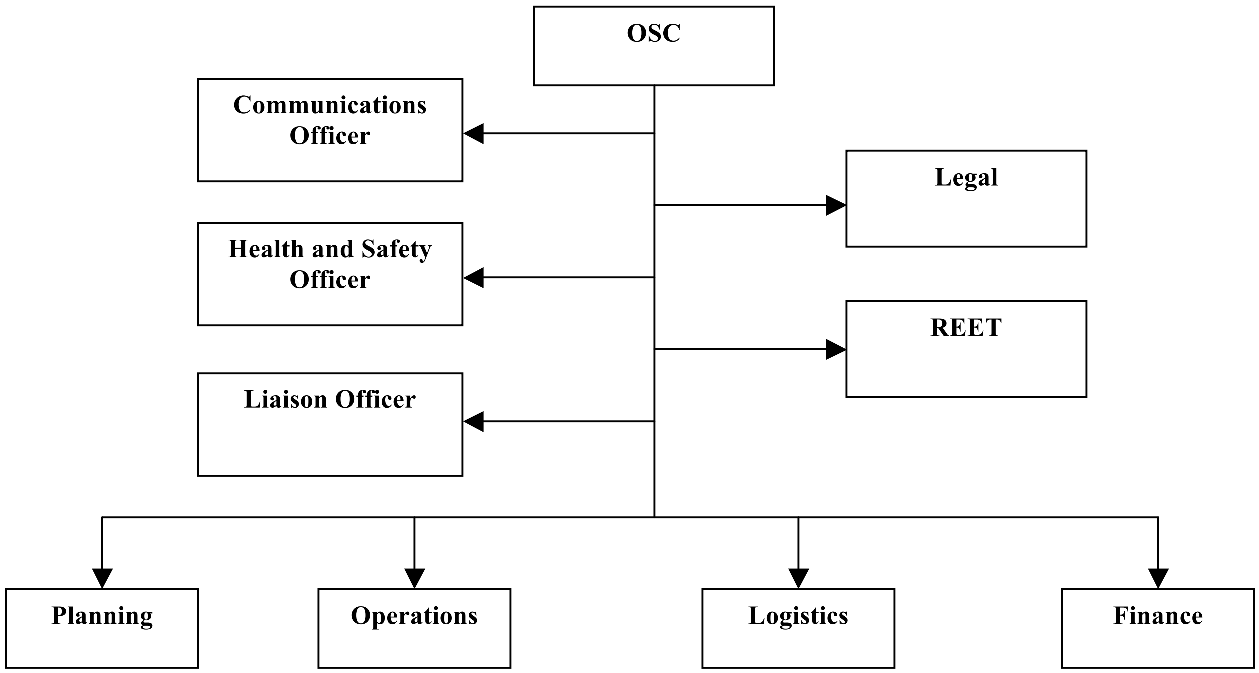


Figure 2-5: Canadian Coast Guard's Response Management System

(Adopted: Department of Fisheries and Oceans, 2006)

Several countries are developing emergency mapping systems using Internet GIS (Baker et al., 2005). Theses systems incorporate various data sources and tools used by the oil spill community. The main component of these emergency mapping systems is sensitivity mapping. There has also been an initiative to incorporate other tools and programs discussed above within theses systems. Some of the research is incorporating SCAT data with sensitivity mapping systems (Lamarche et al., 1996; Lankford et al., 2008). There have also been incentives to incorporate oil spill detection data within such mapping systems for quick dissemination of data (Abreu et al., 2006).

2.3 Oil Spill Emergency Management Systems in Canada

This section introduces a number of emergency mapping systems that have been developed in Canada. **ASMAP** is the first GIS developed by Environment Canada in the Atlantic Region. Its development dates back to the early 1990's and it has been used since 1995 by different partners in the Atlantic region for environmental emergencies management. ASMAP is a standalone application (software) for installation on personal computers and laptops. It has most of the main tools and features of GIS software. It allows users to display thematic layers over National Topographic Database base maps, performs pre-spill and resources reports, views shoreline videos and edits map layouts for incidents (Environment Canada, 2004). This system is purely a desktop system and has no Web component; hence it is tough to integrate with other organization datasets. Therefore, it causes a problem with interoperability and the updating of different datasets. Another problem is that it uses software that is not compatible with other GIS programs commonly used by other organizations. Today, many organizations use ArcGIS framework for managing and dissemination of GIS data. Figure 2-6 shows a screen shot of the mapping interface.

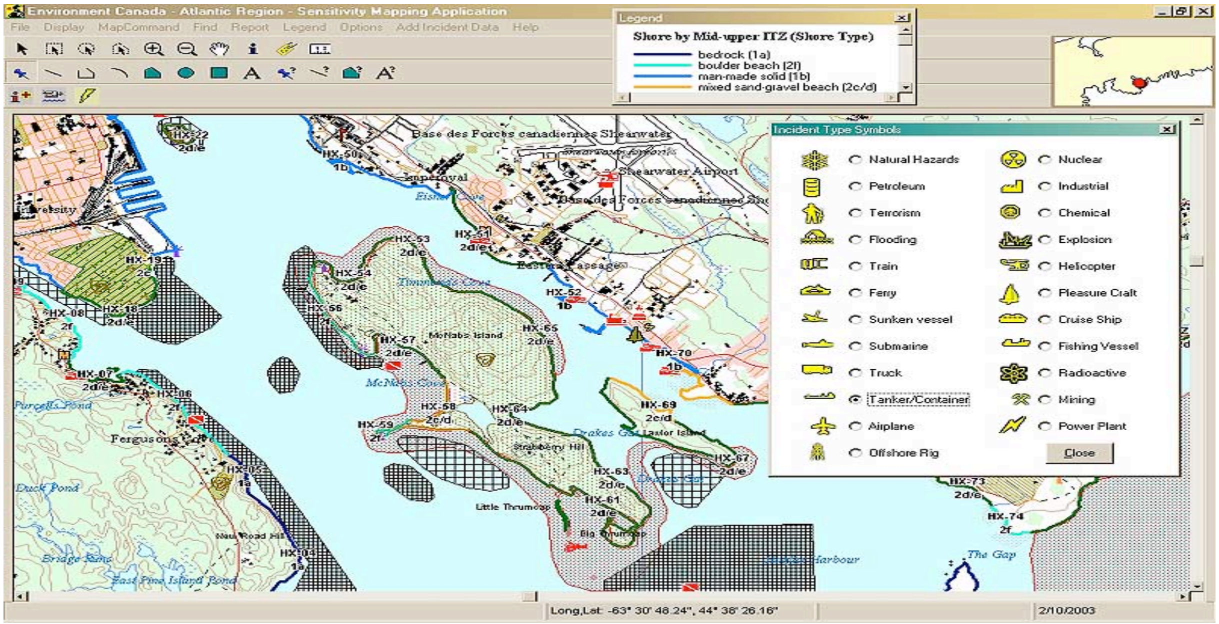


Figure 2-6: ASMAP interface

(Source: Environment Canada, 2004)

E-MAP is a mapping application accessible via the Internet. It was developed by the Environmental Emergencies Section in the Quebec Region. It has been fully operational since the spring of 2002. E-MAP has similar functions as ASMAP. However, since E-MAP is on the Internet, it is capable to have real-time data, such as weather conditions. It allows users to upload their personal data on the main server to share it with other users. It also creates maps online with Adobe® SVG technology without any mapping software needed (Environment Canada, 2004). This system again uses software that is not compatible with ArcView products, causing problems with interoperability. Thus, this system could not be adopted effectively in others regions in Canada. Figure 2-7 shows the Web mapping interface for E-MAP.

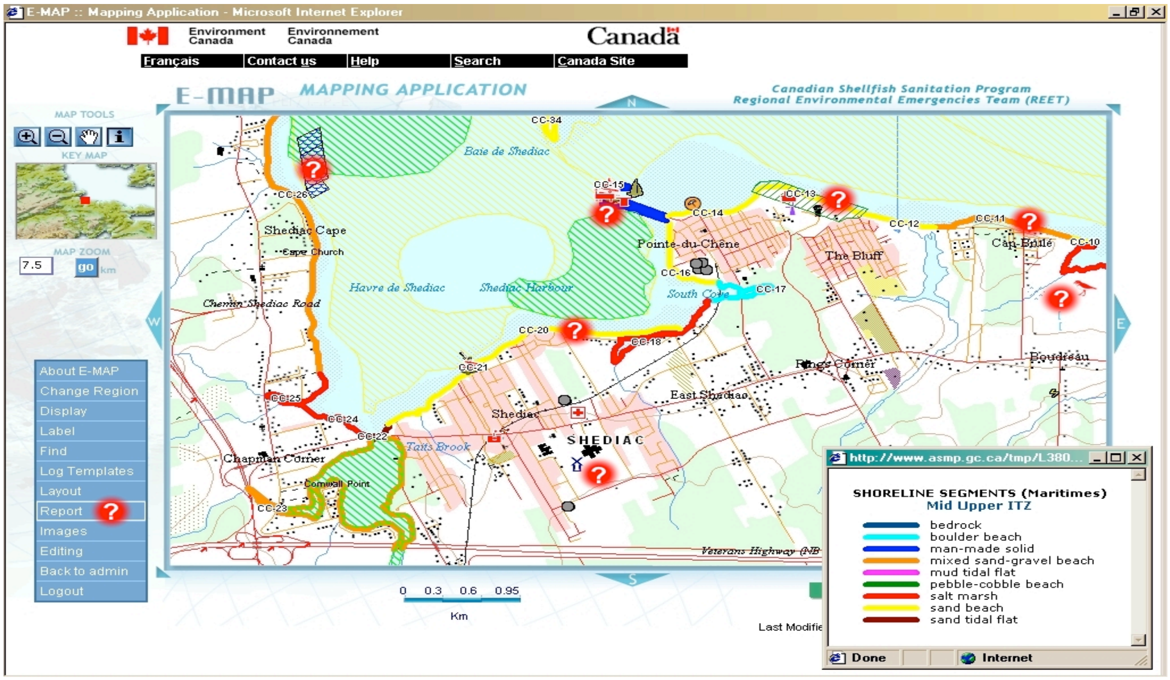


Figure 2-7: E-MAP Web mapping interface

(Source: Environment Canada, 2004)

E2MS or the Environmental Emergency Management System was developed in 2006 (Environment Canada, 2004). E2MS was not developed with the purpose of being a mapping tool, instead, an information management decision-making tool. It allows spill responders to make better decisions by improving their access to shared data, information, and knowledge. This project was a national project that included all the regions in Canada while past projects only developed regional systems. The vastness of this project led to its failure and the system is no longer used today. Also, it adopted software used by E-MAP, which was hard to be integrated with other systems.

The main components of theses systems were sensitivity mapping. They did not incorporate other tools and programs used in Canada, which include oil spill detection using

RADARSAT images, GRP and SCAT. They were designed mainly for viewing sensitivities in a region of impact.

2.4 Chapter Summary

This chapter has presented an overview of the development of Internet GIS. Section 2.1 provides a brief history of Internet GIS and the evolution of Internet GIS through different phases. ArcGIS Server is introduced and looks at its architecture, system and development of applications. This section ends by outlining some of the advantages and disadvantages of Internet GIS.

Also, this chapter has provided an in-depth look at oil spill emergency management and its framework. It reviews the literature in relationship to emergency management and GIS. Section 2.2.2 introduces the comprehensive emergency management structure used for most large-scale emergencies while providing an overview of each phase, which includes mitigation, preparedness, response and recovery. The role of GIS is examined in each of these phases. An overview of the response management system is examined. Section 2.3 concludes the chapter by providing various examples of emergency mapping systems developed for oil spill management in Canada.

CHAPTER 3

Oil Spill Emergency Mapping System

This chapter provides an in-depth look at the development of the Oil Spill Emergency Mapping System (OSEMS). Section 1 identifies the users of OSEMS. Then a framework for OSEMS combining sensitivity mapping, oil spill detection using RADARSAT images and SCAT is introduced in Section 3.2. The data used to develop OSEMS are described in Section 3.3.The conceptual design is then presented in Section 3.4 followed by an outline of how OSEMS has been implemented in Section 3.5.

3.1 Potential Users and Their Needs

It is important to identify needs, capabilities and preferences for the way users perform activities within an application. This understanding in turn influences the design and implementation of a system in order to match the users requirements and the work the users need to accomplish (Haklay & Tobon, 2003). One of the goals for the development of this application was to take large amounts of spatial data and make it available through a medium that is accessible to most stakeholders and responders for easy access during an oil spill. Most oil spill responders and stakeholders have minimal experience in use of desktop GIS or other local area network (LAN) based applications. This section outlines the potential users of such a Web-based oil spill emergency mapping system. This system is developed to be used by expert groups in British

Columbia that deal with oil spill planning. There are three types of users that will be outlined in relationship to oil spills. They include users that have no GIS experience, users that have some GIS experience and very advanced GIS users. Most agencies and organizations that deal with oil spills have all three levels of users.

Advanced users: These users usually include GIS professionals that have formal GIS training. Most organizations that deal with spatial data have one or many of this type of user. They are responsible for managing spatial data within the organizations. Some of the tasks they perform include data collection, sharing and manipulation. These users utilize desktop GIS that have very complex functionality. They are able to perform special analysis, complex queries and professional map making.

Intermediary users: These users are individuals who utilize GIS products and tools but do not necessarily have formal GIS training. They are users of GIS but do not perform complex analysis or queries and use GIS tools and applications to aid in their performance in their job or role within the agency or organization. Additionally, this group of users includes members of the public that participate during an oil spill. These users may also include scientist, planners, responders, technical experts and focus group members.

Novice users: Consists of users who have no understanding of GIS or formal training. These users only view sensitivity data in order to carry out their jobs or tasks more efficiently. They include response personnel, clean-up crews, equipment operators and the general public involved with an oil spill.

The development of this application is mainly for intermediary and novice users that play important roles in the planning and management of oil spills. Advanced users have access to most of theses data sets using advanced GIS software. These advances functionalities are not yet available within commercial Internet GIS products. The functionality of products like ArcIMS and ArcGIS Server is still very limited compared to desktop GIS applications. ArcGIS Server can carry our very limited functions like queries, finds and buffers (Peng, 1999).

The application that will be developed as part of this thesis will have very easy functionality that will give users the ability to view large amounts of spatial data related to oil spills over the Web. It will also give the stakeholders the ability to view data from other programs and operations that use GIS. Once an oil spill has been detected off the coast of British Columbia for example, users can view sensitivity data near the location of detection. This will immediately indicate to stakeholders what is at risk in a specified area which in turn facilitates a better response. Stakeholders and responders can view GIS data through every level of an oil spill, from detection though response and onto recovery. This will help to reduce environmental impacts and help with making more informed decisions.

The potential users of oil spill emergency management mapping systems have a number of needs related to different types of oil spills. A tiered response approach identifies the types of spills (Baker et al., 2005), which include:

Tier 1: Very small-localized spills. For example, a hose line breaks on a ship and spews 50 liters of oil into the water within a port.

Tier 2: Medium sized spills. These would include a ruptured tank in a ship that caused a few thousand litres of oil to be spilled into the environment. This spill can cause damage to the environment and effect shoreline and other resources in the vicinity

Tier 3: Major accidents. These are spills that can release thousands of tons of oil into the environment and would cause significant environmental damage.

Usually after a spill occurs or is detected, the use of GIS and online mapping tools becomes very important. GIS and maps are used at different levels of a response. When a large spill, several kilometres offshore is detected with remote sensing satellites, responders are unable to predict what areas of the shore will be impacted. Initially maps that cover large areas showing the most important resources are required for all potential areas that can be impacted. The authorities in the projected area of impact can be notified and preparations can then be made to combat the spill and its damaging effects. As time passes it becomes clearer which areas a spill is going to impact. Maps showing areas of protection and indicating possible booming points will be needed. Also after a shoreline is impacted, surveys will be carried out and information regarding the type of shoreline is required (Baker et al., 2005).

In addition to spill response teams, other agencies and groups that protect the resources at risk will be interested in this data. These groups include fisheries departments, conservation groups, local first nation communities, business owners, members of the community and the general public. In some cases the different interests of these groups may conflict depending on the specific area. Hence it is important to include all stakeholders when making decisions about protection of areas. Since this is inherently a spatial problem it is important for all stakeholders to understand what is at risk in the area. By viewing the sensitivity data in an area, stakeholders will have a better understanding of what is at risk based on different perspectives. Using a common platform to view this data will facilitate better decision-making (Baker et al., 2005).

It is important to develop a user centric system. Also, it is essential to identify the user in order to influence the design of such an application. A usability study is essential to ensure that the needs of the user are met. The design process encompasses the understanding of how people carry out their work in order to implement systems that can allow users to accomplish their tasks effectively, efficiently and satisfactorily for all stakeholders (Haklay & Tobon, 2003).

3.2 Framework

Existing oil spill emergency mapping systems mainly provide sensitivity mapping as a stand-alone system for oil spill response. None of the systems developed in Canada incorporates other aspects of oil spill planning and management. Recently there have been initiatives to incorporate other programs and tools used for oil spill planning within the existing sensitivity mapping systems (Abreu et al., 2006; Lamarche et al., 1996; Lankford et al., 2008), which include oil spill detection using RADARSAT images and SCAT.

3.2.1 Sensitivity Mapping

During an oil spill, readily available information regarding location and vulnerability of resources at risk is important for an effective response as this will help reduce environmental impacts. The main objectives during an oil spill are to reduce environmental impact and promote effective cleanup efforts. These objectives are best achieved if the locations of sensitive environments are pre-identified and mapped. Knowing this information beforehand can help identify protection priorities and develop clean-up strategies (Percy, 2005). Responders have a very narrow window of time to respond to a spill and have no time to contact different agencies and organizations to gather resource information on areas that are sensitive. Hence, it is very important to have sensitivity mapping capabilities available during oil spills. For sensitivity mapping to be effective, it must be an integral part of the overall planning activity (Jensen et al., 1998). A number of research studies on sensitivity mapping for oil spills have been conducted, they include (Adler & Inbar, 2007; Carmona et al., 2006; Cooper, 2005; Harper et al., 1991). Sensitivity mapping may also be referred to as the Environmental Sensitivity Index (ESI) in relation to oil spills. This concept first emerged in 1979, when a prototype sensitivity map was created before a major oil spill into Texas waters from the *Ixtoc-I* well blowout in the Gulf of Mexico (Jensen et al., 1998). Sensitivity mapping applications are spatial information systems that are composed of different types of data. There are three main components of data including shoreline segmentation data, biological data that can be impacted by oil spills and human activities data, which includes commercial and recreational areas and areas of high value. Many efforts have been made to develop sensitivity mapping for oil spill planning around the world. Consequently, different approaches have been adopted to develop such systems by many countries, including the USA, United Arab Emirates, Israel, Jordan, El Salvador, Germany, South Africa, Mauritius, and New Zealand. An in-depth review of different sensitivity mapping systems can be found in the literature (Baker et al., 2005).

Map atlases of different areas were created before in a paper format for areas susceptible to oil spills. Since 1989, digital sensitivity map atlases have been prepared using GIS (J. R. Jensen et al., 1998). This began a shift from hardcopy maps to digital maps that could be viewed on personal computers using GIS software. Today, Internet GIS makes sensitivity mapping available through the WWW, which increases the ability to distribute such information to a much larger audience (Laflamme & Percy, 2005).

In Canada, as was described in the last chapter, similar efforts have been made to develop sensitivity mapping systems. In British Columbia, a system has not yet been developed specifically for oil spill sensitivity mapping. In this thesis, Internet GIS will be utilized to develop an emergency mapping system that includes sensitivity mapping. It will also demonstrate how other applications and programs using GIS can be integrated into one large system for viewing spatial data related to oil spills. Figure 3-1 provides a framework for sensitivity mapping system using Internet GIS. The main components of the system are spatial data from different organizations, which include base map, shoreline, and biological, economic and cultural sensitivity data. The other components include the map server, Web server and the client viewer. Principles adopted in Canada will be used to develop the sensitivity-mapping component of the system (Laflamme & Percy, 2005).

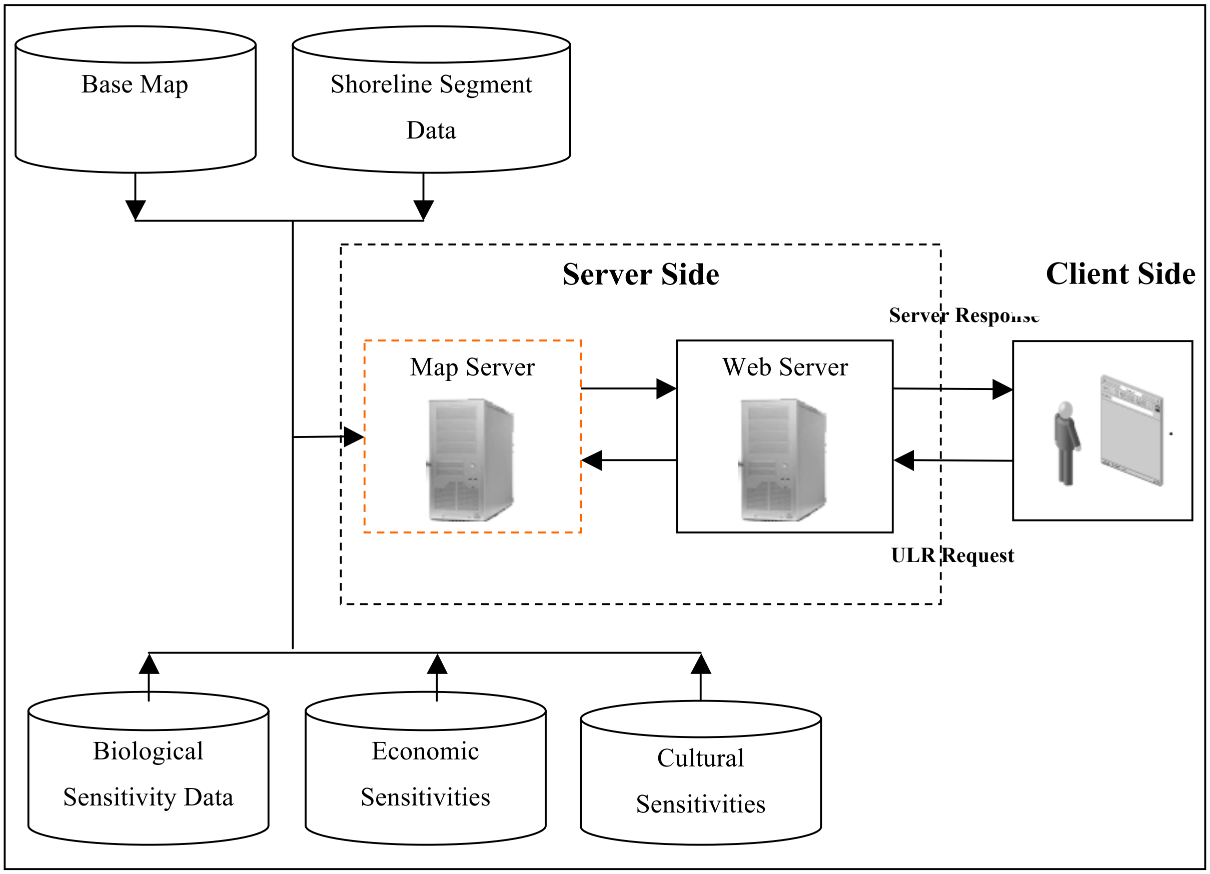


Figure 3-1: Framework for developing a sensitivity mapping system for oil spills

3.2.2 Oil Spill Detection Using RADARSAT Images

In 2006, Canada began to monitor oil spill pollution in its marine and coastal areas using RADARSAT Synthetic Aperture Radar (SAR) images. Canadian Ice Service (CIS) implemented this program. The name of this program is the Integrated Satellite Tracking of Pollution (ISTOP) and it was funded by the Canadian Space Agency (CSA). The ISTOP program uses RADASAT-1 data to identify potential oil pollution from ship sources. When oil waste is illegally discharged by ocean vessels into coastal waters, it has a severe impact on the marine ecosystems. Without mitigation this problem will only worsen. With the passing of Bill C-15 in 2005, the government moved to strengthen its ability to detect oil waste being released at sea (Abreu et al., 2006). Implementation of new surveillance techniques was the key to meeting the goals of the new bill. Canadian Space Agency, Environment Canada and Transport Canada partnered with MDA Geospatial to demonstrate the use of RADARSAT-1 to optimize oil pollution monitoring and surveillance in Canada. The use of SAR to detect oil on water has been used around the world. MDG receives near real-time RADASSAT-1 data over Canada's east and west coast. Using a GIS interface, image analysis is carried out to identify potential oil and source targets, ships and offshore platforms. The results are sent off to the different enforcement agencies and the National Aerial Surveillance Program (NASP). NASP uses aircraft to survey Canadian waters for pollution (Abreu et al., 2006).

Satellite detection can be used for identifying oil pollution and in turn can help during a response. Monitoring coastal waters is a part of mitigating activities in the comprehensive emergency management structure. Different sensors can be used to perform this task, which include ultraviolet sensors, visible sensors, infrared sensors, and microwave sensors. An excellent comparison of different sensors can be found in (Jha et al., 2008). Even though there are a number of sensors being used, much attention has been given to the use of SAR. It is an active microwave imaging system that transmits short directional electromagnetic (EM) waves and then operates as a reviser to record the backscatter signals to form a 2D image (Richards & Jia, 2006). SAR is used as a tool for monitoring oil spills for a number of reasons. It is an active microwave system that can provide energy on its own, SAR is independent of solar illumination and functions day and night (Richards & Jia, 2006). This is an asset since illegal oil discharge usually occurs at night (Gade & Alpers, 1999). Short directional EM waves can penetrate clouds, fog and rain, which allows SAR to function independently of weather conditions (Richards & Jia, 2006) SAR can monitor large areas of ocean, which is very cost effective (Brekke & Solberg, 2005).

Manual, semi-automatic, and completely automatic methods can be used to detect oil spills from SAR images (Topouzelis, 2008). In Canada, the semi-automatic method is used. Data is acquired by MDA and then sent to CIS for detection activities. Once images are received at CIS level, CEOS SAR data is split into two streams. In the first stream, the data is re-projected and converted into an Erdas Imaging file format and it is stored in a geodatabase that is the Ice Service Integrated System catalogue. The second stream of CEOS SAR data is imputed into the Ocean Monitoring Workstation (OMW). This workstation, developed by Satlantic Ltd, provides capabilities for automatically detecting oil and ships in SAR images (Abreu et al., 2006). This workstation provides analysts with an accurate and objective first guess at the presence of oil and ships in incoming imagery. The OMW spits out XML outputs, which are then converted into shape files. These files are sent to an ISIS catalogue (Abreu et al., 2006). The ISIS catalogue also contains a variety of visible, infrared and microwave imagery, as well as other related data layers, e.g. coast lines, bathymetry. CIS analysis looks at the images using a workstation that was developed to provide the analyst with a geospatial workspace, where they could review and overlay the SAR imagery. The custom ArcView application allows for creation of reports for when oil spills are detected. ISTOP reports are distributed automatically to different clients via the CIS Product Distribution System (PDS) (Abreu et al., 2006). Figure 3-2 illustrates the workflow of ISTOP.

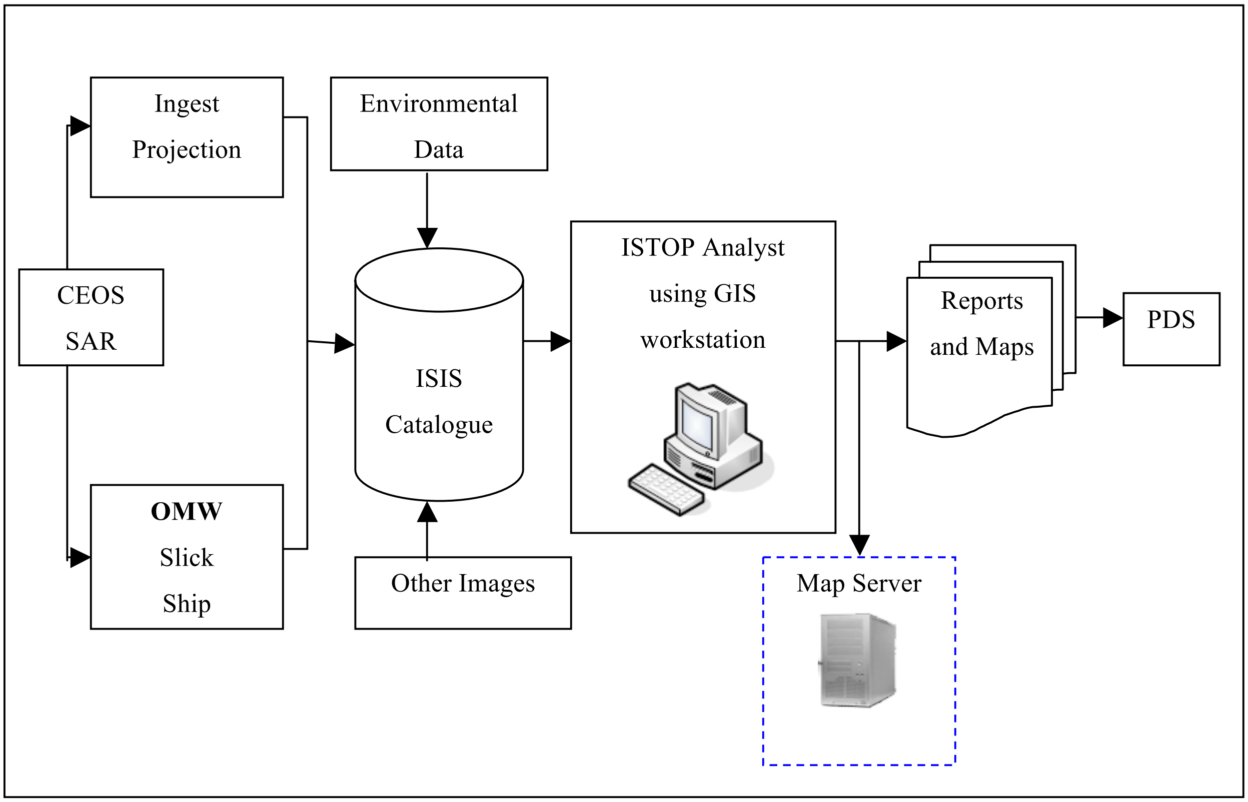


Figure 3-2: ISTOP workflow and integration with Map Server

(Adopted: Abreu et al., 2006)

Once spills have been detected using the process outlined above, the data must be disseminated rapidly to different stakeholders and enforcement agencies so they can act on this information. Traditionally this data has been passed down in a form of a report with attached maps. If this information was published on the Web, it would allow the stakeholders to view the data in real time. In this thesis, the results from the ISTOP program will be published using a map server. This map server, which can be seen in Figure 3-2, will be integrated with sensitivity mapping. A user will then have the ability to view sensitivity data in the vicinity of the detected spill.

3.2.3 Shoreline Cleanup Assessment Technique

The SCAT process is now an important part of oil spill clean-up process and has been adopted in many countries around the world including Canada. There are different variations of SCAT based on the spill including aerial surveys by one person or ground surveys by multiple teams. Before the development of the SCAT, a number of different methods were used to identify the oiling conditions of a shoreline (Finkelstein & Gundlach, 1981; Gundlach et al., 1993). Before the SCAT, operational personnel would carry out a survey and then direct the clean-up operations. The use of the SCAT started in Environment Canada in 1977, and is still used today (Owens & Sergy, 2003). The first description of the formal application of a checklist of a spill response was described by (Owens, 1990).

Once a spill occurs and oil has impacted the shoreline, it is important to understand the extent and amount of oiling that has occurred on the shoreline. SCAT is an assessment technique used to survey the impacted area. A systematic survey of the area affected by the spill is carried out to provide rapid and accurate geo-referenced documentation of shoreline oiling conditions (Moore, 2007). This information is used to develop real-time decisions and to implement shoreline treatment planning and response operations (Owens & Sergy, 2003). As part of the recovery phase, the SCAT teams systematically survey the areas impacted by an oil spill. Some of the main components of the SCAT include assessment surveys, data management and data application. The field survey teams use specific and standard terminology to describe and define shoreline-oiling conditions. The SCAT process itself, however, is flexible and the assessment activities are designed to match the unique spill conditions (Lamarche & Tarpley, 1997). SCAT surveys provide a geographic or spatial component for the oiling conditions or shoreline. After the survey is carried out, the teams make recommendations regarding appropriate clean-up methods and also provide constraints and limitations on the applications of clean-up techniques to reduce further damage to the shoreline. The main objective of the SCAT is to provide operational support. Some of the main activities include collecting and documenting real-time data on oil and shoreline conditions in a rapid, accurate, systematic manner (Owens & Sergy, 2003). The SCAT surveys provide information used to build a spatial picture of the area affected. Understanding the nature and extent of shoreline oiling conditions is key for an effective response (Owens, 1990). The information gathered during the survey is in a format that can be implemented and applied effectively by planners and decision makers. In addition to its primary objective outlined above, the SCAT surveys can be used for development of treatment or cleanup recommendations, standards or criteria, net environmental benefit analysis, post-treatment inspection and evaluation as well as help with long-term monitoring (Owens, 1990).

One of the main elements of the SCAT during the response phase is to make sure that the data needed to carry out the SCAT is readily available to the users in the planning and shoreline operations. Database management is critical when responding to large spills and the type of data mainly needed for a SCAT is shoreline information, which includes shoreline type, structure and wave exposure (Lankford et al., 2008). After the initial response period, when the SCAT teams typically progress at a slower pace, data management remains an integral part of the process to ensure that maps and data tables are kept up-to-date, and that the data is suitably stored (Lamarche & Tarpley, 1997). Usually, data management requires specially designed software that is in a database format that can be lined up to a GIS system for map production and results display

(Lamarche & Owens, 1997; Lamarche et al., 1998; Williams et al., 2005). Now, new technologies and programs have also led to the use of computers and hand held devices in the field to collect this data. These devices usually integrate a Global Positioning System (GPS), which can then be integrated with the database system at the command post (Simecek-Beatty & Lehr, 1996). The main advantage of these tools is that they help in streamlining the process of data management and displaying results. Figure 3-3 shows how the SCAT is integrated with GIS.

All data collected in the field can be integrated with GIS and then absorbed into a Web mapping system that will provide rapid dissemination of the data. Different stakeholders and field personnel can view data in real time to carry out rapid clean-up operations. As part of this thesis SCAT data will be published using a map server. This map server, which can be seen in Figure 3-3, will be integrated with the sensitivity mapping system. Users will have the ability to view SCAT data once it has been collected and integrated with GIS. It will also give the user the ability to view sensitivity data in the areas that have been impacted by the spill.

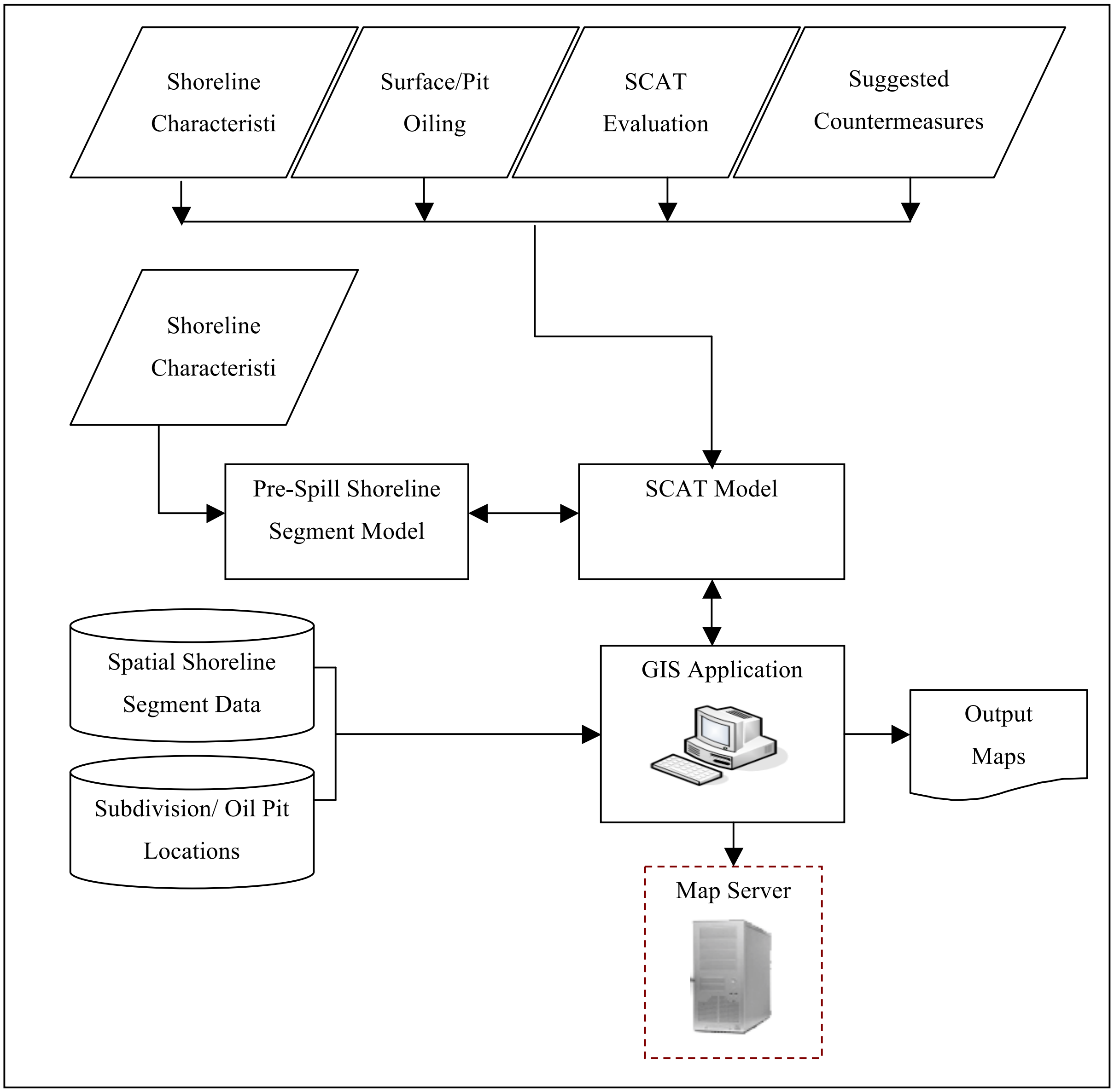


Figure 3-3: System design for SCAT process and integration with Map Server

(Adopted: Lamarche & Owens, 1997)

3.2.4 System Integration

As discussed above, a number of aspects of oil spill planning use GIS. Through the integration of sensitivity mapping, oil spill detection using RADARSAT images and SCAT into a common interface, stakeholders are more easily able to view large amounts of spatial data simultaneously. This integration will also help in faster dissemination of data since time is of the essence when responding to an oil spill. A common interface can foster faster and better decision-making during a spill. By using Internet GIS as a framework, these systems can be integrated. The workflow of each of these systems is outlined above. Conceptually, different map servers would be developed in the respective organizations that implement each of these programs. These servers would publish maps and images over the Internet. The Web Map Services can be integrated into a common interface where the oil spill community can access the data. Figure 3-4 outlines a framework how these systems can be integrated. This is a conceptual design of the system.

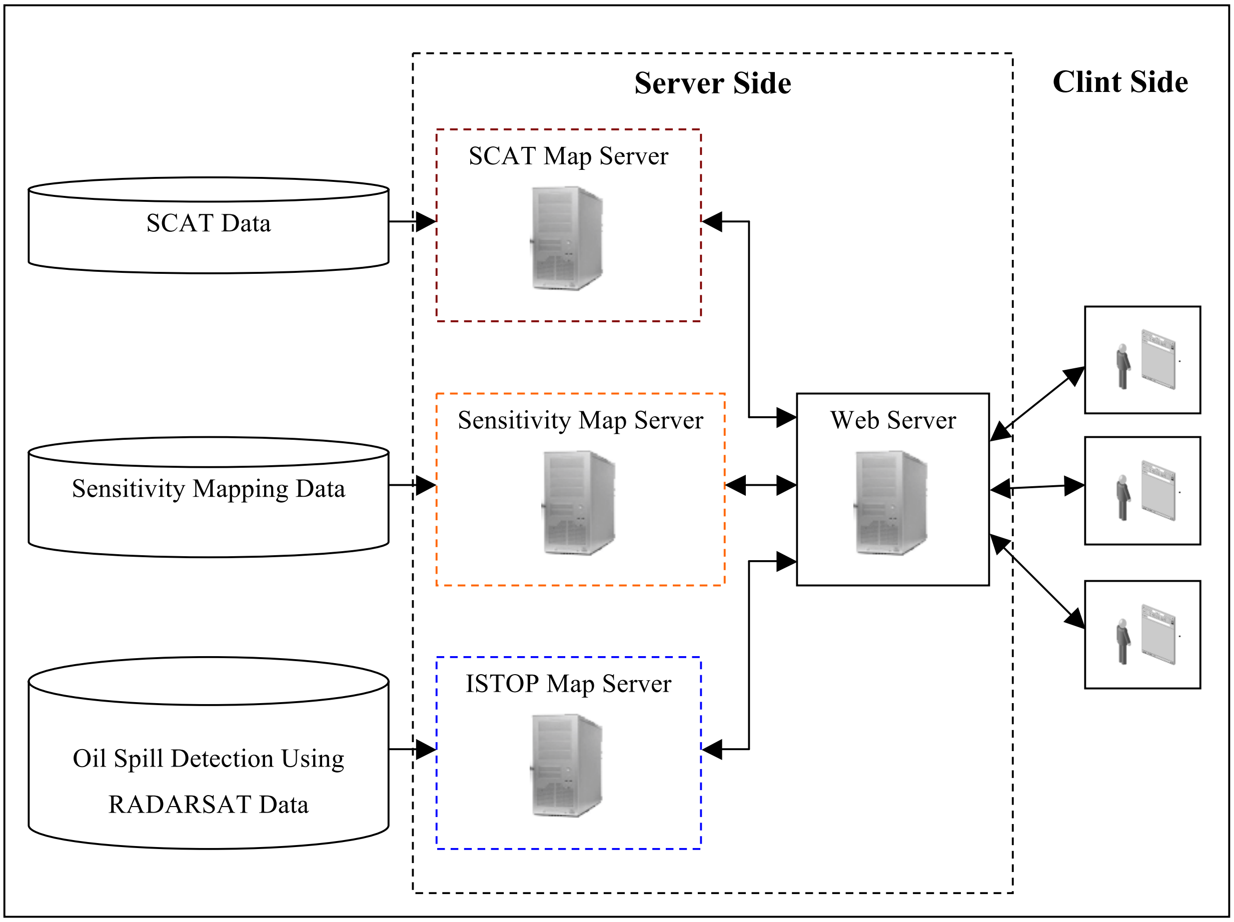


Figure 3-4: Framework for integrating sensitivity mapping, oil spill detection and SCAT

3.3 Data

Data is one of the most important components for this project. In order to develop such a system, data was acquired from different government agencies and organizations in British Columbia. Three different datasets were required for the development of this application. They included data for the sensitivity mapping, detection data and shoreline cleanup and assessment data. This section will outline the different datasets used. It will provide an overview for how the data was pre-processed and optimized for use with ArcGIS Server. One of the hardest tasks in developing this project was data acquisition since a large volume and variety of data was required.

3.3.1 Geographic Data

Sensitivity Mapping Data

In order to develop a sensitivity mapping system for oil spills a number of data sets are required. Once an oil spill occurs many resources in an area are impacted due to the harsh characteristics of oil. Oil spills can affect the physical environment, the biological diversity of the area and socio-economic characteristics in an area. Some of the main datasets that have been identified for oil spill sensitivity mapping include the pre-spill database or shoreline data, commercial fisheries, environmental protection areas, shellfish data, bird migration, bird colonies, species at risk, wildlife data, archaeological sites, and base map data (Jensen et al., 1998; Krishnan, 1995; Laflamme & Percy, 2005)

Base-Maps: The base maps form a foundation for developing this project. NTDB topographic digital maps from Natural Resources Canada Centre were used as base maps. Three different scales were used which include 1:50,000, 1:250,000 and 1:1,000,000. The different scales were used because users need to have the ability to view data at different extents. Not all the themes under NTDB were used for the project. The main themes used to develop the base map included transportation, landcover, boundaries and text. The 1:50,000 British Columbia Watershed Atlas was used as the hydrology layer. This dataset is a topologically structured digital representation of all aquatic-related features streams, lakes, wetlands, obstructions, dams and it is available for all of British Columbia. This dataset was obtained from the British Columbia

Ministry of Sustainable Resource Management data portal. Some of the other datasets used to develop the base map include the 1:10,000,000 base maps of Canada, which were acquired from Natural Resources Canada.

Shoreline Data: The objective of the pre-spill data is to collect information that would be required by spill resource management teams in the development of planning priorities and operational decisions. This dataset plays an important role in the definition of resources potential priorities. This dataset usually includes shoreline segmentation data (type of shoreline), relative exposure to wave and tidal energy, slope, substrate and bio-logical productivity and sensitivity (Owens & Sergy, 2003). It was obtained from the British Columbia Ministry of Sustainable Resources Management. The dataset obtained only included shoreline type, the other fields were not provided and some areas had no data since they were collected by other agencies. In reality, a full dataset will be needed when developing such a system. This data was collected at 1:20000 scale and it did not overlay very well in some areas since the base-maps were at a 1:50000 scale.

Bird Data: In British Columbia there is significant activity of migratory birds along the coast. Birds are usually the most noticeable casualties of oil spills. For this thesis bird colony data was obtained from the British Columbia GeoBC GIS data portal. This dataset provides major bird colonies along the coast of British Columbia. Bird migration data is also collected by the Canadian Wildlife Services (CWS); however, this data set also was not obtained due to restrictions to public access. This information is very important when developing such a system since it provides the time of the year some birds would be in a particular location.

Species at Risk (SAR): There are a number of species at risk along the coastline of British Columbia. It is important to know the location of these species. Species at risk data is managed by Canadian Wildlife Services. A 2005 data set was acquired from Environment Canada.

Wildlife Data: Along the coast there is a concentration of various wildlife species. Most of the activities of different wildlife are near water. Hence, they are prone to oiling. It is important to know their locations. Species Inventory Wildlife Observations data was obtained from the British Columbia GeoBC GIS data portal.

Fishery and Shellfish Data: Fish may ingest large amounts of oil through their gills. Fish that have been exposed to oil may suffer from changes in heart and respiratory rate, reduced growth, fin erosion and a variety of effects at biochemical and cellular levels (Fingas, 2001). Fishery information was obtained from the Department of Fisheries and Oceans. The Fisheries Information Summary System (FISS) data was used. It includes information about Chinook, Chum, Coho, Cutthroat, Sockeye and Steelhead. This information is linked to the Watershed atlas outlined above. Very little is also known about the effects of oil on shellfish except for the fact that contamination with oil will make shellfish taste and smell bad (Fingas, 2001) This makes it impossible to use them as a food source. The shellfish location data set was not obtained for this project since it is restricted to the general public.

First Nation Data: A number of First Nations communities live along the coastal regions of British Columbia. Many of the traditional sites, agrological sites, burial grounds and traditional hunting and fishing grounds are located in coastal areas. Band location data and reserve land data were obtained from the British Columbia GeoBC GIS data portal. Other datasets including burial sites and agrological sites were not available to the general public.

Vancouver Port Data: Vancouver port is one of the largest ports on the west coast of Canada. There is constant activity of ships and other large sea vessels. Along the port, there are a number of oil processing refineries. The Port of Vancouver is a high-risk area for a spill to occur, consequently having accurate data surrounding the port is important. Port data was obtained from Port Metro Vancouver. It provides detailed GIS data of the area included under Port Metro Vancouver.

Parks and Protection Areas: British Colombia is famous for its beaches, foreshore parks, recreational waterways and natural areas. If a spill occurred close to one of these areas it could have a major impact. This dataset was obtained from the British Columbia GeoBC GIS data portal. It provides information about all the parks and protection areas along the British Columbia coastal region.

Commercial Fisheries Data: Fishery harvesting is a big business in British Columbia. It is very important to know major locations of harvesting activities along the coastline. If an oil spill occurred in a region of harvesting it would really impact the economy for fisheries in the region. This data set was obtained from the British Columbia Ministry of Sustainable Resources Management.

Canadian Ice Service Data

In order to show how detection data can be integrated with the sensitivity mapping, data from the Canadian Ice Services was acquired. The process of how the program works and the workflow of detecting oil spills in Canadian waters has been outlined in the last section. Data that is acquired from the process is categorized. The detection data is classified into four categories. If the detection of an oil slick is associated with a ship, it is classified as Category 1A; if there are ships within 50 km radius of the slick it is classified as category 1B; if there are no ships within 50 km of the slick it is classified as Category 2; the slicks that have the least confidence will be labelled as Category 3. Data for 2007 and 2008 was acquired from the Canadian Ice Services. Only detection data for British Columbia was used. The data includes an overview polygon of the area of detection, ships detected in the area, digitized oil slick and RADARSAT image.

SCAT Data

SCAT is carried out after a spill impacts on shoreline. The process of SCAT was outlined in the last section. GIS is used to display the results after the assessment of the impacted shoreline. SCAT data is usually collected after a large spill has occurred. The last major spill in British Columbia was on August 4, 2006 at Squamish dock terminal. This spill caused approximately 29,000 litres of bunker fuel to be released into the environment and then the high winds blew the oil on the shore near the terminal and into the estuary of the Squamish River. The SCAT data from this spill was not available. Shoreline segmentation data outlined above was used to build the SCAT database. Data for the impacted shoreline in Squamish (Howe Sound) was clipped from the shoreline segmentation data. The database was developed using the environmental impact assessment documents (Polaris Applied Sciences, 2006). A new field was imputed into the clipped shoreline segment data and oiling conditions added as of August 11, 2006. This data is disseminated through an environmental impact assessment to different stakeholders and agencies.

3.3.2 Data Processing

Data processing is one of the most tedious tasks in relation to GIS. Most of the data was secondary data and was not developed for this project. Hence, the data had to be processed to fit the needs of this project. Data was acquired from different agencies in different formats and geographical extents.

To conduct all the data processing, ArcGIS 9 (ArcCatalog, ArcMap, ArcToolbox) was used. Some datasets like the shoreline database obtained in ArcInfo Coverage format was converted into a shapefile. The database was provided in the form of an access database. Then the ArcGIS and the spatial file which was converted was linked using the table add join tool. Initially all the datasets obtained were in different projected co-ordinate systems. In order to use all the data they were re-projected to the standard BC Albers Projection. This projection has been officially adopted by the British Columbia Government as one of the standard projections to use for spatial data. The BC Albers projection is based on the Albers Equal Area Conic projection (Province of British Columbia-Resources Inventory Committee, 1998). A number of the datasets obtained were not for British Columbia alone, they included data for other provinces and territories. These datasets were clipped to the British Columbia boundaries.

3.3.3 Data Optimization

The data for this thesis was required for only coastal areas of British Colombia. Using ArcGIS 9, a buffer of eighty kilometres was created from the shoreline segmentation dataset. The buffer created was combined with the ocean polygon. The created shapefile was used to clip datasets that included data for the entire province of British Columbia. In order to reduce the size of some of the datasets, the tabular data that was not needed was removed. Also the shapefiles were indexed to increase performance.

3.4 Conceptual Design of OSEMS

OSEMS is structured in two parts: (1) a Website that provides the user access to the application and background information about the application, and (2) the actual OSEMS map application that is contained within the Website.

3.4.1 Functionality of the OSEMS Application

Based on the user's needs identified in Section 3.1, a very simplistic and easy to use application is needed since most of the users are not advanced GIS users. OSEMS is created using ArcGIS Server. Basic navigational tools are needed for navigating within the map. Also making markups on the map is important during presentations using the application. Basic mark up tools will also have to be incorporated. Finding places is critical for identifying areas of impact and thus a find location tool will also have to be incorporated. A measurement tool will also be implemented. Table 3-1 provides a list of all the tools needed for the development of OSEMS.

Table 3-1: Tools and Factions Identified for OSEMS

Navigation Tools	Mark Up Tools	Query	Other Functions
Zoom In	Draw Points	Location Finder	Tabs to Change Servers
Zoom Out	Draw Lines	Measure Lines	Ability to Turn Layers on/off
Full Map Extent	Clear Markups		Print
Previous Extent			
Next Extent			
Map Pan			

The user will require the ability to switch between map services accordingly tabs were developed to easily change between each service. Users will need the ability to turn on and off different layers within each map service. The OSEMS application is being developed for users that are new to GIS. It is important to provide the user with enough information about how to use the application. A help section is incorporated within the application and informational section is also provided for each server.

3.4.2 Selection of Web Mapping API

As outlined in Section 2.1.2, a number of different ArcGIS Web mapping APIs are available for use with ArcGIS Server. Web Mapping APIs and ArcGIS Server can be used to build and deploy the Internet applications that include GIS functionality and ArcGIS Services. The APIs include

ArcGIS API for Flex, ArcGIS API for Microsoft Silverlight and ArcGIS API for JavaScript. Based on the tools and functionality outlined above, ArcGIS API for JavaScript is used to develop the OSEMS application. The simplicity of JavaScript API programming allows for the development of robust applications.

3.4.3 OSEMS Website

The purpose of this website is to provide the user of the OSEMS application with background information. Feedback is important when developing such client-based systems. The website gives the user the ability to provide feedback about the application and report issues and problems when using OSEMS.

3.4.4 Symbology

Symbology is important for the development of OSEMS. It is critical to consider the symbology to be used for most of the datasets. A number of the datasets for sensitivity mapping have pre-identified symbology. There is no standard symbology developed for sensitivity mapping in Canada.

The same symbology is used for the datasets that had pre-identified colours and symbols, for example shoreline segmentation data. For datasets that did not have pre-identified symbology, appropriate colours and symbols should be selected. The correct use of colors and symbols is very important in sensitivity mapping.

3.5 Implementation of OSEMS

This section outlines how OSEMS was implemented. The system was developed using ArcGIS Server. As outlined in Section 2.1.2 ArcGIS Server is a tiered system. This system was developed based on this tiered structure. The development of the website and OSEMS testing are also outlined.

3.5.1 Authoring

The data for this project was collected from a number of sources. In the desktop authoring tier, ArcGIS Server projects have to be set up before they are published on the Web. Three sets of data were used to develop OSEMS; these have been outlined Section 3.3.1. ArcMap was used as the desktop authoring tier. Using ArcMap the data was compiled into three different projects. Three separate projects had to be developed since three different Web Mapping Services were needed which consisted of sensitivity mapping, ISTOP program and SCAT. For each of the projects, data was combined and layered using ArcMap. Appropriate symbology was used for each of the data layers. In order for layers to come on at different scales, zoom extents were set for each layer in each project. This would give the user the ability to view individual or combination of map layers at different scales. Most of the map layers were set so they were scale-dependent, so more data and annotation would become visible when the user zooms into regions, cities or neighbourhood. In the proposed framework three servers were needed for implementing OSEMS. To demonstrate how OSEMS can be implemented, only one map server was used and three different Web Map Services (WMS) were created. A Web Map Service (WMS) is a standard protocol for serving geo-referenced maps and images over the Internet that are generated by a map server using data from a GIS database (Doyle, 1997).

3.5.2 Server and Publishing

For the proposed framework, a map server was used to publish the data over the Internet. Three different Web Map Services were created which include sensitivity mapping, the ISTOP program and SCAT. In order to develop the map server ArcGIS Server was used. This stage is part of the server and publishing tier of ArcGIS Server. Before the three projects were published to the Web, a test was carried to optimize the performance of the project files. ArcMap includes a set of tools that helps to optimize the project file. In order to optimize the Web Map Services the Map Service Publishing toolbar was used. Carrying out this step helped with improving map display and performance. All three Web Map Services are dynamic in nature.

3.5.3 Client Viewer

The client viewer falls under the client or consumption tier of ArcGIS Server. OSEMS application was created using The ArcGIS JavaScript API. The application was developed and tested using Adobe Dreamweaver. The application needed to incorporate all three Web Map Services outlined above. The client also had to have the ability to turn on and off multiple layers within each service. ArcGIS JavaScript API allows for incorporation of multiple services within one application. Most of the code for this project was adopted from the sample code provided within the ArcGIS JavaScript API (ESRI, 2010). Explicit layer coding was used in order to make all three Web Map

Services run simultaneously within the application and also have the ability to turn layers on and off. ArcGIS JavaScript API also allows for incorporating queries and find tasks. Using this functionality a “find location” tool was developed. ArcGIS JavaScript API was used to develop the navigational tool, mark-up tools, find location tool and access the map and layers from each Web Map Services. In order to develop a measurement tool, scale bar and co-ordainments on the map the geometry server within ArcGIS Server was used. The geometry server helps application carry out geometric calculations such as calculating length, projecting and buffering.

ArcGIS JavaScript API was created to incorporate Dojo, this helps in simplifying the development of Web applications. Dojo insures that the application will function the same in different browsers. Dojo is an open source JavaScript library/toolkit designed to help in the creation of cross-platform JavaScript applications (ESRI, 2010). Dojo helps to write robust and efficient JavaScript code. It uses widgets, or "dijits", to add pre-packaged user interface components to the applications. Dojo has many existing dijits to choose from such as text boxes, buttons, menus and sliders and was incorporated with the ArcGIS JavaScript API to develop all the tabs, buttons, sliders and information boxes used in the development of OSEMS.

The application was developed within an HTML page. JavaScript code can be embedded directly into the HTML page. HTML was used to develop the layout of the application, as well as embedding text and images within the application. HTML was used for the placement of images, text and checkboxes within OSEMS.

The entire application was developed within one HTML page for better performance. The OSEMS application was developed by integrating ArcGIS JavaScript API, Dojo and HTML.

Using the process described above, the development of a robust and easy to use Web-based application was created. The application also provides multiple stakeholders high performance access OSEMS on the client side.

3.5.4 Website Design

A website was created in order to host the application and provide users with background information about the OSEMS. The website was created using Adobe Dreamweaver. The website provided the user with access to the application as well as additional information. The website consists of five sections:

- **About** section, which provides background information about OSEMS,
- **Application** section, which provides the user with access to the OSEMS application,
- **Data** section, which provides the user the ability to view all the data, used for the development of OSEMS,
- **Other Links** section, which provides the user with information about the oil spill response community in British Columbia, and
- **Contact** section, which lets the user contact the developer and provide feedback about OSEMS.

The Web server is managed and maintained by the Faculty of Environment's Mapping, Analysis and Design (MAD) at the University of Waterloo. The website and applications were hosted on the Web server at MAD.

3.5.5 Testing OSEMS

Interest in Human–Computer Interaction (HCI) has been a part of Geographical Information Science for a long time (Haklay & Zafiri, 2008). As GIS and Web GIS have grown there is a need to understand the usability of applications from a users' perspective. This can be achieved by focusing on Usability Engineering (UE) for GIS. UE is a part of HCI, which emerged in the mid 1980s with the aim of addressing system usability in a reliable and replicable manner (Haklay & Tobon, 2003). UE is a systematic method for designing interfaces that can be learned quickly and easily operated.

In order to test the OSEMS application a questionnaire was developed. The main purpose of the questionnaire was to test the usability of the application, examine if the system could be used in conditions that simulate some key aspects of real world conditions and ensure that the data required by each stakeholder was effectively delivered using OSEMS. Usefulness is measured by the ability of a system to achieve a desired goal. It can be further divided into utility and usability. Utility looks at the functionality of the system and usability is the question of how well the user can use the functions to perform a task. Usability refers to the effectiveness of interaction between humans and computer systems and can be specified in terms of how well potential users can perform and master tasks on the system (Butler, 1996). A system's usability can also be measured in terms of its learnability, efficiency, recall ability, error rate and user satisfaction as outlined by (Nielsen, 1993). Nelson saw usability as one of many attributes of system acceptance. System acceptability determines whether the system sufficiently satisfies all the needs and requirements of the users, which include cost, compatibility, reliability and usability. Learnability refers to how easy an application was to learn in a given amount of time. Efficiency refers to the level of productivity that the user must gain once the system has been learned. Memorability measures how well a person can remember how to use an application after a period of time. An error is defined as any action that does not accomplish the desired goal (Nielsen, 1993). Through counting these actions a system error rate can be measured. Satisfaction refers to how the user rates their experience while using the system. Questionnaires are useful tools for analysing the usability of systems. They can be used at different stages of development of a single system and they can be used to evaluate user's perceptions of different systems (Dix, 1993; Shneiderman, 1992). User satisfaction of an application is an important measure for its acceptance (Haklay & Zafiri, 2008). Consequently, a questionnaire was created for evaluating OSEMS, see Appendix.

The questionnaire was implemented in two ways. For experts that were located in British Columbia the questionnaire was emailed to them and they were asked to fill it out. For the rest of the participants they were given the questionnaire in person. Both groups were asked to go though the questionnaire by themselves. The questionnaire was divided into four sections. At the start of the questionnaire participants were given a brief introduction to OSIMS, they were also asked to provide information about the level of computer usage, the ability to use web mapping application, GIS skills and the knowledge about oil spill planning. The first section was developed to introduce the participants to the OSEMS application. They were given a brief overview of the tools and functionality provided. Based on the data and the proposed framework of OSEMS, three real world oil spill scenarios were created. Each scenario was developed from a different stakeholder's perspective. The different perspectives that were chosen include an emergency response officer, Canadian Cost Guard Officer and a First Nation liaison. The participants had to work through each of the scenarios and carry out different tasks. At the end of each scenario users were asked to evaluate the usability and utility in relation to satisfaction of OSEMS. They were also asked if the system delivered the data they required as the stakeholder in each scenario. A feedback section was also provided for future improvements of OSEMS. In order to implement the questionnaire ethics clearance was obtained from the Office of Research Ethics at the University of Waterloo.

3.6 Chapter Summery

In this chapter, a framework for developing a new oil spill emergency mapping system was introduced. The proposed framework will integrate sensitivity mapping, oil spill detection and response system into one interface. A conceptual model for the development of OSEMS is provided and outlines some of the functionality required. The details of implementation of the proposed framework have been presented. An Overview of the testing process has also been outlined.

CHAPTER 4

Results and System Evaluation

This chapter describes OSEMS in detail and also discusses the results of the usability testing. It provides a discussion about several issues encountered during the development of OSEMS. Section 4.1 provides an overview of OSEMS and its functionality. Section 4.2 provides the results from the usability testing.

4.1 OSEMS Overview

The website of OSEMS (http://www.environment.uwaterloo.ca/u/ggomes) was created to provide the end users with information about the system. The application can be accessed from http://www.environment.uwaterloo.ca/u/ggomes/OilSpillApp/Oil Spill Emergency Mapping Systemt.html. The major components of the website include five key sections, namely **About**, **Application**, **Data**, **Other Links**, **and Contact** for users to provide feedback. Figure 4-1 shows a screenshot of the OSEMS website. The application can be launched from the website.

Figure 4-1: Home page of OSEMS

OSEMS is built in JavaScript under the ArcGIS JavaScript API framework. OSEMS is a user-friendly graphical user interface (GUI). As shown in Figure 4-2, the three main sections in blue are the **Map**, **Toolbar** and **Table of Contents (TOC) control panel**. The toolbar consists of two different tools that are the map navigational tools and the mark-up tools. A map displays the data from each WMS, which includes sensitivity mapping, oil spill detection from RADARSAT images and SCAT. The TOC control panel contains the main tabs as well as the ability to access layers from each service.

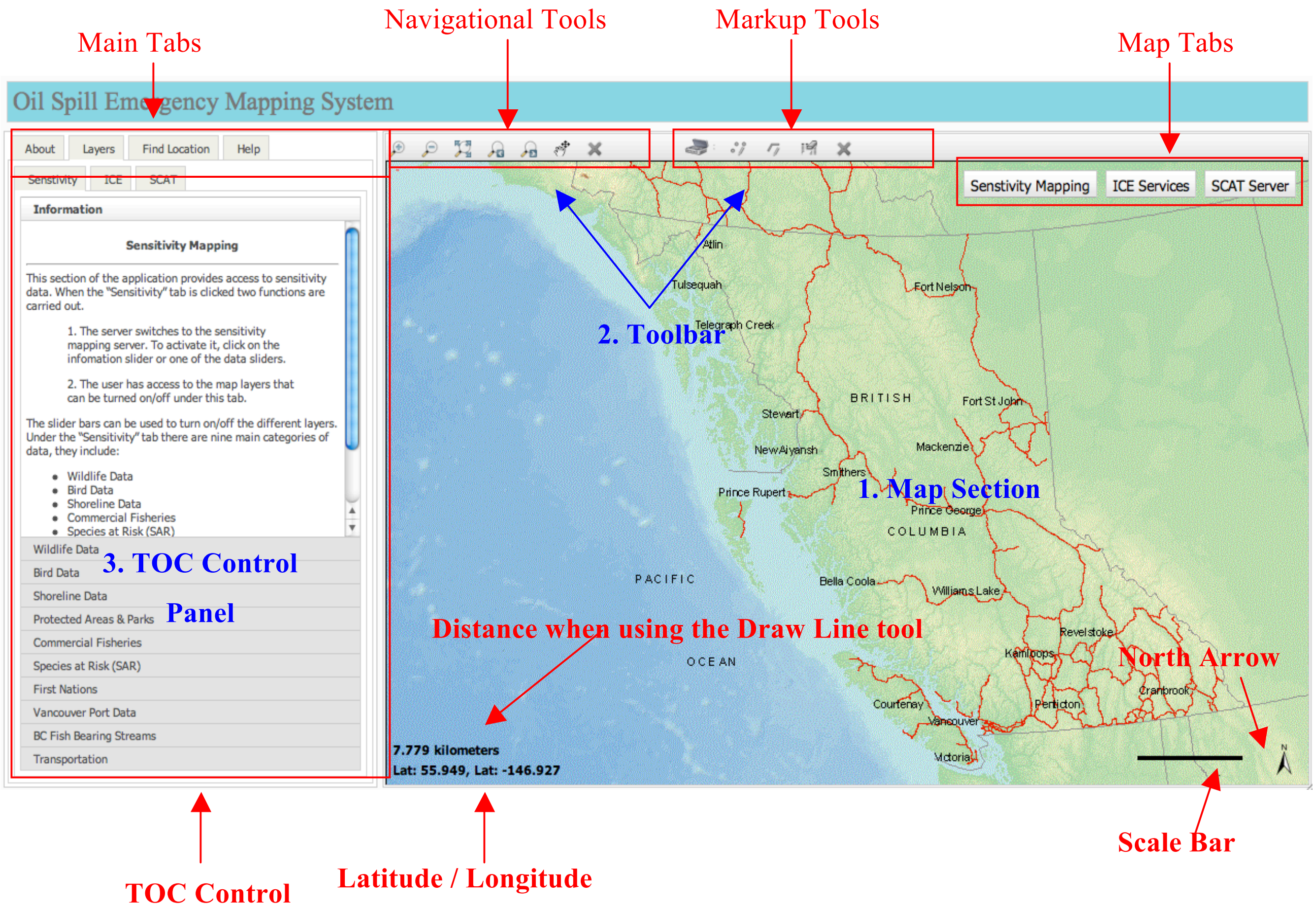
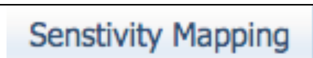
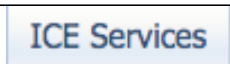
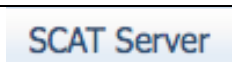


Figure 4-2: Graphical user interface of OSEMS

4.1.1 Map Section

The **Map Section** provides users with the ability to view the maps form the three different WMS's. It also consist of other features including an accurate scale bar, north arrow, latitude and longitude based on the movement of the cursor and map tabs. The map tabs allow users to change map services, see Table 4-1 for more information. The map tabs were added for easy access when users look at data in different services at the same time.

Table 4-1: Description of map tabs within the map section

Map Button	**Usage**
	This tab is used to access the sensitivity mapping WMS. Once this tab is clicked, users can view sensitivity data using the "Sensitivity tab" under the Layers tab.
	This tab is used to access the CIS WMS. Once this tab is clicked, users can view CIS data using the "ICE tab" under the Layers tab.
	This tab is used to access the SCAT WMS. Once this tab is clicked, users can view SCAT data using the "SCAT tab" under the Layers tab.

4.1.2 Toolbar Section

The **Toolbar** section of OSEMS provides users with two sets of tools that include the map navigational tools and the mark-up tools. Map navigational tools provide users with basic functionality to navigate within the map section. Tools include **Zoon In**, **Zoom Out**, **Full Extent**, **Zoom to Previous Extent**, **Zoom to Next Extent** and **Pan**. More information about these tools can be found in Table 4-2.

Table 4-2: Description of navigational tools within the Toolbar section

Icon	Name	Usage
	Zoom In	The Zoom In button allows users to zoom into a particular area on the map. Using the mouse, "left click" on the Zoom In button and then: • Define a window by "left clicking" on a point and, keeping the mouse button depressed, "pull" the rectangle being formed until it covers the area of interest and release the mouse button. If you have "windowed in" too far, use the Zoom Out button to "back out" (approximately 2X each "click") until the appropriate area has been defined.
	Zoom Out	The Zoom Out button allows you to zoom out from a particular area on the map. Using the mouse, "left click" on the Zoom In button and then: • Define a window by "left clicking" on a point and, keeping the mouse button depressed, "pull" the rectangle being formed until it covers the area of interest and release the mouse button.
	Full Extent	This button zooms to the full extent of the map. The full extent is the extent of the map displayed when the application is initially launched.
	Zoom to Previous Extent	When you press this button, the map extent changes to the extent that it was before the last extent change.
	Zoom to Next Extent	When you press this button, the map extent changes to the extent that is was previous to the new or last extent.
	Pan	The Pan tool is used to move the area shown in the map window to the left, right, up or down. This is accomplished in two ways: • Simply click on the map, and the map will be centered at the location you click • Drag the map by "left clicking" the mouse cursor, keeping the left button pressed, dragging the map window until the adjusted area of interest is displayed. When the mouse button is released, the map will redraw.

	Deactivate Navigation Tools	This button will deactivate the above navigation tools. In order to use the mark up tools, the navigations tools must be deactivated first.

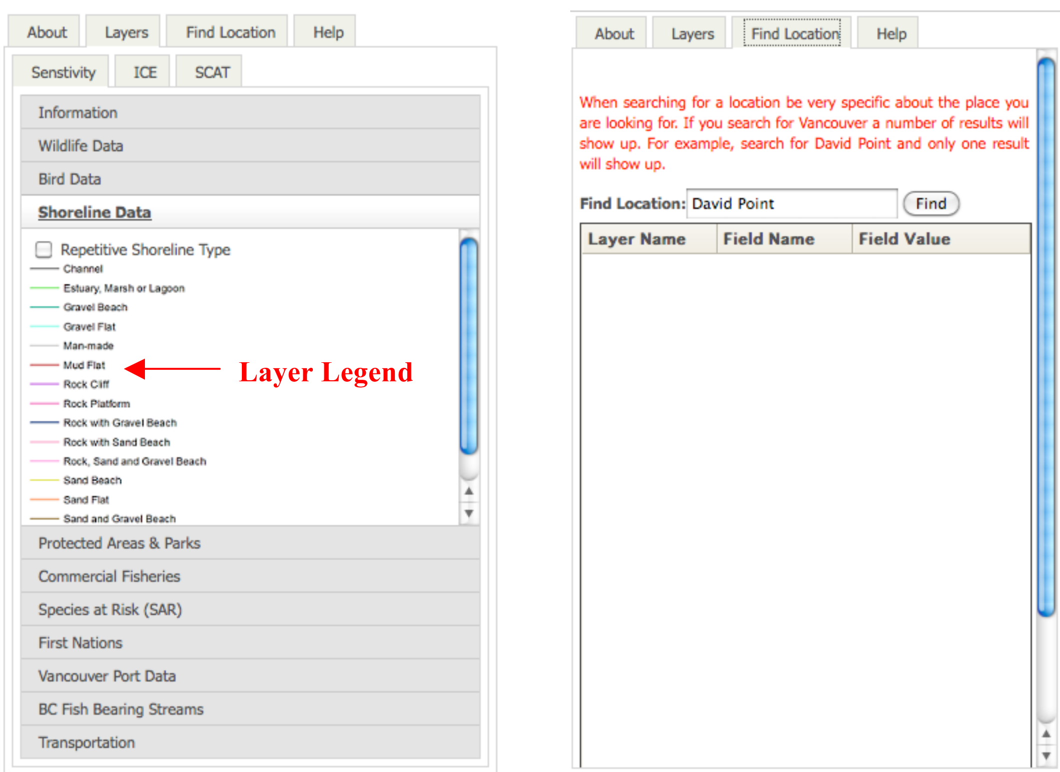
The mark-up tools can be used for marking annotations on the map. Tools include draw a point, draw a line and clear the map, see Table 4-3. The draw line tools can be used to measure straight-line distances on the different map services. Once a desired line has been drawn the distance will appear in the bottom left corner of the map, see Figure 4-2.

Table 4-3: Description of mark-up tools within the Toolbar section

Icon	Name	Usage
	Draw Point	This tool is used to draw points over the map at the extent you are looking at.
	Draw Line	This tool is used to draw lines on the map at the extent you are looking at. The Draw Line tool can also be used to calculate straight-line distances. When you draw a line you will see the distance appear above the latitude and longitude, in the bottom left corner of the map.
	Clear Mark-up	This button will clear any mark-ups on the map.
	Deactivate Drawing Tools	This button will deactivate the drawing tools. It is very important to deactivate these tools before using the navigational tools.

4.1.3 TOC Control Panel

The **TOC Control Panel** consists of four main tabs which include the About section of the application, Layers which are used to turn on/off layers in each service, the find location tool and the help section. Under the layer tab there are three sub-tabs that include Sensitivity, ICE and SCAT. These sub tabs have two functions, one is to access the different layers under each service and the second is to change between map services, see Figure 4-3(a). Users have the ability to turn on/off layers within the desired service. The layers can be accessed through slider bars. Appropriate legend symbols are within these sliders. It also provides an information section about each service when the sub tabs are clicked. The find location tool can be used to find any place in British Columbia and displayed on the map, see Figure 4-3(b).



(a) (b)

Figure 4-3: Table of Content control panel: (a) layer section, and (b) find location tool

The system combines an oil spill sensitivity mapping system, oil spill detection system, and a response system (SCAT) on one interface. Users have the ability to access each of these systems simultaneously. OSEMS has been implemented based on the framework proposed in Section 3.2. A combination of these systems provides users the ability to access the data effectively and timely. It also provides multiple stakeholders to access the same data using the same interface. This in turn can help in better planning and response to oil spills. This integration makes it simple to select data of interest from different systems, and easy-to-use functionality with a customized display.

4.2 Usability Evaluation

The user interface is a window to the users of the system, and hence it is important to develop an easy to use GUI, which will gain acceptance by the end user. It is important to gain feedback from the end users of OSEMS and critical to understand this information to determine if the system meets users' needs in relation to the problem of oil spills.

4.2.1 User Participation

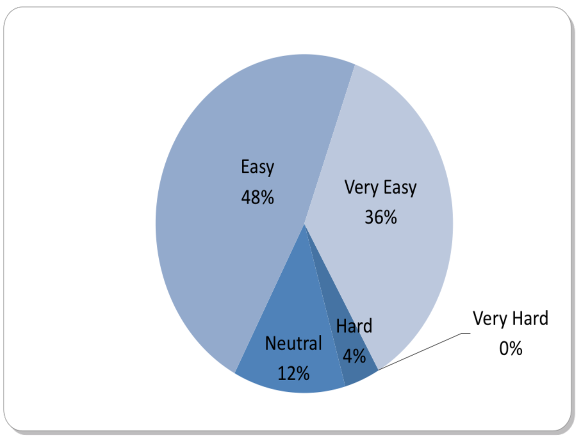
For usability testing, participants were selected randomly. In total 25 participants tested OSEMS. Out of the 25 participants, 6 were directly involved in oil spill planning in British Columbia, which is 28% of total participants. The remaining 19 participants were students and staff from the University of Waterloo. The main goal of testing OSEMS was to identify if the application is satisfactory from a usability standpoint. In the first section of the questionnaire, questions were asked to identify some key characteristics of the user, which include their ability use the Internet, web mapping applications and level of GIS skills. Most of the participants are novice users and intermediary users of GIS, which is consistent with the OSEMS users identified in Section 3.1. Additional characteristics of the participants are given in Table 4-4.

Table 4-4: Characteristic of participants

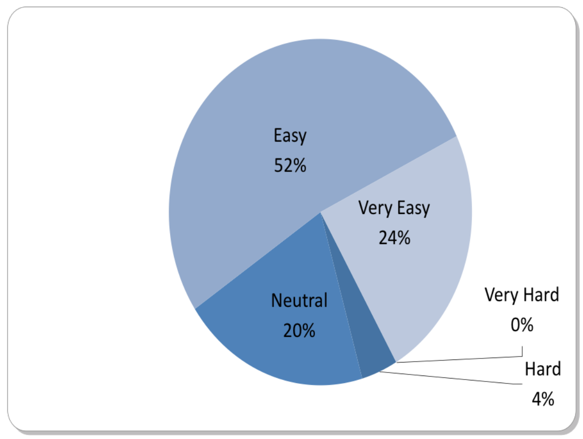
Characteristics	Possible Choices	Percentage Share [%]
Internet/PC Usage	Never	0
	Sometimes (1 to 5 times)	0
	Often (5 to 20 times)	4
	Frequent (20 to 40 times)	24
	Very Frequent	72
Web Mapping Usage	Never	4
	Sometimes (1 to 5 times)	36
	Often (5 to 20 times)	32
	Frequent (20 to 40 times)	16
	Very Frequent	12
GIS Skills	Novice User	44
	Intermediary User	44
	Advanced Users	12
Prior Oil Spill/GIS Knowledge	Yes	28
	No	72

4.2.2 Utility Evaluation

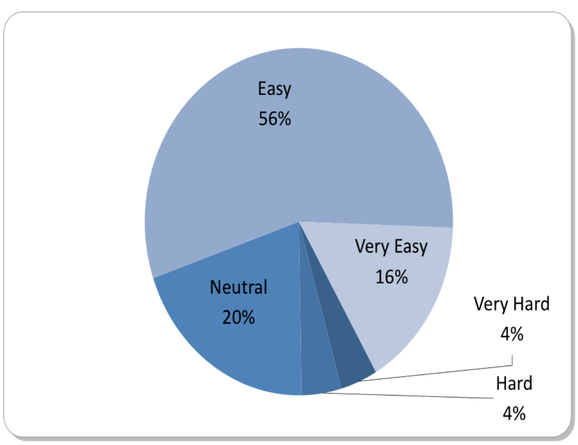
The participants were asked to evaluate the utility of some of the map functions provided. Utility refers to the functionality of the system. The functions provided within OSEMS were used to carry out the task as part of the scenarios. These functionalities were evaluated after the participants finished each scenario. To evaluate utility, participants were asked to rank difficulty of using the tools and also asked how useful the tools were. The levels of difficulty of some of the utilities are shown in Figure 4-4. Participants found the functionality of the application very easy to use. The TOC control uses sliders, which is a bit different from most GIS desktop applications. 36% of the participants found the sliders very easy to use. Mark up tools allow users to annotate the map, 52% of the participants found them easy to use.



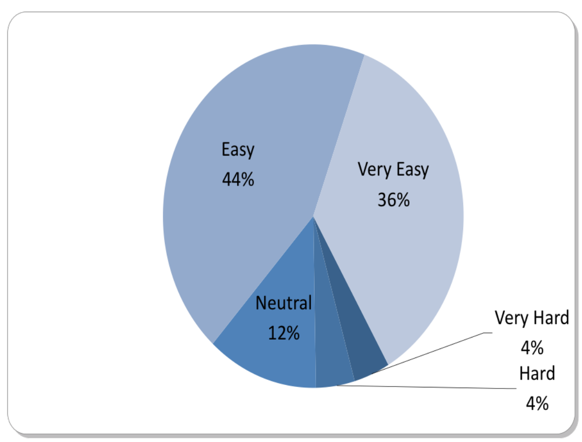
(a) Participant response on Navigational tools



(b) Participant response on Markup tools



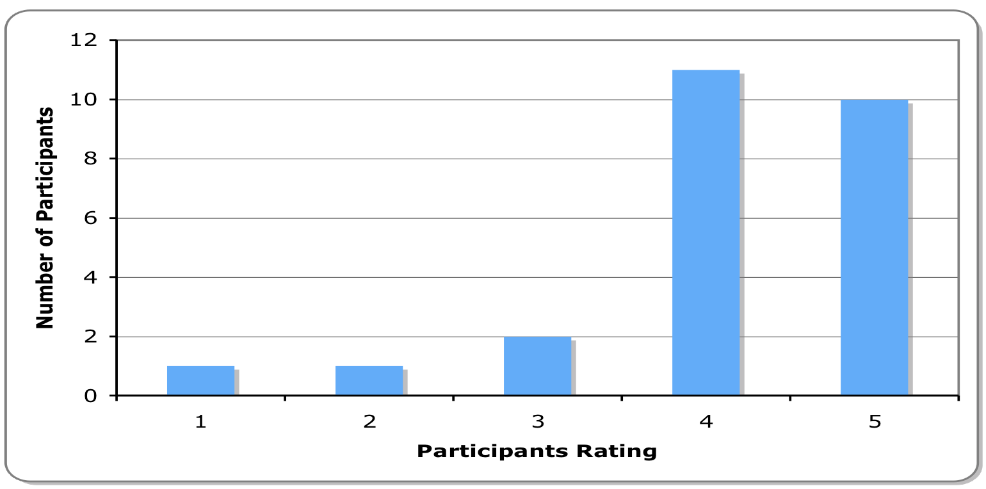
(c) Participant response on Find Location tools



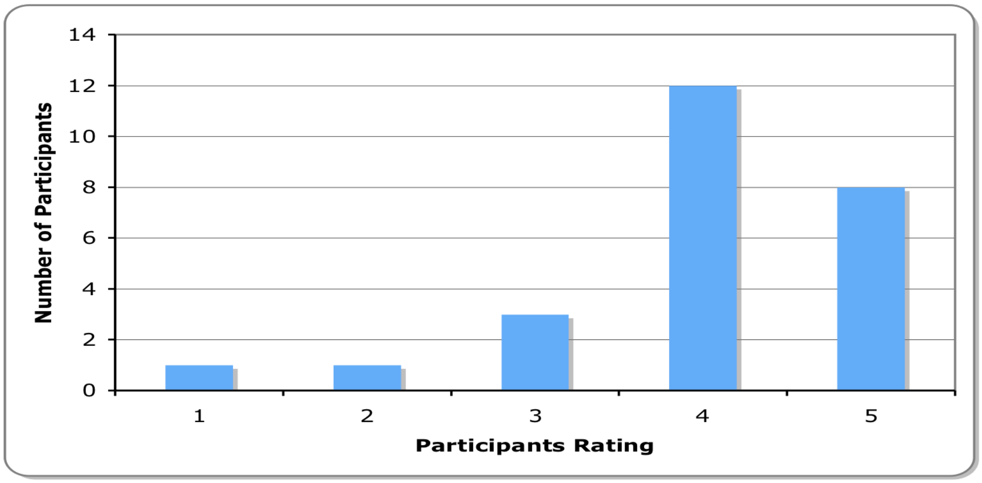
(d) Participant response on TOC control

Figure 4-4: Evaluating Difficulty of the functionality within OSEMS

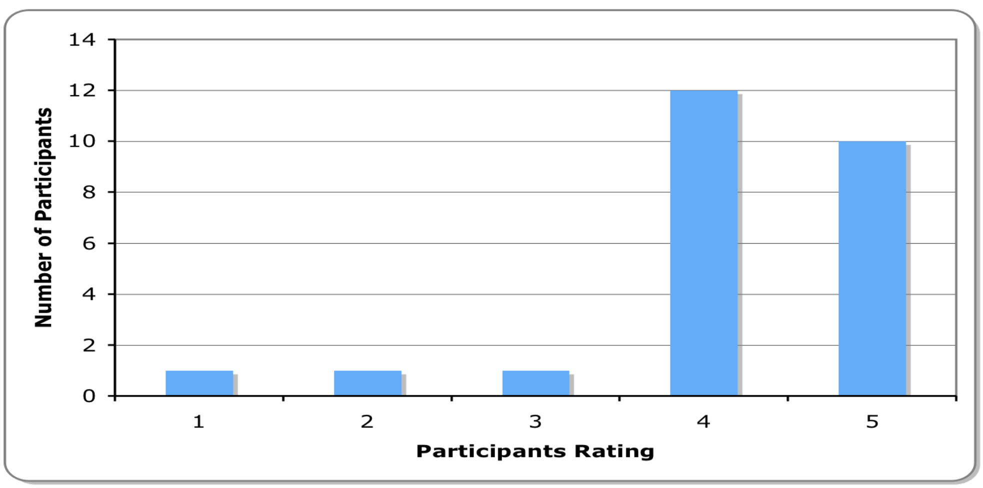
The participants were also asked to evaluate the usefulness of some of the functionality provided within OSEMS. Various other Web mapping applications have eliminated navigational tools. In the case of OSEMS, navigational tools were added and participants found them very useful. Participants were asked to rate the different tools on usefulness using a 5-point Likert scale from 1 to 5, 1 being not useful and 5 being very useful. On this rating scale, 21 participants rated the navigation tools between 4 and 5. A measuring tool was also added to OSEMS. Participants found the measuring tool very useful. For the measurement tools, 20 of the participants rated its usefulness between 4 and 5. Figure 4-5 presents the results on the usefulness of some of the functionality.



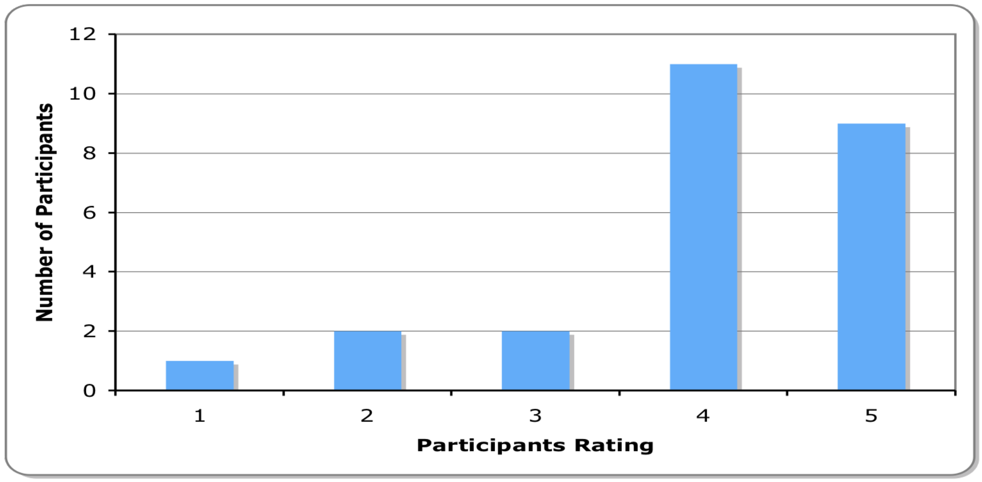
(a) Usefulness of Navigational Tools on a range from 1 to 5, 1 being not useful to 5 being very useful



(b) Usefulness of Markup tools on a range from 1 to 5, 1 being not useful to 5 being very useful



(c) Usefulness of TOC Control on a range from 1 to 5, 1 being not useful to 5 being very useful

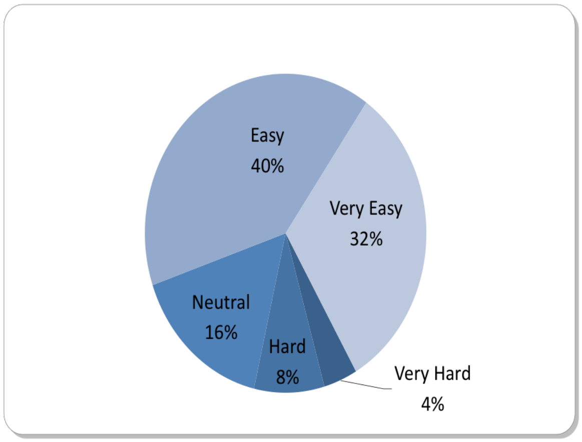


(d) Usefulness of Measurement Tool on a range from 1 to 5, 1 being not useful to 5 being very useful

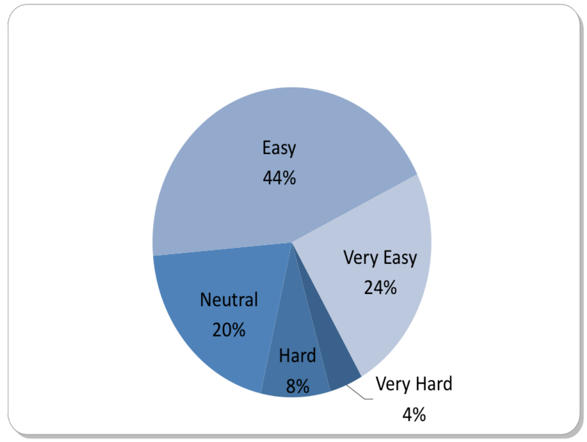
Figure 4-5: Evaluating Usefulness of the functionality of OSEMS

4.2.3 Usability Evaluation

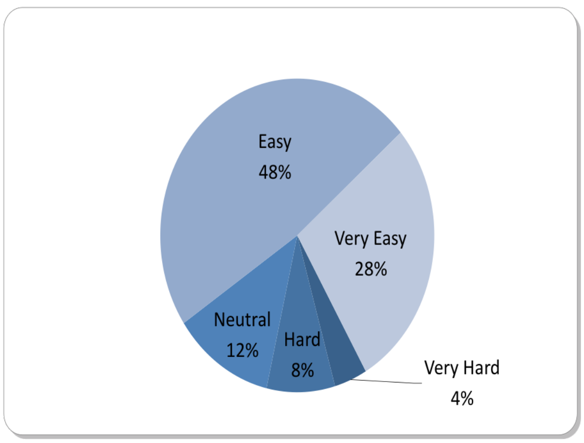
The participants were asked after each scenario if they were able to access the required information while completing the scenario. Usability determines how well the user can use the functionality provided to perform a task within an application. In the case of the three scenarios, the participants took on roles as an oil spill response officer, a Canadian Coast Guard officer, and a First Nation liaison. These would be the same individuals using OSEMS as a tool to perform their work. Most of the participants reported that OSEMS was able to deliver the required data to evaluate the situation in the scenario, see Figure 4-6.



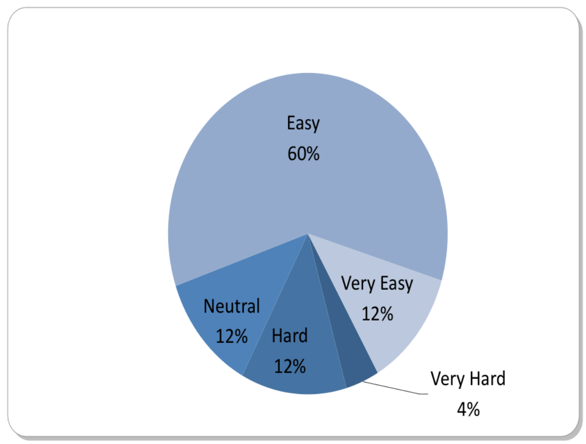
(a) Participant response on usability for Scenario One



(b) Participant response on usability for Scenario Two



(c) Participant response on usability for Scenario Three



(d) Participant response on overall usability for OSEMS

Figure 4-6: Usability evaluation of OSEMS

After working through the three different scenarios the participants were asked to rate the overall usability of the application. Figure 4-6(d) shows 60% of the participants rated OSEMS easy to use and 12% rated it very easy to use. From a usability standpoint, the participants were satisfied when using OSMES for each scenario. From a learnability standpoint, it was very easy for the participants to learn the application in a short period of time. Only 2 out of the 25 participants could not complete the scenarios.

Some differences were observed between the participants involved in oil spill planning in British Columbia and the other participants in the questionnaire. From the six participants directly related to oil spill planning it was observed that they were more familiar with the data being used. They were looking more at the functionality of the application and how it would help them achieve the given goal. The comments by this group were focused more on the integration of the system and the advantages and disadvantages of the integration process. One expert user noted, "This system would be very useful in British Columbia with some more functionality. The ability to integrate sensitivity mapping with coastal oil spill mentoring seems to me a good idea. Implementation of this system seems realistic and feasible."

Other participants who were not familiar with the data were more involved in understanding what the data was trying to portray. Some of the participants commented about not being able to identify sensitivities in the area since they lacked prior knowledge about the data used as part of the scenarios. Comments by this group were mainly focused on the functionality of the application.

4.2.4 Changes to OSEMS Based On User Feedback

The participants were asked to provide suggestions on how OSEMS can be improved to better perform the tasks at hand. A number of users reported that it would be beneficial to see all the data for the three different map services within one map and not have the ability to switch between services. They also reported that using the map tabs to switch services was not beneficial and was time consuming. Changes to OSEMS were made, as the main goal of usability testing is to incorporate the users' perspective in order to improve the system. However, the initial design of OSEMS was maintained. Initially, the user had the ability to switch between services using the map tabs and layer sub-tabs. Based upon the feedback, this functionality was disabled and the map tabs were removed. Also, users had the ability to view data from the different services in different maps. OSEMS was modified so that layers from the different Web services would appear within one map. OSEMS Version 2.0 can be accessed from the following link http://www.environment.uwaterloo.ca/u/ggomes/OilSpillApp/Oil%20Spill%20Emergency%20Mapping%20Systemt2.html.

4.3 Discussion on OSEMS Development Cycle

OSEMS followed a development cycle, which aids in the effective implementation of such a system. Developing an Internet GIS application for a specific problem is not as easy as buying the appropriate software or hardware. An implementation strategy had to be developed to meet the need of users. Figure 4.7 shows the development cycle of OSEMS, which has eight major stages.

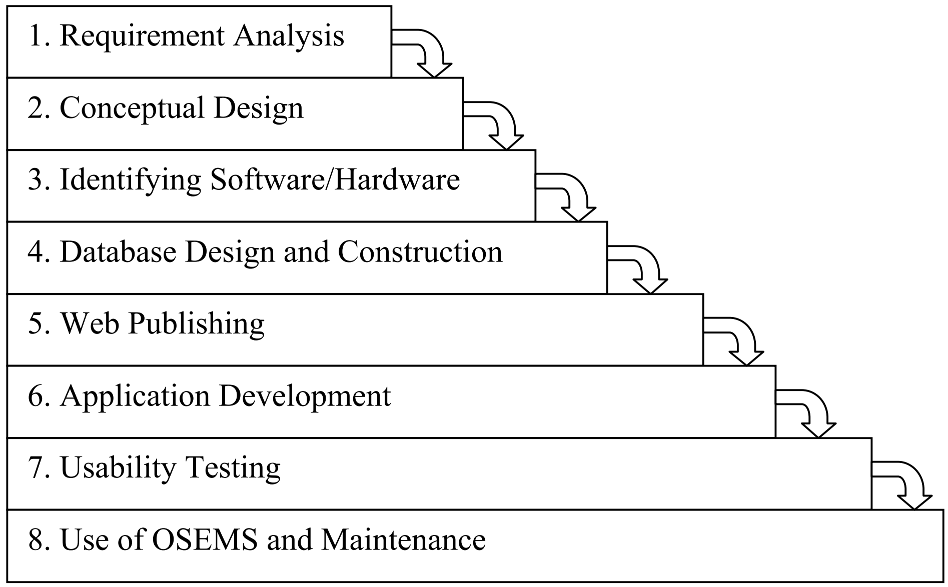


Figure 4-7: Development cycle of OSEMS

Initially a requirement analysis was carried out to identify the overall requirements of the system. The functionality as well as a detailed list of data required to developing OSEMS was identified. Requirement analysis is important for developing the conceptual design of OSEMS. A conceptual model was outlined to identify the structure of the system and how different systems can be incorporated into one interface. This step is important because it helps identify what can be implemented and what will have to be excluded. Identifying software and hardware is an important step when developing systems like OSEMS. It usually depends on the availability of funding for such a project. In the case of OSEMS, the software and hardware used were based on the availability programs at the University of Waterloo. This stage would be important for implementing such a system within a government emergency unit. The database design and construction is a critical step in the implementation of OSEMS. At this stage, data were pre-processed to fit the need of OSEMS. The database design includes how the data are symbolized, how different files are structured, identifying how active layers at different extents were identified, and how scale dependency for each layer was identified. Some other activities that have to be kept in mind at this stage include security levels for data access and defining the procedures for updating, expanding and maintaining the database. Once the database design and construction is completed, the maps can be published on the Web for application development. This stage is important as it provides a window to the user. The most important part of application development is taking users' needs into account, which was identified during the requirement analysis. An interface was developed to incorporate three different systems into one common interface. A combination of JavaScript, HTML and Dojo was developed for this application. Bug testing is also important as it helps eliminate any problems within the system. The next stage was to test the OSEMS from a usability standpoint, which included developing a questionnaire for the participants using real world scenarios on how the application would be used in reality. The last stage includes use of OSEMS and maintenance procedures being implemented for updating the system. This development cycle or a variation of this cycle can be used to implement OSEMS in reality. It is extremely helpful to follow such a cycle as it can help in improving systems like OSEMS and reducing the development time.

4.4 Problems Using ArcGIS JavaScript API

A **Table of Content** (TOC) control is a very important aspect of any GIS application. The ArcGIS JavaScript API does not have the ability to add the TOC information for map layers. The ability to see visible/active layers and also have the ability to turn them on/off on the map is essential. In the case of OSEMS, a TOC was a must. The TOC control had to be developed from scratch using explicit JavaScript coding and Dojo. There were many issues faced during the development process due to some of the limitations of the API. Multiple functions had to be developed to enable the TOC control to work simultaneously within the three different Web services. Another important aspect of a TOC is having dynamic legend/symbology information. ArcGIS JavaScript API did not have the ability to add symbology. For OSEMS, individual images were clipped for the .mxd project file and converted to a .png format. The symbology images were manually imputed into the TOC control-using HTML. This manual process can cause difficulties when updating or expanding the database, as additional programming time would be needed to do this.

Scale bar is an important aspect of any GIS application. ArcGIS JavaScript API does not have the ability for imputing a scale bar into the map. For OSEMS, a scale bar was implemented by creating a separate function. This function used a basic calculation to identify the scale of the map. As the extent changed the map scale was calculated and displayed on the map.

Initially in the requirement analysis, a printing tool was outlined as a feature that would be included within OSEMS. In order to develop such a tool a srvelet had to be deployed within the servlet container on the server side. Access to the server was restricted since it was operated by the MAD office at the University of Waterloo. As a result the print tool was not implemented in OSEMS.

4.5 Database Issues and Maintenance

In order to develop OSEMS, geospatial data were obtained from a number of government agencies in British Columbia. Most of the databases are updated and changed by the different agencies. In order to keep OSEMS operational, database maintenance plays a critical role. Some of the main components of database maintenance include database expansion, updating and enhancement (increasing performance). It is also important to keep in mind that changes made to the system should not affect the user in anyway. Users can be affected by major changes or expansions. If major changes are to be made there has to be a user review process in effect.

4.5.1 Data Agreements

For the implementation of OSEMS, a number of data agreements would have to be developed with different agencies for effective sharing of geospatial data. These data sharing agreements would allow for the acquisition of new versions of the data already being used. In order to keep OSEMS operational, these data sharing agreements will play an important role. When developing such systems quality control (QC) of the data is also necessary. Quality control is influenced by factors such as incompleteness, error and topological errors. Quality control of the data used in this study was assumed a responsibility of the sources as most of the data came from secondary sources. For OSEMS some of the data may contain errors and thus it is important to determine which data has had QC.

A number of datasets that could be useful were not obtained when developing OSEMS due to security and data sharing issues. The data that were not obtained are identified in Section 3.3. Some of these datasets are important for sensitivity mapping. Special agreements would have to be developed with the agencies that have data. To publish this information on the Web, a passwordprotected system would have to be implemented in order to assure the security of those restricted datasets.

4.5.2 Data Updating and Maintenance

Once the new databases have been acquired it is important to update the existing data. In order to do this the .mxd projects files must be updated using ArcMap. The databases would also have to be optimized and symbolized appropriately. Some of the issues include changing the JavaScrip code in the application file to incorporate changes. It would be easier to make a maintenance schedule for making changes to the existing data which allows for a one-time update to the system. This will help reduce the amount of time the system would have to be shut down. If new data has to be added to the system, the JavaScript code will also have to be changed to incorporate these additions. Any expansions and updates will have to be implemented on a fixed schedule in order to reduce inconveniences to the user. Oil spills can happen any time and it is important to have OSEMS running 24/7 in order for it to be an effective tool.

The oil spill detection system that is the CIS section of the application would have to be updated depending when a spill has been detected off the coastline of British Columbia. In order to carry out this task, operators of the system would have to update the .mxd project file when a spill is detected. This process could be automated to reduce the time required to publish the data on the Web.

A backup system should be in place when developing such a system. If the system ever crashed due to technical issues, a backup system can be used to restore OSEMS. This will prevent loss of data as well as help restore the system in a timely manner. A backup schedule can also be implemented along with the schedule in order to keep the backup system updated.

4.6 Performance Issues

During the application testing, it was reported that some users found that displaying the map takes time. Web mapping systems process data on the server side. Hence, the performance of the system largely depends on the network speed, bandwidth and the performance of the server. In order to develop OSEMS a map server in the MAD office was used. The server is very old and performance is much lower than newer servers and it was the main reason for slower performance. This thesis does not discuss server performance as the server is maintained and operated by the MAD office.

The simplest way of dealing with performance issues is to provide the end user with some indication that a user action is being processed. Web mapping applications have the ability to access data from different sources and view them in one map interface. Most data sources differ in the time it takes to respond to a user's request. Once the data request is returned to the browser the application renders map data. Sometimes some portions of data are visible before others sections. Hence, it is important to let the user know that the application has not finished loading the map data. In order to inform the users the data are still loading, a loading icon was used. A function was developed that will show the loading icon when the map data is not completely loaded. This did not solve the performance issues but just provided the user with the ability to know if all the data have been loaded.

4.7 Chapter Summery

In this chapter, the results derived from the implementation of OSEMS have been presented. The OSEMS application was evaluated using a questionnaire. This chapter outlines the usability testing and the results of the testing process. The results prove that the utility and usability of OSEMS are satisfactory. It also proves that OSEMS is very learnable. The development cycle of OSEMS, database maintenance issues and performance problems were discussed.

CHAPTER 5

Conclusion and Recommendations

This chapter outlines the conclusions derived from the results of this study. Recommendations for future research and enhancement of OSEMS are presented.

5.1 Conclusion

The oil spill pollution problem is inevitable and unpredictable and causes service damage to the environment, economy and society. Oil spills cannot be evaded but a number of mitigation measures can be put in place to reduce the impact and severity of oil spills. This thesis develops a system that integrates a sensitivity mapping system, oil spill detection system and a response system (SCAT). A framework for integrating these systems is proposed. A system called OSEMS was developed based on this framework. The system was also tested from a usability standpoint, which proved that it is easy to use and effective in delivering the needs of the end users.

Possessing a system for viewing environmental sensitivity data is important for oils spills. Many important decisions can be made when deploying resources during clean-up operations and monitoring the impact area when using such a system. As part of this thesis an Internet mapping system was developed for British Columbia. A framework was proposed to integrate a sensitivity mapping system, oil spill detection system and a response system (SCAT). Integrating these systems is beneficial as stakeholders can view all this data within one interface and effectively make decisions based on the data. It also allows for faster dissemination of data within the oil spill community. Internet GIS provides a framework for developing such a system. It is being used to develop many emergency-mapping systems and now this technology is being utilized for managing oil spills. Internet GIS provides for fast access to data and helps in reaching a wider audience. ArcGIS Server is commercially available software that was utilized to create the OSEMS application. ArcGIS Server provides the ability to develop custom applications that fit the needs of the user. The client viewer was developed using ArcGIS JavaScript API. The OSEMS application was developed, by integrating ArcGIS JavaScript API, Dojo and HTML to create a robust and highly functional Web mapping application. When developing such a system it is important to follow a development cycle, in the case of OSMES an eight stage cycle was used.

In order to verify the effectiveness of OSEMS from a usability standpoint, testing was carried out. As the use of Internet GIS has grown there has been a need to understand the usability of applications from a user's perspective. In the past not much attention was given to usability testing. The functionality and usability of OSEMS was tested using a questionnaire. Participants were first asked to learn the application in a short training session. After they learned the application they were asked to work through three scenarios. These scenarios were developed based on how OSEMS would be used in reality. The participants were asked to evaluate the functionality and overall satisfaction of using OSEMS to carry out the given task. They found the application very easy to use. Based on the three scenarios, 60% of the participants rated OSEMS easy to use and 12% rated it very easy to use. This proved that OSEMS is satisfactory from a user's standpoint. The participants also found the incorporation of navigational tools and measurement tools very useful. Users also reported that they would like to view all the data within one map and not need to switch between services. Hence, changes were made to OSEMS based on user feedback.

Oil spill monitoring and management has greatly benefited from the use of Internet GIS. Some of the works carried out in this thesis have already been implemented in Canada and other parts of the world. This is the first attempt to develop such a system in British Columbia. It is also the first attempt to integrate different systems used for oil spill planning into one interface. The lessons learned in the implementation of this system point out that there is a need for an easy to use GIS applications for a specific problem like oil spills. The combination of systems is effective and beneficial. The integration of GIS, remote sensing and real time visualization systems can lead to the development of a totally integrated system to monitor and effectively mange oil spills. This will also lead to better oil spill contingency planning.

5.2 Recommendations for Future Research

Most mapping systems would have to be implemented over different stages as the end user utilizes it. Once the functionality provided have been familiarized by the end user, new and improved functionality can be developed. Some of the most important features to be developed would be an improved search tool that can search not only names but as well as latitude and latitude, map printing capabilities, analysis tools that can calculate distance from oil slick to land automatically and a report generating system that would produce reports with the environmental sensitivities in a given region.

5.2.1 Integrating Geographic Response Plans

In order to prevent spills from happening and reducing impacts when a spill occurs, contingency planning is critical. Actions taken during the initial hours of response to a spill can be critical to the effective protection of sensitive areas. Timely protection depends upon having a structure in place to systematically guide responders (Mutter et al., 2003). These plans are known as geographic response plans (GRPs). GRPs are site-specific response plans. They include response strategies tailored to specific areas and are meant to minimize impact on sensitive areas threatened by the spill. Each GRP has two main components, that is, to identify sensitive natural, cultural or significant economic resources and to describe and prioritize response strategies. A GRP combines local knowledge of sensitive areas and are integrated with proven operational and logistical techniques into a document, which provides specific guidance for a rapid response. Usually GRPs include site maps, photographs, and tables of information about resources to protect, operational techniques to carry out the protection, equipment and personnel needs and site access (Robertson et al., 2000). Sites are selected based on environmental sensitivities, the risk of an oil spill occurring and the ability to protect the site. After they are developed they are sometimes tested in the field to ensure feasibility (Heimowitz, 2005). GRPs are developed through public workshops involving different levels of government and emergency response experts. In British Columbia GRPs have yet to be developed, but there are plans for development in the near future. GRPs have been developed in some states in the US, for example the Washington State Department of Ecology has developed GRPs along the entire coastline of the state as well as inland sensitive river systems. The GRPs are displayed as a set of static clickable maps, which are linked to the reports.

Some states in the U.S., like Massachusetts, have proposed the development of a Web GIS system for displaying these plans. A GRP viewing system can be integrated with OSEMS. Users would have the ability to access the GRPs for specific areas using OSEMS. This would be beneficial, as it would allow responders to identify sensitivities in real time as well as access response strategies.

5.2.2 Integrating Weather Data

Weather has been recognized as one of the most important factors in predicting oil spill fate and behavior (Lehr & Simecek-Beatty, 2000). It is very important to have weather forecast information during an oil spill. Forecast information is an important factor of oil spills as it can influence the clean-up operations. Incorporating coastal weather information in such a system is important as it provides users with the ability to deploy resources and develop clean-up operations effectively. At this point in time there is no WMS for coastal weather being broadcast by Environment Canada. Once a coastal and marine WMS is broadcast it can be incorporated with OSEMS. Users would have the ability of view weather forecast information along the coastal area of British Columbia. This will make the system more dynamic and will provide real time data for responders.

5.2.3 Caching Base Maps

Implementing a map caching or tile server is a very useful method to make the map rendering much faster. When a map cache is used, the server draws the entire map at different scales. It saves copies of the map in an image format. When a user requests to view a map, these images are used. It is much easier for the ArcGIS Server to process a request when the map services are cached. Some of the main advantages of using cached maps are that performance is much higher and the quality of the map is not affected. The disadvantages are that it takes up large amounts of storage space; it is time consuming and it can only be used with layers that do not have to be updated very frequently. In the case of OSEMS it would be beneficial to cache the base maps being used at different zoom extents. This will help increases performance of the system and help for faster rendering of maps. A cached map service for the base maps was not implemented due to storage space constraints.

5.2.4 Usability Testing

Usability is often not considered when evaluating most GIS and Web GIS applications. According to (Pinto & Onsrud, 1993) ease of use is one of the most important factors in overall satisfaction when implementing GIS applications. In most cases when applications like OSEMS are developed, usability questions arOSde left out. Acceptance by the user is very important when developing such applications. It is important to incorporate user input at every stage of development. Usability engineering is a continuous process, which should be carried out during the entire development cycle of a system. In the case of OSEMS, many tools and functionality have to be incorporated. It is very important to incorporate the user at every step of the development process. As part of this study only 6 participants were directly related with oil spill planning in British Columbia. More participation within the oil spill realm would be essential for the overall acceptance of OSEMS. The testing carried out as part of this study demonstrates the importance of usability engineering for GIS and the possibilities of developing methodologies within this field. The most important thing learned in this study when carrying out the usability testing is that ease of use and usability are concepts that are very difficult to understand when developing such applications. Simplistic methods such as developing a questionnaire can be used to understand if the system meets the end users needs.

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APPENDIX

Questionnaire Used to Test OSEMS

Introduction

This application has been developed to view sensitivity data in relation to oil spills in British Columbia. This application has been developed using Internet GIS technology. The main reason for developing this application is so that is can be used during an oil spill in British Columbia. Right now there is no sensitivity mapping system implemented in British Columbia for use during oil spills. This application also integrates other tools that are used in the oil spill planning that produce GIS data. Theses tools include Oil Spill Detection Using RADARSAT and Shoreline Cleanup Assessment Technique (SCAT).

In 2006, Canada started to monitor marine coastal areas for oil spill pollution using satellites with Synthetic Aperture Radar (SAR). Canadian Ice Services (CIS) implemented this program. The name of this project is ISTOP and it was funded by the Canadian Space Agency. The ISTOP program uses RADASAT-1 data to identify potential oil pollution from ship sources. Oil waste is illegally discharged by ocean vessels into coastal waters and this has a severe impact on the marine ecosystems. This detection process produces data in GIS format. The developed application integrates detection data so that it can be viewed simultaneously with sensitivity data. It also helps in data dissemination to multiple stakeholders.

The Shoreline Cleanup Assessment Technique (SCAT) process is now an important part of oil spill clean up and it has been adopted in many countries around the world. There are different variations of SCAT based on the spill, they include aerial surveys by one person, or they can include ground surveys my multiple teams. Once a spill occurs and oil has impacted the shoreline, it is important to understand the extent and amount of oiling that has occurred on the shoreline. An assessment technique called the Shoreline Cleanup Assessment Technique (SCAT) is used to survey the impacted area. Some of the main components of the SCAT include assessment surveys, data management and data application. This application is designed to view the results of the SCAT, which are in GIS format. This provides rapid dissemination of data over the Web to multiple stakeholders. It also provides the user with the ability to view sensitivity data alongside SCAT to understand what has been impacted and needs to be fixed.

Three different servers have been integrated within this application. The user has access to oil spill sensitivity data, oil spill detection data and SCAT data. The user has the ability to view all of this data within one interface. It also gives the user the ability to turn on/off different layers of their choice and view data simultaneously between servers.

Your Background Information:

How often do you use the computer and Internet in a week?

❑ Never ❑ Sometimes (1 to 5 times) ❑ Often (5 to 20 times) ❑ Frequent (20 to 40 times) ❑ Very Freq

How often do you use web-mapping applications in a week? (google map, map quest or other Web-GIS application)?

❑ Never ❑ Sometimes (1 to 5 times) ❑ Often (5 to 20 times) ❑ Frequent (20 to 40 times) ❑ Very Freq

How would you classify your self as a GIS user?

❑ Novice User ❑ Intermediary User ❑ Advanced Users

Do you have any prior knowledge of the use of GIS for oil spill planning?

❑ Yes ❑ No

If yes, please explain in what areas you have experience?

____

____

____

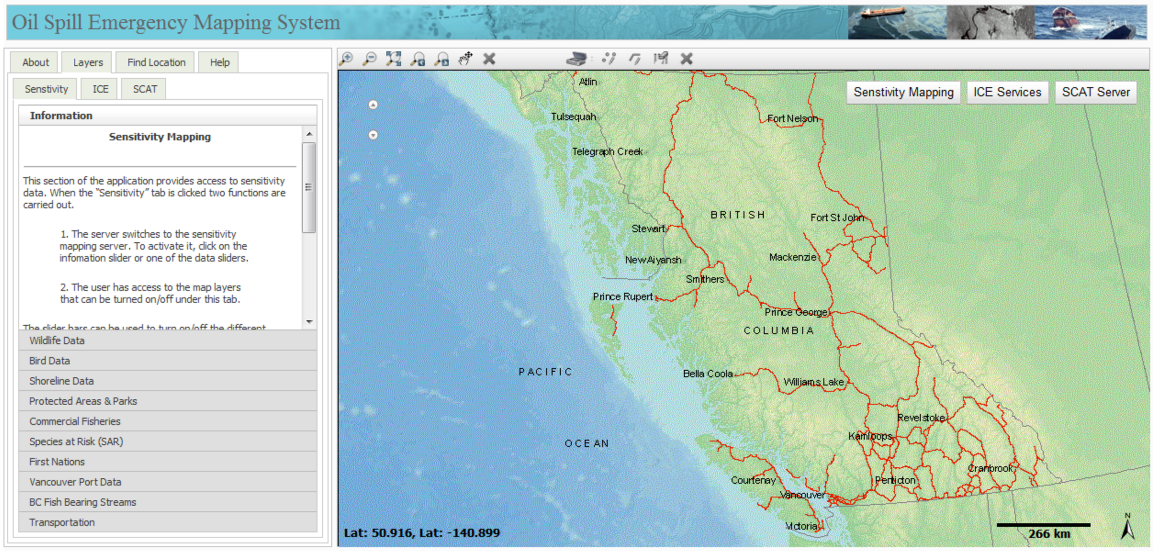
____

Section 1: Familiarizing Your Self with the Application

This section of the questionnaire is designed to make you familiar with the Oil Spill Emergency Mapping System (OSEMS)

1. First you will need to access the application, this can be done by going to the following web site (http://www.environment.uwaterloo.ca/u/ggomes/).

2. You will see the screen below; make sure you wait until the map loads before you move on to the next step.

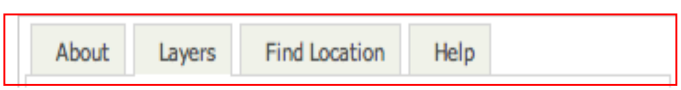


3. You will want to maximize your browser. You can do this by clicking on the F11 key on you key board.

4. In this section we will explore some of the main tools and tabs that make up this application. They include:
   - Tabs and information/layer sliders
   - Navigational and mark-up tool bar above the map
   - The Map tabs within the map

5. We will start by exploring the tabs and sub tabs in the left of the application.

6. There are four main tabs. They are About, Layers, Find Location and Help.



7. Now explore each of these tabs.

   - **About:** Shows the about page for this application.

   - **Layers:** Opens the layers for the three different servers within this application. Within the layers tab there are three more sets of tabs that include Sensitivity, ICE and SCAT.

- **Find**: Allows you to easily find specified locations on a map.
- **Help**: Opens a page that contains help for all tools and tabs in the application.

8. Once you are done exploring the tabs go back to the layer tab. The layer tab consist of three sub tabs they include Sensitivity, ICE and SCAT.

- **Sensitivity:** Used to control the different sensitivity data layers under the sensitivity-mapping server. It is also used to switch between servers. To change servers, click on the information box or the other sliders within this tab.

- **ICE:** Used to control the different ICE services' data layers under the "Ice Services Server". It is also used to switch between servers. To change servers, click on the information box or the other sliders within this tab.

- **SCAT:** Used to control the different SCAT Servers' data layers under the "SCAT Server". It is also used to switch between servers. To switch servers, click on the information box or the other sliders within this tab.

9. Lets try using these tabs. When you click on the "ICE" tab you will see different sliders than the ones shown in "Sensitivity" tab. Now click on the slider named "Oil Spill Detection 2007". Once you click on it you will see that the server changes and the map looks different.

10. Now lets turn on a layer under this server. Check the box next to "Feb 03 Cat-B1 Overview". You will see the layer appear in the map. A red overview polygon will appear.

11. Try this with the SCAT tab and once you are done, return back to the "Sensitivity" tab and click the informational slider to change the server.

12. Now we will look at the Navigational tools. These tools are used to navigate within the map.

13. Explore theses tools. If you have any problems refer to the "Help" tab.

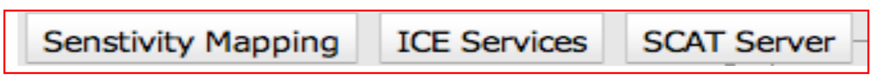
14. Now we will look at the Mark-Up tools. These tools are used to make drawings on the map (lines and points).

15. The Draw Line tool can also be used to calculate straight line distance. When you draw a line you will see the results show up above the latitude and longitude in the bottom left corner of the map.

Before you use these tools make sure you deactivate the navigational tools my clicking on the “Deactivate Navigation Tools”. Once you are done using the mark-up tools make sure you deactivate them using “Deactivate Drawing Tools”.

16. After making some mark-ups, make sure you clear them by using the Clear Markup button.

17. Lastly we will explore the Map tabs. They include three tabs: Sensitivity Mapping, Ice Services, SCAT Server. Theses tabs are used to switch between servers easily when looking at data in each server. Explore them by clicking on each map tab. When changing between map tabs, the map view changes at the same scale.



18. If you have questions about any of the tools and tabs, feel free to ask me before we move onto the different scenarios.

Section 2: Scenario One

In this scenario you will consider yourself an oil spills response officer working for a federal agency who is involved in responding to oil spills. A citizen has called the emergency line and reported an oil spill. They say the have seen a fairly large slick of black oil near the Tyee Spit in Campbell River. The caller reports that the oil is moving towards Grouse Island.

- Location: Tyee Spit
- Time: 1300 hrs

Another call comes in from a different citizen saying they have seen oil closer towards Grouse Inland. They also believe that it will wash up into the cove shortly.

- Location: Near Grouse island
- Time: 1315 hrs

As an oil spills response officer your job is to know what is at risk in that area. You are not familiar with that location so you will use the OSMIS application to gain background on the area of the spill. Right now your main concerns are with shoreline type and birds in the area.

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1. Launch the application by going to the link provided in section 1. Wait for it to load before you start using it.

2. The first thing you want to do is search for the location that the citizen has given you. Click on the "Find Location" tab, type in **Tyee Spit** and hit the find button.

3. You will see a red and green circle on the map indication the location. Now you will want to zoom into this area. Use the zoom-in tool to do this.

4. Once you have zoomed-in enough to see all the road names and other annotations you are ready to see what is at risk.

5. Now switch back to the layers tab and make sure you are under the Sensitivity sub tab.

6. At this point you want to check out the shoreline type and if there are birds in the area. You can do this by turning the layers on.

7. First click on the Bird Data slider and check the box next to “BC Bird Colonies”. Do the same thing with Shoreline Data Slider.

8. Now zoom in and out to examine the area and gather some information about what is at risk. Also, make sure you use the pan tool as well as the previous and next extent tools.

9. Immediately you will notice that the area is sensitive. Quathiaski Cove has many beach areas where oil can wash up and also a bird colony.

10. As an oil response officer immediately you will get a sense as to what is at risk in the area. This in turn will help you notify the appropriate agencies that will help protect this area or deploy resources needed for clean up.

Questions:

1) How easy was it to use the map navigation tools above the map?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

2) How easy was the Find Location tab to use?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

3) How easy were the layer sliders to use?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

4) As an oil response officer using the application, how easy was it for you to get the data you were looking for?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

5) Please make a note of any difficulties or problems you encountered while working thought this scenario:

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Section 3: Scenario Two

In this scenario we will be taking a different approach than the last scenario. In this scenario you are a Coast Guard Officer who works in the emergency unit and responsible for oil spills. You are responsible for deploying booms and other equipment when a spill occurs. You are also responsible for gathering information about ships in the area of the spill and passing it on to enforcement agencies.

On February 3, 2007 at about 9am you get a call from the Canadian Ice Services ISTOP program. The have detected on oil spill near Vancouver close to the University of British Columbia. They have rated it a Category B1 spill. Knowing this is close to the port of Vancouver you want to deploy resources so no oil will impact shipping routes in the area. Your first task is to see where the oil is and then try and develop a booming strategy. Also, you are interested in the birds and wildlife in the area. As part of your operations procedures you must notify the environmental agencies about any wildlife and birds in the area of the spill.

____

1. Launch the application by going to the link provided in section 1. Wait for it to load before you start using it.

2. Now click on the ICE Tab and then click on the information slider. Make sure you read the information section to understand the different categories of spills.

3. You will see that the map has changed. Now click on the “Oil Spill Detection 2007” slider. The first title is Feb-03-Category 1B. This is the one you are interested in.

4. Turn on all the layers related to this incident. Clicking on the check box next to them can turn them on.
    - Feb 03 Cat-1B Overview
    - Feb 03 Cat-1B Ship Target
    - Feb 03 Cat-1B Oil Slick
    - Feb 03 Cat-1B SAR Image

5. Now zoom-in near Vancouver and as you zoom in the SAR image and other layers will turn on.

6. Examine the area and now you will want to calculate the distance from the slick to the closest shoreline. For this you will use the mark-up tools. Turn off the Feb 03 Cat-1B SAR Image before you do this.

7. First deactivate the navigational tools by clicking on the Deactivate Navigation Tools button.

8. Using the Draw Line tool, draw a line from the oil slick to the shoreline.

9. Record the distance here _________. You will see that the oil is very close to the shoreline and can impact the shoreline. You need to respond to the spill.

10. Now that you know where the spill is you want to develop a booming strategy[1] to show to other crewmembers.

11. Clear the screen using the Clear Mark-up Tool.

12. Now use the mark up tools to draw lines and points to develop a booming strategy. It should look like the image below.

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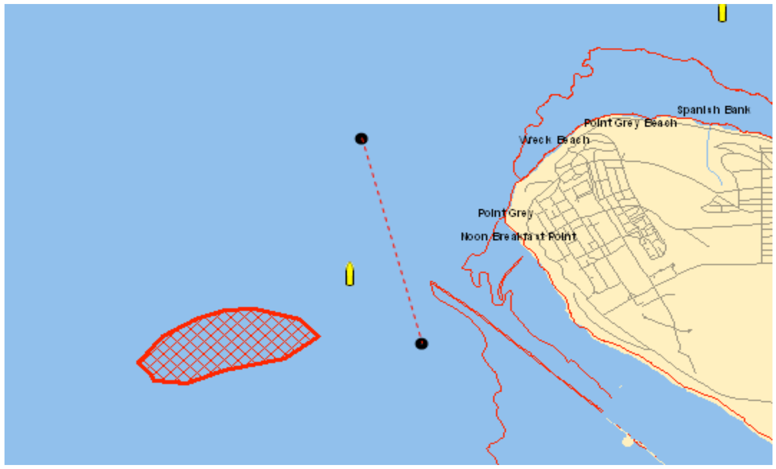
[1] **Booming Strategy:** A boom is a floating, physical barrier, placed on the water to contain, deflect or divert oil. Usually strategies are developed to carry out one of theses tasks. In this scenario we are trying to contain the oil.



13. Now record the distance here _________. This will be the approximate length of boom required to develop the booming strategy.

14. Now you will want to see if there are any birds and wildlife in the area. So you will have to switch servers using the Sensitivity tab. Click on the sensitivity tab and then click on the Wildlife Data slider. You will notice that your mark ups have remained there.

15. Now turn on the Wildlife and Bird Data by using the sliders.

16. Immediately you will notice that there are birds and wild life in the area and you will have to notify the appropriate Environmental agencies.

17. Now we will use the map tabs to change between servers. Click on the "Ice Services" map tab in the map to change the server. Then click on the "Sensitivity Mapping" map tab. Keep doing this to look at the different data. Clear the markups by clicking the Clear markup button and then click on the Deactivate drawing Tool button.

Questions:

1) How easy was it to use the mark-up tools above the map?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

2) Do you find the measure distance feature useful?

	1	2	3	4	5	
Not Useful	❑	❑	❑	❑	❑	**Very Useful**

3) Was it easy to switch between servers using the map tabs?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

4) Do you find the map tabs useful since you can already switch servers using the layer tabs?

	1	2	3	4	5	
Not Useful	❑	❑	❑	❑	❑	Very Useful

5) As a Coast Guard Officer using the application, how easy was it for you to get the data you were looking for?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

6) Please make a note of any difficulties or problems you encountered while working thought this scenario:

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Section 3: Scenario Three

On August 4, 2006 at Squamish dock terminal, just north of Vancouver the *M/V Westwood Anette*, departing under tow from the Squamish docks during high wind conditions, punctured a fuel tank on a metal piling. This caused approximately 29,000 liters of bunker fuel to be released into the environment. The high winds blew the oil on the shore near the terminal and into the estuary of the Squamish River; this impacted the shoreline in Howe Sound. In this scenario you are a First Nation liaison and you are working for the local First Nation band in the area of impact. Your job is to work with government agencies and other organizations to make sure all the concerns of the band are taken care of. As part of your job you have to keep the local band Leaders up to date about what is going on with the clean up efforts and what First Nations resources have been impacted. On August 11, 2006 government officials carried out a Shoreline Clean-up Assessment Techniques (SCAT). You want to access the results of the SCAT that is the oiling conditions in the area of impact. You want to identify any First Nation land that has been impacted.

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1. Launch the application by going to the link provided in section 1. Wait for it to load before you start using it.

2. Click on the "SCAT" layer tab and then open the Squamish, BC- August 11, 2006 slider. Turn on the Shoreline Oiling Conditions layer.

3. The server will change and you need to zoom into the red overview polygon or you could use the "Find Location" tab to search for Squamish Harbour.

4. Now examine the oiling conditions in the area. After you have done this you will want to see first nations sensitivities in this area.

5. Click on the "Sensitivities" Layers tab and open the First Nations Slider. Turn on First Nations Reserves layer. This layer provides information about first nation land in British Columbia. Pan around the area to get an understanding of what is at risk.

6. Now switch servers back and forth using the map tab (Sensitivity Mapping and SCAT) to see if any first nation land has been impacted.

7. Immediately you will notice that a section of the Defense Islands has light oiling. None of the First Nations land at the mouth of the river has been impacted.

Questions:

1) As a First Nation liaison using the application, how easy was it for you to get the data you were looking for?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

2) Please make a note of any difficulties or problems you encountered while working thought this scenario:

____

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3) Over all how hard was it to use this application?

❑ Very Hard ❑ Hard ❑ Neutral ❑ Easy ❑ Very Easy

4) Please rate the usefulness and complexity each of the tools and tabs in this application on a scale of I to 5

<u>Navigation Tools</u>

	1	2	3	4	5	
Not Useful	❑	❑	❑	❑	❑	Very Useful
Complicated	❑	❑	❑	❑	❑	Simple

Mark-up Tools

	1	2	3	4	5	
Not Useful	❑	❑	❑	❑	❑	Very Useful
Complicated	❑	❑	❑	❑	❑	Simple

Main Map Tabs

	1	2	3	4	5	
Not Useful	❑	❑	❑	❑	❑	Very Useful
Complicated	❑	❑	❑	❑	❑	Simple

Layer Tabs

	1	2	3	4	5	
Not Useful	❑	❑	❑	❑	❑	Very Useful
Complicated	❑	❑	❑	❑	❑	Simple

Map Tabs

	1	2	3	4	5	
Not Useful	❑	❑	❑	❑	❑	Very Useful
Complicated	❑	❑	❑	❑	❑	Simple

4) Can you recommend any further improvements to the application?

5) Do you have any general comments regarding this research?

Thank you for your time and effort in participating in this research. If you have any further comments or suggestions please feel free to email me at ggomes@uwaterloo.ca. A copy of my thesis will be sent out if you at your request.