Environmental Health and Safety data integration using Geographical Information Systems

by

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A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Environmental Studies
in
Geography

Waterloo, Ontario, Canada, 2008

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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

Environmental Health and Safety (EHS) departments in many organizations are faced with two interrelated problems which limit their ability to make accurate decisions based on quality data. First, many EHS departments follow a reactive business management model and need to work towards a proactive continuous improvement model to better manage EHS. The second is a lack of data integration and interoperability between the numerous different EHS data sources and systems. EHS departments are challenged with managing large quantities of data generated through tracking and monitoring programs to continuously improve EHS performance. EHS data can be in many forms paper, digital files, spreadsheets, images, relational databases and proprietary software applications. EHS data have strong spatial relationships, which makes the use of Geographical Information Systems (GIS) a very cost effective and feasible solution for integrating and managing EHS data. This thesis will outline how GIS brings to EHS the advantages of traditional IT methods with the added benefit of spatial analytical operations such as map overlay, relationships and querying, and informative visual presentation through maps, floor plans, and imagery through the implementation of a GIS database for EHS called GeoSpatial Environmental Health and Safety (GEO-EHS).

Acknowledgements

I have been asked many times over the past twenty months by friends and family “it must be allot of work completing a Masters degree on a part time basis while working full time”? I always answered that it did not feel like work to me and I enjoyed what I was trying to achieve. Much of this can be attributed to the strong support that everyone has provided throughout the whole process.

I would like to thank Janet Baird-Jackson superintendent of business at the Avon Maitland District School Board (AMDSB) for acknowledging my idea was possible and for supporting the completion of my Masters degree based on the concept. Without the support and funding of the AMDSB this thesis would never have been possible. Dan Root from the IT department at AMDSB disserves an ongoing thank you for all his hard work, continued support and expertise with the technical aspects of implementing a system like this. I would also like to thank my supervisors Peter Deadman and Doug Dudycha for recognizing my idea could be implemented as a Masters project, their time, guidance, support, insight and expertise while completing this thesis. Without the help of 4DM consulting the project would never have gotten of the ground due to limited personal in the EHS department. 4DM provided excellent service, knowledge and insight to the world of GeoSpatial technology. Last but certainly not least my wife Tina George disserves a big thank you for her continued support and for putting up with my “pet project” over the past two years.

Dedication

This thesis is dedicated to all those who have lost their lives, have been injured or have contracted an occupational illness while on the job due to a workplace hazard.

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Chapter 1
Introduction

1.1 Why GIS for Environmental Health & Safety (EHS)?

In many organizations, Environmental Health and Safety (EHS) departments operate on a reactive business management model due to a number of factors including minimal staff, limited budgets and an inadequate corporate safety culture (Mohamed 2003). A lack of resources and support leads to EHS departments only being able to react to problems due to unmanaged hazards/risks rather then be proactive by assessing and mitigating risks before problems occur.

Problem 1: One of two key problems at the Avon Maitland District School Board (AMDSB) is "how to move from a reactive EHS management approach towards a proactive continuous improvement approach for managing EHS". The problem with reactive management is that an accident, incident, or disaster needs to happen before policies, procedures, and programs are implemented to prevent these types of events. There is a need in the EHS profession to identify ways to manage EHS in a more proactive way and move towards a business model based on continuous improvement. By moving towards a proactive model, accidents and incidents can be prevented before an unmanaged hazard/risk leads to these events. A key outcome of a proactive business model is an organization being able to prove "Due Diligence" which is being able to prove you have done everything reasonably possible to prevent an accident.

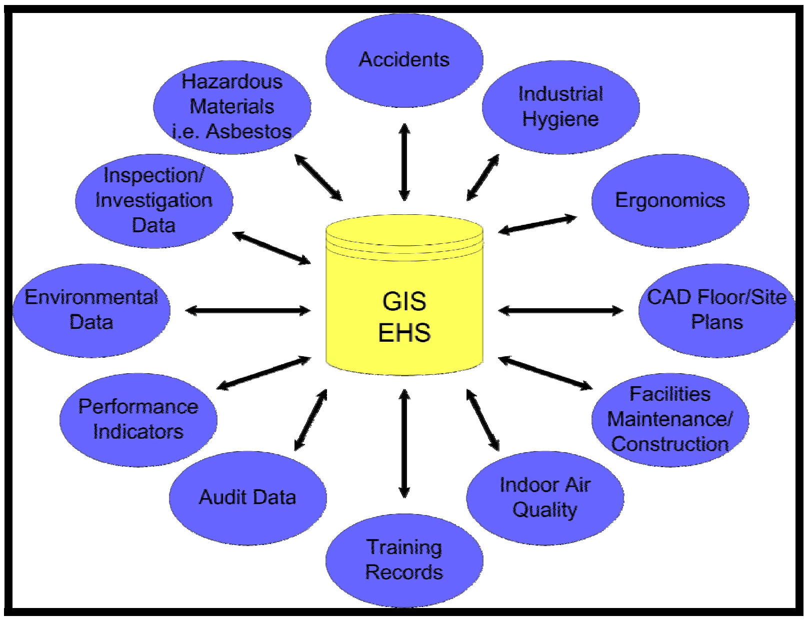
Initial research began with trying to find the best business model for proactive EHS management. The model chosen was OHSAS 18001 (Occupational Health and Safety Management Systems – Standard), which is the most universally accepted Occupational Health and Safety Management System used for proactive EHS management (BSI 2002). OHSAS 18001 is a standard developed by the British Standards Institute (BSI) in 1999, which parallels the International Organization for Standardization (ISO) 9000 (quality) and 14001 (environmental) standards that have been widely accepted and used in the business world (Roig et al. 2008). It is based on the continuous improvement approach Plan, Do, Check, Act, which ultimately leads to processes being monitored and improved for better health and safety management. One of the key concepts behind the model is that it is based on a hazard risk assessment approach, all the hazards/risks in an organization are identified and prioritized so the most severe risk can be dealt with first and mitigated (Roig et al. 2008). Since the release of OHSAS 18001 in 1999 countries have started to create their own similar models such as the Canadian CSA Z1000 and the United States ANSI/AIHA Z10 both released in 2005. At the inception of this project the Canadian and United States standards were not released and OSHAS 18001 was the best option.

The migration to a proactive approach is a time consuming and lengthy process. Also the procedures and processes that come out of an 18001 implementation generate large amounts of data, which is required to be monitored and analyzed. Each process usually has its own method of data collection, which leads to many different data collection systems within an organization (for example EHS at AMDSB has over 30 + different sources). This data can exist in many forms such as paper, open databases (MS Access, File MakerPro), electronic files (pdf, MS word), spreadsheets (Excel, QuatraPro), Images, or proprietary software applications with closed backend databases (COBOL, DBF, SQL).

Problem 2: This leads to the second key problem – "lack of data integration and interoperability between the numerous different EHS data sources and systems". Two commercial-of-the-shelf (COTS) EHS data management systems were explored to see if they could help implement and manage the data generated by an OHSAS 18001 model while at the same time integrate all the existing EHS data sources (Intelex - Safety Management Software and ESS - Health and Safety Software). The systems were designed to help organizations implement an OHSAS 18001 type model so they would help with problem one but would not help with problem two. They were stand alone databases consisting of modules that would not integrate all existing EHS data and portions of the systems overlapped with existing systems already in place (e.g. the Parklane accident management system). Other disadvantages were that the two COTS systems were costly, they did not provide flexibility for customization (only at an additional cost), and they did not provide a spatial component. It was decided to explore Geographical Information Systems (GIS) as a solution for integrating/managing all EHS data sources (Figure 1) because EHS data is very spatial in nature and GIS software provides great flexibility for customization and data integration with existing data sources. The outcome is envisioned as a comprehensive hazard/risk management GIS database for managing EHS called GeoSpatial Environmental Health and Safety (GEO-EHS).

GEO-EHS would enable a one person department to better manage the EHS in AMDSB. It would allow the ability to use, integrate, join, disseminate, maintain, and display information in a spatial context over the 30 + different data sources (a detailed list of EHS data sources can be found in Table 1 on page 57). It would also allow correlations to be made between all data sets, which can lead to new discoveries and solving problems such as finding out why accidents happen.

Figure 1 - Data Integration Vision of EHS Data



1.2 Uniqueness of Research

This topic is unique in the sense that there has been very limited research/development in the area of using GIS to integrate/manage all business functions of EHS as will be revealed in the literature review of Chapter 2. This thesis is meant to act as a catalyst for further research and development in the area of GIS and EHS.

1.3 GIS and EHS in Ontario School Boards

The following discussion is based on my experience, internal surveys, and involvement with two Ontario wide school board groups: 1) the District School Boards of Ontario GIS user Group (DSBO-GIS) and the Ontario Association of School Business Officials - Environmental Health and Safety committee (OASBO-EHS). School boards in Ontario are currently using GIS for educational purposes and administrative purposes such as student enrollment planning, school catchment planning, facilities planning, land use planning, and transportation planning. The majority of boards that are using GIS for overall planning purposes are using ESRI software and/or MapInfo. For transportation planning boards are using tailored GIS transportation packages such as GEOREF, Edulog, Trapeze, SPS, Busstops, Manifold or MapNet. The use of GIS usually falls under the planning and transportation departments and based on my knowledge GIS is not being used by EHS departments within other Ontario boards. EHS data management in other boards seems to be handled in the same manner as AMDSB where many different systems and data sources are used with no central point of integration.

1.4 Background of Study Area

The Avon Maitland District School Board (AMDSB) operates 54 schools employing approximately 2,500 staff, which are spread over 6,000 square kilometres in Huron and Perth counties of Southern Ontario, Canada. The Board serves about 20,000 students through elementary and secondary education as well as distance education and continuing education programs. It is responsible for all aspects of school operations within its jurisdiction, including school planning, financial management, facility management, student transportation, and EHS to name a few. A national and regional view of where AMDSB is located are displayed in (Figure 2) and (Figure 3).

Figure 2. National View of AMDSB Location

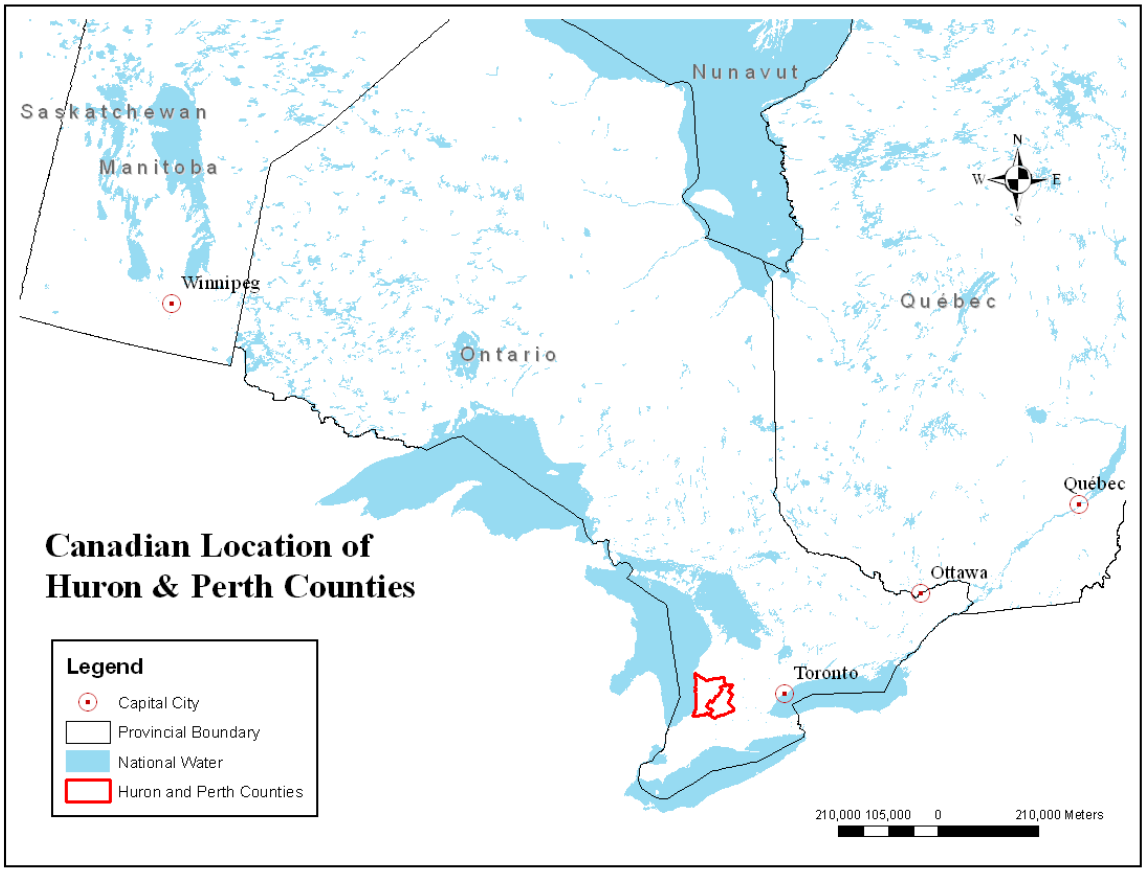
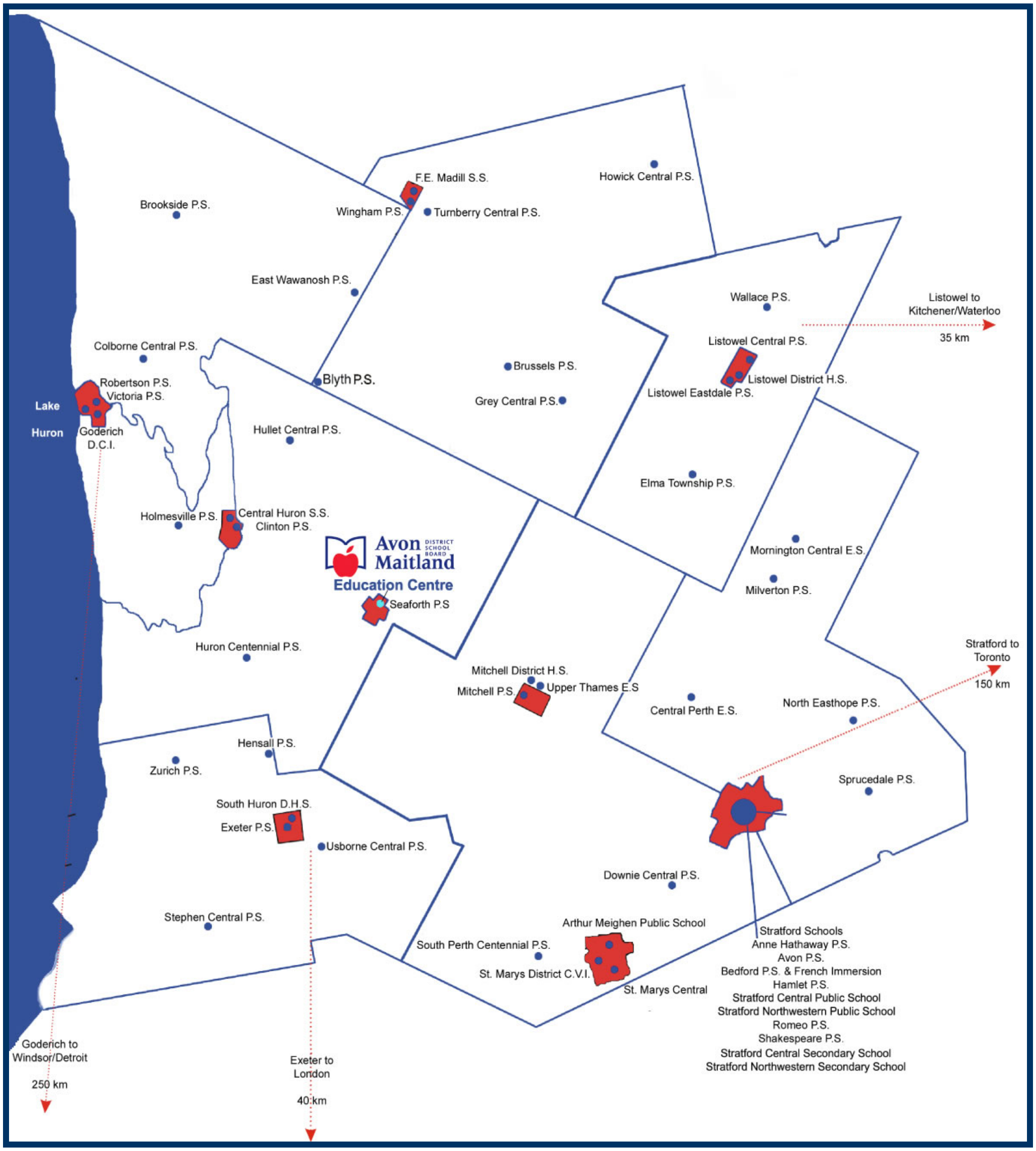


Figure 3. Regional View of AMDSB Location



1.5 Environmental Health and Safety (EHS) Department

The EHS department currently consists of only one full time employee, the EHS Officer (EHSO), who can also draw on other resources within the school board. The EHSO has a dual reporting structure directly to the Superintendent of Business and Administrator of Facilities. The EHSO also works closely with the Superintendent of Human Resources and HR department.

The EHS department also has many connections to entities outside the school board, such as government agencies (Ministry of Education, Environment, Labour, Public Health Units etc.), Organizations (Workplace Safety and Insurance Board, Safe Workplace Associations, etc.), and outside companies (building contractors, labour unions, environmental laboratories etc.).

1.5.1 Role and Responsibilities

The EHS department is responsible for the development, implementation, management, and monitoring of the Avon Maitland District School Board's EHS management system, policies and programs. The department serves as an EHS resource to the school board to assist staff and students in ensuring and maintaining an environmentally safe and healthy working environment. The department has a primary responsibility of employee safety which is mandated by safety legislation in Ontario for all employers. Students are not covered by the safety legislation because they are not employees and therefore principals have student safety as one of their primary responsibilities. There is overlap between staff and student safety (e.g. gym and playground equipment inspections) and the EHS department includes student safety in any safety planning. The employee/student safety divide is evident by the fact that EHS maintains an accident/incident database for all AMDSB employees and the department responsible for risk management/insurance maintains a separate database for student accidents.

The EHS department fulfills its role through; the development and implementation of new and enhancement of existing policies and procedures, the training of staff, responding to requests or concerns over environmental health and safety, and monitoring quality of the environment in the schools and operations. Specific duties of the EHSO include:

1) Program/professional development– develop new and enhance existing programs, policies and standard operating procedures related to environmental health and safety.

2) Investigations and assessments– investigate employee accidents, occupational illnesses, and property damage; make recommendations to prevent future accidents; follow-up to ensure corrective actions have been taken.
3) Inspections– perform/organize regular inspections of school properties as related to EHS.
4) Research, training and training development– conduct accident and occupational analysis to determine high risk areas; develop and implement staff training programs.
5) Industrial hygiene testing– conduct industrial hygiene sampling and testing (e.g. indoor air quality - IEQ, etc.) in response to environmental quality concerns reported by schools.
6) Hazardous materials management – ensure proper storage and use of hazardous materials; maintain the material safety data sheet database.
7) Waste management – perform inventories of non-hazardous waste, coordinate annual hazardous waste disposal.
8) Product/equipment testing – test new products and equipment for EHS performance.
9) WSIB claims management and return to work program – act as a resource to Human Resources for dealing with related issues such as ergonomics.
10) Resource – serve as a key EHS resource to the board and the schools.
11) Well water quality management – manage and coordinate well water quality testing and proper functioning of the disinfection equipment.

1.6 Vision of GeoSpatial Environmental Health and Safety (GEO-EHS)

The GIS application for EHS is envisioned as an integrated web based system that would consist of a web mapping interface displaying geo-referenced school floor/site plans linked directly to available database information in a secure manner. The EHS Database would house the information collected from inspection and monitoring processes at the source (e.g., schools) and would be linked to other existing databases. Spatial data mining and querying would provide rapid EHS awareness and analytical capability. GEO-EHS was designed initially to help the EHS department integrate EHS data related to employees with the long term goal of including student information. This topic is explained further in 3.4.

1.7 Analysis Capabilities for EHS

GIS can bring to EHS the advantages of traditional IT quality with the added benefit of spatial operations such as map overlay, relationships and querying, and informative visual presentation through maps, floor plans, and imagery.

Types of possible analyses for EHS:

1) Visual overlay – e.g. distribution of accidents throughout the Board (school by school), dispersion of accidents within a given school (room by room).
2) Identification of relationships between data sets – (e.g. indoor air quality complaints linked to facilities data).
3) Ability to search across all datasets to find correlations and solutions – (e.g. show all accidents for Avon PS, all IEQ complaints, all facilities maintenance work).
4) Able to query individual datasets – (e.g. 1- show all completed Joint Health & Safety committee (JHSC) inspections for certain time period, 2- show me list/location of science chemicals for a certain school).
5) Used to maintain one central, historical, visual, spatial database.
6) Used for maintaining up to date facility floor/site plans.
7) Data sharing of facility floor/site plans.
8) A comprehensive Hazard/Risk assessment tool – all schools/rooms would have a hazard/risk rating depending on job functions, room usage, hazardous materials, equipment, past events, accidents, and unique scenarios could be added e.g. how a construction project would influence the ratings.

Other departments would also benefit from the geospatial data and the applications developed. Examples would include asset management for facilities, purchasing, and IT, demographic analysis for planning, school chemical inventory, and transportation planning.

1.8 Thesis Scope, Purpose and Objectives

The scope of this thesis is a key component of an ongoing project being implemented at AMDSB. Prior to starting the thesis in September of 2006 the design and implementation of GEO-EHS had been underway since March of 2005. Throughout the thesis reference is made to work completed that is not part of the thesis scope but provides important background information on the overall project which helps put the thesis into context. The thesis scope consists of an overall purpose that will be achieved through six main objectives as listed below.

Purpose:

To demonstrate that GIS technology is a feasible option for data integration and interoperability of EHS data.

Objectives:

1) Review of academic and GIS industry literature related to EHS and GIS to provide background and proof that the development of a GIS EHS database is possible and a valid option for managing EHS data,

2) Creation of the GEO-EHS data model based on the Environmental Systems Research Institute (ESRI) geodatabase model which will include Hazmat Inspector used for asbestos data management, Parklane used for accident data management, electronic documents, and also describe what and how other data sources will eventually be integrated,

3) Development of a desktop GEO-EHS prototype which incorporates Hazmat Inspector, Parklane, and electronic data sources such as documents and images,

4) Development of a web system platform used initially to share GIS data and school floor plans with AMDSB staff and external organizations such as the Ontario Provincial Police (OPP) and local Fire services for emergency planning purposes. The long term plan being that the desktop GEO-EHS will evolve into a web system and data will be maintained/updated using the web system by external users (e.g. principals inputting classroom usages at the beginning of each year to ensure the floor plan data is correct or principals maintaining an up-to-date chemical inventory for each school),

5) Identify limitations and future directions of GEO-EHS.

6) Identify areas for future research

The remaining parts of the thesis are structured as follows: Chapter 2-Related Literature discusses GIS system design and implementation using the methodology provided by (Aronoff 1989) and (Tomlinson 2003), GIS system architecture design, geodatabase design, analytical comparison of EHS to similar disciplines, and internet GIS and open source software. Chapter 3- GEO-EHS Design

Methodology discusses the topics of design methodology, GIS user needs assessment, system architecture design, hardware & software, spatial database building/conversion, and testing types of analysis GEO-EHS will enable. Chapter 4-GEO-EHS Data Model and Prototype Design covers GEO-EHS data structure and example Queries, Overlays, and Analyses. Chapter 5-Web GIS Implementation gives an overview of the web platform design and future uses. Chapter 6-Discussion and Conclusions provides detailed discussion about each step in the design and implementation ending with future steps in GEO-EHS development and suggested further areas of research.

Chapter 2
Related Literature

2.1 GIS System Design/Implementation

The implementation of a GIS system is unique to the needs of each organization or department and can be a time consuming and tedious process that requires long term commitment from management and staff. A GIS system can take many forms, from simple (desktop mapping - e.g. with ESRI ArcView) to very complex (design and implementation of an enterprise GIS). A simple low cost implementation could be the purchase of a desktop GIS product like ArcView from ESRI which an experienced GIS professional could be using the same day for map production. At the other end of the spectrum the development of an enterprise GIS for a municipality could take years to implement depending on the scale and size of organization.

Before a GIS system can be implemented there needs to be an understanding of what is involved and how each step of the process works in order for an implementation to be successful. The following overview compares two implementation approaches described by two different sources, one from the earlier literature and the other more recent. (Aronoff 1989) describes the process from a text book overview and (Tomlinson 2003) describes the process from a consulting view, which could be used as a step by step method for implementation.

2.2 Aronoff – Text Book Implementation View

(Aronoff 1989) – "Geographic Information Systems: A Management Perspective" presents an overall view of what GIS is and how it can be implemented through a text book style approach. Aronoff describes the implementation of GIS as the point where people and technology meet. He also states that information is power and the implementation process can be very political because "wherever people interact there are politics". He breaks the implementation process down into the following six phases, which are briefly described below:

1) Awareness
2) Development of System Requirements

3) Evaluation of Alternative Systems

4) System Justification and Development of an Implementation Plan

5) System Acquisition and Start Up

6) Operational Phase

2.2.1 Phase 1 – Awareness

Before a GIS system is developed someone ultimately needs to come up with the idea and it needs to be “sold” to the rest of the organization. This can happen from the Top-Down when management pushes the idea down to the workers or Bottom-Up when workers become aware of how the technology can improve their workflow and sell the idea to management. Both have their pros and cons but this is not a discussion for this paper. Ultimately there needs to be a champion who takes on the project and keeps it moving forward, this could even be a third party consultant or outside agency with experience in GIS implementation. Before phase two can be reached the following needs to be addressed: What are the benefits of a GIS? What types of problems can a GIS address? Who will analyze the needs for a GIS?

2.2.2 Phase 2 - Development of System Requirements

Possibly the most important step in the process is determining the needs for a GIS, which is done through a user needs analysis. This evaluates current systems, existing workflows, and determines future needs. Some items identified during this phase are how data should be standardized, software/hardware, and functional requirements. The user needs analysis acts as the foundation or blue print for a GIS implementation and is referred to on a regular basis just like architects blue prints for a house would be during construction of a new home.

2.2.3 Phase 3 – Evaluation of Alternative Systems

During this phase a set of candidate systems (or software) are identified and analyzed based on a set of requirements identified in the user needs analysis. They should be broken down into essential and nice to have requirements for easier comparison. When comparing systems the selection criteria can be divided into three categories, hardware, software, and user friendliness. Once a few selected systems are chosen they can be tested with users data in order to benchmark the systems with a systematic process. The final step of this phase can be a pilot project where a system is chosen and a real data set is tested to demonstrate the more important functional requirements identified in the user needs analysis.

2.2.4 Phase 4 – System Justification and Development of an Implementation Plan

System justification is tied back to the awareness phase where the benefits of a system were identified. The costs and benefits are presented here in order to justify the purchase or development of a system. This phase can be a formal step or can be informally developed as the project moves forward. An assessment should be done of the current system costs and benefits, which can be compared to the (to be purchased or developed) GIS system costs and benefits. Aronoff makes the comment that the decision to purchase or develop a GIS system is rarely based on cost-benefit grounds. For example the decision may come down to the need for a GIS system e.g. a municipality may be required to provide more accurate and detailed geographic information due to environmental concerns. In this situation a need for a GIS is already determined and the questions become when, how, and at what cost the GIS will be implemented.

2.2.5 Phase 5 - System Acquisition and Start Up

After gaining the support and commitment to develop or acquire a GIS system the next step is to begin the implementation. This involves acquiring the hardware/software and possibly contracting out for development services if it can't all be done in-house. If contracting out for services is necessary the terms of contracts should be negotiated and tailored to suite the users needs and reviewed by a lawyer. Standard contract agreements shouldn't be used because they may not meet the GIS System needs. Some items that should be included in the contract agreements are system integration statements (ensuring all software/hardware/external systems are properly integrated), agreement of an acceptance test (after the system has been finalized and implemented a test should be done ensuring everything operates properly), maintenance arrangements (which make sure the hardware/software and system operate smoothly through service), software upgrades (this item makes sure the software purchased has proper upgrades over the years so it does not become out dated and in operable). Consultants and contractors can provide successful approaches and techniques without the cost of trial and error (e.g. used for data conversion to jump start a project). They should be used were needed but shouldn't be used as a crutch because in-house staff will need expertise with the system in order to support and use it.

During the start up process it is important to keep managers and users updated on the progress and demonstrate useful applications along the way based on representative projects. The projects should be carefully evaluated by all users and suggestions made on how things could be improved.

2.2.6 Phase 6 - Operational Phase

This is when the end users are making effective use of the system for day to day uses. The organization has developed procedures to maintain data quality, software, hardware, and keep staff current on GIS developments. It is important to continually promote benefits of the system through project accomplishments in order to maintain support moving forward.

2.3 Tomlinson – Consulting Implementation View

(Tomlinson 2003) – "Thinking about GIS: Geographic Information System Planning for Managers" presents a consulting step by step approach which can be followed for a successful GIS implementation. Tomlinson lays out a ten step planning/implementation methodology throughout the book which has also been developed into a course offered by ESRI called "Managing a GIS". The methodology shows the reader how to describe and prioritize the GIS needs of an organization in order to plan a GIS system that meets those needs. Below the ten step methodology is listed followed by a brief summary of each step:

1) Consider the Strategic Purpose
2) Plan for the Planning
3) Conduct a Technology Seminar
4) Describe the Information Products
5) Define the System Scope
6) Create a Data Design
7) Choose a Logical Data Model
8) Determine System Requirements
9) Consider Benefit-Cost, Migration, and Risk Analysis
10) Make an Implementation Plan

2.3.1 Stage 1: Consider the Strategic Purpose

The strategic purpose of the organization within which the system will be developed should be considered (e.g. goals, objectives, mandates). This ensures the process and final system fit the organizations structure and allows for assessment of how the GIS information will impact the business strategy.

2.3.2 Stage 2: Plan for the Planning

In this stage a case is made to senior management about what needs to be done for planning and implementation of a GIS project. The end result is a project proposal designed to gain approval and required resources to move forward with the project.

2.3.3 Stage 3: Conduct a Technology Seminar

The specific GIS requirements are defined in this stage. Future users of the system are met with to define the actual requirements from the users perspective. An effective way to gather this information is through technology seminars where the nature of GIS can also be explained along with its benefits. By involving users in this stage it helps to ensure participation throughout the project. Initial discussion about end information products also starts in the stage.

2.3.4 Stage 4: Describe the Information Products

The information a GIS generates is described as its information products. The end users need to be interviewed to determine what their jobs involve and what information they need to perform their tasks. Items determined are things like how the information products should be made and how frequently, what data is needed to make them, how much error can be tolerated, and the benefits of the new information produced.

2.3.5 Stage 5: Define the System Scope

After the information products have been determined the scope of the whole system can be defined. This involves defining items such as what data to acquire, when it will be needed, data volumes that need to be handled, production timing of information products.

2.3.6 Stage 6: Create a Data Design

In the conceptual system design phase the requirements from earlier stages are reviewed and used to begin developing a database design.

2.3.7 Stage 7: Choose a Logical Data Model

A logical data model describes those parts of the real world that concern the organization. It can be simple or complex but must fit the organization in a logical manner so data can be easily retrieved and analyses carried out efficiently. Some items to consider are the advantages and disadvantages of different database design approaches, data accuracy, update requirements, error tolerance, and data standards.

2.3.8 Stage 8: Determine System Requirements

This stage examines the system functions and user interface needed, along with the interface, communications, hardware, and software requirements. Review of the information product descriptions will help determine the functions needed to produce them.

2.3.9 Stage 9: Consider Benefit-Cost, Migration, and Risk Analysis

After determining the conceptual system design it is required to plan how the system will be taken from the planning stage to actual implementation. At this point the focus is on “how to put the system in place – an acquisition plan” rather then what is needed to meet the system requirements. Items addressed here are institutional interactions, legal matters, existing legacy hardware/software, security, staffing, and training. The final product of this stage is an acquisition plan that includes an implementation strategy and benefit-cost analysis, which can be used to obtain funding and as an implementation guide.

2.3.10 10: Make an Implementation Plan

The implementation plan is the final report produced that will allow for a successful GIS implementation. Items it should contain are a review of the organization’s strategic business objectives, the information requirements study, details of the conceptual system design, recommendations for implementation, time planning, and funding alternatives.

2.4 GIS System Architecture Design

A good system design process promotes the successful deployment of GIS technology. Environmental Systems Research Institute (ESRI) has developed a system design process, which promotes successful implementation of GIS technology solutions. The process is described in detail by (Peters 2005). A good process supports existing infrastructure requirements and provides specific recommendations for hardware and network solutions based on existing and projected user needs. It provides specific deployment strategies and associated hardware specifications based on identified operational workflow.

System performance and load on the system is a key factor to consider in designing a system. Servers, workstations, and storage should have adequate performance and capacity to support peak loads. Bandwidth over communication networks is another key factor to consider in the design. The ESRI system design process starts with a GIS User Needs Assessment, which dictates the system architecture design.

The Peters 2005 paper discusses all stages in a GIS deployment project but this section only speaks to the system performance aspect (e.g. hardware and communication networks). Specific details on the design process for this project (similar to those described by Peters, 2005) are addressed in Chapter 3-GEO-EHS Design Methodology. The paper by Peters is a detailed source specific to ESRI technology but (Aronoff 1989) and (Tomlinson 2003) are also very good sources for the design and deployment of GIS technology.

2.4.1 Geodatabase Design

The geodatabase is unique to ESRI, it is their common data storage and management framework for ArcGIS (ESRI software solutions). It can be used on desktops, servers (including the Web), and in mobile devices. It supports all the different types of data that can be used by ArcGIS such as, attribute tables, geographic features, satellite and aerial imagery, surface modeling data, and survey measurements (ESRI-1 2007). AMDSB chose ESRI software as a solution which therefore dictated the use of the ESRI geodatabase model and system design strategies. Research into other types of data models and system design strategies is not part of this thesis.

2.4.2 Overview of the Geodatabase Approach

The geodatabase is a geographic data model, which is a representation of the real world that employs a set of data objects that support map display, query, editing and analysis. It is capable of representing natural behaviors and relationships of features, which makes the features in a model smarter. Object oriented data modeling lets you characterize features more naturally by letting your define your own types of objects through topological, spatial, general relationships and how the objects interact with other objects (Zeiler 1999). Object oriented data modeling is a methodology based on the classification concepts of objects and attributes, classes and members, and wholes and parts (Norman 1991).

Common Geodatabase Elements

The following is a description of some common geodatabase elements used in designing a geodatabase model drawn from (Arctur and Zeiler 2004) and (Zeiler 1999).

Feature Classes (FC):

A feature is a collection of features representing the same geographic elements, such as wells, parcels, or soil types. Each feature class represents one type of spatial representation (e.g. point, line or polygon). Spatial and attribute relationships can also be defined

Feature Datasets (FD):

Feature datasets are organized collections of related feature classes. One of the primary advantages to organize the data this way is to manage spatial relationships among related feature classes.

Topologies and Networks:

Topologies define how features share geometry and control their integrity through rules and editing behavior. Networks are used to model connectivity and flow between features.

Subtypes:

Subtypes of feature classes and tables are a powerful modeling technique to preserve coarse grained models, helps display performance, geoprocessing, and data management.

Relationships:

Besides topological and spatial relationships, there are general associations for features and objects, which model how features and objects are related to each other.

Raster Datasets and Rater Catalogs:

Images and other raster datasets are important to GIS processes. A number of raster mechanisms are used to assign behavior and to mange large raster collections.

2.4.3 Geodatabase Design Steps

The design starts with defining thematic layers for your applications and information requirements. Each thematic layer is then defined in more detail and the characterization of each thematic layer results in defining feature classes, tables, relationships, raster datasets, subtypes, topologies, and domains.

(Arctur and Zeiler 2004) provides a great ten-step overview for designing geodatabases. The process is broken down into three phases: 1) conceptual design, 2) logical design, and 3) physical design. The conceptual design steps help in identifying and characterizing each thematic layer. The logical design phase begins to develop representation specifications, relationships, and geodatabase elements and properties. In the physical design phase, the design is tested and refined through a series of initial implementations and ultimately documented. In order to define the ten-step process (Arctur and Zeiler 2004) provided a ten-step diagram which briefly explains each step, which is outlined below. The EHS geodatabase design is described in detail in chapters 3, 4, 5, and 6.

Conceptual Design
1) Identify the information products that will be produced
2) Identify the key thematic layers based on your information requirements
3) Specify the scale ranges and spatial representations for each thematic layer
4) Group representations into data sets

Logical Design
5) Define the tabular database structure and behavior for descriptive attributes
6) Define the spatial properties of your datasets
7) Propose a geodatabase design

Physical Design
8) Implement, prototype, review, and refine your design
9) Design work flows for building and maintaining each layer
10) Document your design using appropriate methods

2.4.4 Discussion about Relationships

The geodatabase provides the framework to define relationships among features and objects, which can be managed to ensure feature integrity. (Zeiler 1999) describes how ArcGIS uses three main ways to define relationships: topological, spatial, and general. Topological relationships are built into the data when a geometric network or planar network is created and are managed through the topological environment in ArcGIS. Spatial relationships are those that define what is spatially related (e.g.

whether one feature touches, coincides with, overlaps, is inside of, or is outside of another feature). General relationships are explicitly defined relationships that form a persistent tie between a feature or object from an origin class to a feature or object in a destination class. There are four basic types of general relationships 1) one-to-one, 2) one-to-many, 3) many-to-one, and 4) many-to-may.

(Zeiler 1999) defines a ***relationship*** as an association between two objects, which can be nonspatial (objects) or spatial (features). Relationships are organized into ***relationship classes*** and each relationship in each relationship class has the same origin class and destination class (Arctur and Zeiler 2004). Relationships are important to the EHS data design because they allow for EHS data integration through the GIS spatial data. ArcGIS acts as the main interface for accessing EHS data through relationships set up between the spatial data and EHS tabular data.

2.4.5 Related Disciplines with Similar Design Needs to EHS

From the literature the closest example of a data model related to EHS design needs was found in the environmental management (EM) literature. (Ross 2001) is a detailed manuscript outlining the design and implementation of an environmental geodatabase used for regulatory compliance management by the United States Environmental Protection Agency (USEPA). This model lends itself very well to be used as a starting point for the design of an EHS geodatabase model. The model focuses on environmental compliance inspection data specific to buildings and the land which they reside on. The safety and health aspect are not covered as part of the model and it did not speak about how existing systems could be integrated. Therefore disciplines related to EHS including public health (PH), emergency response management (ERM), environmental management (EM), and automated mapping/facilities management/GIS (AM/FM/GIS) were researched as they relate to GIS and data integration, which are discussed in detail in the next sections.

2.4.6 Analytical Comparison of EHS to Similar Disciplines

Environmental Health and Safety (EHS) also known as Occupational Health and Safety (OHS) is defined as a cross-disciplinary profession concerned with protecting the safety, health and welfare of people engaged in work or employment, which also includes employers, customers, suppliers, contractors, and public who may be influenced by the workplace (ASSE-BCSP 2007). The Environmental aspect in EHS consists of protecting the natural environment from the workplace and protecting the people from environmental hazards. Some sub-disciplines, which define the EHS profession, include risk management, accident prevention, safety engineering, environmental management, emergency response management, ergonomics, fire prevention, health & wellness, workers compensation, EHS auditing, regulatory compliance, industrial hygiene, and security. Each of these sub-disciplines is than further broken down into their major functions, which makes for a very diverse profession. Due to the vast amount of information generated by each discipline only two disciplines will be looked at for the purpose of this paper, industrial hygiene (IH) and environmental management (EM).

IH and EM will be used as examples of EHS disciplines where spatial analyses can be applied using GIS to make informed visual decisions. The intent of this section is to make it evident that spatial decision support (SDS) has a place in EHS which can act as a building block for future development of a decision support system (SDSS) specifically for EHS as a whole discipline.

Before proceeding it is important to define what IH, EM and SDSS are in order to put everything in context. IH – Industrial Hygiene is the science and art devoted to the anticipation, recognition, evaluation, and control of those environmental factors or stresses arising in or from the workplace that may cause sickness, impaired health and well-being, or significant discomfort among workers or among citizens of the community (Plog et al. 1996). EM – Environmental Management is the effective and active measures taken for the protection, conservation and preservation of the environment, heritage and natural resources for which a government, organization or individual is responsible (AG-DEH 2006). SDSS – Spatial Decision Support Systems can be regarded as systems designed specifically to support a decision research process for complex spatial problems. They provide frameworks for integrating database management systems with analytical models, graphical display and tabular reporting capabilities with the expert knowledge of decision-makers (Geertman and Stillwell 2004).

2.4.7 Core Functions of IH (Safety) and EM

The core functions of IH include air monitoring (general indoor air quality and more in-depth chemical and biological air sampling for contaminants), physical agent exposure assessment such as noise, radiation, thermal stress (hot/cold), and ergonomics. Also included in the IH discipline are the grass root functions of safety management such as physical hazard evaluations, equipment hazard evaluations, safety device inspections, accident analyses, hazard/risk assessment/analyses, and hazardous materials management (e.g. asbestos) to name a few. For the purpose of this paper IH will represent the industrial hygiene and safety disciplines of EHS.

EM consists of functions such as water quality management, air emissions control, emergency response/management, hazardous waste management (PCBs, lead, asbestos, oil, etc.), and remediation of contamination to air/water/land.

2.4.8 Safety Literature

An extensive search for journal articles, papers and presentations in the core “safety” and “IH” literature related to the design and implementation of a GIS database or SDSS for the management of EHS as a whole discipline uncovered one source (Douglas 1995). Douglas describes the implementation of an environmental health and safety GIS specific to industrial facilities with a focus on the environmental discipline (described below in section 2.4.8.1). Further sources were identified that are using GIS as a decision support tool for managing at least one sub-discipline of EHS, which were all found in the IH discipline (Henricy and Stewart 2006), (Lacey et al. 2006), and (Westhuizen 2005). All four sources identify a need for further research into ways GIS can be used for managing/integrating all disciplines of EHS and how GIS can be used for spatial analyses in EHS.

The above conclusion was drawn from searching the topics of Environmental, Occupational, Health, Safety, and GIS through traditional academic journals, safety trade publications, ESRI website and annual ESRI international conferences (ESRI 2008), and the prominent safety organizations and conferences such as the American Industrial Hygiene Association (AIHA 2008), Canadian Centre for Occupational Health and Safety (CCOHS 2008), International Occupational Hygiene Association (IOHA 2008), Ontario Industrial Accident Prevention Association (IAPA 2008), World Health Organization (WHO 2008), and the US Occupational Safety & Health Administration (OSHA 2008).

2.4.8.1 EHS and GIS “System Design and Implementation”

A book written by (Douglas 1995) tilted “Environmental GIS Applications to Industrial Facilities” describes the application of information technology to address environmental, safety, and health (ES&H) information management through the integration of AM/FM and GIS systems. The book describes approaches from an organizational/cooperate standpoint.

Douglas states that

> *"Using available information sources and integrating the flow of information is preferred to growing new systems and creating redundancy. The emphasis should be on the intuitive and graphical interface to the information by relating spatially to the geography and the physical objects that are part of facilities being managed. The objectives being to assist industrial organizations in dealing with their environmental, safety, and health information management needs in the context of the overall corporate information flow and to make the information more easily accessible"*.

Douglas then goes on to say

> *"Emerging geographic information system (GIS) technology is being applied with increasing frequency to manage industrial facilities. This tool will become a standard in the 21st century for dealing with information. Those organizations who adapt and take advantage of the power of GIS will find applications that transcend the traditional facility management role"*.

This book is the only comprehensive source I found which describes how GIS can be used for integrating existing EHS functions/systems and facilities management systems to create one system used to better manage EHS data. The focus is more on the environmental side of EHS such as air emissions and site remediation but it also includes items such regulatory compliance, chemical inventories and provides an excellent detailed view of how EHS data can be integrated with floor plans and facilities data to form an EHS GIS system. Although it is not a current source and some of the content is outdated (e.g. types of hardware/software) it still provides a great EHS specific step by step approach of how to implement a GIS system tailored to EHS data needs.

2.4.8.2 PH, ERM, EM, and AM/FM/GIS Literature

A broader search was conducted across the related disciplines to EHS of public health (PH), emergency response management (ERM), environmental management (EM - defined above) and automated mapping/facilities management/geographic information system (AM/FM/GIS) as they relate to EHS, GIS and SDSS. Before the literature is examined the related disciplines are defined below to provide a better understanding of what they are. PH is defined by (NACCHO 2005) as governmental public health departments responsible for creating and maintaining conditions that keep people healthy. (NACCHO 2005) defines ten key standards (each with sub-standards) which a public health department should be implementing:

1) Monitor health status and understand health issues facing the community,
2) Protect people from health problems and health hazards,
3) Give people information they need to make healthy choices,
4) Engage the community to identify and solve health problems,
5) Develop public health policies and plans,
6) Enforce public health laws and regulations,
7) Help people receive health services,
8) Maintain a competent public health workforce,
9) Evaluate and improve programs and interventions, and
10) Contribute to and apply the evidence base of public health.

ERM can be defined as the coordination, development and implementation of prevention, mitigation, preparedness, response and recovery strategies to maximize the safety and security of individuals (EMO 2007). (Douglas 1995) defines AM/FM/GIS as a computerized integration of database management system (DBMS) technology with automated mapping (AM) and a facilities management (FM) technology to capture, store, retrieve, and display information graphically in order to facilitate its use an interpretation for reporting, planning, and decision making. The GIS takes the AM/FM concept further by providing tools for analyzing and relating the data spatially.

The search for PH related literature uncovered mostly project based cases using GIS as a tool for specific spatial analyses not as an SDSS. Example topics include, metal contamination in park soils using spatial distribution analyses of trace metals (Lee et al. 2006), relationships between pollution and asthma using dispersion modeling to identify individual exposures to air pollutants based on where individuals work and live (Crabbe et al. 2006), respiratory health related to flooding using overlay techniques to identify schools within flooded land (Guirdy and Margolis 2005), and risk of elevated blood levels in children using mapping to illustrate homes with a high risk of lead contamination overlaid with locations of children that have been screened for lead poisoning (Roberts et al. 2003).

PH research is closely related to EHS but the AM/FM/GIS, ERM and EM literature revealed the most information on spatial analyses, which can be directly related to EHS use. For this reason these three disciplines were used as the core reference material for illustrating the spatial benefits GIS and can bring to EHS. Proposed spatial analyses examples within EHS are presented and comparisons drawn to similar uses in the AM/FM/GIS, ERM, and EM literature in order to illustrate how the spatial component is important and beneficial to EHS decision making. The spatial examples fall under the categories of simple ***visualization*** through (floor plans, imagery, reports, and inspection data), map ***overlay*** techniques, and ***query/relationships*** through more complex spatial analyses. The examples are largely based on how GIS floor plans and site plans could be used for spatial analysis.

2.4.9 EHS Spatial Links

From an EHS perspective the key spatial components linking all sub-disciplines and functions together are: 1) the activities occur within a building/facility, or 2) on the land where the facility resides, and 3) more often then not organizations operate many facilities dispersed across local regions such as counties or municipalities, nationally across provinces or states, and internationally across countries and continents. This creates a perfect opportunity for spatial analyses from the non-traditional micro scale (e.g. facility floor plan room-by-room) to the more traditional macro scale land based analyses.

2.4.10 IH Spatial Analyses

Visualization would be very similar for all the IH functions such as viewing data linked to equipment, rooms, facilities, and land. This could be in the form of images (room layout, equipment, chemicals, types of asbestos, accident scene), reports (past air quality or ergonomic reports in pdf format), and inspection data (ventilation inspections logs, custodial cleaning logs, safety inspections). Similar uses have been implemented by (McConnell 2002), (Pfeffer 2001), (Milliken et al.205), and (Srivastava and Wellington 2000) where they linked photographs of buildings, dams and mechanical building equipment, work order requests, maintenance records, and facility survey reports. The overlay and querying analyses are unique to each function as discussed below.

2.4.10.1 Air Monitoring

Indoor air quality

General indoor air quality monitoring usually consists of a visual inspection of a concern area along with sampling and analysis of general comfort parameters, such as relative humidity, temperature, carbon monoxide, and carbon dioxide.

Floor plans could be overlaid to see relationships between past investigations on different floor levels and equipment schematics overlaid to see problems/relationships with ventilation/electrical/plumbing. (Sandhaus 1999) illustrated this example by creating GIS thematic floor plans of navy shore facilities, which were overlaid for visualization of spatial relationships between floors.

A potential string of queries could be, show me all rooms with past indoor air quality investigations, similar complaints, and past water leaks. When was the ventilation last inspected, serviced and filters changed? What is the age of building and specifically the age of the rooms with concern? Show me all areas in a school housing hazardous chemicals and areas where activities can influence air quality (e.g. welding, auto body repair, or science experiments). Show the proximity of these areas to rooms with concern and list square footages. In a slightly different context for school board facility planning purposes (Kilical and Kilical 2006) used GIS to run similar queries, such as show all schools built before 1950, having leaky roofs, and which require more than $500,000.00 to bring the school to a good state of repair.

Chemical and biological air sampling for specific contaminants

In situations where there are possible source contaminants influencing air quality investigation and sampling strategies are developed to assess the contaminants. These could be chemicals within certain products (dry cleaning fluids, auto body filler, paint, dust or cosmetics). Biological sources could be items such as mould growth, viruses, or bacteria.

Again the floor plan and equipment schematic overlay would be beneficial to identify the spatial relationships between types of equipment and processes, which may be causing contamination releases. This would also allow for visualization of possible exposure routes (e.g. ventilation systems) and surrounding areas that may be affected. A similar scenario was proposed by (Henricy and Stewart

2006) where they used GIS floor plans and schematics during IH investigations to identify contaminant sources and spatial relationships between sources and surrounding equipment.

Complex dispersion modeling techniques could be used to perform what if scenarios if a chemical were released indoors. For example, by using floor plans, schematic plans, and chemical inventories a model could be integrated to identify exposure routes, rates of exposure, exposure concentrations and areas affected for evacuation planning and emergency response. An example of this exact scenario was not found but comparisons can be drawn from (Heino and Kakko 1998) where possible industrial air contamination scenarios were modeled to identify dispersion patterns of a plume in the natural environment to predict rates of exposure and populations affected.

2.4.10.2 Physical Agent Exposure Assessment

<u>Noise, radiation, and thermal stress (hot/cold)</u>

Proactive exposure prevention programs and reactive regulatory compliance investigations require exposure readings to determine if individuals are being overexposed to certain physical agents so controls can be implemented to reduce the risk. Sampling strategies for noise, radiation, and thermal exposure are based on scientific modeling techniques and require the collection of a representative number of samples over a certain period. This generates large quantities of sampling data, which can be linked to rooms and facility layout.

Sampling data are usually recorded as points on floor plans for visual representation. Within a GIS, those points can be linked to the actual data, which would allow contour floor plan maps to be produced. Different zones of exposure could be identified to determine high-risk areas where controls need to be implemented such hearing protection for noise, engineering controls for radiation, or where cooling/heating units are required for thermal stress. Buffering could also be used to create buffer zones around high noise areas or elevated radiation areas. As a comparison, (Henricy and Stewart 2006) created noise level contour maps based on GIS floor plans to highlight high decibel areas or areas with noise levels beyond regulatory limits.

Once contour maps are produced and there is an ongoing sampling strategy in place future maps could be overlaid to determine if controls are working to see if further work is required. (Westhuizen

2005) illustrated the use of GIS floor plans to locate and identify areas where deterioration in noise levels took place over a certain period within an industrial brewing facility.

Ergonomics

Ergonomics involves fitting the task or space to the individual in order to minimize physical stress on the body, which may result in injuries such as repetitive strain e.g. carpel tunnel syndrome. The spatial benefits here mostly relate to visualization as described in the opening paragraph, but overly could also be used.

For example, during an ergonomic office evaluation floor plans are usually used to redesign the workspace in relation to the workers concerns, such as re-position of desk, computer monitor, keyboard, mouse, and other office furniture. Before and after plans could be kept for future reference and overlaid to re-evaluate the situation if any modifications are required. This scenario lends itself to an example related to space management using GIS, (Xia 2004) uses GIS floor plans for the space management of university libraries addressing issues such as furniture placement and reorganization, utility locations, and book shelve placement.

2.4.10.3 Asbestos Management

Asbestos is a hazardous material used in many building materials prior to the 1980s. Asbestos management largely consists of keeping an inventory and physical condition records of existing asbestos within buildings (e.g. ceiling tiles, floor tiles, and sprayed insulation) and in the natural environment such as water and sewage lines. The main goal is exposure prevention and removal of all asbestos over time.

GIS floor plans could be used as the inventory system for tracking where asbestos is located (room-by-room), what conditions it is in (good, fair, poor), what type it is (chrysotile or amosite), what quantities there are (square footage or linear feet), what materials it is contained within, were it has been removed with air monitoring/inspection results to prove proper removal. The floor plans would act as a visual inventory system, which could be colour coded based on the risk to the public. Floor plans could be overlaid when construction or maintenance work is planned to quickly identify areas where safety precaution or removal will be required. (Henricy and Stewart 2005) discusses one aspect of this approach where GIS floor plans are used to produce colour coded theme maps that describe the distribution of asbestos throughout a building. Data such as described above was linked to the plans, which provided all required information in a visual context for planning purposes.

During air quality investigations, the asbestos information could be queried to identify if there is any risk to individuals, such as show me areas where asbestos is located in poor condition, any areas where removal has taken place, and air monitoring results. During construction or renovation projects, the system could be queried to show asbestos type, building materials it is contained within, and quantities in the proposed construction area for planning a removal project prior to construction. (Stementelli et al. 2002) uses GIS for the identification of asbestos water mains in poor condition in the city of Nacogdoches, Texas. GIS was used for planning an asbestos removal project based on the quantities identified, costs for removal and other utilities that would be affected.

2.4.10.4 Hazard Risk Assessment/Analyses

<u>Physical and equipment hazard evaluations and safety inspections</u>

A large amount of data is collected through facility/equipment inspections and evaluations, which determines the safety rating and whether or not an item requires repair or should not be used if there is a high probability for an accident. Buildings, facilities and equipment are inspected on a regular basis for physical hazards that pose a threat of causing accidents due to tripping, falling, electrocution, laceration, amputation, chemical exposure etc. There are also compliance inspections, which are done to ensure devices are in safe working conditions (e.g. fire extinguishers/sprinklers, fire alarms, fire doors, security systems, elevators, auto hoists, playgrounds, fork lifts, etc.).

All the above types of inspections are based on a physical item, which has a location within a facility or on a property. A simple visual inventory could be maintained based on the floor and property plans. Each item could be represented by a different symbol identifying its exact location. Plans could be overlaid to plan inspection routes, illustrate compliance that all required equipment is maintained, or simply show where safety devices are in the event of emergencies. (Keyworth and Healey 1996) describes similar activities by using GIS floor plans combined with attached data to prioritize facilities for compliance audits, plan asbestos removals, and develop emergency response plans. The study used a pilot project implemented for the U.S. Army Corps of Engineers New England Division.

The types of queries are endless; examples include show all rooms not inspected for hazards in the past month? Show all areas with tripping hazards? Show equipment with safety deficiencies that require repair? Show fire extinguishers not inspected in past six months? Identify playgrounds not adequate for use? (Keyworth and Healey 1996) also provides examples of similar situations where queries such as above could be used to comply with environmental regulations, relocate personnel, prioritize facilities for wastewater system upgrades, and plan for pollution prevention projects on army facilities.

Accident analyses

Accident statistics are tracked for prevention and workers compensation purposes. Accidents happen in space and time and can be accurately linked to a specific location where the event took place. Most organizations conduct detailed accident analyses, which they base their prevention strategies on. They look at where accidents happened (wood shop, playground, or soccer field), what types they were (slip, fall, electrocution, violence, ergonomic), what body parts were affected, what the cause was (snow covered pavement, faulty electric outlet, violent student, poor workstation set up).

Accident statistics could be plotted on floor plans in the specific location they occurred (e.g. wood shop, band saw) and hazard assessment data could be overlaid to see if the equipment and room was inspected properly and on time. On a broader scale slip/fall statistics could be plotted by school and weather pattern data overlaid to see if there are any correlations with poor weather conditions such as snow. To illustrate the above possibilities an example is used from (Yiannakoulis et al. 2003) where fall injuries (hospital emergency statistics) in the elderly were plotted according to their home locations and overlaid with census data, standard base layers such as streets, and housing information to identify zones of high risk within the city of Edmonton, Alberta.

Data can be queried to see how accidents are dispersed within a building over a certain time period e.g. show all slip/falls by location within building A over the past two years. This could show if there are any spatial patterns by room location. Analyses can also be done over the more traditional land area to see if there are spatial patterns by building location e.g. show total accidents by building location, which could be displayed as bar graphs or representative symbols to show the quantity as they are dispersed over a geographic area. An auto crash example from (Kam 2003) is used to illustrate a possible accident analysis using GIS. Buffering was used to identify accidents with in a certain travel corridor and crash rates were estimated for individuals in different age-sex groups according to time of day and day of week.

2.4.11 EM Spatial Analyses

As with IH, Visualization would be very similar for all EM functions. Some examples of images could be (water disinfection equipment, industrial buildings within close proximity to property, hazardous materials, contaminated areas), reports (past water quality or hazardous materials removal reports), and inspection data (water quality logs, well inspection logs, fume hood inspections, chemical inventories, underground storage tank inspections). As discussed in the IH section similar uses are identified by (McConnell 2002), (Pfeffer 2001), (Milliken et al.205), and (Srivastava and Wellington 2000). The overlay and querying analyses are discussed in detail below.

2.4.11.1 Water Quality Management

Water quality management consists of ensuring potable water is free of contamination and safe for the end consumer. Disinfection systems along with rigid biological and chemical water sampling strategies are required to make sure water is safe for consumption.

Plumbing schematics can be overlaid on floor plans to help determine the best water sampling points. Well locations can be overlaid with existing surrounding land use, farming, and water body data to determine if there is a threat of contamination to the water supply. (Contini et al. 2000) demonstrates these possibilities through showing the damage zones of an explosion superimposed on an industrial plant layout, road network, and population distribution. This can be related to water contamination by putting it in the context of a groundwater contamination issue were a dispersion plume could be overlaid instead of explosion zones.

Detailed data modeling could be conducted to determine the exposure and mortality rate of a hypothetical bacterial outbreak in a well water supply. Data modeling could also be used to determine possible contamination of a water supply by a close by industry or farming operation. More simple searches could be conducted to show all industries and farming operations within a certain radius of a facility. (Al-qurashi 2004) provides an example data modeling scenario where a gas release is modeled and combined with topography, maps, and real time weather to determine the effect of a gas plume on people and facilities originating from the Uthmaniyah gas plant in Saudi Arabia.

2.4.11.2 Air Emissions

Air emissions have many similarities to water quality management in the sense that dispersion patterns can be modeled. Organizations that produce hazardous air pollution are required to limit and reduce the emissions. On the opposite end are organizations concerned with receiving the pollution as a contaminate source within their facility.

Weather patterns could be used with existing land use, industrial operations, and farming data to determine if there is a threat of air emissions influencing a facility.

Again detailed modeling techniques could be used to run what if scenarios to determine the worst case possibility if an industrial air release occurred within close proximity to a facility. An example could be a chlorine gas release and its toxic impact in the area surrounding a swimming pool as described by (Mustapha et al. 2004). A GIS was used to determine the impact of a gas release from a swimming pool at the university of Putra Malaysia on surrounding residential areas by using spatial queries and buffering techniques for evacuation planning purposes.

2.4.11.3 Emergency Response Management

Emergency response management is directly linked to all the items discussed so far. Emergency personnel such as fire, ambulance and police require information at their finger tips which is up to date and accurate when entering into an emergency.

Floor plans indicating all hazards, equipment, inspections, safety equipment, elevators etc. could be overlaid to give the emergency responders an accurate view of what they are entering. On more of a micro scale facility personnel could access floor plans to determine the best evacuation route in the event of fire or other emergency. The September 911 disaster provides an example of how real time air monitoring at ground zero was integrated with GIS to provide the most accurate information to the public and emergency workers. Ongoing monitoring for asbestos, particulates, metals, and organics was linked to a web based GIS so individuals could access the information (Simon and Gallo 2002).

One of the most important questions fire, ambulance and police have when they arrive on scene is what chemicals or biological agents can they be exposed to if they enter the scene. This could be answered quickly by simply submitting a query requesting an inventory of all known chemicals, biological agents and hazardous materials based on the location where the incident is taking place. The inventory would be displayed with images and by floor plan layout to give an accurate visual representation. (Grady 2001) describes the use of a hazardous materials management system linked to GIS floor plans in a navel shipyard situation. The floor plans act as a visual inventory system indicating types of chemicals, quantities, and location for easy access and awareness.

2.4.11.4 Hazardous Waste Management

This parallels asbestos management very closely as discussed above. The main difference being all environmental hazards are included such as PCBs, lead, oil tanks, ammonia etc.

A simple overlay could be conducted to illustrate all locations in a facility and on a property that contain hazardous materials. (Valcik and Huesca-Doramantes 2003) discuss mapping hazardous chemicals, biological agents, and radioactive elements on a room-by-room basis within GIS floor plans for the University of Texas Dallas, which allows police and emergency personnel to have access remotely for planning purposes.

For environmental compliance purposes queries could be conducted to show all inspection records, abatement reports, and waste manifests for a specific facility by room and outdoor locations to give a visual view with tabular data. (Silvia et al. 2006) used GIS for prevention of silicosis by using GIS to map and identify high-risk industries for compliance inspections, to conduct spatial analyses, and use as a database of workers exposed to Silica in Italy.

2.4.11.5 Remediation of Contamination to Air/Water/Land

Again, this parallels asbestos management and hazardous waste management very closely as discussed above. The difference is that the main goal is tracking the actual removal and remediation of waste to ensure a clean natural environment.

Locations of underground oil tanks could be related to drinking water supply sources and natural waterways to see if there is a threat to public safety or the ecosystem.

A simple search identifying all locations with underground oil tanks could be conducted for the purpose of remediation. The added advantage of the spatial component would be that the actual location would be visible on a property site plan with all the associated data such as age of tank, type of oil, last inspection date, any spills etc. (Douglas and Martin 1996) addresses both the scenarios above through a GIS system they implemented to comply with growing U.S. environmental policy for a U.S. Army site in western Texas. They used GIS to analyze wells and create groundwater surface maps, which correlate with geological data. For remediation purposes they integrated all site inspection data such as soil chemistry through a GIS and linked it to site plans to illustrate where underground oil tanks were located for eventual removal.

2.4.12 Review of Findings

This section provides a view into the EHS profession and how spatial analyses can aid in the decision making process by looking at two sub-disciplines of EHS namely industrial hygiene (IH) and environmental management (EM). Proposed spatial analyses for the core functions/activities of each sub-discipline were explored through comparing existing or similar examples in the AM/FM/GIS, ERM and EM literature. Based on the information presented and comparisons drawn I believe GIS can be used for integration of EHS data. The lack of research in the safety and IH fields related to the use of GIS indicates this is a new field for exploration. Possible reasons for a lack of research could be: the EHS field is unaware of GIS and its uses, EHS departments are under funded in many organizations and a GIS option may be too costly to implement, EHS departments are usually small in organizations and may not have the time to explore GIS as an option for aiding in the decision making process, its hard to get buy in form senior management and get them to think spatially in an EHS context, and finally GIS projects are a long term commitment and it may be easier/faster to go with off the shelf relational database software for each problem.

A good cross section of key EHS functions was provided as they relate to spatial analyses but further benefits could be explored for other EHS disciplines not touched on in this section. The spatial benefits have been identified for EHS and as (Douglas 1995) indicates the larger picture of data integration, interoperability and GIS design are all possible and beneficial for EHS.

2.5 Internet GIS and Open Source Software

The topics of internet (Web) GIS and web open source software could each be addressed through their own thesis project. This paper will only provide an introductory view into each area and the discussion will be treated as one topic to illustrate how they are related. Internet GIS is a fast advancing environment with new state-of-the-art technologies appearing on a regular basis, because of this some of the products referenced below may be outdated by the time this paper is completed.

2.5.1 Web GIS

GIS originated as a desktop tool (e.g. ESRI ArcInfo) which individuals used for solving specific problems or answering specific questions (e.g. where to locate a restaurant or how will a new road influence local wildlife). Since the popularization of the internet in the early 1990s as an excellent low cost means to share information the desktop GIS also started evolving with the internet into Web GIS where spatial information could be shared over the internet. Two examples of this are MapQuest® for finding locations and defining driving directions and the other is from the real estate market where the Multiple Listing Service (MLS ®) uses GIS for locating and advertising properties for sale over the internet. Early commercial-off-the-shelf (COTS) proprietary Web GIS products such as ESRI ArcIMS could be deployed out of the box with little or no programming required to share maps over the internet. If users wanted more in-depth analytical functionality such as query and search tools extra programming was required. The Web GIS environment is now evolving into an area where complex analytical functions can be done (similar to the robust desktop software capabilities like ArcInfo). At the time of writing this paper proprietary Web GIS products (such as ESRI ArcServer) are including out of the box functionality which make it simple for the user to create and add analytical capabilities without any programming required. Other proprietary web mapping products worth mentioning are MapExtreme form MapInfo, GeoMedia WebMap by Intergraph, and MapGuide by Autodesk. The Web GIS products are moving from simple map presentation tools to more in-depth spatial analytical products like their desktop counterparts.

Web GIS can be defined as “network-based geographic information services that utilize both wired and wireless internet to access geographic information, spatial analytical tools, and GIS Web services” (Zhong and Ming 2003). They describe Internet GIS as that which focuses on internet technology and utilizes a distributed architecture frame work which represents a paradigm shift from closed centralized GIS to open distributed GIS services. They also make the comment that the traditional desktop GIS model encouraged the development of proprietary one-size-fits-all GIS programs and now by adopting the internet GIS design concept will lead to open GIS programs that can interface with other programs and service providers. This leads into the discussion below about Web GIS open source software (OSS).

2.5.2 Web GIS Open Source Software (OSS)

(Ramsey 2006) provides a very good overview of open source software (OSS) in the Refractions Research publication titled "The State of Open Source GIS". Ramsey defines the OSS technology as software in which the source code is available for modification and redistribution by the general public and the Open Source Initiative is the arbiter for OSS licenses. The different types of OSS are supported through online communities of shared interest and generally are free to the user or developer without any licensing fees. There are generally two programming backgrounds for the OSS, being C and Java. Four items that Ramsey identifies as requirements for a successful OSS are: 1) the software itself is designed in a modular manner, 2) the software is extremely well documented and supported, 3) the software core design and development process is transparent, and 4) the core development team itself is modular and transparent.

There are OSS products available over the internet which can be used to build a totally open Web GIS without the need to use any proprietary products. The products can be categorized into GIS libraries, Web Mapping/Viewing applications and tools, relational databases, and spatial databases. The following summary is taken from (Ramsey 2006):

<u>GIS Libraries</u>

- GEOS (C)
- OGDR/GDAL (C)
- Proj4 (C)
- Mapnik (C)
- GeoAPI (Java)
- GeoTools (Java)
- WKB4J (Java)
- JTS Topology Suite (Java)

<u>Web Mapping/Viewing Applications and Tools</u>

- OpenEV (C)
- OSSIM (C)
- GRASS (C)
- Mapserver (C)

- QGIS (C)
- MapGuide OS (C)
- GMT (C)
- TerraLib (C)
- GeoServer (Java)
- OpenMap (Java)
- DeeGree (Java)
- gvSig (Java)
- uDig (Java)
- JUMP (Java)

<u>Relational Databases</u>

- PostgresSQL (used by C and Java)

<u>Spatial Databases</u>

- PostGIS (used by C and Java)

There are disadvantages and advantages to using OSS for the design and implementation of a GIS. COTS products and OSS products should be compared in the initial stages of the GIS planning process so the appropriate software is selected to suite the needs of the organization. Just because OSS is free does not mean it is an automatic first choice, a GIS implementation using OSS requires someone very knowledgeable in programming, design of web based GIS systems, core internet technologies, and GIS analytical skills (Anderson and Moreno-Sanchez 2003). The specialized programming/design costs of implementing an OSS GIS solution are often much more then a COTS GIS solution and the time required to implement a OSS solution can take longer then a COTS solution. Service and support should also be considered when comparing COTS and OSS, with a pre-packaged COTS system help is only a phone call away which is usually included in annual maintenance fees of the software. With OSS you rely on the programming community for support over the internet and you will need the programming knowledge to fix any bugs or problems with the software.

Some of the advantages to using OSS for a GIS solution are outlined by (Anderson and Moreno-Sanchez 2003) as follows: 1) no software costs, 2) no need to commit to a proprietary Web-GIS, database management system (DMS) or web software with their associated costs, 3) flexibility to implement geo-processing capabilities currently non-existent in commercial Web-GIS software, and 4) because the system is designed with the open source framework the final system has the potential to interoperate with other systems better then a proprietary COTS solution.

Chapter 3
GEO-EHS Design Methodology

3.1 Design Methodology

The overall goal of the large project is to design, develop, test and implement a GIS database for managing EHS in AMDSB and a key step in this process will be data model/database design. The data model/database design is envisioned to include all relevant EHS business functions and data systems (existing and to be developed in future). GEO-EHS will be implemented in phases with the initial research focused on two specific data sets and electronic files (over time all other business processes will be integrated). The two core data sets to be integrated will be an Accident Analysis System – (Parklane) and a Hazardous Materials Inventory System – (Hazmat Inspector). Electronic files used by EHS will also be included such as reports, photographs, audio and video files.

Examples of future data sets that will come on line later are JHSC inspections, science chemical inventory, water quality management, hazardous materials removal, facilities equipment (RECAP), playground/gym safety inspections, and existing spreadsheet data sets. The following outline provides a broad overview of the design methodology including all steps of the larger project, which includes the scope of the thesis as described in section 1.8:

A) **PROJECT PROPOSAL AND JUSTIFICATION –** *Larger project*
B) **GIS USER NEEDS ASSESSMENT–** *Larger project*
C) **SYSTEM ARCHITECTURE DESIGN –** *Thesis and Larger project*
D) **HARDWARE AND SOFTWARE –** *Larger project*
E) **SPATIAL DATABASE BUILDING/DATA CONVERSION –** *Larger project*
F) **TESTING TYPES OF EHS ANALYSES GEO-EHS WILL ENABLE –** *Thesis*
G) **EHS DATA MODEL/DATABASE CREATION (Desktop System) –** *Thesis*
H) **INTERFACE/FUNCTIONALITY/SECURITY DESIGN (Desktop & Web system) –** *Thesis*
I) **WEB GIS SYSTEM DESIGN/IMPLEMENTATION –** *Thesis*
J) **FINAL TESTING of DESKTOP AND WEB SYSTEMS –** *Larger project*
K) **DATA QUALITY CONTROL –** *Larger project*
L) **GEO-EHS IMPLEMENTATION –** *Larger project*
M) **REVIEW OF IMPLEMENTATION –** *Larger project*

3.2 Project Proposal and Justification

In March of 2005 EHS made a business case presentation to senior management explaining why and how GIS could be used to manage and integrate data within AMDSB using EHS and facilities management as an example. Approval was giving after this meeting to use EHS as a pilot project, which would later be used to determine if this concept would be applied to facilities management and other business functions such as information technology, purchasing and planning for data integration and management.

3.3 GIS User Needs Assessment

The very first phase in the overall project started with a GIS user needs analysis in order to define the EHS concerns and requirements for designing a GIS database. Proposals from four different companies were received and reviewed by EHS and a company called 4DM Inc. was chosen to conduct the user needs analysis. This was completed in October 2005. The user needs assessment was essential in identifying the responsibilities and core business activities within EHS and how they relate to the implementation of a GIS. The approach used was as follows (4DM 2005):

- Research was conducted into the business functions, roles and responsibilities of the AMDSB from available information to provide an understand of current and future activities, including the data integration needs on a Board wide scale and to broader extent implementing into the schools
- AMDSB was educated on enterprise geospatial technology and data and how it may apply to daily work tasks and Board level – benefits and limitations, case studies, commercial off-the-shelf COTS application vs. open source technology, customization tools etc.
- Interviews were conducted with key persons on how geospatial data and technology would fit into the their tasks and encourage interoperability between departments – identify strengths and limitations
- All research and interview information was collated to identify gaps and needs with respect to geospatial information and technology by AMDSB and including identifying those government agencies and private data sources that may exchange geographic information with AMDSB
- At a high-level implementation was examined and included costs and funding opportunities

After the user needs analysis was complete ESRI ArcGIS technology was selected versus other COTS applications or open source software. The main reasons for this choice were 1) educational institutions receive a fifty percent discount of the commercial cost of ESRI software, 2) ESRI is the leader in GIS technology and has excellent support and training services, 3) most other school boards in Ontario that are using GIS technology are using ESRI products which forms another support network, 4) the creation of a custom open source system was too costly and would require ongoing support from a consultant to maintain the system, 5) ESRI products allow for the design of an in house system that can be maintained internally eliminating the need to rely on the expertise of a consultant, and 6) if the EHS Officer moves on from AMDSB ESRI technology can be easily learned and maintained by another individual.

3.4 System Architecture Design

As described in section 1.6 the GIS application for EHS is envisioned as an integrated web based system that would consist of a web mapping interface displaying geo-referenced school floor/site plans linked directly to available database information in a secure manner. The figures below (Figure 4), (Figure 5), and (Figure 6) provide a graphical representation of what the EHS GIS architecture may look like when completed.

Figure 4. Three-tier conceptual model of the EHS GIS (4DM 2005).

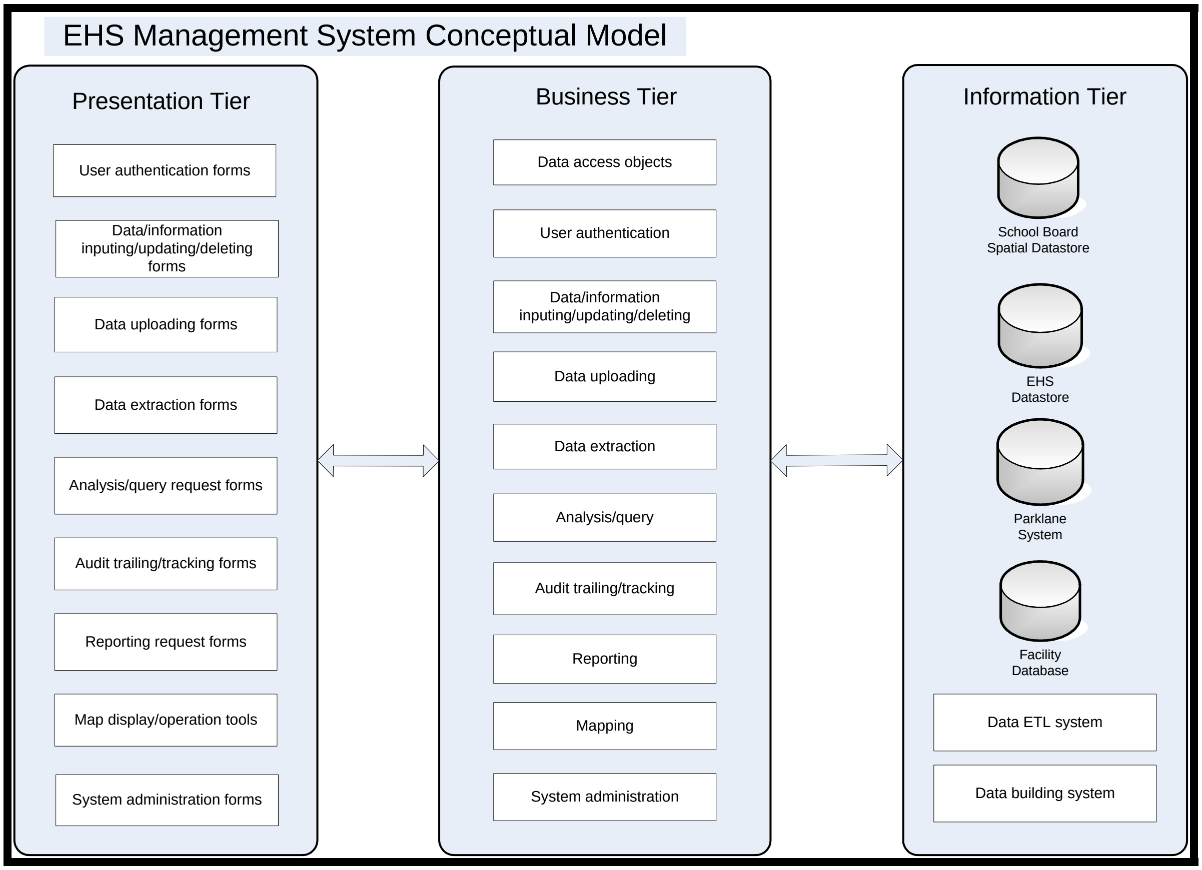


Figure 5. Fully Web-based solution architecture using ESRI ArcGIS technology (4DM 2005).

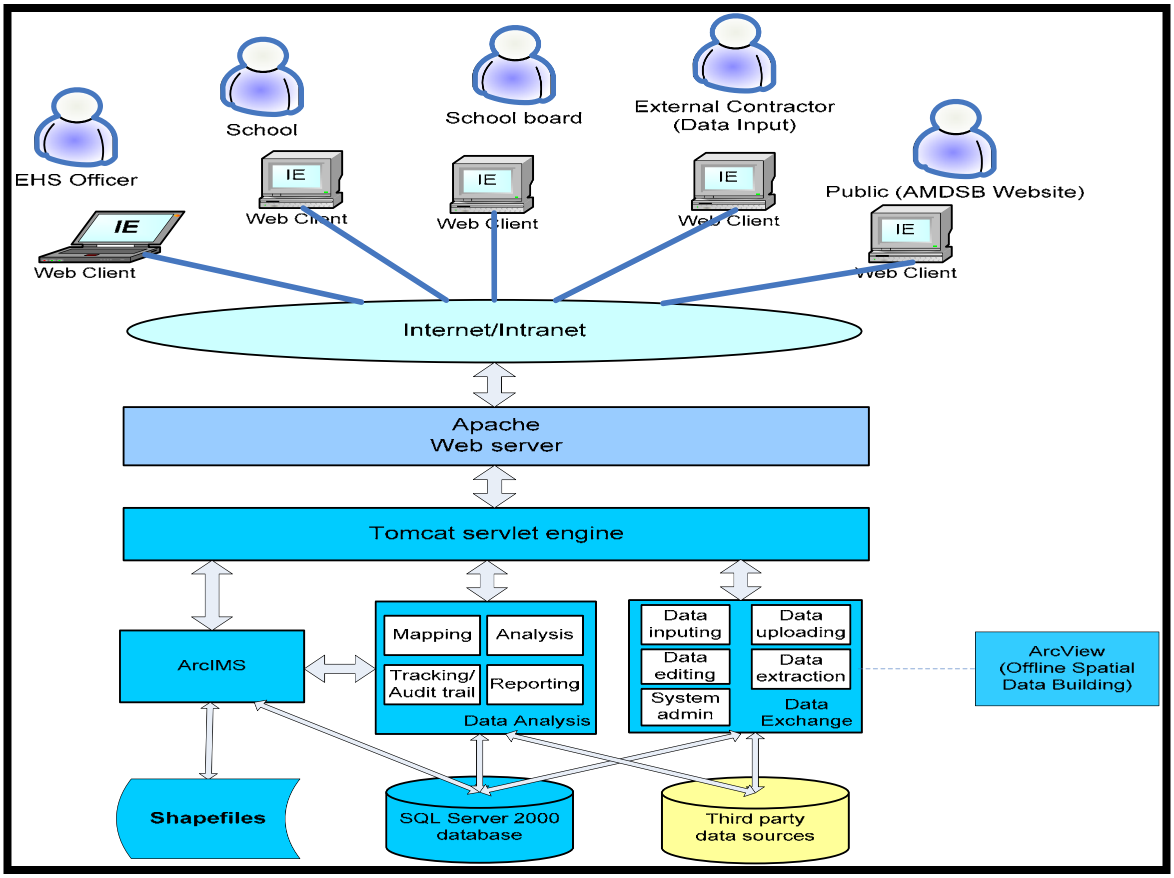
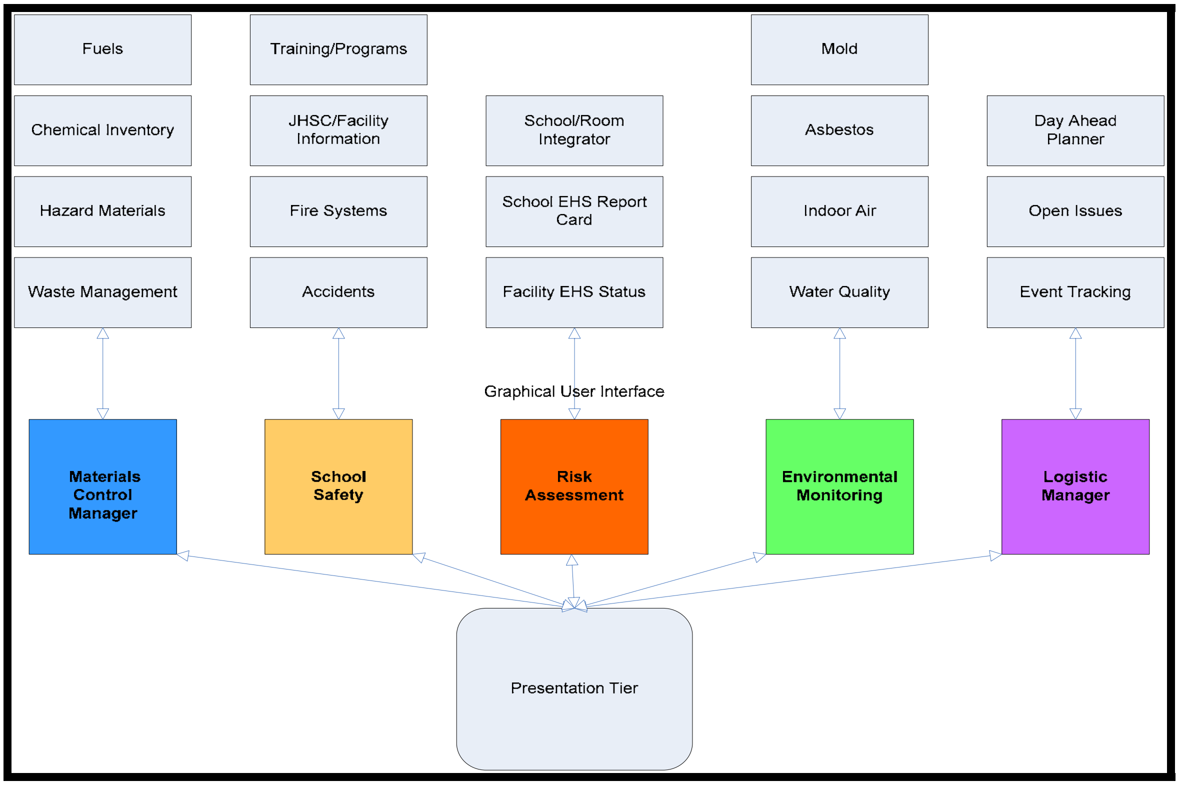


Figure 6. Possible Graphical User Interface (GUI) structure (4DM 2005).



3.5 Hardware & Software

Determining what hardware and software to use has been an ongoing decision process. ArcView was selected as the desktop GIS platform which will also act as the main interface for the integrated system. Certain items such as desktop workstation and laptop selection were easy because existing hardware in use was adequate and met envisioned system performance loads.

- Laptop - Toshiba Terca TE2100 with 766 MB memory running Windows XP.
- Desktop - is an OEM new computer running Windows XP second edition with 500 MB RAM.

Hardware and software required to enable a web based GIS has been a longer process due to changing ESRI technology and funding constraints. The web software/hardware was purchased and the database server has been installed along with the software. The hardware/software specifications are as follows:

Server/web Hardware

- ML370 G4 or HP Proliant DL380 G4
- Dual 3.80 Ghz Xeon Processors
- 6GB PC2-3200 Ram
- Smart Array 6i Controller
- x 146.8GB 10K SCSI HDD's (= approx 1 terabyte of usable data space)
- Redundant Power Supply
- Redundant Fans
- Embedded NC7782 Dual Port Gigabit NIC
- Tape Backup Drive
- DVD-ROM

Server/web Software

- Microsoft Windows Server 2003 Standard w/10 or 30 CALS
- Microsoft SQL Server 2005 Standard w/10 or 30 CALS
- Microsoft Office 2003

- Firewall Software
- SSL (internet secure encryption)
- GIS web system platform – ArcServer Standard Workgroup 9.2
- GIS desktop platform – ArcView 9.2
- Tomcat
- Other Proprietary Software as Required

3.6 Spatial Database Building/Conversion

The second phase in the overall project consisted of two parts – 1) the collection and organization of spatial base layer data and 2) data building of school floor and site plans. This was a joint effort between EHS and 4DM Inc. conducted between January to August 2006. The coordinate system for the base mapping data is Universal Transverse Mercator (UTM), Zone 17, North American Datum (NAD) 83. The scale ranges from 1:600,000 at the full extent where all school locations can be viewed over both Huron and Perth counties down to 1:100 where room level details are available. The orthophotography is at a 30cm resolution which serves EHS purposes for viewing building level detail.

<u>Part 1 – Spatial Base Layers</u>

This consisted of identifying the key spatial layer datasets relevant to the project, acquiring certain datasets from outside sources, conversion of some internal sources into usable formats, and finally organization of the datasets. The following is a list of the spatial base layers:

1) GEOREF (existing transportation data) – street network, school locations, student locations, school boundaries for walking/busing, bus routes/drop points.
2) DMTI Route Logistics (Ontario)/CanMap– comprehensive base mapping layers including transportation network, land uses, zoning, building locations, hydrology, water networks, topology, etc…
3) COUNTY DATA (Huron/Perth) – land parcels
4) MPAC – land parcels for Huron Perth County
5) IMAGERY – orthophotography for Huron/Perth County

Part 2 – School/Site plans data building

This consisted of converting existing school/site AutoCAD plans into GIS format and georeferencing the plans to the orthophotography of Huron/Perth County. The following outlines the steps involved:

1) Conversion of AutoCAD plans into GIS format (Shapefiles, personal geodatabases)
2) Creation of the site (school property), building, room/corridor layers
3) Populating room layers with relevant attributes, (e.g. room number, usage)
4) Spatially adjusting site and floor layers to ensure that site and all floors were properly aligned (e.g. display properly on top of each other)
5) Normalizing the data for each school geodatabase
6) Georeferencing school site/floor plan data to orthohpotography – transformed all spatial features (schools) to the UTM Zone 17 coordinate system

3.7 Testing Types of Analysis the GEO-EHS will Enable

Before a geodatabase model could be designed the types of analyses that GEO-EHS will enable were tested. This step allows the designer to walk through test scenarios with the data to see what types of analyses will and will not be possible. It also flushes out possible problems with the data, data integration, and system interoperability.

The following are some possible uses and types of analyses GEO-EHS could support:

- Maintain a visual/historical database – EHS data
- Integrate data and systems with one central access point
- Keep visual Inventories – fire extinguishers, eyewashes, inspection records, hazardous materials etc.
- Query data – e.g. identify all schools with more than 5 accidents within the past year?
- Overlay data to find themes – accidents/hazards/equipment/maintenance records etc.
- Proximity analysis – e.g. show all rooms within a 10 metre distance from an asbestos removal location?
- Distance/measure – fastest route to a school, square footage of a room or school
- Display output data – Maps, charts, graphs, reports, images, 3D views,
- Share output data dynamically – via internet, intranet, files

3.7.1 Testing a Subset of Analysis Scenarios with Data

As stated earlier the data integration and design process will start with two existing proprietary data systems currently in use at AMDSB 1) Parklane – Accident Inventory/Analysis System and 2) Hazmat Inspector – Asbestos Inventory System. The data of each system needs to be addressed in its own unique manner because they are proprietary systems and access to the raw data tables is different for each system.

The ideal situation would be to access the data directly through ArcGIS and be able to query and analyze the data in an open manner as in the case of an open SQL or MS Access database. This would provide a dynamic link to the data by providing a real time connection. This is ideal because the data would be maintained by the existing database system and there would be no required data maintenance as is the case when data is exported and maintained in a secondary database. However, because they are proprietary systems this is not possible. Parklane required an Open Database Connection (ODBC) driver be purchased in order to access the tables directly but limitations of how ArcGIS reads the data and it being view only lead to the requirement of using an exported version moving forward. In the case of Hazmat Inspector it is not possible to access the tables directly and an export of the data was required, which also required additional software be purchased to make the export possible.

One test scenario was run for each system in order to determine the following:

- if certain types of analyses, queries, graphing, charting, mapping, and reporting were possible with the data
- if there were any issues with connecting to the Parklane data via ODBC
- if there were any issues using the exported Hazmat Inspector data
- how the data tables can be linked/joined/related in ArcGIS to run analyses and queries (e.g. unique ID fields)
- what type of spatial data is best for certain analyses (Regional school level or Local room level) e.g. point, polygon or geodatabase
- how the spatial data (feature classes, shape files, and personal geodatabases) can be linked/joined/related to the table data to run analyses and queries

3.7.2 Test Scenario 1 Parklane System – Accident Analysis

An analysis was done on a Regional school scale to see if there were spatial patterns by building location e.g. show total accidents, by type, by building location, which could be displayed as bar graphs or representative symbols to show the quantity as they are dispersed over a geographic area.

This scenario used a point shapefile of all school locations to link table data with. Three different methods for testing the data were required due to ODBC connection problems. The ***first method*** used was a direct connection to the Parklane data through the ODBC connection. There were problems connecting to the data in this manner due to ArcGIS not mapping Parklane fields correctly. Parklane is programmed in COBOL which ArcGIS does not support through ODBC so the direct ODBC method (Parklane to ArcGIS) was not an option. A ***second method*** used a workaround with MS Access and was able to test the ODBC connection but by adding an additional step of connecting to Parklane through MS Access. MS Access was used to connect to Parklane through the ODBC and a live linked database was created, which was then accessed through ArGIS to run queries/analysis. This option worked for running the analysis but there were limitations with joining and relating tables with the spatial data. Because the Parklane tables do not have an OID field the related or joined table data could not be viewed through the join/relate feature, but the joined/related data could be viewed by using the identify feature and selecting one of the point features. The ***third and last method*** used an exported data set from Parklane saved as an MS Access file. This option worked the best and different types of analyses, queries, graphing, reporting, and charting could be tested. One problem did arise when the accident data was to be displayed as bar graphs over each school, in order to display the data (in the preferred presentation style) fields were manually added to the shape file and the data entered. The data exported from Parklane was not in a format which allowed the display of accident data by type with total numbers. The same result could have been achieved by creating a separate table (containing the preferred data) and joined to the shape file. See (Figure 7) and (Figure 8) for views of the analysis.

Figure 7. Display of Accident Analysis View 1

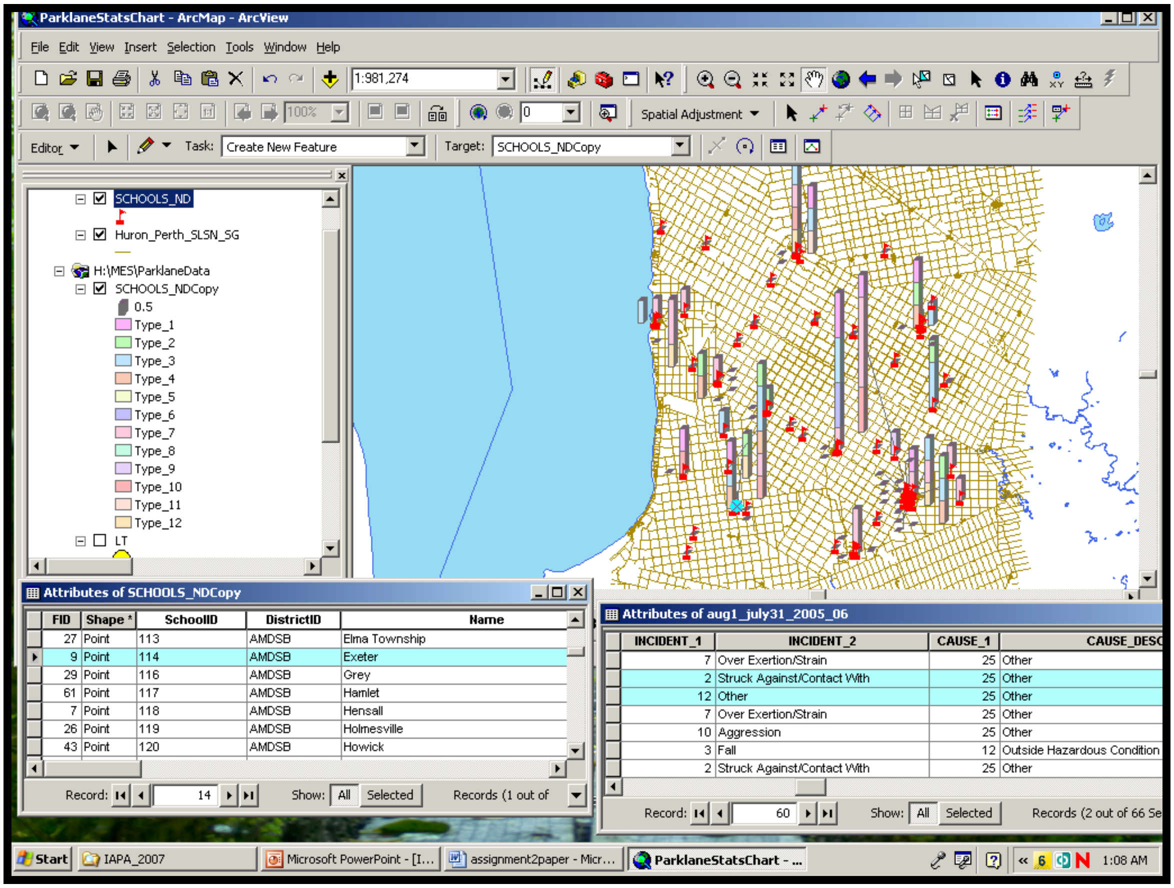
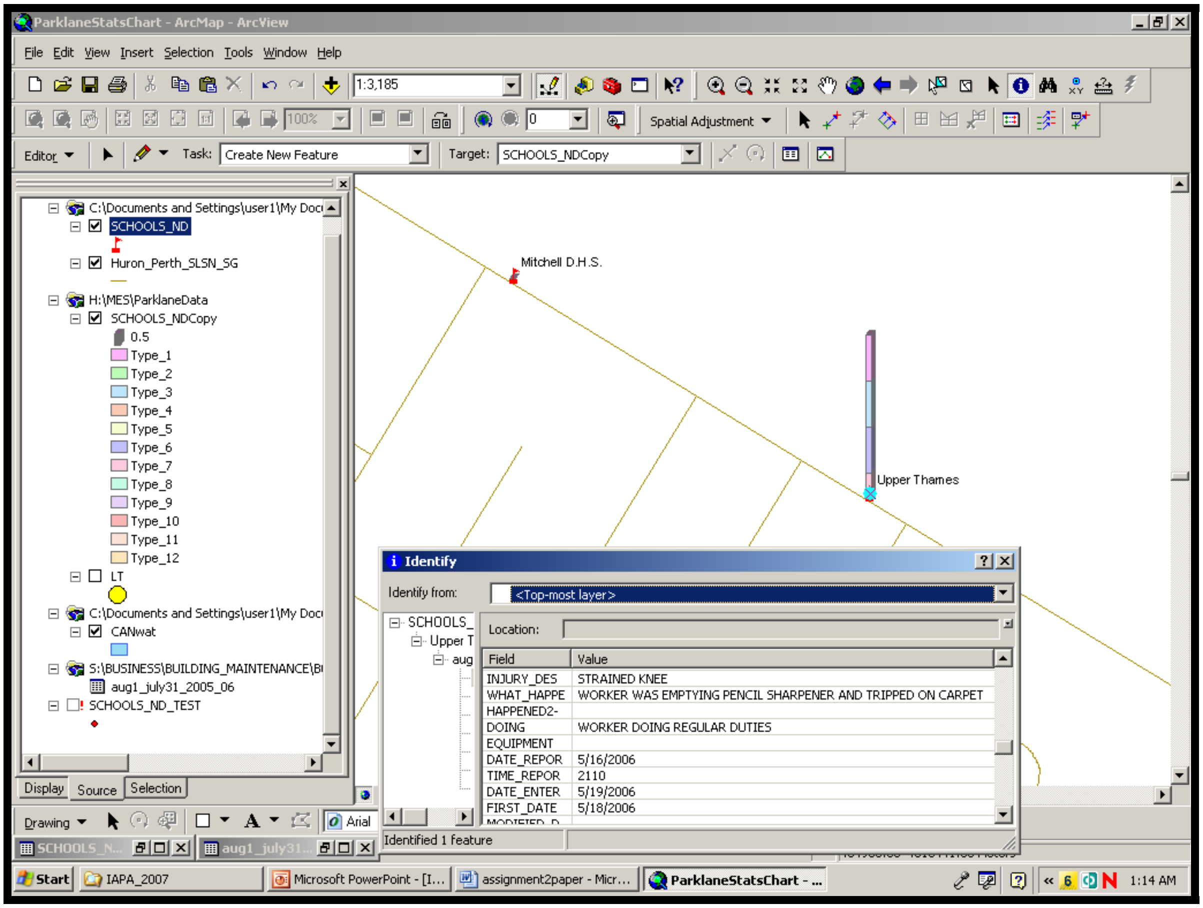


Figure 8. Display of Accident Analysis View 2

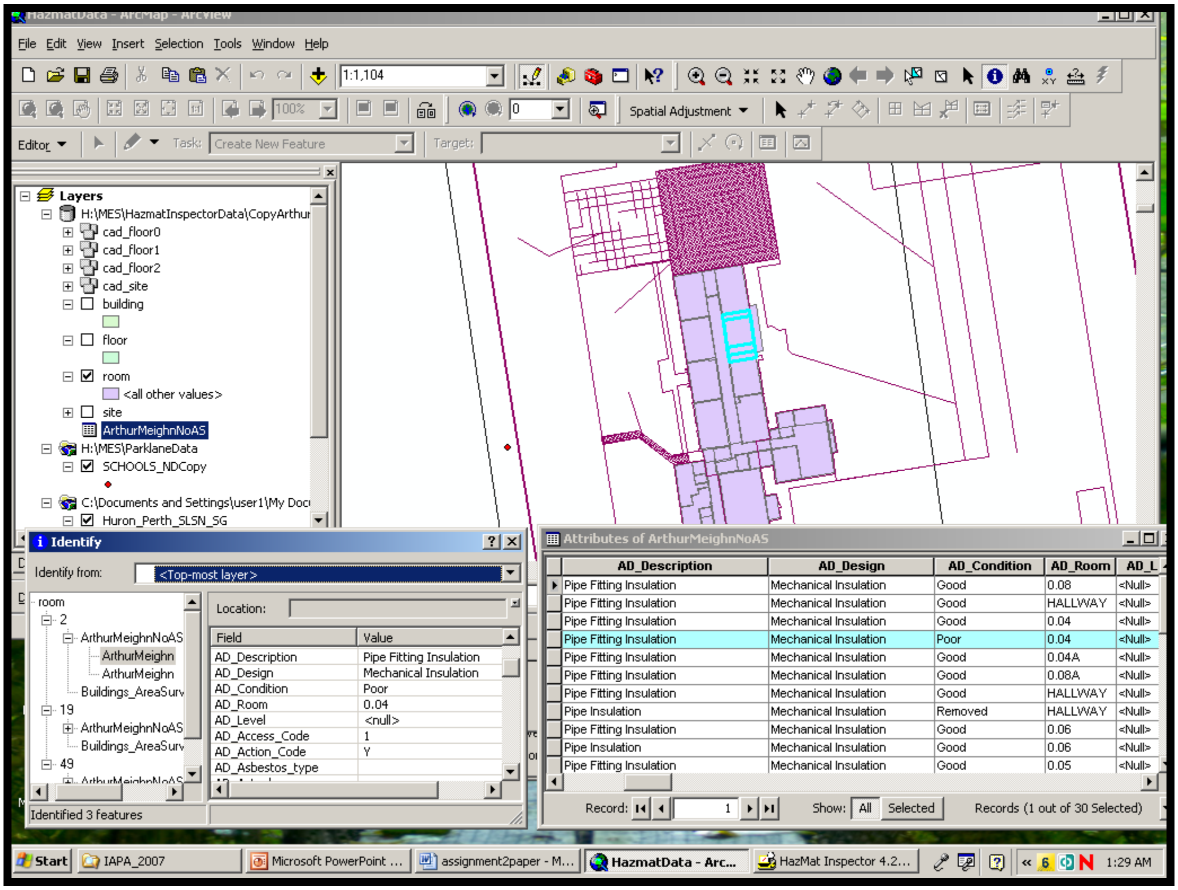


3.7.3 Test Scenario 2 Hazmat Inspector System – Asbestos Inventory

GIS floor plans were tested to see if they could be used as the inventory system for managing asbestos: e.g. location (room-by-room), condition (good, fair, poor), type (chrysotile or amosite), quantities (square footage or linear feet), what materials it is contained in, were it has been removed with air monitoring/inspection results to prove proper removal.

This scenario used a personal geodatabase feature class file to link the table data to. The data was exported from Hazmat Inspector as three separate tables (Buildings, Area Details and Area Surveyed) and saved as MS Access tables in an MS Access database. There were problems with converting the data to MS Access such as some of the data in certain fields was not converted due to the type of field it was saved as (e.g. was text but new field is numeric) and certain data was just not exported from the original export. The three tables were analyzed for the unique ID in order to link them together. The unique IDs were identified (***Building_ID*** and ***Header_ID***) and tables were linked. ArcGIS is not able to recognize one-to-many relationships that exist between external tables (as in the case of Hazmat Inspector tables) so a test analysis was unable to be performed by linking the (related) Hazmat tables to the spatial data. In order to test the spatial analysis capabilities one test table was created, which had a unique ID to link the table with the spatial data. Queries could be made and the data viewed spatially. Three additional concerns were raised through this process 1) a need to determine the best way the data can be related to the individual school geodatabases e.g. room, floor, or school feature class, 2) should one Board wide geodatabase be created so all schools can be queried and 3) how to separate the room and floor feature classes so the data within them can be viewed separately on each level rather then in one merged feature class. See (Figure 9) which represents a view of the test analysis.

Figure 9. Hazmat Inspector Test Analysis



3.7.4 Summary of Problems and Road Blocks

One of the main functions of the two test analyses was to identify any problems that needed to be rectified before being able to move into the geodatabase design stage. The following is a summary of items noted above that required attention. They are listed as questions below which will be answered throughout the remaining thesis as to how they were resolved. The remaining steps noted in the design methodology will also be addressed in the following chapters.

<u>Test Scenario 1 Parklane System – Accident Analysis</u>

1. Is a point shapefile of all school locations the best spatial feature to use in this scenario?
2. Why were there problems connecting directly to the data via the ODBC connection (possibly due to ArcGIS not mapping Parklane fields correctly)?
3. Is a workaround with MS Access for an ODBC connection a feasible option? Or will the limitations with joining and relating tables with the spatial data because the Parklane tables do not have an OID field prevent this as an option?
4. Is an export of the data as a static data set the only other option? Or will we need to create an exported copy of the database in SQL server and keep this updated at regular intervals in order to use the data seamlessly?
5. Displaying the data as bar graphs over each school fields had to be manually added to the shape file and the data entered. Can joins or relates achieve the same results? Or another automated step?

<u>Test Scenario 2 Hazmat Inspector System – Asbestos Inventory</u>

1. Is a personal geodatabase feature class file the best option to link the table data to? Or is there an easier way to create links with tables inside a geodatabase?
2. Should one Board wide geodatabase be created of all schools (besides the 54 individual school geodatabases) in order to run queries such as show all schools with 1000sq/ft of total asbestos that requires removal?
3. Why were there problems with converting the data to MS Access, such as some of the data in certain fields was not converted due to the type of field is was saved as (e.g. was text but new field is numeric) and some data was just not exported from the original export.
4. How will the unique Ids identified for the 3 tables be used to link them together and to the spatial data (e.g. room, floor, or building feature class)?
5. How to separate the room and floor feature classes so the data within them can be viewed separately by each level rather then in one merged feature class of all 3 levels?

Chapter 4
GEO-EHS Data Model and Prototype Design

4.1 Overview

As described in section 3.7 above there were many obstacles identified in the testing phase that required solutions before an EHS data model could be finalized. Additional hurdles were encountered as the design process continued as will be described in the subsequent sections along with solutions. Before the EHS data model structure is explained a high level overview of all the existing EHS data sources will be provided to offer an understanding of the magnitude of data that requires integration. Following the EHS data source overview the EHS data model will be unveiled through a detailed description of the datasets used to produce the GEO-EHS desktop prototype (Spatial data, Hazmat Inspector Asbestos System, Parklane Accident System, Electronic files, and how future datasets will be integrated). Once the data model is presented the GEO-EHS prototype will be used to illustrate how typical queries, overlays, analyses and reporting will be conducted.

As indicated in section 1.1 the main problem the EHS department at AMDSB faces is the lack of data integration and interoperability between the numerous different data sources used. Throughout the thesis there has been multiple references made that EHS requires access to many data sources but with little explanation of what each source consists of. The following table (Table 1. EHS Data Sources) provides a detailed view of each data set categorized by whether the data is a proprietary database, open database, spreadsheet, floor/site plans, email system, electronic documents, images, video files, audio files, or paper documents. The data is further broken down into its name, function, format, accessibility, and location. The table illustrates the problem that each dataset cannot be accessed from one central point or used for integrated analyses. In order to perform integrated analyses each source is required to be referenced separately and analyzed within its proprietary/open/or spreadsheet system, visualized in different locations, and paper records reviewed and manually analyzed. The results then need to be manually amalgamated and only then can an integrated analysis be performed. The current data structure prevents integrated analyses because the process is time consuming, manual, and data intensive. An integrated approach would allow for better more accurate decisions resulting in proactive EHS management.

Table 1. EHS Data Sources

Proprietary Databases	Name of Data	Data Function	Data Format	Data Access	Data Location
	Hazmat Inspector	Asbestos Inventory (Compliance)	Proprietary System (Basebridge)	Web	Basebridge Web Server
	Parklane	Accident Reporting (Compliance)	Proprietary System (Parklane Systems)	AMDSB Network	AMDSB Server (Geoquery)
	ISYS Works	HR Data/Training	Proprietary System (ISYS Works)	AMDSB Network	AMDSB Server (HR only access)
	SFSIS	Facilities Data (Planning)	Proprietary System (Ministry of Education)	Web	Ministry of Education Web Site
	RECAP	Facilities Data (Planning)	Proprietary System (Ministry of Education and Capital Planning Solutions Inc.)	Web	Ministry of Education Web Site
	HWIN	Hazardous Waste Inventory (Compliance)	Proprietary System (Ministry of the Environment)	Web	Ministry of the Environment
	Industrial Hygiene Data (Numerous Types of Equipment)	Industrial Hygiene Data (Compliance)	Proprietary Systems (Numerous)	AMDSB Network	S: Drive/ Instruments
Open Databases					
	EHS Reporting	EHS Project Management, Compliance, Auditing	File Maker Pro	AMDSB Network	(Dave G) H: Drive
Spread Sheets					
	Water Quality Data	Water Regulations (Compliance)	MS Excel		S: Drive

Floor/Site Plans	Name of Data	Data Function	Data Format	Data Access	Data Location
	School Floor and Site Plans	Building Construction and Maintenance	Auto Cad and pdf	AMDSB Network	S: Drive
First Class Email					
	Email	Communication	First Class Open Text	Intranet/Web	First Class email System 100mb storage limit
Electronic Documents					
	Playground Reports	Compliance	pdf	AMDSB Network	S: Drive
	Lifting Device/Gym Reports	Compliance	pdf	AMDSB Network	S: Drive
	Asbestos Inspection Reports	Compliance	pdf	AMDSB Network	ftp: Site
	EHS Inspections	Compliance and Auditing	pdf, MS Word, Word Perfect	AMDSB Network	S: Drive
	Mould/IEQ Investigations	Compliance	pdf, MS Word, Word Perfect	AMDSB Network	S: Drive
	Building/ Maintenance requests	Building Construction and Maintenance	Quask database/forms	AMDSB Network	S: Drive
	Accident Investigations	Compliance	pdf, MS word, Word Perfect	AMDSB Network	S: Drive
Images					
	Supporting documents for Inspections and Investigations	Compliance and Auditing	jpeg, tiff, pdf, png, psd, nef, bnp, gif	AMDSB Network	S: Drive

Video	Name of Data	Data Function	Data Format	Data Access	Data Location
	Supporting documents for Inspections and Investigations	Compliance and Auditing	wmv, mpg, swf, qt, mov,	AMDSB Network	S: Drive
Audio					
	Supporting documents for Inspections and Investigations	Compliance and Auditing	mp3, wav, wma	AMDSB Network	S: Drive
Paper Documents					
	JHSC & Site Inspections	Compliance	Paper	EHS Office	EHS Office Files
	Hazardous Materials Inventory	Compliance	Paper	EHS Office	EHS Office Files
	Scaffolding Inspections	Compliance	Paper	EHS Office	EHS Office Files
	Fire Protection Systems Inspections	Compliance	Paper	Facilities Office	Facilities Files
	Elevator/Stair Lifts Inspections	Compliance	Paper	Facilities Office	Facilities Files
	Cafeteria Fume Hoods inspections	Compliance	Paper	Facilities Office	Facilities Files
	HVAC Systems Inspections	Compliance	Paper	Facilities Office	Facilities Files
	Boiler Inspections	Compliance	Paper	Facilities Office	Facilities Files
	Electrical Inspections	Compliance	Paper	Facilities Office	Facilities Files
	Tech/Science Inspections	Compliance	Paper	Tech/Science Head Office	School
	First Aid Kit Inventories	Compliance	Paper	School Office	School
	Training Records	Compliance	Paper	EHS Office	EHS Office Files

4.2 Spatial Data

The spatial data was compiled and created as described in section 3.6. which set the foundation for creating the overall EHS data model. 54 individual personal geodatabases (PGDB) were created representing each facility owned by AMDSB. The PGDBs are used for micro scale “Local” room analyses requiring room level information specific to a facility. Each PGDB consists of:

1) GIS converted AutoCad floor and site plans - Each floor level and site is housed in a feature dataset (FD) consisting of five feature classes (FC) with the most useful being annotation and lines. The GIS floor/site plans are used for background reference only, the following FC’s are used for spatial analytical purposes.
2) Building outline – polygon FC
3) Elevator (only if facility has them) – polygon FC
4) Floor outline – polygon FC
5) Room – polygon FC
6) Site outline – polygon FC

In addition to the PGDB’s there are two shape files (SF) which are used for macro scale “Regional” school spatial analyses that require information about many facilities. Another option for future consideration is to house these in a geodatabase as feature classes.

1) School Locations – point SF
2) Buildings – polygon SF

The base layer data used for reference and mapping purposes (as briefly mentioned in section 3.6) consists of the following:

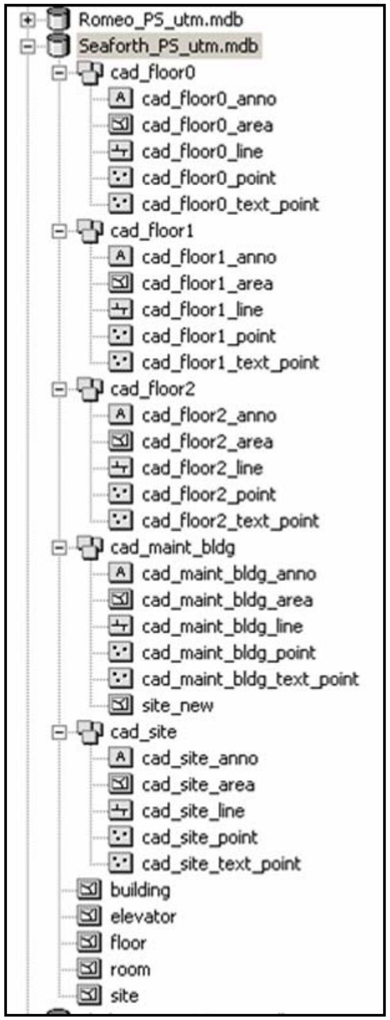
1) Orthophotography for Huron and Perth counties – South Western Ontario Orthophotography Project (SWOOP), Colour 20km x 20km tiles at 30cm resolution. Data was acquired at no cost through the Land Information Ontario (LIO) via an agreement with the Ontario Ministry of Education.

2) Road Network for Huron and Perth counties – DMTI Route Logistics (Ontario/CanMap) – comprehensive base mapping layers including transportation network, land uses, zoning, building locations, hydrology, water networks, topology, etc…Data was acquired at no cost through an agreement with the Ontario Ministry of Education.

3) Land Parcels for Huron and Perth counties – Data was acquired at no cost from the Municipal Property Assessment Corporation (MPAC) through an agreement with the Ministry of Natural Resources (MNR) and LIO.

Below the spatial component of the EHS data model is displayed via images with explanations of the unique fields which are used to integrate external data sources (Figure 10, Figure 11, Figure 12, and Figure 12).

Figure 10. Spatial Component of EHS Data Model - Local Level (Personal Geodatabase - Room)



<u>Seaforth_PS_utm.mdb</u>

To the left is a visual representation of a Personal Geodatabase (PGDB) illustrating the GIS Auto-Cad feature datasets (FD) ***e.g. cad_floor0*** consisting of five feature classes'(FC) ***e.g. cad_floor0_anno***. The only useful FC's for background visualization are ***cad_floor_anno*** and ***cad_floor_line.*** The remaining FC's are byproducts of the AutoCad to GIS conversion and are not useful from a GIS perspective. The remaining FC's are not included as part of the final EHS data model and are only illustrated here to provide information on what spatial data an Auto-Cad file consists of.

The FC's (Building, Elevator, Floor, Room, Site) are the GIS data used for data integration, queries, analyses, and reporting. An example of the Room attributes is provided below.

<u>Details for Room</u>

The FC's (Building, Elevator, Floor, Room, Site) all contain the same attributes of ***OBJECTID, Shape, Shape_Length, Shape_Area, and School***. The Floor FC contains the added attribute of ***Floor*** while Room FC has the added attributes of ***Flor_lev, Room, Subroom, Type, Id, Description, Sq_ft, Area_m, Area_ft, and School_Rm.***

The ***School*** attribute is a unique number (e.g. school #8) for each school/facility and is the "Unique ID Field" common across all FC's used for linking external data sources at the "Regional" school level. The ***Id*** attribute specific to Room FC is a unique number for every School Room and Corridor (e.g. 0.17=Floor0-Room17 or 0.C03=Floor0-Corridor3). The ***School_Rm*** attribute is a combination of ***School and Id*** which is a "Unique ID Field" used for linking external data sources at the "Local" room level specific to each school/facility.

Figure 11. Spatial Component of EHS Data Model - Regional Level (School-Facility)

- school_buildings.shp
- school_ids.dbf
- SCHOOLS_ND_ADJUSTED.shp

School_Buildings and School_ND
These are the two shape files (SF) used for Regional level analyses when common items across all schools are of question.

Details for SCHOOLS_ND
Type of object: Feature Class
Number of records: 76
Attributes
- FID
- Shape
- SchoolID
- DistrictID
- Name
- Type
- Principal
- VicePrinci
- Contact
- Capacity
- PrincipalM
- VicePrinc1
- ContactMai
- Referenced
- Arrival
- AMBell
- Noon
- Return
- PMBell
- Departure
- Extra1
- Extra2

School_ND consists of all school point locations and includes many attributes which are not relevant for EHS purposes. The file was exported from the AMDSB Transportation GEOREF system and includes many items that are specific to Transportation. The relevant attributes to EHS are ***(FID = OBJECTID, Shape, SchoolID, DistrictID, Name, Principal, and VicePrincipal). SchoolID*** is the "Unique ID Field" (school number) used for linking external data sources at the "Regional" school level.

Details for school_buildings
Type of object: Feature Class
Number of records: 53
Attributes
- FID
- Shape
- Shape_Leng
- Shape_Area
- School

School_Buildings consists of all school building outlines and includes the same attributes as all FC's ***(FID = OBJECTID, Shape, Shape_Length, Shape_Area, and School)***. As indicated in Figure 10 the ***School*** attribute is a unique number for each school/facility and is the "Unique ID Field" used for linking external data sources at the "Regional" school level.

Figure 12. Visual Representation of Spatial Data (Room, Corridor, Site, School)

Figure 13. Visual Representation of Spatial Data (GIS CAD annotation and line)

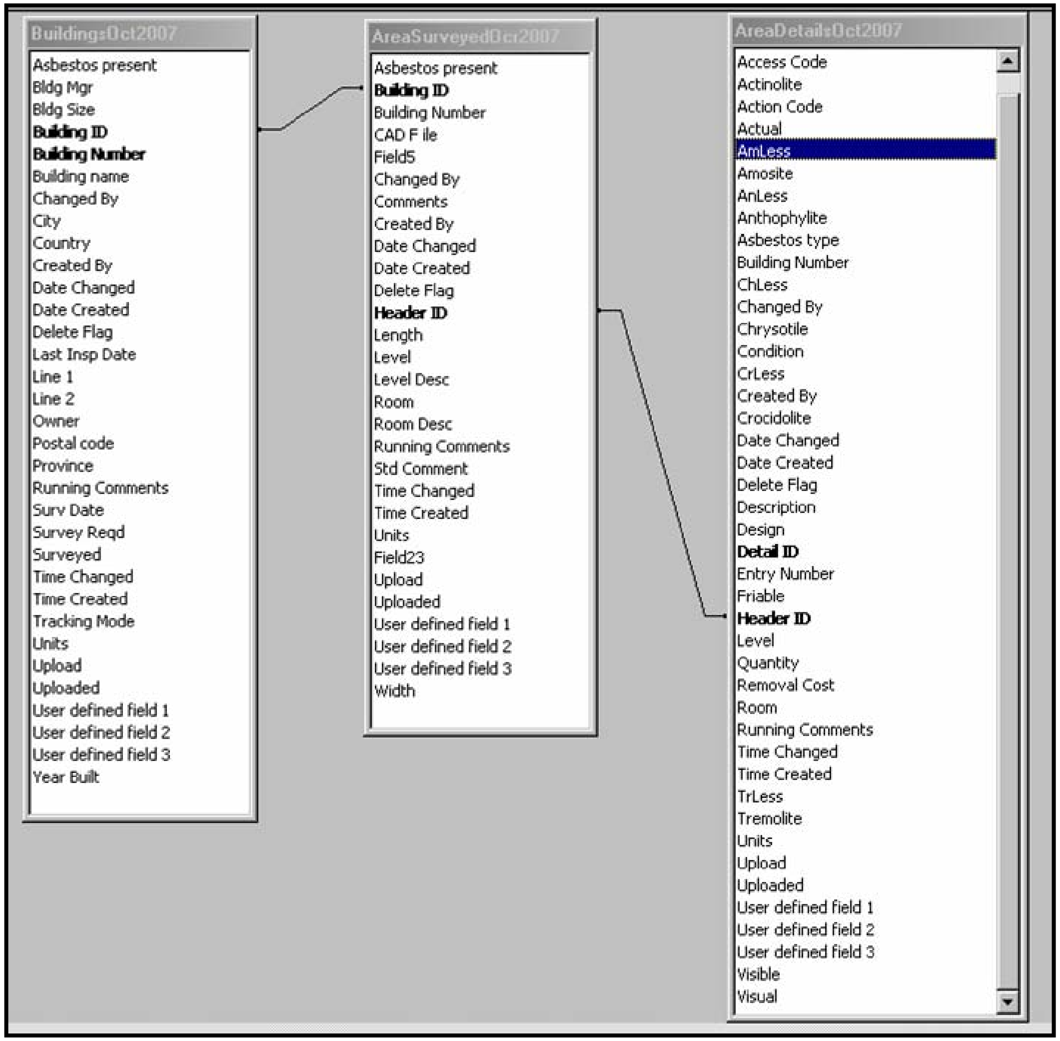
4.3 Hazmat Inspector Data

Hazmat Inspector is a web based database system (supplied by Basebridge Systems) used by EHS for maintaining an asbestos inventory of every facility. Every year staring in May a room by room inspection is conducted of every facility by an outside consultant (T. Harris Environmental) as required by regulations in order to assess the condition of asbestos within the facilities. Asbestos is a natural occurring mineral which was used in the manufacturing of many building materials prior to the 1980’s due to its strength and fire resistance traits (e.g. floor tiles, ceiling tiles, pipe and roofing insulation, drywall joint compound and pipe fitting compounds). In Ontario the use of asbestos in building materials and other materials was banned in the early 1980’s due to the adverse health effects caused by the inhalation of asbestos fibres (e.g. asbestosis - a from of lung cancer). When building materials containing asbestos are disturbed (e.g. during demolition) asbestos fibres are released into the air and can become embedded in the lungs and possibly lead to lung cancer twenty to thirty years later.

The following will outline the Hazmat Inspector data structure and illustrate the unique fields which are used for data integration with the spatial component. Further details about the data integration (e.g. process, problems encountered, and solutions) will be provided in Chapter 6-Discussion and Conclusions. Hazmat Inspector consists of a web based proprietary database housed on the Basebridge Systems server in Nova Scotia and is not accessible in an open manner due to the system being proprietary as mentioned in section 3.7. A standalone desktop version of the software needed to be purchased in order to export the data for integration purposes. Initially the goal was to recreate the database in MS Access or SQL were the data and linkages between tables could be maintained and ArcGIS could access the database through an ODBC driver but due to the limitation of ArcGIS not recognizing linkages between multiple tables this is not possible at this point in the project. Therefore the data was analyzed and one table created from the three tables initially exported (Buildings, AreaSurveyed, and AreaDetails). One table provides all the data required for EHS purposes and allows for integration through ArcGIS.

Below Hazmat Inspector is displayed via images with explanations of the unique fields and how the data is integrated with the spatial data (Figure 14, Figure 15, and Figure 16).

Figure 14. Hazmat Inspector Data Structure (Three Tables)



Hazmat Inspector consists of three exported tables (Buildings, AreaSurveyed, and AreaDetails). Each table has a "Unique ID Field" that allows all three tables to be related and unique fields that allow joining/relating to GIS (described below).

Buildings

The Buildings table includes general information specific to the facility such as building name and address. The ***Building_ID*** field is the "Unique ID Field" that relates Buildings to AreaSurveyed. The Buildings table also contains the ***Building_Number*** (unique school id) which is the "Unique ID Field" used for joining/relating the data to GIS at the "Regional" level.

AreaSurveyed

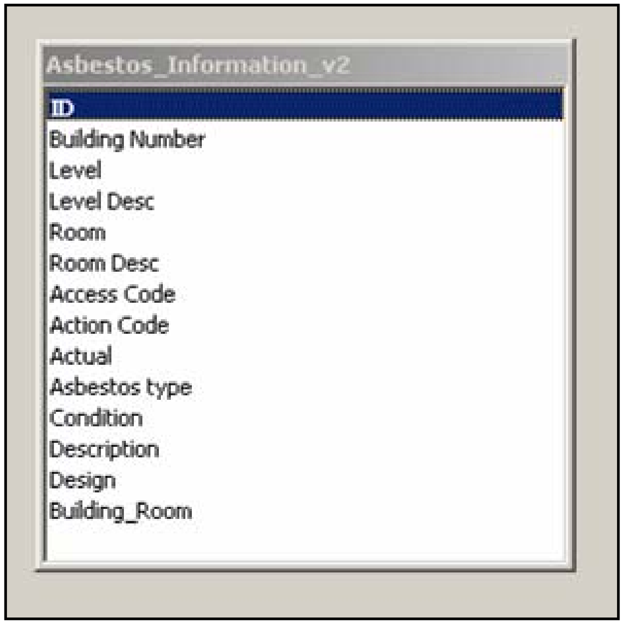
The AreaSurveyed table consists of general information about the rooms inspected such as floor level, room number and room description. The ***Header_ID*** field is the "Unique ID Field" that relates AreaSurveyed to AreaDetails. The AreaSurveyed table also contains the ***Room_ID*** (unique room number) which is the "Unique ID Field" used for joining/relating the data to GIS at the "Local" level.

AreaDetails

AreaDetails includes detailed information about the asbestos inspected such as type, quantity, and condition. The ***Header_ID*** field links to AreaSurveyed.

Figure 15. Hazmat Inspector Data Structure (One Final Table)

Due to the limitation of ArcGIS not being able to recognize one-to-many relationships that may exist between external tables (as in the case of Hazmat Inspector tables) the data structure above (three tables) would not work. Therefore one table containing all relevant data for EHS purposes was created from the three Hazmat Inspector tables.



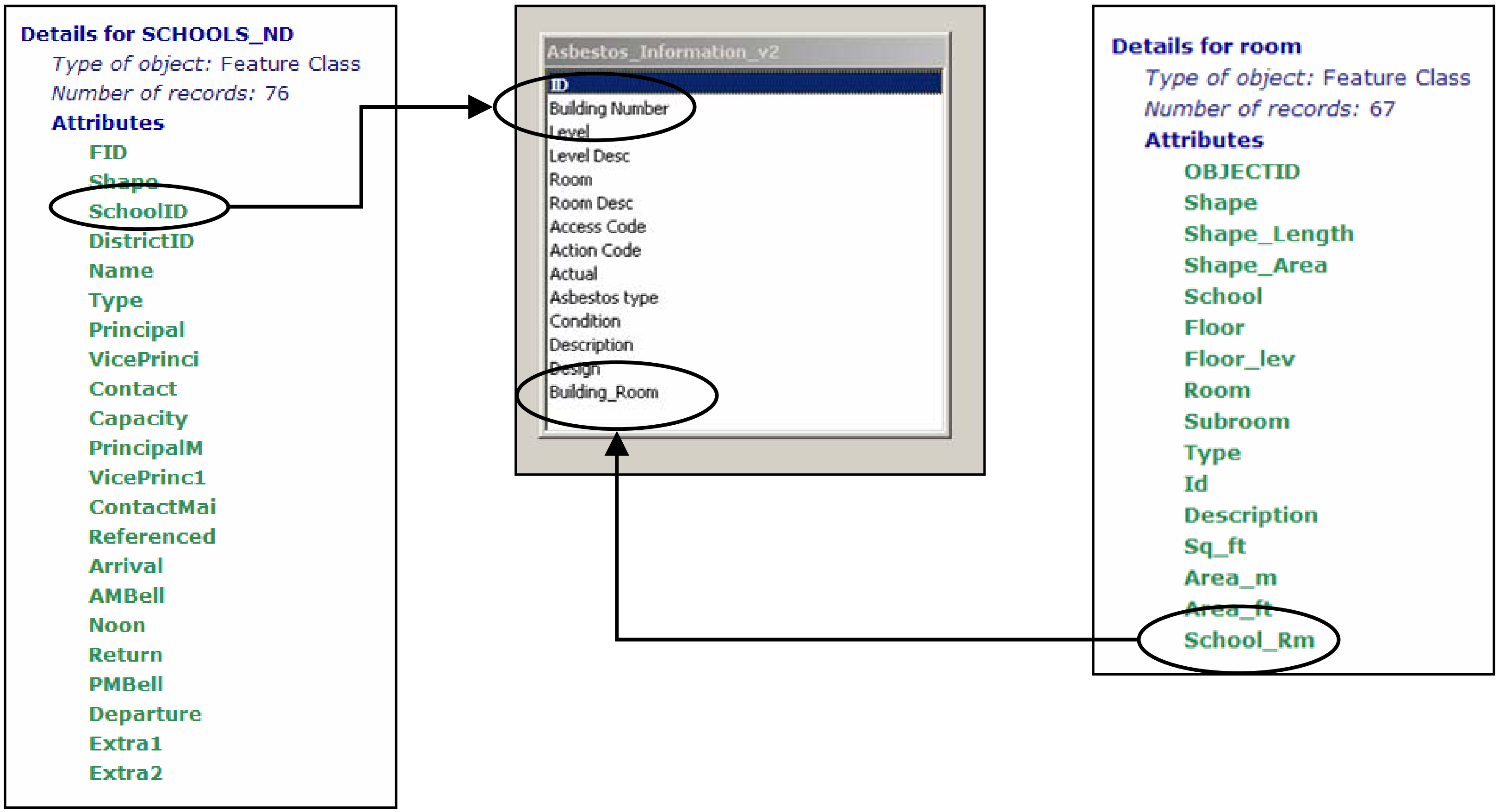
An ***ID field*** (unique number for each row) was also added which is required for ArcGIS to function properly when creating joins, relates and running queries. In ArcGIS terms this is the OID (ObjectID) for tables or FID for layers.

The ***Building_Room*** field was also created by combining ***Building_Number*** and ***Room_ID*** which creates a unique Room filed specific for each facility. ***Room_ID*** alone could not be used for joining/relating data to GIS at the "Local" level because although it is unique for each facility there could be duplicate ***Room_ID's*** across multiple facilities (e.g. room 1.17 at school 3, 4, and 6). So the combination of ***Building_Number*** and ***Room_ID*** solves this problem.

The process for creating the one table along with obstacles encountered, solutions, and future work required will be discussed in detail through Chapter 6-Discussion and Conclusions.

Figure 16. Hazmat Inspector Data – Spatial Relates (one-to-many)

Two relates (each one-to-many) were created from the GIS data to Hazmat Inspector data in order to conduct queries, analyses, overlays, and reporting via the GIS interface. 1) - School_ND shape file representing school locations for "Regional" analyses ***SchoolID*** to ***Building_Number*** and 2) – Room feature class representing rooms for "Local" analyses ***School_Rm*** to ***Building_Room***.



4.4 Parklane Data

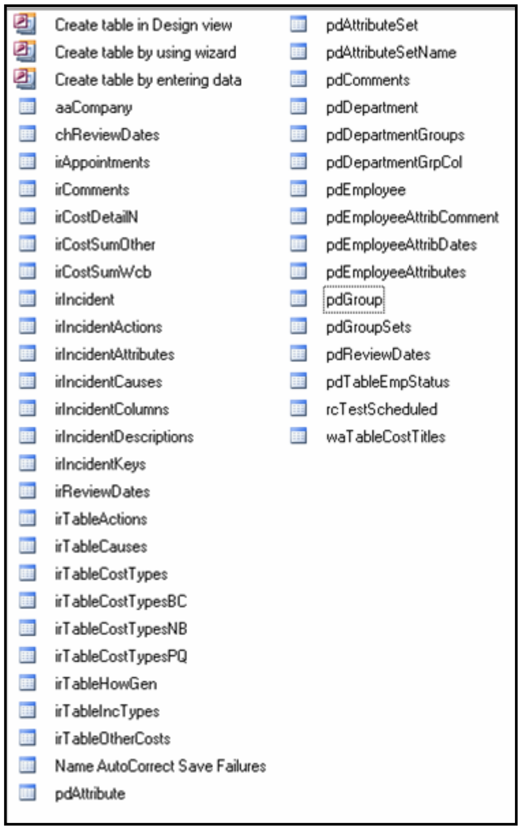
Parklane is a database used by EHS for tracking, maintaining and reporting on incidents and accidents that occur within AMDSB. The software is required as directed by the insurance provider used by AMDSB and most other public school boards in Ontario. The data is only collected at the “Regional” school level and does not go to the detail of “Local” room level as Hazmat Inspector does. The software is a proprietary system designed by Parklane Systems and is installed/accessed via the EHS server. The data tables are in COBOL format but can be accessed through an ODBC driver called Relativity. The tables do not contain an OID field and can not be altered because they are view only so the original strategy of accessing the database directly through ArcGIS is not possible because the tables require OID fields for ArcGIS to function properly. Compounding the above problem was the fact that ArcGIS could not recognize all the COBOL fields through the ODBC driver resulting in missing data. The next plan of action was to recreate the database in MS Access or SQL with proper linkages between tables but as described in section 4.3 Figure 15 this is not an option due to the limitation of ArcGIS not being able to recognize one-to-many relates that exist between external tables. Therefore the last option was to export selected data required using the systems export function. This is not the ideal situation because the data will need to be maintained outside the system and an updating process will be necessary to ensure data is accurate and current. Further details about the data export process (e.g. problems encountered and solutions) will be provided in Chapter 6-Discussion and Conclusions.

Parklane is composed of multiple tables many of which are not used for EHS purposes. All the tables were analyzed to determine which ones were relevant and further to identify what data from each needed to be included in the export. To better understand how the data operates within the Parklane System, entity relationship diagrams (provided by Parklane) were reviewed and tables useful for EHS purposes were imported to MS Access and relationships set up based on unique fields for each table. This process also acts as the initial step if in the future it is determined that a duplicate database is a possible option rather then an export of selected data.

Below Parklane is displayed via images with explanations of the unique fields and how the data is integrated with the spatial data (Figure 17 and Figure 18).

Figure 17. Parklane Data Structure (All Tables)

Parklane is composed of forty plus tables as displayed on the bottom left. Of those seven are relevant to EHS **- irIncident** (all accident/incident details), **pdEmployee** (all employee information), **irTableIncTypes** (incident type descriptors), **pdDepartment** (provides the department name e.g. school-job function), **pdDepartmentGroup** (provides "Unique ID Field" for linking GIS data ***GrpNo*** = unique number for each school), **pdGroup** (includes group name e.g. school name), and **pdDepartmentGrpCol** (supplies information about each GrpSet e.g. GrpSet_01 contains all unique school numbers and GrpSet_04 contains all unique numbers for job function. The "Unique ID Fields" for linking all tables are ***IncType***, ***EmpKey***, ***Department***, and ***GrpSet*** as displayed below to the right. As stated above ***GrpNo*** is the "Unique ID Field" for linking to GIS.



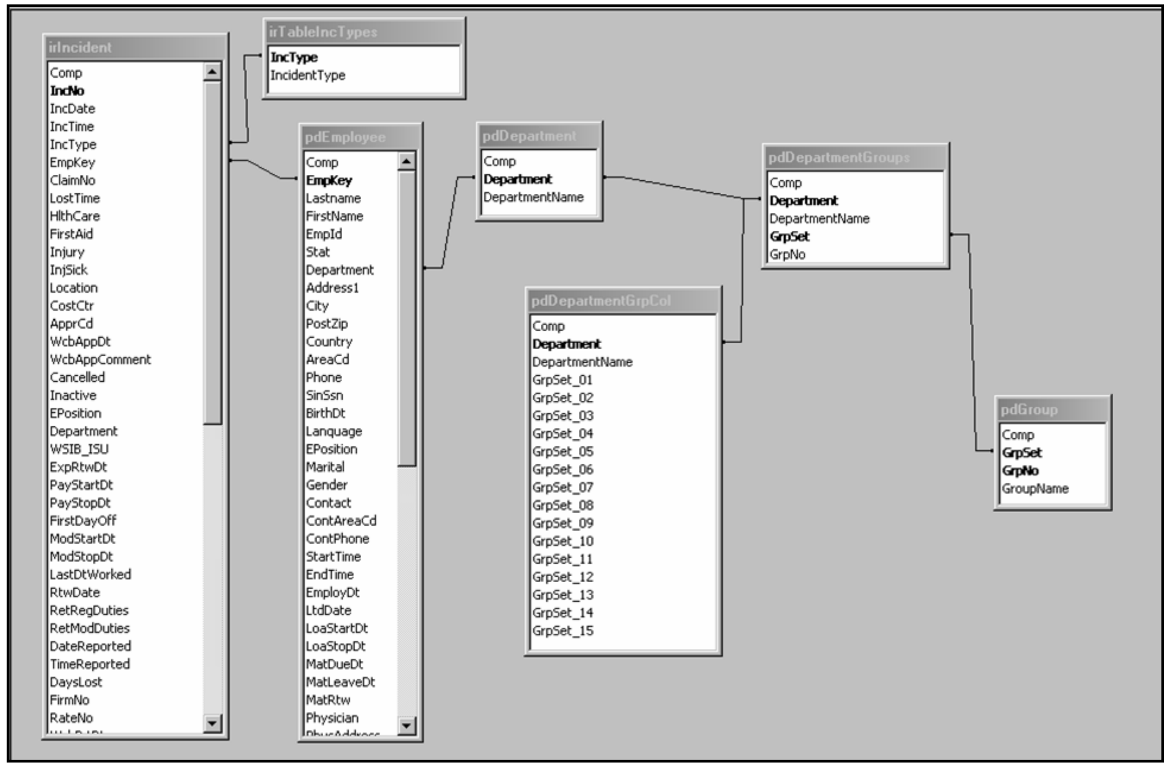
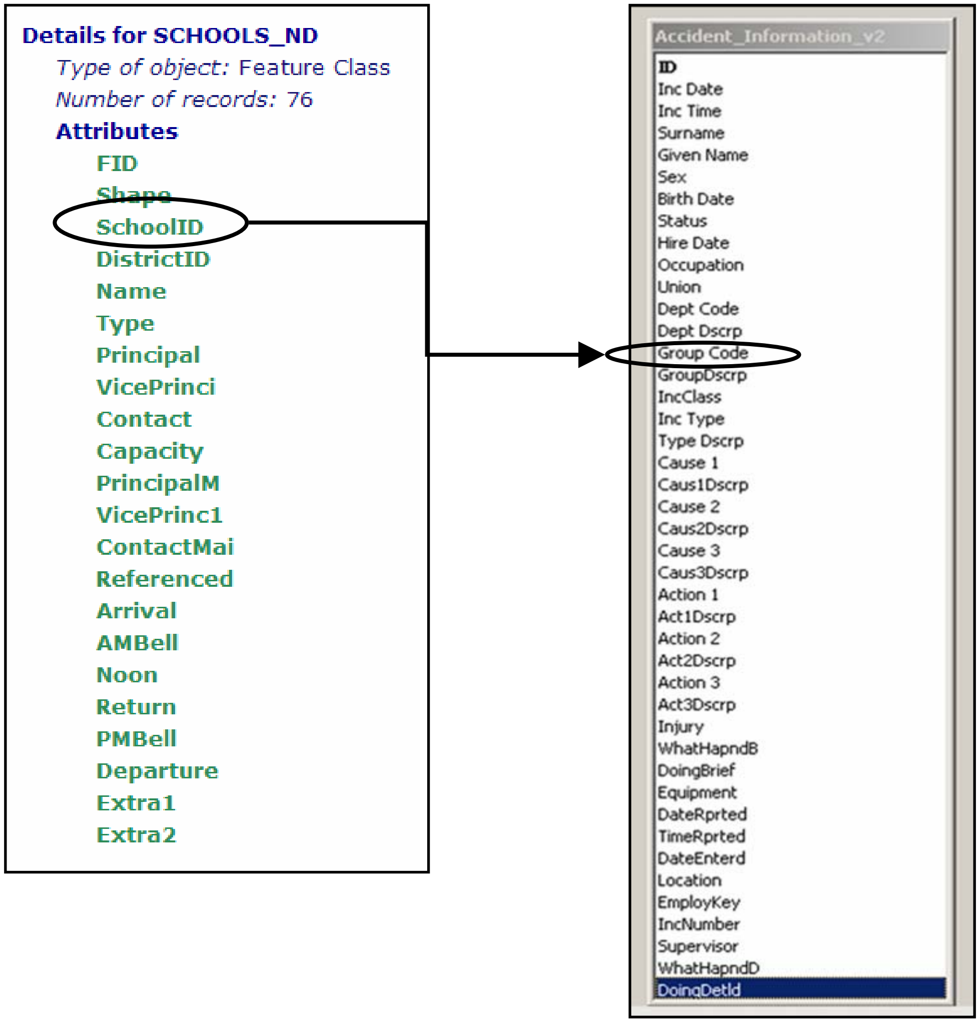


Figure 18. Parklane Data Structure – One Table and Spatial Relate (one-to-many)



As described in section 4.3 Figure 15 ArcGIS is not able to recognize one-to-many relationships that exist between external tables therefore one table containing all relevant data for EHS purposes was created using the Parklane export function.

Similar to the Hazmat Inspector table an ***ID field*** (unique number for each row) was also added which is required for ArcGIS to function properly when creating joins, relates and running queries.

One relate (one-to-many) was created from the GIS data to Parklane data in order to conduct queries, analyses, overlays, and reporting via the GIS interface. As mentioned earlier in this section Parklane data is only collected at the "Regional" school level so there is no relate to the Room spatial data. The School_ND shape file representing school locations is related to the Parklane table by the "Unique ID Fields" of ***SchoolID*** to ***GroupCode.***

The process for creating one table along with obstacles encountered, solutions, and future work required will be discussed in detail through Chapter 6-Discussion and Conclusions.

4.5 Electronic Documents, Images, Video and Audio Files

Electronic documents, images, video and audio files (as described in Table 1. EHS Data Sources) are all data not housed within a database structure they are stored in separate file folders on the EHS server with location depending on the topic. For example playground inspections are in pdf format listed by school name stored on the S: drive under a folder called (S: Inspections/Playground/Year).

This type of data will be accessible via the GIS interface through hyperlinks set up for each data source. Data will be assessed whether it should be accessed from the "Regional" or "Local" level and hyperlinks created accordingly. For example playground inspection reports will be hyperlinked to the School_ND shape file making them available at the "Regional" level while asbestos inspection images will be hyperlinked on a room by room basis to the Room feature class making them available at the "Local" level.

4.6 Future Data Integration

Lessons learned through designing the Spatial, Hazmat Inspector, and Parklane data structure will be used to integrate and develop future electronic data sources as listed in Table 1. EHS Data Sources. The Spatial data structure will be used as the reference point moving forward when integrating new data sources:

1) The ***School*** or ***SchoolID*** attribute (e.g. school #8) is the "Unique ID Field" common across all FC's and SF's used for linking external data sources at the "Regional" school level.
2) The ***School_Rm*** attribute consists of combining ***SchoolID*** and ***RoomId*** to create a "Unique ID Field" used for linking external data sources at the "Local" room level specific to each school/facility (e.g. 80.17 = School8-Floor0-Room17). It is only found in the Room FC's.
3) ArcGIS also requires that any external tables have an ***OID*** field (unique number for each row) which ArcGIS uses to function properly when creating joins, relates and running queries.

Moving forward external data sources will require the ***School***, ***School_Rm***, and ***OID*** fields so they can be integrated properly and function within ArcGIS. Data will be assessed whether it is "Regional" or "Local" which will dictate how it is integrated. After Hazmat Inspector and Parklane data have been integrated and GEO-EHS has been implemented for operational purposes within EHS the next data sources set for integration and development will be:

1) EHS Reporting – (existing open database in File Maker Pro)
2) JHSC & Site Inspections – (currently paper based needs electronic system developed)
3) Hazardous Materials Inventory – (currently paper based needs electronic system developed)
4) Training Records – (currently paper based needs electronic system developed)
5) Water Quality Data – (currently in Excel spreadsheets and pdf's)

For example (JHSC & Site Inspections) are room by room inspections that will require room level detail. By ensuring the above three fields are included the data can be queried at the "Local" room or "Regional" school level as is the case with Hazmat Inspector.

4.7 Example Queries and Analyses

The GEO-EHS prototype is a spatial database that integrates (at this stage) spatial data (orthoimagery, transportation network, school locations, building floor/site plans, and room level geodatabases) with the Parklane accident system, Hazmat Inspector asbestos system, and EHS electronic documents and files. GEO-EHS allows EHS data to be accessed through one central point (being the map interface, see Figure 19) and eliminates the need to open and query multiple databases or search for data in multiple file folder locations. In its simplest form GEO-EHS is a central, historical, and searchable database with the added advantages of spatial visualization, overlay, query, analytical, and reporting capabilities.

4.7.1 Visualization

One large advantage of spatially enabling data is that of visualization, data can be easily and quickly viewed to answer simple questions. For example prior to visiting a school to conduct a safety inspection due to a concern raised about the gymnasium GEO-EHS can be used to answer such questions as where a school is located in the region, who the principal is, how many floors the school has, which floor the gymnasium is located on, and where and what room it is located in (see Figure 20. Visualization – Safety Inspection of Gymnasium). Similar visualizations can be made as part of accident investigations, indoor air quality (IEQ) investigations, JHSC inspections, asbestos inspections, hazardous materials inspections or any general EHS concern.

Figure 19. GEO-EHS Main Interface

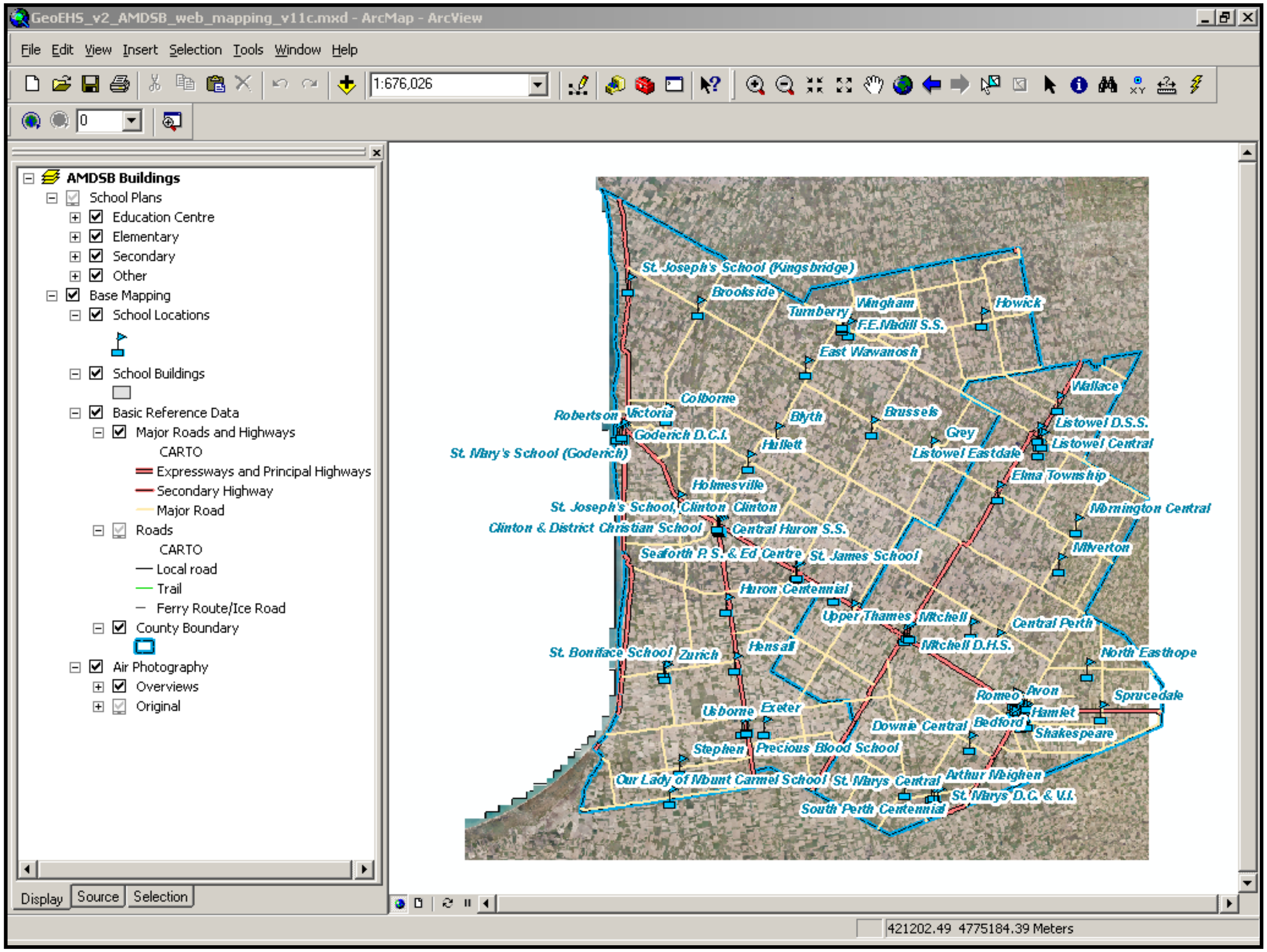
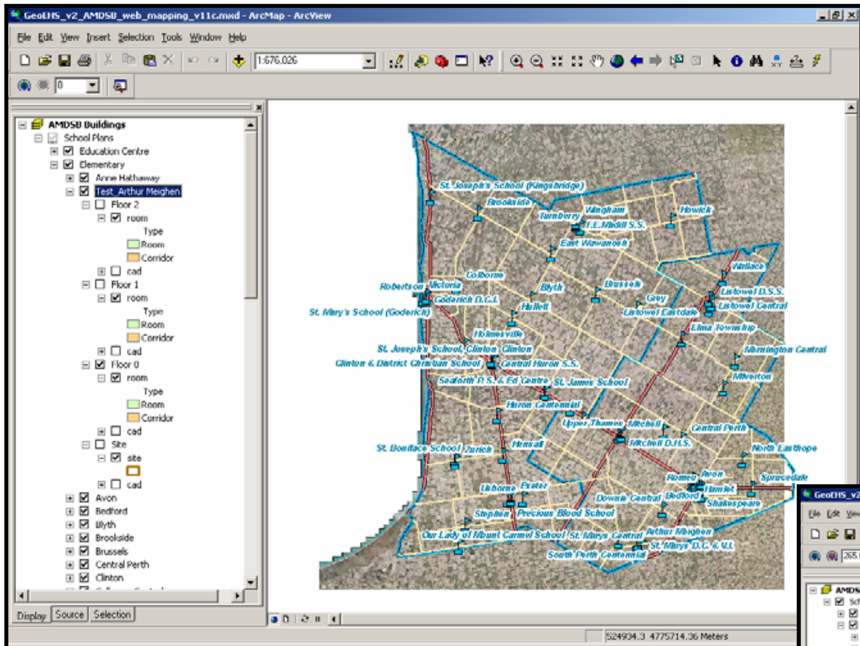
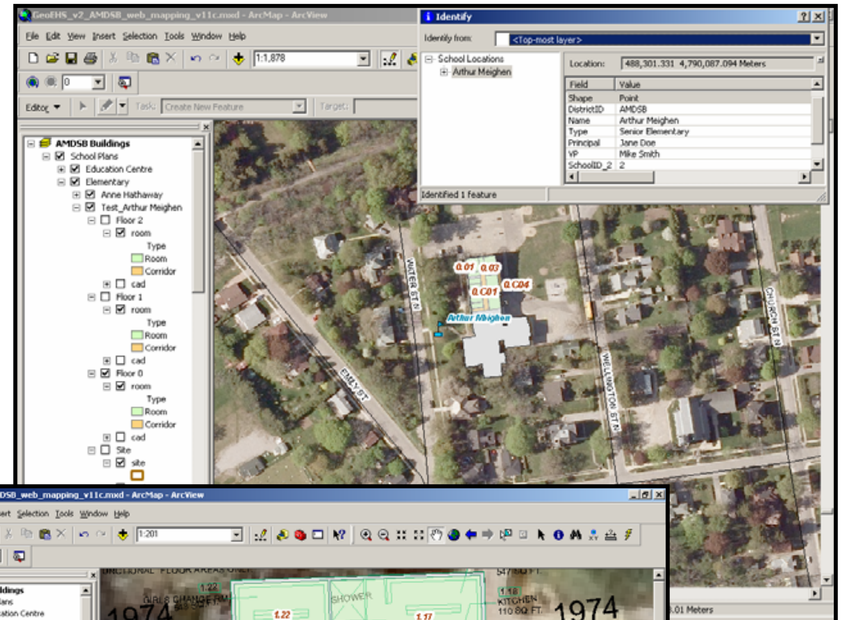


Figure 20. Visualization – Safety Inspection of Gymnasium

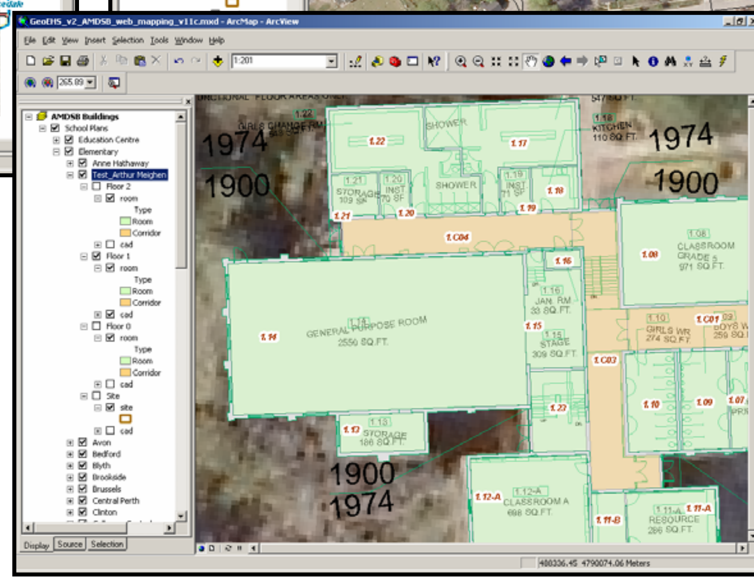
Step 1 – School Regional location



Step 2 – Number of Floors, principal, detailed location



Step 3 – Gym location and surrounding rooms



4.7.2 Overlay

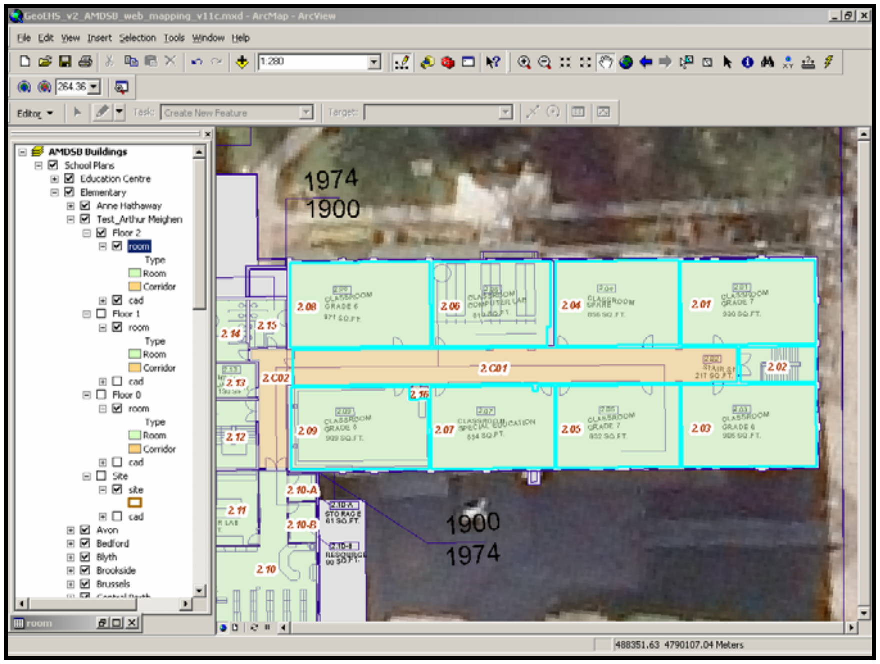
Overlay of data in the spatial context can provide unique hidden information that is not evident without looking at multiple individual different data sources and comparing the results manually. GEO-EHS provides the platform for simple and complex overlay techniques. The more complex overlay techniques involve an analytical component such as running a buffer model and incorporating the results into the overlay analysis. Complex analytical techniques will be mentioned briefly but not discussed in detail as part of this thesis. Existing spatial data within GEO-EHS can be used to perform simple overlays to unveil hidden information not so evident with other data sources. For example in an IEQ concern where there has been a roof leak above a second floor ceiling and the water has made its way down to the lower floors there is now a concern that mould may have started to grow in the areas affected by the leak. In this situation the GIS floor plan data and geodatabase room data can be overlaid to identify adjacent rooms in the area and below the leak to include in the IEQ investigation and possible mould remediation work. In (Figure 21) the area affected by the leak on the second floor is highlighted in blue and when the geodatabase room data for each floor are overlaid the rooms below that may have been influenced are easily identified. Each floor can then be reviewed individually if more detail is required.

4.7.3 Query

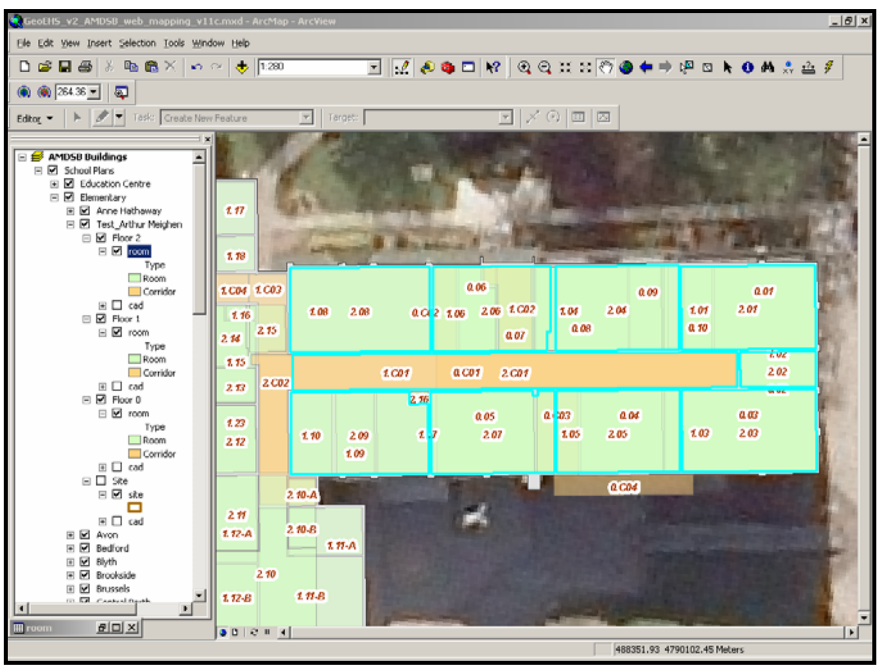
The Querying of data through GEO-EHS may be one of its the most useful functions because integrated external data can be accessed through one central point allowing for all relevant data to be included in the decision making process. Queries can be made in a number of ways through the GEO-EHS interface either by existing tools (buttons) or functions in drop down menus such as identifying data by clicking on the feature in the interface, selecting features, searching for data, viewing data such as reports or images that are hyperlinked, zooming in and out to find data, navigating within the interface by panning to find data, performing measurements, and tabular queries can be made through an SQL tool. Queries are performed through either the spatial or tabular data and each are dynamically linked so when a function is performed through one it is reflected in the other. The following example queries will demonstrate how certain tools and functions are used within GEO-EHS to access information.

Figure 21. Overlay – IEQ Investigation of Rooms that may Contain Mould

Step 1 – Rooms on floor 2 influenced by roof leak highlighted in blue



Step 2 – Floors 2, 1 and 0 (basement) overlaid to identify rooms below floor 2 that may be influenced by leak.



Using the identify tool any spatial data can be queried by simply pointing and clicking and any data associated with the spatial feature will be made available. A Regional and Local example will be used to demonstrate how the data is viewed. The school locations shape file is used as the Regional access point for any data associated with a school facility. By clicking on a school point data about the school (e.g. principal and vice principal) and any data related or joined to the feature are made available. The Parklane and Hazmat Inspector data are related to the school locations so with a simple click on a school someone can find out how many accidents there have been at the school with specific details such as where they happened and what type of injury. They can also find out every room that contains asbestos with details such as condition and type of building material (see Figure 22).

At the Local level the same type of query can be performed by clicking on a room which will provide information about the room (e.g. name and square footage) and all details about any asbestos that may be contained in the room. If there is no asbestos in the room the name of the related Hazmat Inspector table will be visible but there will be no data available. In the cases where there is asbestos in a room because the Hazmat data is also related at the Regional level the Parklane accident data for the school can also be viewed (see Figure 23).

ArcGIS uses the OID field by default as the primary display field when listing the data for Hazmat Inspector due to the structure of the data. The primary display field is not able to be changed when there are relates associated with a table which is a limitation of ArcGIS 9.2 but will be possible at 9.3 release. Ideally the Room ID should be the primary display field so it is easy to identify the room, this would eliminate any confusion of someone thinking the OID is a room number. With the Parklane data by default the surname field is used as the primary display field due to the structure of the data which works well because each accident is associated with a person and this provides a quick list of all accidents by person at the school.

Figure 22. Regional Identify by School Location (Parklane and Hazmat Inspector Data)

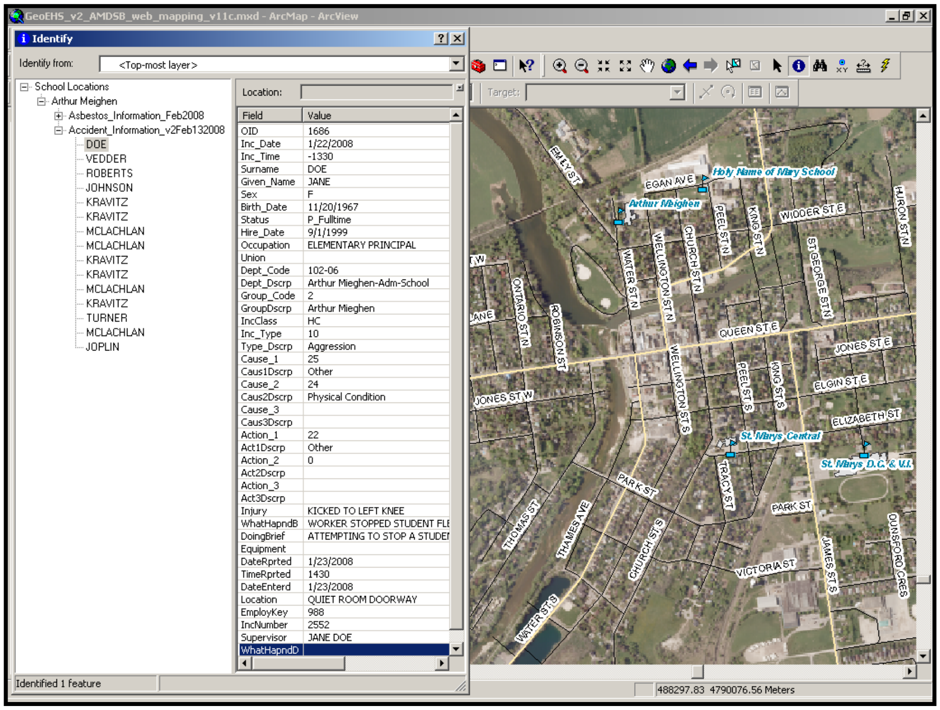
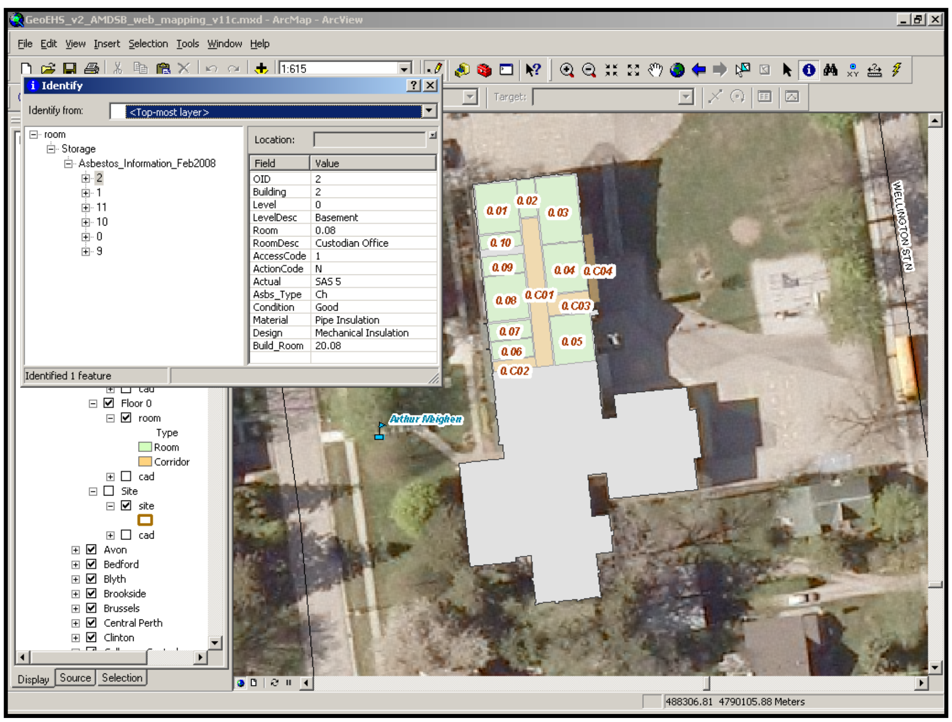


Figure 23. Local Identify by Room (Hazmat Inspector Data)



Specific sets of data can be queried depending on the users needs through the select by attributes function available in the tabular data. This tool is very flexible and allows the user to find and display exact data that is required by the user. The tool uses Structured Query Language (SQL) to form expressions that select the data. With many proprietary systems such as Parklane and Hazmat Inspector the systems use pre-structured queries that generate specific reports and there is no flexibility. The user must work with the pre-structured functions. The select by attributes tool provides a common query function across all data and allows the user to generate tailor made queries and reports. In section 2.4.10 different types of analyses and hypothetical queries were discussed that could be conducted by GEO-EHS. A Local and Regional query example using GEO-EHS will be presented to demonstrate how the system works and how data is displayed.

A common practice (which is regulated) at AMDSB is the repair or removal of any asbestos that is in poor condition. Through the yearly asbestos inspections as described in section 4.3 any asbestos in poor condition is identified and marked as requiring action (repair or removal) within Hazmat Inspector by a Y = action required or N = no action required. GEO-EHS could be used to identify rooms in all schools that require action and a report generated displaying the rooms accompanied by the detailed tabular data describing the asbestos. The asbestos removal contractor used by AMDSB could then use the report as a proactive guide for removing the asbestos. The current process used by AMDSB is cumbersome and time consuming; the asbestos removal contractor uses the paper asbestos inspection reports (54 - one for every school which could be over fifty pages long for a secondary school) as their guide. Figure 24 provides a Local room level select by attributes example of how GEO-EHS could be used to select all rooms in a school that require action (repair or removal) due to asbestos in poor condition. Once the rooms are identified in the table they are highlighted in blue within the spatial data.

As a proactive measure the EHS department would like to know what schools have had lost time (LT) accidents along with the details of each so they can be analyzed and a follow up visit made to each school to identify if there are any measures that can be implemented to help prevent similar accidents from occurring. On a Regional basis GEO-EHS could be used to quickly identify all schools that have had LT accidents along with the details of each (see Figure 25).

Figure 24. Local Room Level "Select by Attributes Query" Asbestos that Requires Action

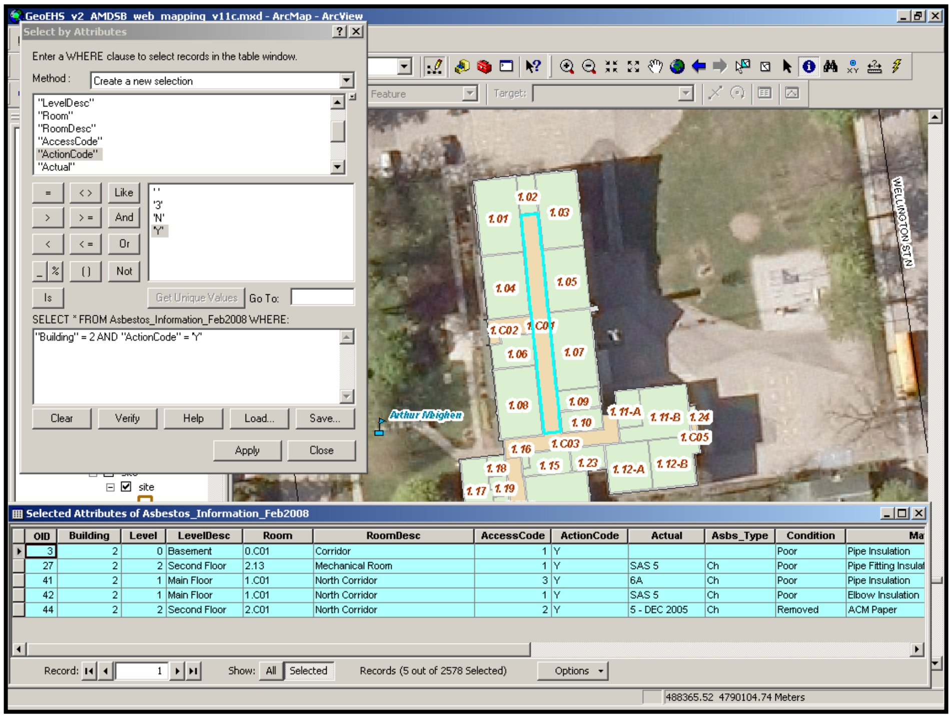
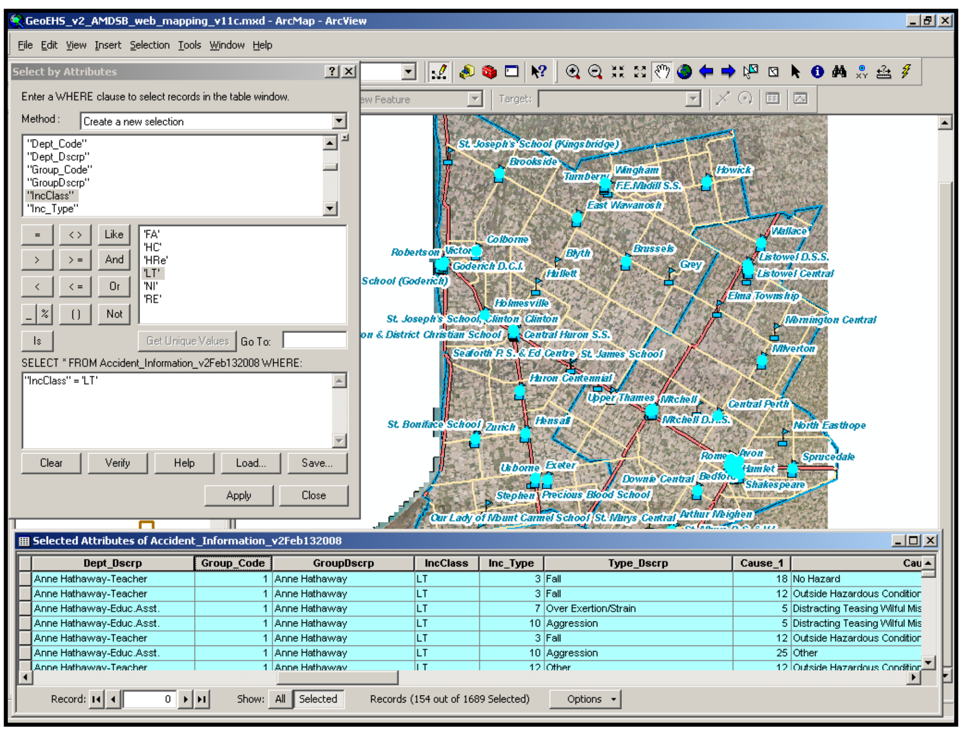


Figure 25. Regional School Level "Select by Attributes Query" Schools with LT Accidents



Preparing for EHS site inspections and investigations or following up on inquiries or concerns raised by staff requires that historical data be accessed and reviewed which may be relevant to the situation. Currently this process for the EHS department is a time consuming and tedious process consisting of accessing data in many locations, different formats, proprietary systems, electronic files and paper files (as discussed in 4.1). The ideal scenario would be to have the ability to access all EHS data though one central point, which GEO-EHS can provide. An IEQ example will be provided to illustrate how GEO-EHS is an integrated EHS system allowing access to EHS data from one central interface. In the case of IEQ investigations there is initially a concern raised by staff which could be for numerous reasons such as someone feeling ill and they think it may be a result of poor air quality in the school or their room, asbestos removal work is being done in their school and they are concerned they may be inhaling fibres, someone may identify an odour that is giving them headaches but the source is not known or concerns about mould growth are raised due to musty smells, water leaks, or something that looks like mould is identified by staff. Any existing historical data related to the situation needs to be accessed and reviewed such as past reported health incidents, asbestos inspection data, asbestos removal reports and air testing, mould investigation reports, past IEQ investigation reports, water quality data, floor plans, mechanical plans (heating/cooling systems, plumbing, electrical) and chemical inventories.

As described earlier the asbestos, health related incident information and floor plans are integrated and accessible through GEO-EHS. Electronic data such as reports, pictures, video, and testing data is also made available through GEO-EHS eliminating the need to access the data from many locations were it stored. This is done by creating hyperlinks from either the Regional school location shape file or the Local room feature class to the data source. Information general to the school that is not room specific (e.g. school photo and asbestos reports) is linked at the Regional level while data specific to rooms (e.g. pictures of asbestos containing materials and IEQ investigation pictures such as materials that may contain mould) is linked at the room level. When the hyperlink tool is activated a red dot appears over the point features and a red line around polygon features. When the highlighted features are clicked with the hyperlink tool the linked data is made available. Figure 26 illustrates examples of data that are available at the Regional school level and Figure 27 represents data that is available through the Local room level.

Figure 26. Regional School Level Hyperlinked Data

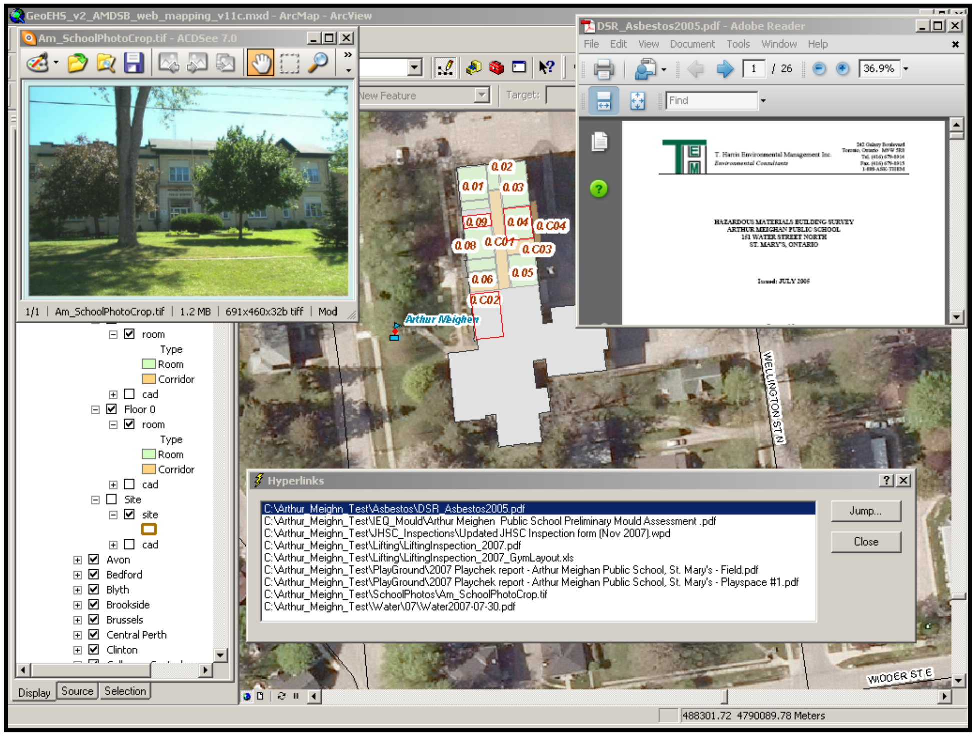
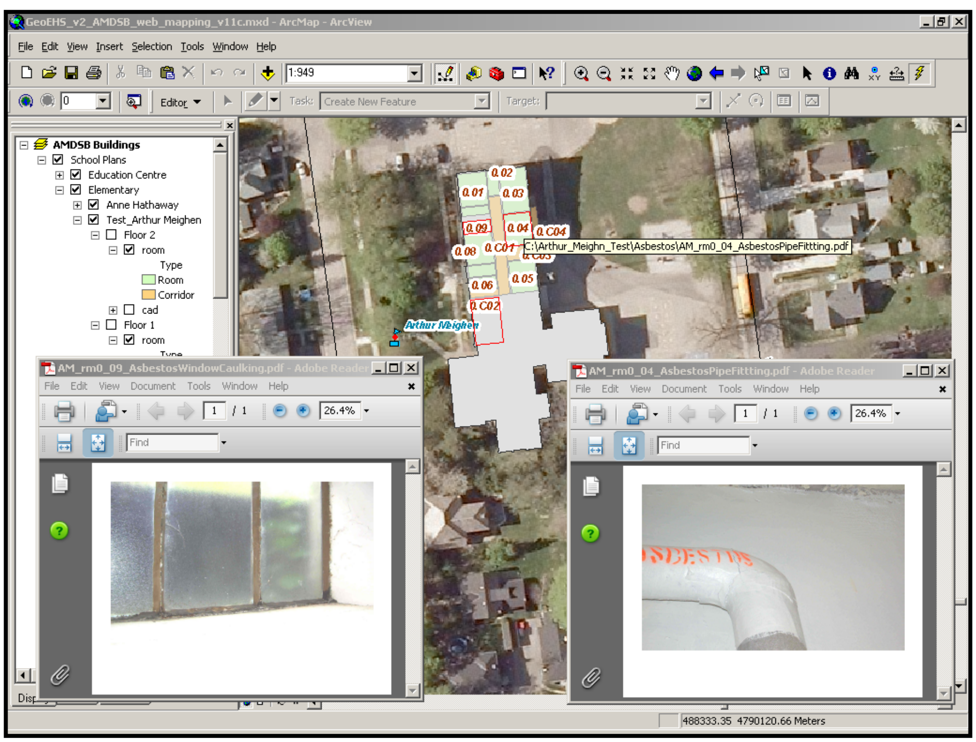


Figure 27. Local Room Level Hyperlinked Data

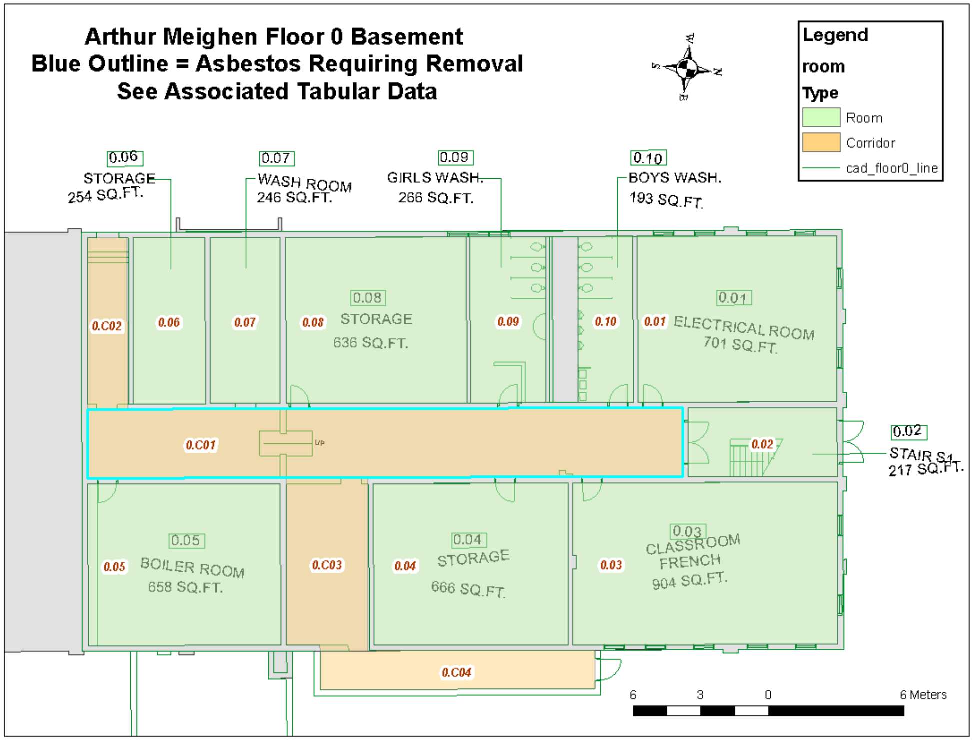


4.7.4 Reporting

After EHS data has been analyzed reporting is usually required in order to make the information available so decisions can be made by management, regulatory authorities or other organizations. ArcGIS provides an open environment for creating reports unlike proprietary closed systems where reporting functions are usually built into the system and little flexibility is available. Within ArcGIS there are a number of ways to create reports, graphs, and maps which can be customized and automated for reports that are required on a regular basis. GIS provides a spatial component to EHS and therefore most reports generated with GEO-EHS would have both a spatial and tabular component. Map layouts are easily produced with ArcGIS and at a minimum include spatial data representing the tabular data analyzed, title, legend, north arrow, and scale bar. Graphs and tabular reports can be created through the ArcGIS tools, third party sources such as Excel, or crystal reports which comes packaged with ArcGIS.

Section 4.7.3 mentioned generating a report for the asbestos removal contractor detailing all asbestos that requires action and is in poor condition for all schools. This example will be used to illustrate a report generated with GEO-EHS. One school is used in the example illustrating the basement floor, with rooms containing asbestos, and requiring removal which are highlighted in blue on a map document accompanied by the tabular data displayed separately in an Excel table (see Figure 28). The full report for one school would include all floors and text explaining the report and asbestos removal process. The integration of spatial and EHS data allows for data to be presented in a visual format such as a map rather then long text style reports. One map could provide the same information as a full text style report making the information more accessible, easier to understand, and communicated more efficiently.

Figure 28. Example Report Identifying Rooms that Contain Asbestos for Removal



Building	Level	LevelDesc	Room	RoomDesc	AccessCode	ActionCode	Asbs_Type	Condition	Material	Design
2	0	Basement	0.C01	Corridor	1	Y		Poor	Pipe Insulation	Mechanical Insulation
2	1	Main Floor	1.C01	North Corridor	3	Y	Ch	Poor	Pipe Insulation	Mechanical Insulation
2	1	Main Floor	1.C01	North Corridor	1	Y	Ch	Poor	Elbow Insulation	Mechanical Insulation
2	2	Second Floor	2.13	Mechanical Room	1	Y	Ch	Poor	Pipe Fitting Insulation	Mechanical Insulation
2	2	Second Floor	2.C01	North Corridor	2	Y	Ch	Removed	ACM Paper	Other

4.7.5 Complex Analyses

The focus of this thesis is on how GIS can be used to integrate data not on complex GIS analyses. It is although very important to mention more advanced types of analyses that can be performed using GIS because it is an extremely powerful tool. The different analyses discussed so far such as visualization, overlay, and query are basic types compared to what GIS is capable of performing. For EHS purposes these more basic types of queries were focused on because they are the most useful at this stage in the overall project. Two more complex methods worth mentioning are proximity and network techniques. Proximity (also known as a buffer function) is a measure of distance between features and is most commonly measured in length (Aronoff 1989). An example of a proximity analysis is provided in section 2.4.11.2 where (Mustapha et al. 2004) describes a situation where chlorine gas was released from a swimming pool and proximity analysis was used to determine the impact on surrounding residence. Network analysis incorporates a set of interconnected linear features that form a pattern or frame work which is used to predict network loading, route optimization, or resource allocation (Aronoff 1989). For EHS purposes network analysis could be used in IEQ investigations or emergency planning purposes. A possible scenario that would lend it self to this type of analysis would be where a chemical is released in a science room and dispersed thought the school by the ventilation system. The ventilation system is a set of interconnected of duct work so the ventilation schematics could be used to predict and pin point where the chemical would be delivered to and how fast.

There are many other types of complex analytical techniques such as thiessen polygons, interpolation, line-in-polygon and point-in-polygon, spread functions, seek or stream functions, and viewshed modeling to name a few (Aronoff 1989). GIS also provides statistical capabilities such as frequency, mean, minimum, maximum, and standard deviation analysis. More complex statistical tools can also be integrated with GIS such as regression, multivariate, and multi-criteria analysis.

Chapter 5
Web GIS Implementation

5.1 Overview

The development of a GIS web system platform and application for EHS was undertaken for three main reasons: 1) to make the GIS data and floor/site plans available to others within AMDSB and organizations outside AMDSB, 2) a tool to help gain interest of other departments in GIS technology which will help support future implementation, and 3) the long term goal is to make GEO-EHS web enabled and the web system platform will already in place for this next step.

The design and function of the web GEO-EHS application is different then the desktop GEO-EHS prototype at this stage in the project. The main purpose of the web GEO-EHS is to make the GIS data available to others for emergency planning purposes and to provide printable floor plans in pdf format. Prior to web GEO-EHS existing the floor/site plans were only available in electronic format (AutoCad) to three individuals in the facilities department who were using AutoCad. Printed paper copies were available to a select few in the business department which were made available though AMDSB's architect.

ArcServer Standard Workgroup (ESRI technology) was chosen for the web platform for the same reasons as listed in section 3.3. The system was designed to operate on out-of-the-box ArcServer with no additional programming or functionality with the exception of printable floor/site plans in pdf format. At the 9.2 ArcServer release there was not a print function available out-of-the-box so a tool was created. The next sections will discuss the implementation process of the system and example images of web GEO-EHS are provided and the end of Chapter 5 (Figure 29, Figure 30, Figure 31, and Figure 32).

5.2 Implementation Process

Implementation of the web GEO-EHS system was occurring simultaneously with the desktop GEO-EHS system design and implementation. The process can be broken down into six key steps each of which will be discussed below: 1) Hardware and Software Acquisition/Configuration,

2) Functionality, 3) Design of Web Map and Configuration of System, 4) Caching of Spatial Data, 5) Web Login Portal, User Profiles and Security, and 6) Testing of System and Implementation.

5.2.1 Hardware and Software Acquisition/Configuration

The web hardware and software was listed in section 3.5, here the structure will be described in more detail. The server was first installed and configured for the best performance followed by installation of Microsoft Windows Server 2003 Standard, Microsoft SQL Server 2005 Standard, Microsoft Office 2003, firewall Software and ArcServer Standard Workgroup 9.2. (other software is added as required). There were problems installing the desktop platform – ArcView 9.2 on the server along with ArcServer so a remote desktop configuration was set up through a dedicated desktop located in the AMDSB server room. ArcView is used off line of the web system for spatial data building and maintaining the system.

The installation and configuration process of ArcServer Standard Workgroup 9.2 had many road blocks due to it being a newly released technology from ESRI. ArcServer is available in ASP.Net and Java platforms, originally ArcServer ASP.Net was installed but after testing and discovering the added functionality of the Java platform ArcServer ASP.Net was uninstalled and ArcServer Java installed. One of the key functions the Java platform provides (and is not available in ASP.Net) is the "zoom to layer function" accessed by right clicking on any layer in the layer table of contents (functionality will be discussed in the next section 5.2.2). Because ArcServer Java platform is used the Apache Tomcat servlet engine is required to serve up the java web pages and Internet Information Services IIS is used to manage the main page and redirect the web traffic to and from Tomcat.

The system configuration is the same as that of the original proposed configuration in Figure 5 only with some software changes and portions that have not been built yet. The following changes to the configuration have been made: 1) IIS is used instead of Apache Web Server (although Apache may be used in future), 2) ArcServer is used instead of ArcIMS, 3) In addition to shapefiles, personal geodatabases are being used, 4) SQL server 2003 replaces 2000, and 4) the data analysis and exchange tools have not been developed and ArcServer is being used for these purposes.

5.2.2 Functionality

ArcServer Java platform out-of-the-box functionality is used for the web system with the addition of a developed print function for printing pdf floor plans. The decision was made to keep functionality as simple as possible for end users because many of the users are not familiar with GIS technology. As described above one of the key functions available with the Java platform is “zoom to layer function” accessed by right clicking on any layer in the layer table of contents. The basic functions available are zoom in/out, pan, measure, zoom to full extent and identify. Layers are able to be turned on and off depending on what the user needs. The print function consists of a drop down menu with all schools listed which are then broken down by floor making the pdf floor plans available (4DM Inc. was contracted to develop this functionality).

5.2.3 Design of Web Map and Configuration of System

Building a web system with ESRI technology involves three main steps and requires at minimum ArcView and ArcServer software. Step one involves designing and producing the map document (MXD file) with ArcView in a desktop environment. Next in step two a map service is created from the MXD using ArcServer and lastly the map service is published over the internet using ArcServer. ArcCatalog is then used to manage the web system moving forward.

The majority of work for step one was completed as part of the data building earlier in the project when all spatial data was sourced, created, and compiled into a final MXD file for use in the desktop GEO-EHS prototype. In a web environment functionality is limited as compared to using ArcView in a desktop environment and the spatial data looks, feels, and reacts differently. 4DM Inc. was contracted to work in conjunction with EHS in order to adjust the original MXD so it would display and perform over the web to meet EHS specifications. During the design of the web MXD items such as which layers to include, how to display them, making the layers able to be turned on/off, symbology, and labeling were addressed. Due to the ArcServer layer limitation the AutoCad GIS layers were left out and only school, room, and background data (streets and orthoimagery) were included. The only limitation this causes is that the AutoCad line detail (e.g. walls, steps, toilets etc..) is not included, otherwise all data is available through the GIS identify tool.

Creation of the map service in step two is a simple process completed using ArcServer where the MXD file is used to create the service and make it available to be published in the last step. Publishing the map service through ArcServer involves creating the look and feel of the website by tailoring items such title heading, logos, images, north arrow, scale bar, copyright information, and configuration of settings so the spatial data is displayed properly. Once steps one to three were complete the data needed to be cached as images to maximize performance and speed of the system.

5.2.4 Caching of Spatial Data

ArcServer can display data either dynamically where the actual data is accessed and rendered (as is the case with desktop GIS) or through a cached process where images are created of the data at set scale levels and the images are displayed instead of actual data. During testing of the final map service it was discovered that due to the large number of layers and amount of data being displayed the dynamic display setting could not be used because it was very, very slow for the end user. Therefore the cached process was used to display the data. Due to ArcServer 9.2 being a new ESRI product many limitations were encountered with the software which ESRI could not provide clear support on (these limitations will be mentioned in section Chapter 6. Discussion and Conclusions).

The cache process is conducted and configured through ArcCatalog and before initiating requires that all details are finalized with the web map design. One of the main decisions before staring the cache process was how many levels and at what scale are required for the best display performance. For GEO-EHS purposes twelve levels were required with level one starting at a scale of 1:1,000,000 and level twelve ending at 1:750. This range provided the required resolution between levels so a noticeable jump was not evident when zooming in and out from the Regional school level down to the Local room level. The 1:750 level is required so the building level detail can be visible. Two limitations with this process were the amount of time required for the cache to complete (thirty days continuous twenty four hours a day) and the large amount of image data produced (one terabyte of data).

5.2.5 Web Login Portal, User Profiles and Security

Due to the sensitive nature of data GEO-EHS will only be made available to select individuals or groups in a secure manner. EHS has an existing website which will be used as the entry point for accessing the web GEO-EHS system through a link called “GEO-EHS”. From the EHS website the users will be prompted by a login page requiring a user name and password to gain access. Once securely logged into GEO-EHS the mapping interface will be displayed for use. The user login page and validation frame work were designed with ASP.Net. Within the validation frame work the following user groups will be given access via a user name and password:

1) EHS Officer (administrative rights)
2) Senior Staff (user rights)
3) Facilities Department (user rights)
4) Principals and Vice Principals (user rights)
5) Managers and Supervisors (user rights)
6) Head Custodians (user rights)
7) Ontario Provincial Police (user rights)
8) Fire Services (user rights)

Users one through six are all internal to AMDSB while the Ontario Provincial Police and Fire Services are external organizations who will be using the system for emergency planning and first response purposes. The EHS server and data are housed behind a firewall and Secure Sockets Layer (SSL) is applied to ensure data is encrypted through the internet in order to eliminate any unauthorized users from accessing the data.

5.2.6 Testing of System and Implementation

Testing of web GEO-EHS has been a continuous process at each step in the implementation to ensure changes and developments were operating properly. Web GEO-EHS is at the stage of implementation where final testing is required prior to releasing the product to all user groups over the internet. Until this point all work and testing has been conducted within a secure environment behind the AMDSB fire wall. The final testing will be conducted live over the internet with a select group of users from senior staff, facilities, and principals in order to identify and fix any bugs prior to final operational implementation. Feedback from the testing will be used in planning for future directions of the system which will be discussed in Chapter 6 Discussion and Conclusions.

Figure 29. Web GEO-EHS Main Interface

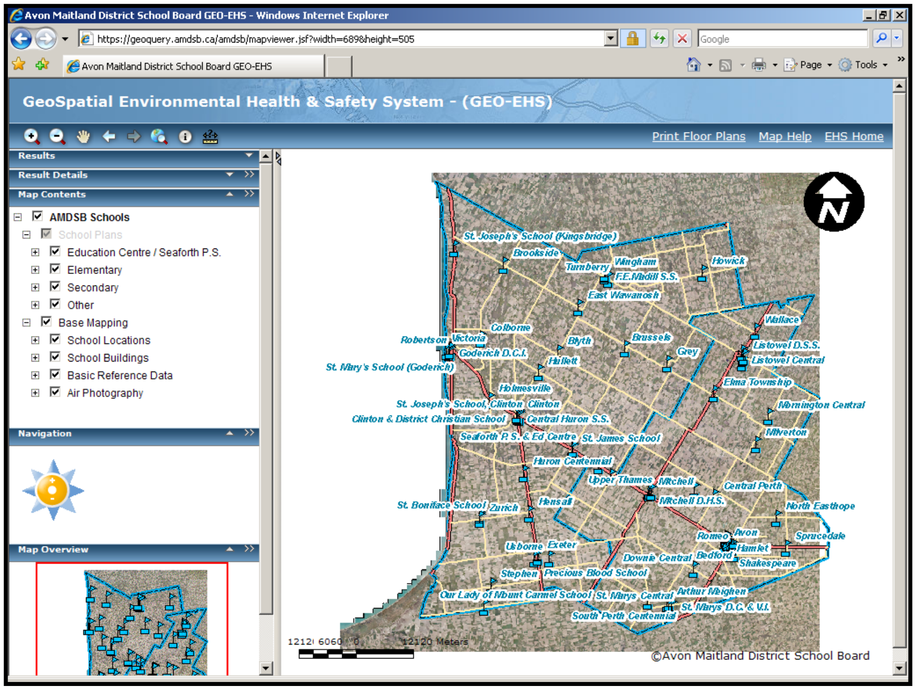


Figure 30. Web GEO-EHS use of Identify Tool

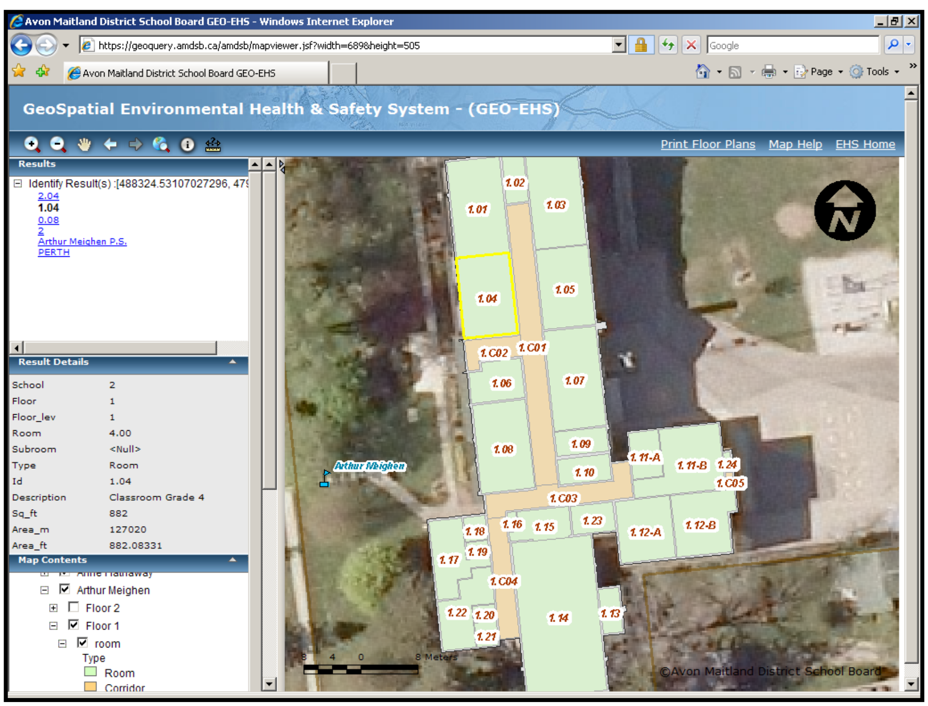


Figure 31. Web GEO-EHS Print Function Menu

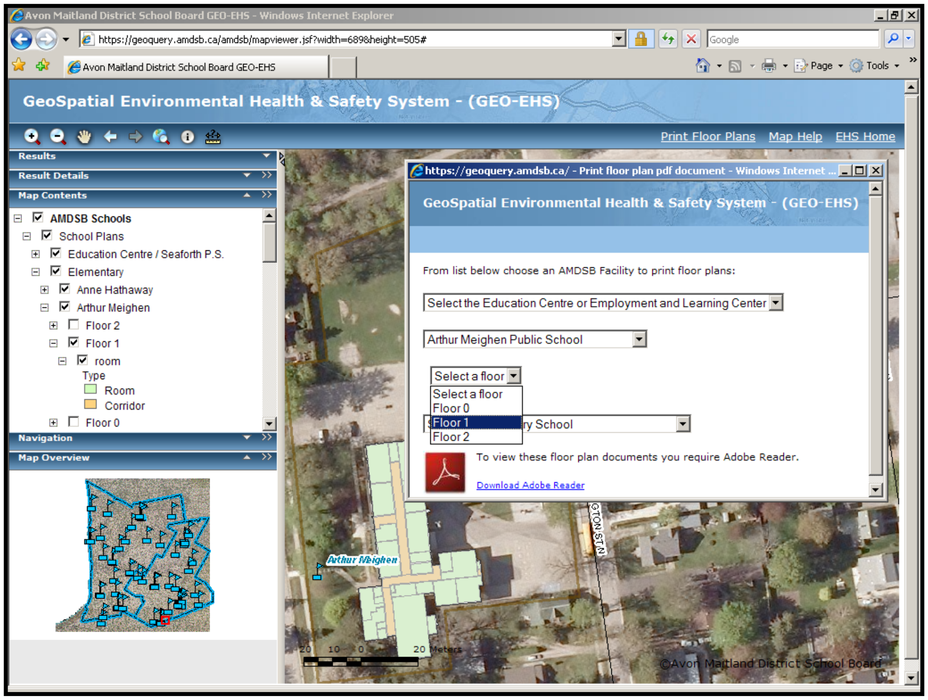
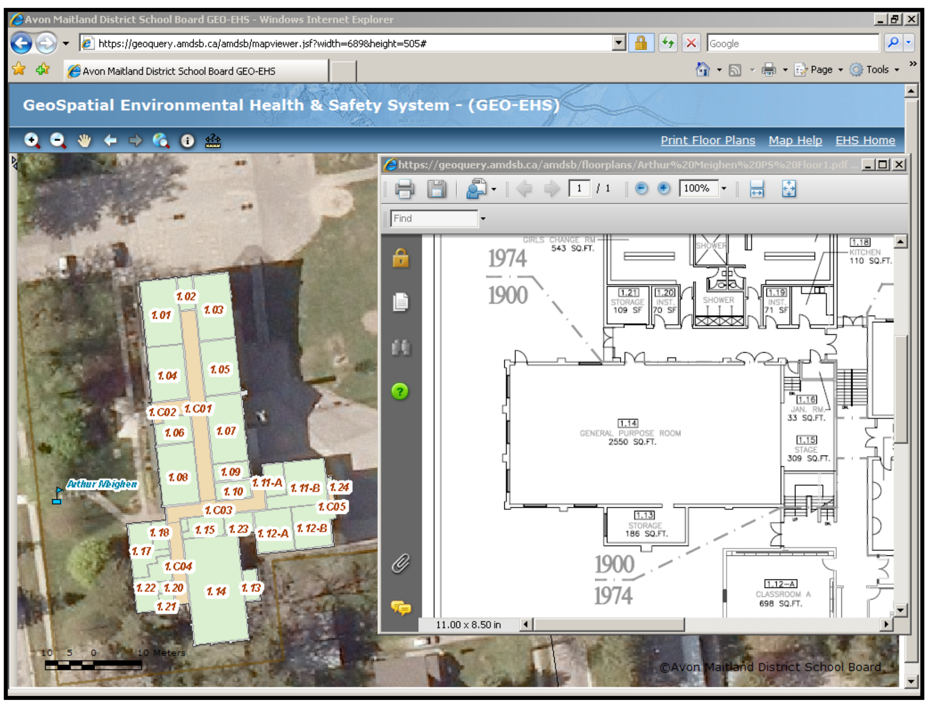


Figure 32. Web GEO-EHS Floor Plan pdf within Main Interface



Chapter 6
Discussion and Conclusions

6.1 Overview

This chapter begins by demonstrating how successful the research was in meeting the thesis purpose through the six objectives set out in Chapter 1 (section 1.8). This is followed by section 6.3 where the limitations and refinement of GEO-EHS are presented, section 6.4 areas of future research, and finally section 6.5 where recommendations are made for others considering an EHS data integration project.

6.2 Conclusions

The main problem facing EHS at AMDSB is a lack of data integration and interoperability between the systems and data used. The main purpose of this thesis was to "*Demonstrate that GIS technology is a feasible option for data integration and interoperability of EHS data*". The thesis purpose was achieved as will be demonstrated through discussion about the six objectives.

The fist objective was to "*Review academic and GIS industry literature related to EHS and GIS to provide background and proof that the development of a GIS database is possible and a valid option for managing EHS data*". A comprehensive search for academic and industry literature was conducted as described in Chapter 2. A search related to core Health and Safety practice and use of GIS for managing "all" EHS functions was conducted using queries including Environmental, Occupational, Health, Safety, and GIS through traditional academic journals, safety trade publications, ESRI website and annual ESRI international conferences, and the prominent safety organizations and conferences. Only one source was found (Douglas 1995) that was using GIS as a decision support tool for many EHS functions, which identified the need for further research in this area. Further sources were identified that are using GIS for managing at least one sub-discipline of core EHS, which were all found in the IH discipline (Henricy and Stewart 2006), (Lacey et al. 2006), and (Westhuizen 2005). These sources also raised the need for further data integration of "all" EHS functions using GIS.

The research net was cast to include sub-disciplines of EHS specifically public health (PH), emergency response management (ERM), and environmental management (EM) as they relate to GIS and SDS. Automated mapping/facilities management/geographic information system (AM/FM/GIS) was also included. The review included the topics of indoor air quality, chemical and biological air sampling, physical agent exposure assessment, ergonomics, asbestos management, hazard risk assessment, accident analyses, water quality management, air emissions, emergency response management, and environmental remediation. Within each of these topics GIS was being used as an analysis or decision making tool which illustrates that GIS is a valid option for managing all functions of EHS. Many of the EHS sub-disciplines are using GIS for spatial analysis or decision support functions but only within their isolated discipline there is not much overlap other than through AM/FM/GIS where environmental and some safety functions are being integrated. EHS as an umbrella discipline has not yet discovered or harnessed the power of GIS for analysis and data integration.

The second objective was to "*Create the GEO-EHS data model based on the Environmental Systems Research Institute (ESRI) geodatabase model which will include Hazmat Inspector used for asbestos data management, Parklane used for accident data management, electronic documents, and also describe what and how other data sources will eventually be integrated*". A data model structure was created meeting the needs of EHS as will be described below. Before a system could be implemented the data model structure needed to be designed. The literature review included an overview of the ESRI geodatabase approach to provide background on the method being used to develop the EHS data model and Chapter 4 detailed how the model was created. Prior to creating the data model a testing phase was conducted in section 3.7 to determine if it was possible to integrate the Parklane and Hazmat Inspector proprietary systems (each with their own data structure and secure backend database) and test possible types of analyses.

The original goal was to continue using the existing systems for entering and maintaining data and use ArcView as the main interface for integrating data and performing analyses using ODBC drivers. This was not possible because 1) Parklane data was not recognized correctly by ArcView through the ODBC, the data did not have OID fields which are required by ArcView to operate properly and the tables were read only resulting in no possible manipulation of the data and 2) Hazmat Inspector data was not accessible through an ODBC. The second approach considered was to export the data from each system using their provided tools and recreate each database in MS Access or SQL where the table linkages and data could be maintained through regular scheduled exports from each system. This was also not possible because ArcGIS is not able to recognize one-to-many relationships that exist in external tables. The last approach considered (and selected) was to create one table for Parklane and one table for Hazmat Inspector each including all data necessary for EHS purposes which would result in possible integration of data.

The testing of possible analyses consisted of two scenarios using sample datasets from each system. An accident analysis scenario was performed using Parklane data at the Regional school level to display bar graphs for each school location through ArcView illustrating total accidents by type for each school. Hazmat Inspector data was used to test if the GIS floor plans could be used as the inventory system for managing asbestos information at the Local room level. Each test scenario proved it was possible to use GIS as the data integration and spatial analyses tool for EHS data management. Another reason for testing was to identify any problems that needed to be rectified before a data model could be finalized.

The data model includes spatial data, Hazmat Inspector asbestos information, Parklane accident data, electronic files, and illustrates how future data will be integrated. The spatial data consists of base layer reference data of orthophotography, road network, and land parcels. The school information includes school locations and building footprints in the form of shapefiles. Personal geodatabases include building outline, elevators, floor outline, rooms, site outline, and background GIS AutoCad information such as building interior details. The spatial data is the foundation of the data model which integrates all other data sources. At the Regional school level each school has a unique school number which acts as the unique ID for linking other data. At the Local room level each room has a unique number and the combination of school ID and room ID creates the unique field for linking data at the room level.

Hazmat Inspector is the asbestos information system used at AMDSB. One table was created from a data export including only the information relevant to EHS. The data is integrated with the GIS at the

Regional and Local levels allowing for queries to be made across all schools or just one school. Hazmat Inspector has a building number unique to each school which is used as the Regional level key field for linking with the spatial data. At the Local level a new field was created from building number and room ID to create the unique field for relating to the school_room field in the GIS data.

Parklane is the accident reporting system used at AMDSB. Again one table was created from a data export with only the fields required by EHS. Parklane data is only integrated at the Regional level because the system does not allow for the collection of room level information in a manner that allows for linking to the GIS. The data contains a field called group code that is a unique number for each school which is used as the key field for relating to the GIS data. Both Hazmat Inspector and Parklane data are integrated with the spatial data through relates created in ArcView.

Electronic documents used by EHS such as reports, images, video, audio were also included as part of the data model. Electronic documents are a large source of data used by EHS for reporting, reference, research, compliance and auditing therefore there was a need to integrate this data as well. The files are housed on AMDSB servers in different file folder locations. ArcView and the spatial data acts as the main interface for accessing this information. Hyperlinks to the data were created at the Regional and Local levels depending on the type of data. As a result all data can be accessed by one click of a mouse rather then searching through folders on many different servers.

Much of EHS data still requires integration and electronic process development to allow this. Moving forward the lessons learned through designing the data model will be used for integrating future data sources. The spatial data and unique keys will act as the building blocks for linking other data sources. Any database will require the unique fields of school_number, school_room number, and OID in order to allow integration.

The third objective was to "*Develop a desktop GEO-EHS prototype which incorporates Hazmat Inspector, Parklane, and electronic data sources such as documents and images*". The desktop prototype is the end product off all the steps completed throughout the project including project justification, user needs assessment, system architecture design, hardware and software, spatial data building, data model design, and prototype testing. The product is called GeoSpatial Environmental Health & Safety (GEO-EHS) which integrates the data sources as described throughout the thesis. ArcView 9.2 is used as the main interface and the tool for integrating all the data sources. No additional programming was necessary because ArcView out-of-the-box functionality was used. GEO-EHS is demonstrated in section 4.7 where example queries and analyses are conducted to illustrate proof of concept. Real world EHS scenarios are used with actual EHS data providing examples of visualization where the data is used to prepare for inspections, investigations, or answer EHS concerns. Overlay was used to illustrate how the data could be used during an IEQ investigation where mould growth is of concern due to a water leak at roof level of a school. The query capabilities of GEO-EHS are limitless and can be conducted through a number of ways such as zooming in and out to find data, navigating within the interface by panning to find data or performing measurements. Further query options were illustrated through examples such as identifying data by clicking on the feature in the interface. By clicking on a school location the user has access to the accident and asbestos information for the school. When a room is selected detailed asbestos information is made available as well as general information such square footage. Tabular data queries can be made through a SQL tool allowing the user to find any combination of information. It was demonstrated using this tool that all rooms within a school, which contained asbestos and required remedial action could be found and highlighted. The tool was also used to identify all schools that have lost time accidents and display details of each accident. When preparing for site inspections or investigations review of historical records is required. Hyperlinks were created to data such as mould reports, asbestos reports, school photos, and asbestos photos. GEO-EHS was then used to confirm that the electronic data could be accessed through one central point such as a school location or room rather the searching for files in many locations.

After data has been analyzed reporting is required to make the information available to interested parties such as senior management, regulatory bodies, auditing agencies, or community groups. With closed proprietary systems (e.g. Parklane and Hazmat Inspector) reporting is usually limited to the pre-packaged reporting structure. ArcView provides many options for creating graphs, reports, and maps in an open manner which can be tailored to suit the needs of the user. An asbestos example was used to show how GEO-EHS could be used for creating a summary report which an asbestos contractor would use for removing asbestos. All rooms in a school containing asbestos that required remedial action were identified and a map created representing the data spatially complimented by a view of the tabular data for further details.

More complex types of analyses were not explored as part of this thesis because the main goal was integration of EHS data using GIS. Although it is worth noting that GIS is capable of many more complex analyses such as proximity, network, thiessen polygons, interpolation, line-in-polygon, spread functions, seek or stream functions, viewshed modeling, and statistical analyses.

The forth objective was to "*Develop a web system platform used initially to share GIS data and school floor plans with AMDSB staff and external organizations such as the Ontario Provincial Police (OPP) and local Fire services for emergency planning purposes. The long term plan being that the desktop GEO-EHS will evolve into a web system and data will be maintained/updated using the web system by external users (e.g. principals inputting classroom usages at the beginning of each year to ensure the floor plan data is correct or principals maintaining an up-to-date chemical inventory for each school)"*. The web GEO-EHS system was developed for three main reasons 1) make GIS data and printable floor plans available to AMDSB staff and outside organizations for emergency planning purposes, 2) creation of the web platform for future migration of desktop GEO-EHS to web GEO-EHS, and 3) act as a product to gain interest and feedback from different user groups for refinement of GEO-EHS and to display that GIS is an option for other departments such as facilities, IT and purchasing for asset management.

Implementation of web GEO-EHS occurred in parallel to desktop GEO-EHS because the overall vision was a web based system for managing EHS data. Many off the initial steps such as spatial data building and data modeling contributed to the design of a web system. The web implementation consisted of six main steps: 1) Hardware and Software Acquisition/Configuration, 2) Functionality, 3) Design of Web Map and Configuration of System, 4) Caching of Spatial Data, 5) Web Login Portal, User Profiles and Security, and 6) Testing of System and Implementation. Steps one through five have been completed and system testing/implementation is currently planned to be completed during April 2008.

ArcServer Java was chosen as the web platform for the same reasons as outlined in 3.3. The hardware and software was acquired and configured and the final system design is very close to the original proposed design in Figure 5 with some hardware/software changes and omission of data analysis and exchange components. The intent was to keep the web system as simple as possible for users by only using the functionality provided by ArcServer such as zoom, pan, identify, and measure. At the ArcServer 9.2 release it did not have a printing function included so one was created to enable printing of the floor plans in pdf format only. The next step was design of the web map interface which was largely completed through the desktop GEO-EHS design phase and only required minor editing to function and properly display through ArcServer. Once the map interface was complete caching of the data was required to enhance the performance and speed of the system. Due to the sensitive nature of the floor/site plan data web GEO-EHS will only be available to select user groups in a secure manner. The system will be accessed through the EHS website already in existence where the users will be directed to a login page requiring a username and password. The system is fully functional and ready for final testing by select users (e.g. facilities, senior management, and a few principals) before it is implemented for operational purposes.

6.3 Limitations and Refinement of GEO-EHS

The fifth objective was to "*Identify limitations and future directions of GEO-EHS*". GEO-EHS desktop and web are both currently in the prototype stage with a planned operational implementation date of April 2008. Moving forward with future system development there are a number of limitations that have been identified which require attention in order to improve GEO-EHS. The limitations will be listed under the headings of Desktop System Configuration, Data, Functionality, and ArcView/ArcServer. After each limitation is described a suggested plan for improvement will be presented. The section will be concluded with discussion around alternative option for GEO-EHS moving forward.

Desktop System Configuration

At this point desktop GEO-EHS is accessed through ArcView installed on the EHS Laptop. A duplicate version of the spatial data is housed on the laptop along with Parklane and Hazmat Inspector tables. Electronic files are kept in their native folders on the servers. Originally this configuration was set up for development purposes because high speed access to the large amounts of data was required outside AMDSBs firewall. Accessing the data through a VPN connection using ArcView on the laptop proved to be to slow. The current configuration allows for duplication and inaccuracy of data. The ideal configuration would be to have one central data source on the EHS server. It is planned to use ArcView installed on a high speed remote desktop system accessible through terminal server and VPN to access desktop GEO-EHS data on the EHS Server.

Data

Desktop GEO-EHS does not have all EHS data integrated at this point. It is an understood limitation that only certain datasets are integrated and total integration is an ongoing project. Student related EHS data was not part of the initial data integration but the long term goal is to extend GEO-EHS to include student data such as accidents/incidents, bus transportation data (available in GEOREF), health planning data (e.g. socioeconomics, demographics, illness/disease), and student achievement data. This would allow principals and senior staff to include EHS as part of the student planning process. For example GIS could combine and analyze data to determine if the community a student lives in, family income, illness rates, and the length of time on a bus have any influence on student achievement results. Hazmat Inspector data requires data cleansing for accuracy within the proprietary system. Certain records were not exported properly due to original data entry problems within Hazmat Inspector (e.g. text within a numeric field). Another issue is that of missing data, some data does not have a room id (e.g. asbestos located on the exterior of the building) and the export tool provided by Basebridge did not work properly resulting in missing information so it is not represented within GEO-EHS. The data cleansing process and final export of data using the fixed export tool prior to system implementation will address these issues. Parklane data is only available at the regional level due to limitations with the proprietary system and the way data is collected with AMDSB. Moving forward this will be an accepted limitation of GEO-EHS and there are no plans to enhance GEO-EHS with local room level accident data due to limited resources. The export process of Parklane and Hazmat Inspector data and conversion into a one table format for integration within GEO-EHS is a manual process. To ensure data is accurate and current an automated process will be explored.

Overall data management is currently a limiting factor due to limited personal in the EHS department and the hurdle of convincing the facilities department that GEO-EHS can be used as the foundation for a facilities management system (FM), currently there is no electronic FM system in place. An example is that the floor/site plan data within GEO-EHS is accurate as of February 2006. Since then there have been modifications to less then ten facilities including renovations or additions that would require updating of the plans. The contracted AMDSB architect oversees any major work completed on the schools and is responsible for maintaining the plans but there is currently no system in place for ensuring floor/site plans are updated and made available to AMDSB. This need has been raised by EHS to the facilities department but to date there is no system in place. EHS has also marketed the idea to the facilities department of using GEO-EHS in combination with Cityworks-Azteca Systems (which is a GIS FM system built as an add on system to ESRI ArcGIS software) to build a tailor made FM system for AMDSB. Until there is a system in place to ensure data is accurate the limitation will be made evident to any end users.

<u>Functionality</u>

The user of desktop GEO-EHS requires moderate to advanced knowledge of GIS and ArcView to run quires, use the system effectively and maintain the data. ESRI provides an extensive number of courses to bring any new users up to speed with ArcView an GIS technology in general. Also functionality and process models can be created to simplify functions for the end user. The web GEO-EHS is a much simpler environment and requires little knowledge or experience with GIS technology.

<u>ArcView/ArcServer</u>

ESRI software has its own set of limitations such as ArcView 9.2 not allowing the primary display field to be changed when there are relates to other tables. By default the OID field is displayed which is not a good descriptor of the data. In the case of Hazmat Inspector data the field describing what the asbestos material is would be the best option (e.g. pipe insulation) or room ID. ArcServer 9.2 has many bugs such as not being capable of displaying all AMDSB GIS data because there are too many layers resulting in the GIS AutoCad layers not being included in web GEO-EHS. In the next release of ESRI software (9.3) these and many other items are planned to be corrected.

GEO-EHS Options Moving Forward

As GEO-EHS moves forward and data integration continues certain options may be considered to refine the design to reduce data redundancy and data integration problems. The web GEO-EHS implementation raised the question about whether all the layers are required. Many of the layers were removed (e.g. all the AutoCad static layers) due to limitations of ArcServer. Within GEO-EHS the layers could be reduced to building, room and site for GIS layers and only the AutoCad line layer which includes detail not captured in the GIS layers such as walls, steps, doors etc. When the project started three years ago the ESRI personal geodatabase had a storage limit of 2 MB. This was a major reason a separate one was created for each school. Now at ArcGIS 9.2 there is a new file geodatabase which eliminates this storage limit. This new file format could be used to create one geodatabase for all schools which would allow for queries to be made across all schools at the Regional and Local level, it may also reduce some of the data integration problems encountered with Hazmat Inspector and Parklane (e.g. table linkages and data import/export), and the school location shape file could be included as a feature class. The new file format may make GEO-EHS data management more efficient and easier moving forward.

6.4 Future Research

The sixth objective was to "*Identify areas for future research*". GIS technology is being used by sub-disciplines of EHS such as emergency and environmental management for solving project based problems but the umbrella discipline of EHS is not using GIS for data integration or managing all EHS functions. Further investigation into reasons why EHS is not using GIS for data management is required. Is it because a change in thinking from tabular to spatial data management is required? Is the EHS field just unaware of GIS and its capabilities for data integration and management? Is it because EHS departments are under funded in many organizations and a spatial decision support option may be too costly to implement? May it be that EHS departments are usually small in organizations and may not have the time to explore GIS as an option for aiding in the decision making process? Or maybe the reason is that GIS projects are a long term commitment and it may be easier and faster to chose an off the shelf relational database software package to manage each problem individually as they are encountered?

This thesis provides proof that GIS is a solution for EHS data integration and management. But based on the limited research in academia, GIS industry, and EHS profession this thesis is a call for further research by these groups (separately and in collaboration) with the ultimate goal of making EHS a common discipline in the GIS research and marketplace similar to public health, emergency management, and environmental management. More complex types of analyses and open source solutions based on the GEO-EHS implementation are also worthwhile paths of investigation. The GEO-EHS implementation was also meant to trigger interest by other disciplines as a means of data integration and asset management such as facilities management, information technology, purchasing, business, finance, and human resources with the ultimate vision of creating an enterprise business GIS for managing all business and operational functions within an organization.

The design and implementation of a GIS for EHS is a long-term vision and requires ongoing commitment and financial support in order to come to fruition. At each stage along the way, small products should be released in order to keep the interest and support of management and to maintain momentum of the project moving forward. An example of this is the web GEO-EHS system developed as part of this thesis. One of the main reasons for its development along side the desktop GEO-EHS was to provide a final GIS product for use by other departments and management which displayed GIS capabilities in an effort to maintain interest and support for the project while at the same time generating feedback for future development. Web GEO-EHS also created the foundation for development of a Spatial Facilities Management System for the facilities department to consider if they decide to implement an electronic system. The absence of visible returns on investment at intervals along system implementation could cause the loss of interest in the project resulting in possible project failure.

6.5 Recommendations for Others Considering EHS Data Integration

The overall implementation of GEO-EHS is an ongoing project that began over three years ago and will continue to evolve as time goes on. There are many steps that have been mentioned without much discussion because the steps were completed prior to the thesis work. The methodology provides an outline of the overall project and steps involved but this section will act as a great summary for others considering an EHS data integration project.

Barriers Crossed

For a spatial data integration project to be successful it is important to follow a well thought out action plan as described by (Aronoff 1989) and (Tomlinson 2003). Initially the project needs to be justified through making business case presentations to senior management. In these presentations questions should be answered such as: What is GIS? What is GIS capable of? How can GIS help your department? How can GIS help the organization as a whole? Why GIS vs. other systems? A cost benefit analyses should also be provided outlining how GIS data integration will save time and money. A great resource to help get started on making a business case for using GIS is a book by (Thomas and Ospina 2004) called *"Measuring Up - The Business Case for GIS"*. The book outlines fourteen benefits of GIS and describes how each benefit adds business value for organizations.

Once the project has been justified and senior management has bought into the idea by providing resources to implement the project the next step is to form an implementation plan identifying project steps, timelines for completing each step, costs involved, resources required (e.g. consulting services), and training needs. A key component which will dictate how long the project will take is deciding if the system will be built in house and be supported internally or will a consultant build the system and provide external support. For GEO-EHS it was decided to build the system in-house and support it internally so there was no need to rely on a consultant for support. Because AMDSB is a small to mid sized school board and EHS has limited resources (personnel and money) GEO-EHS was broken down into components which could be developed over a 4-5 year period. In a larger organization where there are more resources available this time line may be able to be condensed to a 2 year window for project completion.

The first step in the implementation plan should be to conduct a GIS user needs assessment. This will provide the foundation for building the system and will be constantly referred to as the project moves forward. In the user needs assessment department business flows will be analyzed in order to determine what functionality the system requires and how the system should be configured. Another key component of the assessment is to compare more than one software option for implementing the GIS system. One of the options should be open source software (OSS). For GEO-EHS three GIS software options were considered, ESRI ArcGIS, MapInfo, and OSS. A fourth non spatial data integration option was also included for cost comparison purposes. Some of the key reasons ESRI ArcGIS was chosen were: school boards receive a 50% discount on ESRI software, many other school boards are using ESRI software and there is a school board GIS user group for support (DSBO-GIS), the EHS Officer (EHSO) was familiar with ESRI software, and there was no in-house expertise to build a system using OSS.

Other non GIS data integration options could also be included in the software comparison process to determine if a GIS option is the best choice for the organization. An AutoCad option for housing the floor/site plans combined with a tabular database could be one option. This would eliminate the data conversion to GIS format and the associated costs but would also eliminate the spatial analytical benefits. This option was not considered for GEO-EHS because there is no in-house expertise with AutoCad. A non spatial tabular web based option was considered in the GIS user needs assessment. This option was not chosen because there was no in-house expertise to design and implement such a system and it would have required relying on a consultant for implementation and support.

Training needs should also be considered as part of the implementation plan. For GEO-EHS implementation the EHSO completed two introductory courses offered by ESRI (ArcGIS 1 and 2), which provided an overview of the ESRI software and basic skills to start using the software. The majority of required skills were self taught through using the software and through completing this Masters degree. The IT person providing system implementation and configuration expertise did not have any formal GIS training and learned by trial and error while implementing GEO-EHS.

As indicated earlier in the thesis, because a spatial data integration project is a long term commitment it is important to maintain the interest of those who are supporting the project. This can be accomplished by setting millstones along the way where small products are made available to demonstrate progress and benefits of such a system (such as the web GEO-EHS). These products can also be used to gain interest from other departments in the organization for using GIS, which could lay the ground work for justifying the option of an enterprise GIS system used to manage all business functions of an organization.

The following breakdown of the GEO-EHS implementation is meant to provide a general idea of what a GIS system implementation may cost based on the AMDSB experience. A key item worth noting is that the EHSO completed much of the implementation work as part of this Masters thesis in place of using a consultant to design and implement the system. This significantly reduced GEO-EHS costs and made it possible to pursue a spatial data integration option at AMDSB. Included in the user needs assessment were cost comparisons of four different levels of GEO-EHS implementation (see below) based on a consultant designing and implementing the system.

Consultant Design and Implementation Cost Comparisons – 4 Levels of Proposed Systems

1) Fully Web-based Open Source Solution ($113,000 – $194,000)
2) Fully Web-based ESRI Technology Solution ($116,000 – $187,000)
3) Desktop ArcView Solution with Web-based Data Exchange ($95,000 – $168,000)
4) Non-Spatial Solution with Web-based Data Integration ($50,000 – $118,000)

GEO-EHS Implementation Costs (2005-2008)

1)	Project Justification ***(2005)*** – free 30 day trial version of ArcView	***– $0***
2)	Project Approval ***(2005)*** – purchase of 1 ArcView 9.2 license for testing	– ***$1,100***
3)	EHSO Training ***(2005)*** – ESRI ArcGIS 1 and 2	– ***$2,000***
4)	GIS User Needs Assessment ***(2005)*** – consultant fees	– ***$8,000***
5)	Spatial Data Building/Conversion ***(2006)*** – consultant fees	– ***$20,000***
6)	GEO-EHS Design/Implementation ***(2005-2008)*** – EHSO and IT internal	– ***$0***
7)	Web System Hardware ***(2007)***	– ***$12,000***
8)	Web System Software - ArcServer 9.2 ***(2007)***	– ***$7,000***
9)	Web System Map Design ***(2007-2008)*** – consultant fees	– ***$6,000***
Total Cost (does not include annual software or data maintenance costs)		***= $56,100***

Pitfalls to Avoid

The following section will outline some issues encountered during implementation to help others avoid them or be prepared to encounter them. One of the largest issues is that of “Data Compatibility” of existing systems and data sources. Every organization will have their own set of systems in operation with their own unique data compatibility problems. When considering whether to implement such a system it should be made clear that the data compatibility issues can take a great deal of time and effort to solve. If a consultant is being used to implement the system these issues have potential to add significant costs above the initial proposal costs. The following are some integration issues encountered while implementing GEO-EHS.

The Parklane system used for accident/incident tracking by EHS had its set of data integration problems. Parklane Systems Inc. advertises that their database is an open architecture accessible by other software systems. In order to access the database through ArcView it was required to purchase an ODBC driver called Relativity. The initial intent was to keep using Parklane as the accident database and use Relativity for accessing and querying Parklane data through GEO-EHS so a duplicate database would not be required. This proved not possible for a number of reasons, the Parklane database is in a COBOL programming language and ArcGIS is not compatible with the COBOL format and therefore cannot read all the tables properly through the Relativity ODBC driver, the tables are read only through Relativity and cannot be manipulated, and the tables do not have an OID field which is required by ArcGIS to operate properly (e.g. running queries through related tables). These problems made using Relativity for data integration impossible and required an export of the data to make integration possible. At this stage the plan was to make copies of all the Parklane tables using Relativty and re-create the database linking the tables through their unique keys and add OID fields to each table using MS Access or SQL which could then be automatically updated from Parklane at regular intervals. This option also proved to be not possible because ArcGIS cannot recognize one-to-many relates between external tables. The last option considered and chosen was to create one table including all the relevant accident data to EHS using the export function available in Parklane. An OID field was then added to the table allowing for integration with GEO-EHS.

Hazmat Inspector used for asbestos data management is a proprietary web based system with the data housed externally on Basebridges' server in Atlantic Canada. The system has a closed backend database which is not accessible in an open manner. The only way to access the data for integration purposes is through an export function which dumps all the data out into a useable format such as Excel where it can then be manipulated. One table was created with an OID field with all data relevant to EHS. This poses many data management issues such as, the requirement to manage a secondary duplicate database, a need to make sure the data is accurate after exported, and the need to automate the export function so current data is available. Hazmat Inspector is still used as the main database (for maintaining and entering the asbestos data) but the format of some data does not match the spatial component for proper integration of all data (e.g. some data is not linkable to a room location because it was entered into the system in a general manner with out a room id – “floor tiles on all levels” or “paneling on the exterior of the building”). These types of issues require correction in the Hazmat Inspector system so all data is represented in GEO-EHS. Dealing with Basebridge was very difficult because they are located in Atlantic Canada and they were not very co-operative with providing a more efficient means of accessing the data in an open manner. For example a standalone desktop version of the web software was required to export the data from the web system, which ultimately housed the data in a SQL database on the desktop but Basebridge would not provide EHS with open access to the secured SQL database because it was their proprietary system.

The export process is currently manual for Parklane and Hazmat Inspector data. Moving forward this process will be automated by programming a script which will run automatically at set intervals. For Hazmat Inspector this will be quarterly throughout the year and for Parklane it will be on a weekly basis.

Looking forward many of these same issues will be encountered when other existing databases used by AMDSB are eventually integrated with GEO-EHS. For example facilities data are currently housed in two web based systems (RECAP and SFIS) maintained by the Ministry of Education on their servers in Toronto. In order to make integration possible an export of data will most likely be required creating duplicate databases which will require maintaining.

There were much less data compatibility issues with the spatial data. The orthophotography, road network, and school point locations all integrated without problems. The conversion of AutoCad floor/site plans to a GIS format and then georeferencing them to the orthophotography was the most data intensive and time consuming process. On average there were about three sets of AutoCad plans per school which required conversion to a GIS format, adjustment to align with each other, creation of (building/floor/elevator/room/corridor/site) polygon layers, and then finally georeferencing to the orthophotography. Due to a limited budget and time constraints it was decided to use the building outlines in the orthophotography as the spatial reference for georeferencing the school GIS data. An alternate method could have been to collect global positioning (GPS) points at each school which could have then been used as the spatial reference points for georeferencing. This method was not chosen because it would have required field data collection and added extra cost and time to the project.

The process of compiling the spatial database raised minor issues around “Data Sharing”. The process involved communicating with Huron county, Perth county, MPAC, LIO, Teranet, MNR, Ministry of

Education, DMTI, and GEOREF. Data sharing agreements were signed with LIO, MPAC, DMTI, Huron county, and Perth County. The only organization that charged for use of their data was Huron county. GEO-EHS uses the road network and background data (e.g. land use and water) from DMTI. The Ministry of Education has an agreement with DMTI which allows all school boards to use the data at no charge. There are questions whether or not this agreement will be renewed for 2009. If it is not renewed AMDSB may need to start paying for use of the data or consider replacing the data with an alternate source such as the Ontario Road Network (ORN) available through LIO where there is no charge.

Appendix A- List of Acronyms

AIHA – American Industrial Hygiene Association

AM – Automated Mapping

AM/FM/GIS – Automated Mapping/Facilities Management/Geographical Information Systems

AMDSB – Avon Maitland District School Board

ANSI – American National Standards Institute

BSI – British Standards Institute

CCOHS – Canadian Centre for Occupational Health and Safety

COBOL – Common Business Oriented Languages

COTS – Commercial-off-the-Shelf Software

DSBO-GIS – District School Boards of Ontario GIS User Group

DMS – Database Management System

DMTI – Desktop Mapping Technologies Inc.

EHS – Environmental Health and Safety

EHSO – Environmental Health and Safety Officer

EM – Environmental Management

ERM – Emergency Response Management

ESRI - Environmental Systems Research Institute

ESS – Environmental Support Solutions

FC – Feature Class

FD – Feature Dataset

FM – Facilities Management

GEO-EHS – GeoSpatial Environmental Health and Safety

GIS – Geographic Information Systems

GPS – Global Positioning System

GUI – Graphical User Interface

HC – Health Care

HWIN – Hazardous Waste Inventory System

IAPA – Industrial Accident Prevention Association

IEQ – Indoor Environmental Quality

IIS – Internet Information Services

IH – Industrial Hygiene

IOHA – International Occupational Hygiene Association

ISO – International Organization for Standarziation

IT – Information Technology

JHSC – Joint Health and Safety Committee

LIO – Land Information Ontario

LT – Lost Time

MLS – Multiple Listing Service

MNR – Ministry of Natural Resources

MPAC – Municipal Property Assessment Corporation

MXD – ESRI map file

NAD 83 – North American Datum 83

OASBO-EHS - Ontario Association of School Business Officials - Environmental Health and Safety

ODBC – Open Database Connectivity

OHS – Occupational health and Safety

OHSAS 18001 - Occupational Health and Safety Management Systems – Standard

OID – Object ID

OPP – Ontario Provincial Police

ORN – Ontario Road Network

OSHA – Occupational safety and Health Administration

OSS – Open Source Software

PCB’S - Polychlorinated biphenyls

PGDB – Personal Geodatabase

PH – Public Health

SDS – Spatial Decision Support

SDSS – Spatial Decision Support System

SFIS – School Facilities Information System

SQL – Standard Query Language

SSL – Secure Sockets Layer

SWOOP – South Western Ontario Orhtophotography Project

USEPA – United States Environmental Protection Agency

UTM – Universal Transverse Mercator

VPN – Virtual Private Network

WHO – World Health Organization

Bibliography

4DM (2005). User needs analysis for Environmental Health and Safety at the Avon Maitland District School Board, 4DM Inc.

AG-DEH. (2006). "Australian Government Department of the Environment and Heritage." from www.deh.gov.au/soe/2001/biodiversity/glossary.html.

AIHA. (2008). "American Industrial Hygiene Association ", from http://www.aiha.org/Content.

Al-qurashi, F. (2004). "New vision of emergency response planning." Process Safety Processes **23**(1): 56-61.

Anderson, G., and Moreno-Sanchez, Rafael (2003). "Building Web-Based Spatial Information Solutions around Open Specifications and Open Source Software." Transactions in GIS **7**(4): 447-466.

Arctur, D., and Zeiler, Michael (2004). Designing geodatabases – case studies in GIS data modeling, ESRI Press,Redlands, California.

Aronoff, S. (1989). Geographic Information Systems: A Management Perspective (Fourth Printing), WDL Publications, Ottawa, Ontario.

ASSE-BCSP (2007). Career Guide to the Safety Profession., American Society of Safety Engineers Foundation and the Board of Certified Safety Professionals.

BSI (2002). OHSAS:1999 - Occupational health and safety management systems – Specification, British Standards Institute.

CCOHS. (2008). "Canadian Centre for Occupational Health and Safety." from http://www.ccohs.ca/.

Contini, S., F. Bellezza., M. Christou., and C. Kirchsteiger (2000). "The use of geographic information systems in major accident risk assessment and management." Journal of Hazardous Materials **78**: 223-245.

Crabbe, H., A. Barber., R. Bayford., R. Hamilton., D. Jarrett., and N. Machin (2004). "The use of a European telemedicine system to examine the effects of pollutants and allergens on asthmatic respiratory health." Science of the Total Environment **334-335**: 417-426.

Douglas, J. W. (1995). Environmental GIS: Applications to Industrial Facilities, CRC Press Inc., Boca Raton, Florida.

Douglas, W., and I. Martin (1996). "Accessible information." Civil Engineering **66**(6): 59-61.

EMO. (2007). "Emergency Management Ontario." from http://www.mcscs.jus.gov.on.ca/english/pub_security/emo/about_emo.html.

ESRI-1. (2007). "Geodatabase." from http://www.esri.com/software/arcgis/geodatabase/index.html.

ESRI. (2008). "Environmental Systems Research Institute." from http://www.esri.com/.

Geertman, S., and J, Stillwell (2004). "Planning support systems: An inventory of current practice." Environment and Urban Systems **28**: 291-310.

Grady, R. (2001). Integrated facilities data system using web and database technology. ESRI 2001 User Conference.

Guidry, T., and L, Margolis (2005). "Unequal respiratory health risk: using GIS to explore hurricane related flooding of schools in eastern North Carolina." Environmental Research **98**: 383-389.

Heino, P., and R, Kakko (1998). "Risk assessment modeling and visualization." Safety Sciences **30**: 71-77.

Henricy, S., and E, Stewart (2005). GIS in Occupational Health and Safety Service. Twenty-Fifth Annual ESRI User Conference.

Henricy, S., and E, Stewart (2006). USE OF GIS TO MANAGE EHS INFORMATION AND DATA. 2006 American Industrial Hygiene Conference & Exposition (AIHce).

IAPA. (2008). "Ontario Industrial Accident Prevention Association ", from http://www.iapa.ca/.

IOHA. (2008). "International Occupational Hygiene Association ", from http://www.ioha.net/.

Kam, B. (2003). "A disaggregate approach to crash rate analysis." Accident Analysis and Preservation **35**: 693-709.

Keyworth, C., and M, Healey (1996). "Using GIS for environmental management of multiple facilities." Pollution Engineering (Aug 1996): 20-22.

Kilical, F., and A, Kilical (1996). District of Columbia public school system facilities master plan using GIS. ESRI 1996 User Conference.

Lacey, S., R, Espinosa., N, Esmen., and K, Kennedy (2006). DEVELOPMENT OF A GEOSPATIAL TIME DEPENDENT INFORMATION SYSTEM FOR INDUSTRIAL HYGIENE. 2006 American Industrial Hygiene Conference & Exposition (AIHce).

Lee, C., X. Li., W. Shi., S. Cheung., and I, Thorton (2006). "Metal contamination in urban, and country park soils of Hong Kong: a study based on GIS and multivariate statistics." Science of the Total Environment **356**: 45-61.

McConnell, E. (2002). Facility planning and management: information dissemination using ArcIMS. ESRI 2002 User Conference.

Milliken, J., L. Peltz-Lewis., T. Heinzer., and D. Williams (2005). Facilities monitoring and asset management for the mid-pacific region of the U.S. Bureau of Reclamation. ESRI 2005 User Conference.

Mohamed, S. (2003). "Scorecard Approach to Benchmarking Organizational Safety Culture in Construction." JOURNAL OF CONSTRUCTION ENGINEERING AND MANAGEMENT **129**(1): 80-87.

Mustapha, S., T, Hee., M, El-Harbawi., A, Shariff., T, Choong., A, Zakariaz., and R, Mispan (2004). "Chlorine incident and its toxic hazardous chemical release impact in the area surrounding a swimming pool using GIS." Disaster Prevention and Management **13**(5): 387-398.

NACCHO (2005). Definition of a Functional Local Health Department., National Association of County and City Health Officials.

Norman, R. (1991). "Object-Oriented Systems Analysis: A Methodlogy for the 1990s." Journal of Systems Mangement **42**(7): 32-40.

OSHA. (2008). "US Occupational Safety & Health Administration." from http://www.osha.gov/.

Peters, D. (2005). System Design Strategies -An ESRI Technical Reference Document. , Environmental Systems Research Institute, Inc., Redlands, California.

Pfeffer, J. (2001). Facilities information distribution using ArcIMS and Oracle. ESRI 2001 User Conference.

Plog, B., J, Niland., and P, Quinlan (1996). Fundamentals of Industrial Hygiene 4th ed, National Safety Council.

Ramsey, P. (2006). The State of Open Source GIS, Refractions Research Inc.

Roberts, R., T, Hulsey., G, Curtis., and J, Reigart (2003). "Using geographic information systems to assess risk for elevated blood lead levels in children." Public Health Reports **118**: 221-229.

Roig, R., Ruble, B., Brown, R., and Morell, D (2008). 18001 HEALTH AND SAFETY MANAGEMENT SYSTEMS - A Complete Guide to OHSAS and VPP Implementation, Specialty Technical Publishers **2008-115**.

Ross (2001). Environmentally Regulated Facility Geodatabase Model – Manuscript., Ross & Associates Environmental Consulting Ltd.

Sandhaus, D. (1999). Activity land and facilities assets (ALFA) – Navy shore facilities planning using ArcView GIS. ESRI 1999 User Conference.

Silvia, S., P, Penga., A, Angelica., and A, Graziosi (2006). Italian Health and safety GIS applications: an example in INAIL. Twenty-Sixth Annual ESRI User Conference.

Simon, H., and M, Gallo (2002). Integrating environmental monitoring data into GIS for the world trade centre emergency response. ESRI 2002 User Conference.

Srivastava, A., and B,Wellington (2000). GIS-based facility information management systems: an evolving success story. ESRI 2005 User Conference.

Stementelli, A., D, McDonald., and W, Gardner (2002). "A geographic information system-guided cost-effectiveness analysis for waterborne asbestos remediation." Public Works Management and Policy **7**(3): 205-215.

Thomas, C., and Ospina, Milton (2004). Measuring Up - The Business Case for GIS, ESRI Press, Redlands, California.

Tomlinson, R. (2003). Thinking About GIS: Geographic Information System Planning for Managers, ESRI Press, Redlands, California.

Valcik, N., and P, Huesca-Doramantes (2003). "Building a GIS database for space and facilities management." New Directions for Institutional Research **120**: 53-59.

Westhuizen, H. (2005). OCCUPATIONAL HEALTH AND SAFETY DATA BY WAY OF A GEOGRAPHICAL INFORMATION SYSTEM. International Occupational Hygiene Association 2005 IOHA Conference PILANESBERG, SOUTH AFRICA.

WHO. (2008). "World Health Organization ", from http://www.who.int/en/.

Xia, F. (2004). "Library space management: GIS proposal." Library Hi-Tech **22**(4): 375-382.

Yiannakoulias, N., B, Rowe., L, Svenson., D, Schopflocher., K, Kelly., and D, Voaklander (2003). "Zones of prevention: the geography of fall injuries in the elderly." Social Science & Medicine **57**: 2065-2073.

Zeiler, M. (1999). Modeling our world-The ESRI guide to geodatabase design, ESRI Press, Redlands, California.

Zhong, R. P., and Ming, Hsiang Tsou (2003). Internet GIS: Distributed Geographic Information Services for the Internet and Wireless Networks, John Wiley & Sons, Hoboken, New Jersey.